SHRINKING AND SWELLING OF WOOD IN USE

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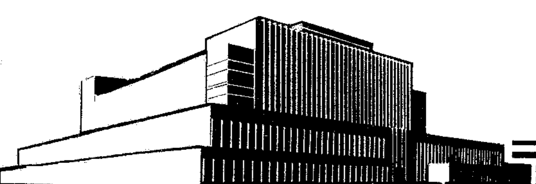

FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

SHRINKING AND SWELLING OF WOOD IN USE[1]

Forest Products Laboratory,[2] Forest Service
U. S. Department of Agriculture

Wood normally shrinks as it dries and swells as it absorbs moisture. These changes in its dimensions are of importance to anyone who uses wood, whether for tanks or toys, shoe lasts or ships, because wood readily takes on or gives off moisture, even from the atmosphere. Successful use of wood for exacting purposes under wide variations in atmospheric humidity shows that the problems arising from the shrinking and swelling of wood can be surmounted.

Good practice, in general, requires that efforts be made to reduce the changes in dimensions that take place while wood is in use and to minimize their effects by methods of installation and construction. Fortunately, wood is somewhat plastic, so that it can conform to a certain amount of dimensional changes without serious damage. On the other hand, the stresses developed in shrinking or swelling may cause a great deal of damage. The use of insufficiently dried lumber that shrinks under service conditions commonly results in subsequent checking, opening of joints, loosening of nails, and the warping and distortion of wood structures as a whole. If lumber is dried too far below the moisture content it will reach in use, swelling may cause drawers, windows, and doors to stick.

Sometimes the swelling and shrinking of wood can be used to advantage, as in operating humidity indicators and regulators. Swelling is employed to close seams in barrels, tubs, tanks, and boats and to tighten handles on tools. This means of tightening is only temporary, however, as it causes compression of the wood followed by greater than normal shrinkage.

The forces exerted in shrinking and swelling are great and have a marked effect on the permanence and serviceability of anything made of wood. The following discussion explains the causes and effects of shrinking and swelling and tells how the shrinking and swelling of wood in use can be minimized.

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[1] Original report issued July 1931.

[2] at Madison Wis., in cooperation with the University of Wisconsin

Causes of Shrinkage in Wood

Wood grows in a tree under moist conditions, and water not only is contained in the fiber [3] cavities but saturates the fiber walls. The structure of the fiber walls is complex, but they can be considered as consisting of small units in the form of relatively long strands between which water lodges. As water leaves the spaces between the strands in drying, they are drawn together, causing the fiber walls to be reduced in thickness and the fibers themselves to be reduced in girth. This contraction of the fibers causes the whole piece of wood to shrink.

When green or wet wood dries, the water leaves the fiber cavities first; only when they are empty does continued drying remove the water from the fiber walls. The moisture content at which the fiber cavities are empty but the walls are still saturated is approximately 30 percent for all species. This condition is known as the fiber-saturation point, and shrinking occurs only at moisture content values below it.

Not all portions of a piece of wood reach the fiber-saturation. point at the same time. Actually, the surface layers dry out, shrink to a certain extent, and even compress the interior of the piece slightly before that part has reached the fiber -saturation point. Consequently, the whole piece may show some shrinkage before the average moisture content reaches the fiber -saturation point. This difference in the drying and shrinking of the surface and interior zones of wood tends to set up severe stresses that may cause such seasoning defects as surface and end checking, honeycombing, case-hardening, and collapse.

The shrinkage of a piece of wood is proportional to the amount of moisture lost below the fiber-saturation point, or 30 percent moisture content. For each 1 percent loss in moisture content, the wood shrinks about one-thirtieth of the total shrinkage possible. Since, for practical purposes, swelling may be considered as the reverse of shrinking, for each 1 percent increase in moisture content, the piece swells about one-thirtieth of the total swelling possible. Thus, wood dried to 15 percent moisture content (thoroughly air-dry) has attained about one-half of the possible shrinkage and about four-fifths of the possible shrinkage when dried to 6 percent (kiln-dry).

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[3] is normally made up largely of elongated cells, or fibers, but other types of cells also occur, which for convenience are here included under the general term "fiber."

Variability in Shrinkage

Wood shrinks most in the direction of the annual growth rings (tangentially), somewhat less across these rings (radially), and very little, as a rule, along the grain (longitudinally). Table 1 gives the average tangential, radial, and volumetric shrinkage for numerous species in drying from the green condition to 20, 6, and 0 percent moisture content. These are average values, and the actual shrinkage of individual boards may vary somewhat from them.

The shrinkage values of table 1 are given in percentages of the green dimensions, which represent the natural size of wood. They can be converted easily to useful units of measurement, since each 3 percent of shrinkage is roughly equivalent to a shrinkage of one thirty-secondth of an inch per inch of green dimension.

Values for longitudinal shrinkage are not given in table 1, but the total longitudinal shrinkage of normal wood usually ranges from 0.1 to 0.3 percent of the green dimension (3) [4]

Formerly, the lesser radial shrinkage as compared with the tangential shrinkage was attributed to the wood rays, which are strips of cells extending inward from the bark. It was thought that these cells did not shrink much in length, and since their length lies in the radial direction, they were believed to oppose radial shrinkage. Now, however, it is known that the structure of the walls of the wood-ray cells permit large shrinkage along their length (5)

The parallel arrangement of the springwood to the summerwood tangentially in the annual rings may account for some of the difference between tangential and radial shrinkage (5) Summerwood shrinks more tangentially than springwood. Because it is denser and stronger than springwood, the summerwood also forces the springwood to shrink more than it would if it were detached from the two adjoining bands of summerwood. The relative position of the springwood and summerwood, however, does not affect radial shrinkage,

The difference between radial and tangential shrinkage may also be accounted for on the basis of the strands in the fiber walls being bent around the pits that predominate in the radial walls of the fibers, rather than being parallel to the long axis of the fiber (5). This arrangement of the strands permits maximum tangential shrinkage but lessens radial shrinkage.

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[4] numbers in parentheses refer to Literature Cited at the end of the report.

Shrinkage not only differs with the three directions of grain, but also differs among species. It varies widely in material cut from the same species and even in material cut from the same tree.

In general, the heavier species of wood shrink more across the grain (transversely) than lighter ones. The over-all, or volumetric, shrinkage of wood also generally increases with an increase in specific gravity. This relationship holds not only within a species but fairly well for a large number of species of both softwoods and hardwoods. Deviations from this relationship are usually caused by stresses, such as those set up in drying, and by water-soluble extractives (6), which reduce shrinkage because of their bulking effect when held between the strands within the fiber walls.

The springwood of an annual growth ring shrinks less transversely and more longitudinally than summerwood of the same ring. Abnormal types of wood, such as compression wood in softwoods and tension wood in hardwoods, shrink more longitudinally but less transversely than normal wood.

The greater longitudinal shrinkage of compression wood, as well as that of springwood, largely can be accounted for by the fact that the strands of the fiber walls of this type of wood make a considerable angle to the axis of the fiber, instead of being nearly parallel to it. Since the water in the fiber walls occurs between the strands, it is obvious that, if all the strands ran parallel with the fiber axis and the fibers were parallel to each other, there would be no longitudinal shrinkage but considerable transverse shrinkage. With increasing slope of the strands, there would be more longitudinal shrinkage and less transverse shrinkage, since the fibers are grown together and cannot twist like a rope, which becomes longer in drying. Although the individual strands cannot be seen with a microscope, their direction can be determined by optical means. The structure of the tensionwood fibers responsible for longitudinal shrinkage has not been fully worked out.

Lightweight wood of any species contains more fibers of the springwood type than of the summerwood type and therefore shrinks more lengthwise than does heavier wood of the same species. This rule, however, does not hold for light and heavy wood of different species. Normal cottonwood, a light wood, does not shrink appreciably more lengthwise than does normal oak, a heavy wood, although tension wood of both species has excessively large lengthwise shrinkage. Frequently, the wood in outer portions of mature trees is more porous and lighter in weight than that nearer the pith, shrinks more along the grain, and consequently causes warping in boards or dimension stock cut from such trees.

Apparent excessive longitudinal shrinkage is caused by cross grain, curly grain, and any other distortion of the fibers from their course parallel to the long axis of a piece of wood. Actually, transverse shrinkage of the misalined fibers is responsible for most of the shortening in such wood.

The conditions under which wood is dried influence its shrinkage considerably; hence shrinkage values, to be comparable, must be obtained under the same conditions. Wood dried in a dry kiln, by means of relatively high temperature, generally shrinks more than wood seasoned in a yard at relatively low temperatures. Where a high relative humidity is combined with a high temperature, the shrinkage is the greatest. Such conditions may shrink the lumber excessively, however.

Some Effects of Shrinking and Swelling

Besides causing changes in dimensions, shrinking and swelling frequently have more harmful effects. Information on the cause and minimization of such harmful effects of uneven shrinkage as checking, warping, case-hardening, and honeycombing during seasoning of lumber is available in other publications of the Forest Products Laboratory (2, 4, and 8 The following comments are therefore confined to the swelling and shrinking that takes place during manufacture or use of wood products.

Shrinking of inadequately seasoned structural members in a house may cause loosening of fastenings and settling of the building, with resulting plaster cracks, distorted openings, uneven floors, and unsightly openings around trim and moldings. Shrinking of studs, sheathing, and siding decreases the weather-tightness of walls, loosens fastenings, and reduces the mechanical strength and stiffness of walls.

In products with exacting use requirements, such as furniture, interior finish, flooring, musical instruments, sash and doors, and caskets, swelling and shrinking may cause splitting and cracking, warping, opening of joints, and marring of finishes.

Even in products that are not customarily thoroughly seasoned before being put in service, the effects of shrinking and swelling can be harmful, In large timbers used in heavy construction, such as for mills, docks, trestles, or bridges; in ties, piles, poles, and posts; and in low-grade lumber for rough usage, pulling and loosening of fastenings, checking and splitting, warping, and opening of joints may occur. If the items are preservative-treated, shrinking may cause cracks to open and penetrate into parts beyond the depth of treatment.

Splitting, buckling, pulling of nails, or opening of joints frequently occur when two pieces of different species, unmatched grain, or different moisture content are fastened together and subsequently attempt to swell or shrink by different amounts. Thus, if pieces of wood of different species or kinds or at different stages of dryness are glued together to make plywood, veneered panels, or laminated stock, the glue joints may open up, cracks may develop, or the finished article may warp as a result of differences in shrinkage. If the plies of veneered panels are thick, changes in their moisture content will induce severe stresses in the glue joints. Thin veneer will not induce such severe stresses. The proper treatment of wood for gluing has been fully discussed in other publications of the Forest Products Laboratory (10).

The combined effects of radial and tangential shrinkage change the shape of cross sections of pieces of wood as they dry (fig. 1). Round pieces that do not have the pith at the center become oval as they dry; square pieces with the rings extending diagonally from corner to corner become diamond-shaped; and square pieces with the rings parallel to two faces become oblong. Round holes bored in green wood become oval as the wood dries. Dead knots may loosen and even fall out of lumber that is being seasoned because they shrink differently than the surrounding wood.

Since wood shrinks more tangentially than radially, quarter-sawed lumber shrinks less in width but more in thickness than plain-sawed lumber. If a quarter-sawed and a plain-sawed board are placed edge to edge in the same panel, one may become thinner than the other with change in moisture content. If they are glued together one on top of the other, as in built-up or laminated construction, the stresses set up due to differences in shrinking with changes in moisture content may cause marked irregularities on the side surfaces, the glue joints to open up, or the whole block to warp, unless it is made of species in which there is little difference between radial and tangential shrinkage. Furthermore, plain-sawed lumber has a natural tendency to cup as it dries, because the position of the annual growth rings with respect to the two faces of the board is not the same.

Another effect of the difference between radial and tangential shrinkage is that logs, timbers, and other stock containing the pith almost invariably crack open in one or more places during seasoning. These cracks not only weaken timber and permit moisture and decay fungi to enter but are unsightly in finished products, such as ceiling beams, girders, and columns. The amount of such cracking differs considerably with species.

When the surfaces and ends of lumber dry considerably faster than the interior, either checks develop or the portions that dry first become set, thereby retarding the shrinkage of the portions that dry last; one typical effect is casehardening, which causes residual stresses in the lumber even when it later becomes uniformly dry. Such stresses are responsible for cupping and other deformation when the lumber is resawed or otherwise worked up. If the surfaces or ends of lumber absorb moisture more rapidly than the inner parts, the center may crack open. This happens occasionally to glued-up cores that, after drying, are close-piled under damp conditions.

Case-hardening stresses can be relieved by conditioning the lumber. The surface layers absorb moisture, become permanently compressed, and on redrying shrink more than before, thereby relieving the case-hardening stress,

"Compression set," which may be defined as the permanent compression, or crushing, of wood in swelling under confined conditions, may cause trouble. An extreme case is the loosening of barrel staves each time the barrel dries out. The hoops can be driven up tightly when the staves are dry, but if the staves are resoaked, they will become permanently compressed as the result of swelling and therefore will shrink an additional amount and loosen again when dried. Similarly, metal strapping on boxes, or any other metal parts tightly fitted to dry wood, become loose if the wood absorbs considerable moisture and dries out again.

When a dry board is fastened down with nails, absorption of moisture will cause the wood to swell against the underside of the nail head. If the nail holds in the underlying member, the wood may be compressed against the nail head. If it does not hold, the nail is pulled slightly. This process, combined with the loosening effect of the joint between the nail and the board, contributes to a general loosening and pulling of nails and they tend to work out in time. The warping of boards also contributes to the pulling of nails.

Flooring that absorbs an undue amount of moisture may become compressed and develop wide cracks between the pieces when it dries out. These cracks become filled with foreign matter, which causes further compression set each time the floor absorbs moisture, with the result that the cracks widen farther when the wood dries again (7).

The so-called "weathering" of unprotected woodwork exposed to the weather is due to the same basic principles. When the surface layers of a dry board become damp, they try to swell but are restrained by the dry interior. As a result, the surface layers of fibers become crushed somewhat. As the surface dries out again, the crushed wood shrinks more than originally causing fine cracks to open up. If this is repeated over and over again, as is the case in unpainted wood outdoors, numerous little cracks develop that not only mar its appearance but permit the deeper penetration of moisture. Although moisture will pass through protective paint, it does so slowly and, as a result, such large differences in moisture content between surface and interior layers do not develop, and serious compression set does not occur (9). Paint is particularly effective against wetting by rain, because the painted surface sheds water.

Slight differences in moisture content, especially with a gradual change, are taken care of by the elasticity of wood and do not result in permanent deformation of the cells.

"Raised grain" that occurs particularly on the bark side of dressed flat-grain softwood lumber is due to the gradual raising of the hard summerwood layers that were pounded by the planer knives into the softer springwood underneath (3) Absorption of moisture may hasten this process by causing the crushed springwood to swell.

Wood that has been mechanically compressed, as when dented by a hammer, or has collapsed in drying can be brought back largely or entirely to its original size if moistened, especially with hot water or steam, which heat the wood to about 200° F.

Minimizing Shrinkage and Swelling During and After Manufacture

The following points should be considered in the selection and preparation of lumber and in the treatment of manufactured products whenever shrinking and swelling are important.

1. Dry the wood uniformly to the proper moisture content before it is put through the wood-working machines and assembled, so that subsequently it will neither give off nor take on a great deal of moisture from, the air. What the proper moisture content is depends on conditions under which the wood is to be used. Table 2 and figure 2 show the recommended moisture content values and tolerances for wood used in interior and exterior parts of heated buildings. The values for exterior trim and siding can be applied to lumber used outdoors and in unheated buildings., Lumber for the manufacture of products such as furniture, cabinets, case goods, musical instruments, caskets, tool handles, turning stock, and sporting goods should be kiln dried to an average moisture content of between 5 and 8 percent

2. Use quarter-sawed lumber if shrinkage across the width of a board is likely to be serious. A floor made from quarter-sawed material develops narrower cracks than one made from plain-sawed material. It should be remembered, however, that quarter-sawed lumber shrinks more in thickness than does plain- sawed lumber.

3. If a minimum of change in dimensions is highly essential, select a species having low shrinkage, such as eastern white and sugar pine for patterns, and the cedars in general for boat planking. Use a wood of as light weight as will have the necessary strength, because, as a rule, the lighter kinds of wood will not shrink and swell so much as the heavier kinds.

4. Use cross-banded material, thin veneers glued together so that the grain of each layer is at right angles to that of the adjacent layer. This material represents the ultimate in reduction of shrinking and swelling in the lateral direction, although not in thickness. To avoid stresses that might cause warping, the construction should be symmetrical; that is, it should consist of an odd number of plies so arranged that for any ply of a particular thickness on one side of the center or core, there is a parallel ply of the same thickness, species, density, grain, and moisture content on the opposite side of the center ply. Wide, plain surfaces, such as table tops, counter tops, and panels should be cross banded.

5. Make allowances in construction for a reasonable amount of shrinking and swelling in use wherever possible.

6. Under certain conditions, it may be practical to use wood that has been subjected to high temperatures. This reduces the capacity of wood to absorb moisture, although the more effective the temperature, the greater also is its weakening effect on the wood.

7. Several coats of oil, paint, shellac, lacquer, varnish, enamel, or paraffin, or impregnations with linseed oil, creosote, paraffin, or other water-resisting materials will reduce the change in dimensions of wood that is subjected to variations in humidity for limited periods of time. There is, of course, considerable difference in the effectiveness of these materials and their suitability for different use conditions. If, however, the wood is to be exposed to any given humidity condition continuously, or for the greater part of the time, such treatments will not prevent the wood from ultimately coming into equilibrium with the surroundings. Protective coatings of various kinds also are advantageous in that they prevent great differences in moisture distribution, especially between the surface and the interior. Such coatings should be applied to all raw surfaces, and particularly to end-grain surfaces -- not merely to visible parts to be most effective.

For more information concerning the effect of various coatings in keeping the moisture content of wood fairly uniform, the reader is referred to other publications of the Forest Products Laboratory (1).

8. In so far as it is practical, protect the wood against extreme changes in atmospheric humidity or direct contact with water during and after manufacture. This may be done in the shop and storage room by installing humidity-control apparatus in connection with the ventilating system. For furniture and similar stock, the need usually is to raise the temperature in cold, damp rooms, so as to lower the humidity, rather than to raise the humidity because the air is too dry. If this is not feasible, simpler but less efficient precautions should be taken, such as keeping windows and doors closed in damp weather and being

careful not to place wood parts in damp rooms, near cold walls in winter, or near steam coils, radiators, or hot-air registers. These precautions should also be observed when the article is in use.

In preparing for the transportation of articles likely to be seriously affected by changes in atmospheric humidity, they should always be properly packed and entirely surrounded with oiled paper or other types of vapor barriers.

Literature Cited

1. HUNT, G. M.
   1930. Effectiveness of Moisture-Excluding Coatings on Wood. U. S. Dept. Agr. Circular 128, 22 pp., illus.

2. KOEHLER, ARTHUR, and THELEN, ROLF
   1926. The Kiln Drying of Lumber. New York, 293 pp., illus.

3. KOEHLER, ARTHUR
   1946. Longitudinal Shrinkage of Wood. Forest Products Laboratory Rept. No. R1093, 8 pp., illus. (revised).

4. MATHEWSON, J. S.
   1930. The Air Seasoning of Wood. U. S. Dept. Agr. Tech. Bull. 17 56 pp., illus.

5. RITTER, G. J. and MITCHELL, R. L.
   1952. Fiber Studies Contributing to the Differential Shrinkage of Woc Paper Industry Vol. 33, No. 10, pp. 1189-1193.

6. STAMM, A. J. and LOUGHBOROUGH, W. K.
   1942. Variation in Shrinking and Swelling of Wood. Transactions of American Society of Mechanical Engineers Vol. 64, No. 4, pp 379-386.

7. TEESDALE, L. V.
   1930. Preventing Cracks in New Wood Floors. U. S. Dept. Agr. Leaflet No. 56, 5 pp., illus. (Revision in press).

8. THELEN, ROLF
   1929. Kiln Drying Handbook. U. S. Dept. Agr. Bull. 1136, 86 pp., illus.

9. TIEMANN, H. D.
1924. Does Paint Preserve Wood? Scientific American Vol. 130, pp. 314-315.

10. TRUAX, T. R.
1929. The Gluing of Wood. U. S. Dept. Agr. Bull. 1500, 78 pp.,

Table 1.--Shrinkage values of wood based on its dimensions when green

Species	Shrinkage: Dried to 20 percent moisture content[1]			Dried to 6 percent moisture content[2]			Dried to 0 percent moisture content		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
SOFTWOODS									
Baldcypress (Taxodium distichum)	1.3	2.1	3.5	3.0	5.0	8.4	3.8	6.2	10.5
Cedar:									
Alaska- (Chamaecyparis nootkatensis)	.9	2.0	3.1	2.2	4.8	7.4	2.8	6.0	9.2
Atlantic white- (Chamaecyparis thyoides)	1.0	1.8	2.9	2.3	4.3	7.0	2.9	5.4	8.8
Incense- (Libocedrus decurrens)	1.1	1.7	2.5	2.6	4.2	6.1	3.3	5.2	7.6
Eastern redcedar (Juniperus virginiana)	1.0	1.6	2.6	2.5	3.8	6.2	3.1	4.7	7.8
Northern white- (Thuja occidentalis)	.7	1.6	2.4	1.8	3.9	5.8	2.2	4.9	7.2
Port-Orford- (Chamaecyparis lawsoniana)	1.5	2.3	3.4	3.7	5.5	8.1	4.6	6.9	10.1
Western redcedar (Thuja plicata)	.8	1.7	2.3	1.9	4.0	5.4	2.4	5.0	6.8
Douglas-fir (Pseudotsuga taxifolia):									
Coast type	1.7	2.6	3.9	4.0	6.2	9.4	5.0	7.8	11.8
Intermediate type	1.4	2.5	3.6	3.3	6.1	8.7	4.1	7.6	10.9
Rocky Mountain type	1.2	2.1	3.5	2.9	5.0	8.5	3.6	6.2	10.6
Fir:									
Subalpine (Abies lasiocarpa)	.9	2.5	3.1	2.1	5.9	7.5	2.6	7.4	9.4
Balsam (Abies balsamea)	1.0	2.3	3.7	2.3	5.5	9.0	2.9	6.9	11.2
Corkbark (Abies lasiocarpa arizonica)	.9	2.5	3.0	2.2	5.9	7.2	2.8	7.4	9.0
Grand (Abies grandis)	1.1	2.5	3.7	2.7	6.0	8.8	3.4	7.5	11.0
Noble (Abies procera)	1.5	2.7	4.6	3.6	6.6	11.0	4.5	8.2	13.8
Pacific silver (Abies amabilis)	1.5	3.3	4.6	3.7	7.8	11.0	4.6	9.8	13.8
California red (Abies magnifica)	1.3	2.4	4.1	3.2	5.8	9.8	4.0	7.2	12.2
White (Abies concolor)	1.1	2.4	3.3	2.6	5.7	7.8	3.2	7.1	9.8
Hemlock:									
Eastern (Tsuga canadensis)	1.0	2.3	3.2	2.4	5.4	7.8	3.0	6.8	9.7
Western (Tsuga heterophylla)	1.4	2.6	4.0	3.4	6.3	9.5	4.3	7.9	11.9
Larch, western (Larix occidentalis)	1.4	2.7	4.4	3.4	6.5	10.6	4.2	8.1	13.2
Pine:									
Eastern white (Pinus strobus)	.8	2.0	2.7	1.8	4.8	6.6	2.3	6.0	8.2
Jeffrey (Pinus jeffreyi)	1.5	2.2	3.3	3.5	5.4	7.9	4.4	6.7	9.9
Limber (Pinus flexilis)	.8	1.7	2.7	1.9	4.1	6.6	2.4	5.1	8.2
Lodgepole (Pinus contorta)	1.5	2.2	3.8	3.6	5.4	9.2	4.5	6.7	11.5
Table-mountain (Pinus pungens)	1.1	2.3	3.6	2.7	5.4	8.7	3.4	6.8	10.9
Ponderosa (Pinus ponderosa)	1.3	2.1	3.2	3.1	5.0	7.7	3.9	6.3	9.6
Red (Pinus resinosa)	1.5	2.4	3.8	3.7	5.8	9.2	4.6	7.2	11.5
Southern yellow:									
Loblolly (Pinus taeda)	1.6	2.5	4.1	3.8	5.9	9.8	4.8	7.4	12.3
Longleaf (Pinus palustris)	1.7	2.5	4.1	4.1	6.0	9.8	5.1	7.5	12.2
Pitch (Pinus rigida)	1.3	2.4	3.6	3.2	5.7	8.7	4.0	7.1	10.9
Pond (Pinus rigida serotina)	1.7	2.4	3.7	4.1	5.7	9.0	5.1	7.1	11.2
Shortleaf (Pinus echinata)	1.5	2.6	4.1	3.5	6.2	9.8	4.4	7.7	12.3
Slash (Pinus elliottii)	1.8	2.6	4.1	4.4	6.2	9.8	5.5	7.8	12.2
Sugar (Pinus lambertiana)	1.0	1.9	2.6	2.3	4.5	6.3	2.9	5.6	7.9
Western white (Pinus monticola)	1.4	2.5	3.9	3.3	5.9	9.4	4.1	7.4	11.8
Pinyon (Pinus edulis)	1.5	1.7	3.3	3.7	4.2	7.9	4.6	5.2	9.9
Redwood (Sequoia sempervirens):									
Old-growth	.9	1.5	2.3	2.1	3.5	5.4	2.6	4.4	6.8
Second-growth	.7	1.6	2.4	1.8	3.9	5.7	2.2	4.9	7.1

Table 1.--Shrinkage values of wood based on its dimensions when green (Continued)

Species	Shrinkage								
	Dried to 20 percent moisture content[1]			Dried to 6 percent moisture content[2]			Dried to 0 percent moisture content		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
SOFTWOODS									
Spruce:									
Black (Picea mariana)	1.4	2.3	3.8	3.3	5.4	9.0	4.1	6.8	11.3
Engelmann (Picea engelmannii)	1.1	2.2	3.5	2.7	5.3	8.3	3.4	6.6	10.4
Red (Picea rubens)	1.3	2.6	3.9	3.0	6.2	9.4	3.8	7.8	11.8
Sitka (Picea sitchensis)	1.4	2.5	3.8	3.4	6.0	9.2	4.3	7.5	11.5
Tamarack (Larix laricina)	1.2	2.5	4.5	3.0	5.9	10.9	3.7	7.4	13.6
Yew, Pacific (Taxus brevifolia)	1.3	1.8	3.2	3.2	4.3	7.8	4.0	5.4	9.7
HARDWOODS									
Alder, red (Alnus rubra)	1.5	2.4	4.2	3.5	5.8	10.1	4.4	7.3	12.6
Apple (Malus sp.)	2.0	3.5	6.1	4.7	8.4	14.7	5.9	10.5	18.4
Ash:									
Biltmore, white (Fraxinus biltmoreana)	1.4	2.3	4.2	3.4	5.5	10.1	4.2	6.9	12.6
Black (Fraxinus nigra)	1.7	2.6	5.1	4.0	6.2	12.2	5.0	7.8	15.2
Blue (Fraxinus quadrangulata)	1.3	2.2	3.9	3.1	5.2	9.4	3.9	6.5	11.7
Green (Fraxinus pennsylvanica)	1.5	2.4	4.2	3.7	5.7	10.0	4.6	7.1	12.5
Oregon (Fraxinus oregona)	1.4	2.7	4.4	3.3	6.5	10.6	4.1	8.1	13.2
Pumpkin (Fraxinus profunda)	1.2	2.1	4.0	3.0	5.0	9.6	3.7	6.3	12.0
White (Fraxinus americana)	1.6	2.6	4.5	3.8	6.2	10.7	4.8	7.8	13.4
Aspen:									
Quaking (Populus tremuloides)	1.2	2.2	3.8	2.8	5.4	9.2	3.5	6.7	11.5
Bigtooth (Populus grandidentata)	1.1	2.6	3.9	2.6	6.3	9.4	3.3	7.9	11.8
Basswood, American (Tilia americana)	2.2	3.1	5.3	5.3	7.4	12.6	6.6	9.3	15.8
Beech (Fagus grandifolia)	1.7	3.7	5.4	4.1	8.8	13.0	5.1	11.0	16.3
Birch:									
Alaska (Betula papyrifera neoalaskana)	2.2	3.3	5.6	5.2	7.9	13.4	6.5	9.9	16.7
Gray (Betula populifolia)	1.7	....	4.9	4.2	....	11.8	5.2	....	14.7
Paper (Betula papyrifera)	2.1	2.9	5.4	5.0	6.9	13.0	6.3	8.6	16.2
Sweet (Betula lenta)	2.2	2.8	5.2	5.2	6.8	12.5	6.5	8.5	15.6
Yellow (Betula alleghaniensis)	2.4	3.1	5.6	5.8	7.4	13.4	7.2	9.2	16.7
Buckeye, yellow (Aesculus octandra)	1.2	2.7	4.2	2.9	6.5	10.0	3.6	8.1	12.5
Butternut (Juglans cinera)	1.1	2.1	3.5	2.7	5.1	8.5	3.4	6.4	10.6
Catalpa, northern (Catalpa speciosa)	.8	1.6	2.4	2.0	3.9	5.8	2.5	4.9	7.3
Cherry:									
Black (Prunus serotina)	1.2	2.4	3.8	3.0	5.7	9.2	3.7	7.1	11.5
Pin (Prunus pennsylvanica)	.9	3.4	4.3	2.2	8.2	10.2	2.8	10.3	12.8
Chestnut (Castanea dentata)	1.1	2.2	3.9	2.7	5.4	9.3	3.4	6.7	11.6
Cottonwood:									
Eastern and southern (Populus deltoides and Populus deltoides virginiana)	1.3	3.1	4.7	3.1	7.4	11.3	3.9	9.2	14.1
Northern black (Populus trichocarpa hastata)	1.2	2.9	4.1	2.9	6.9	9.9	3.6	8.6	12.4

Table 1.--Shrinkage values of wood based on its dimensions when green (Continued)

Species	Dried to 20 percent moisture content[1]			Dried to 6 percent moisture content[2]			Dried to 0 percent moisture content		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
HARDWOODS									
Cucumbertree (Magnolia acuminata)	1.7	2.9	4.5	4.2	7.0	10.9	5.2	8.8	13.6
Dogwood, flowering (Cornus florida)	2.5	3.9	6.9	5.9	9.4	16.6	7.4	11.8	20.8
Elm:									
American (Ulmus americana)	1.4	3.2	4.9	3.4	7.6	11.7	4.2	9.5	14.6
Rock (Ulmus thomasii)	1.6	2.7	4.7	3.8	6.5	11.3	4.8	8.1	14.1
Slippery (Ulmus rubra)	1.6	3.0	4.6	3.9	7.1	11.0	4.9	8.9	13.8
Greenheart (Ocotea rodiaei)	1.1	1.4	2.7	2.7	3.4	6.4	3.4	4.2	8.0
Hackberry (Celtis occidentalis)	1.6	3.0	5.6	3.8	7.1	13.5	4.8	8.9	16.9
Hickory:									
Pecan (Carya cordiformis, Carya aquatica, Carya myristicaeformis and Carya illinoensis)	1.6	3.0	4.5	3.9	7.1	10.9	4.9	8.9	13.6
True:									
Shellbark (Carya laciniosa)	2.5	4.2	6.4	6.1	10.1	15.4	7.6	12.6	19.2
Mockernut (Carya tomentosa)	2.6	3.7	6.0	6.2	8.8	14.3	7.8	11.0	17.9
Pignut (Carya glabra)	2.4	3.8	6.0	5.8	9.2	14.3	7.2	11.5	17.9
Shagbark (Carya ovata)	2.3	3.3	5.6	5.6	8.0	13.4	7.0	10.0	16.7
Holly, American (Ilex opaca)	1.6	3.3	5.6	3.8	7.9	13.5	4.8	9.9	16.9
Honeylocust (Gleditsia triacanthos)	1.4	2.2	3.6	3.4	5.3	8.6	4.2	6.6	10.8
Hophornbeam, eastern (Ostrya virginiana)	2.8	3.3	6.5	6.8	8.0	15.5	8.5	10.0	19.4
Iroko (Chlorophora excelsa)	1.1	1.6	2.8	2.7	3.8	6.8	3.4	4.8	8.5
Ironbark, gray (Eucalyptus paniculata)	1.9	2.8	4.7	4.5	6.7	11.2	5.6	8.4	14.0
Khaya (African mahogany) (Khaya sp.)	1.4	1.9	2.9	3.3	4.6	7.0	4.1	5.8	8.8
Lauan, red (Shorea negrosensis)	1.1	2.7	3.9	2.6	6.4	9.4	3.3	8.0	11.7
Laurel, California- (Umbellularia californica)	1.0	2.8	4.1	2.3	6.8	9.9	2.9	8.5	12.4
Locust, black (Robinia pseudoacacia)	1.5	2.4	3.4	3.7	5.8	8.2	4.6	7.2	10.2
Madrone, Pacific (Arbutus menziesii)	1.9	4.1	6.0	4.5	9.9	14.5	5.6	12.4	18.1
Magnolia, southern (Magnolia grandiflora)	1.8	2.2	4.1	4.3	5.3	9.8	5.4	6.6	12.3
Mahogany (Swietenia macrophylla)	1.2	1.7	2.7	2.9	4.0	6.4	3.6	5.0	8.0
Mangrove (Rhizophora mangle)	1.8	....	5.3	4.3	....	12.6	5.4	....	15.8
Maple:									
Bigleaf (Acer macrophyllum)	1.2	2.4	3.9	3.0	5.7	9.3	3.7	7.1	11.6
Black (Acer nigrum)	1.6	3.1	4.7	3.8	7.4	11.2	4.8	9.2	14.0
Red (Acer rubrum)	1.3	2.7	4.4	3.2	6.6	10.5	4.0	8.2	13.1
Silver (Acer saccharinum)	1.0	2.4	4.0	2.4	5.8	9.6	3.0	7.2	12.0
Sugar (Acer saccharum)	1.6	3.2	5.0	3.9	7.6	11.9	4.9	9.5	14.9

Table 1.--Shrinkage values of wood based on its dimensions when green (Continued)

Species	Shrinkage								
	Dried to 20 percent moisture content[1]			Dried to 6 percent moisture content[2]			Dried to 0 percent moisture content		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
HARDWOODS									
Oak:									
Black (*Quercus velutina*)	1.5	3.2	4.7	3.6	7.8	11.4	4.5	9.7	14.2
Bur (*Quercus macrocarpa*)	1.5	2.9	4.2	3.5	7.0	10.2	4.4	8.8	12.7
California black (*Quercus kelloggii*)	1.2	2.2	4.0	2.9	5.3	9.7	3.6	6.6	12.1
Canyon live (*Quercus chrysolepis*)	1.8	3.2	5.4	4.3	7.6	13.0	5.4	9.5	16.2
Chestnut (*Quercus prinus*)	1.8	3.2	5.6	4.4	7.8	13.4	5.5	9.7	16.7
Laurel (*Quercus laurifolia*)	1.3	3.3	6.3	3.2	7.9	15.2	4.0	9.9	19.0
Live (*Quercus virginiana*)	2.2	3.2	4.9	5.3	7.6	11.8	6.6	9.5	14.7
Oregon white (*Quercus garryana*)	1.4	3.0	4.5	3.4	7.2	10.7	4.2	9.0	13.4
Pin (*Quercus palustris*)	1.4	3.2	4.8	3.4	7.6	11.6	4.3	9.5	14.5
Post (*Quercus stellata*)	1.8	3.3	5.4	4.3	7.8	13.0	5.4	9.8	16.2
Northern red (*Quercus rubra*)	1.3	2.7	4.5	3.2	6.6	10.8	4.0	8.2	13.5
Rocky Mountain white (*Quercus utahensis*)	1.4	2.4	4.2	3.3	5.8	10.0	4.1	7.2	12.5
Scarlet (*Quercus coccinea*)	1.5	3.2	4.6	3.7	7.8	11.0	4.6	9.7	13.8
Southern red (*Quercus falcata*)	1.5	2.9	5.4	3.6	7.0	13.0	4.5	8.7	16.3
Swamp chestnut (*Quercus michauxii*)	1.7	3.6	5.5	4.2	8.6	13.1	5.2	10.8	16.4
Swamp white (*Quercus bicolor*)	1.8	3.5	5.9	4.4	8.5	14.2	5.5	10.6	17.7
Water (*Quercus nigra*)	1.4	3.1	5.5	3.4	7.4	13.1	4.2	9.3	16.4
White (*Quercus alba*)	1.8	3.0	5.3	4.2	7.2	12.6	5.3	9.0	15.8
Willow (*Quercus phellos*)	1.7	3.2	6.3	4.0	7.7	15.1	5.0	9.6	18.9
Osage-orange (*Maclura pomifera*)	......	....	3.1	......	....	7.4	......	....	9.2
Persimmon, common (*Diospyros virginiana*)	2.6	3.7	6.4	6.3	9.0	15.3	7.9	11.2	19.1
Sassafras (*Sassafras albidum*)	1.3	2.1	3.4	3.2	5.0	8.2	4.0	6.2	10.3
Sweetgum (*Liquidambar styraciflua*)	1.7	3.3	5.0	4.2	7.9	12.0	5.2	9.9	15.0
Sycamore, American (*Platanus occidentalis*)	1.7	2.5	4.7	4.1	6.1	11.4	5.1	7.6	14.2
Tangile (*Shorea polysperma*)	1.4	3.0	4.4	3.4	7.3	10.6	4.3	9.1	13.3
Teak (*Tectonia grandis*)	.8	1.4	2.3	1.8	3.4	5.4	2.3	4.2	6.8
Tupelo:									
Black (*Nyssa sylvatica*)	1.5	2.6	4.6	3.5	6.2	11.1	4.4	7.7	13.9
Water (*Nyssa aquatica*)	1.4	2.5	4.2	3.4	6.1	10.0	4.2	7.6	12.5
Walnut, black (*Juglans nigra*)	1.8	2.6	4.3	4.4	6.2	10.2	5.5	7.8	12.8
Willow:									
Black (*Salix nigra*)	.9	2.7	4.8	2.1	6.5	11.5	2.6	8.1	14.4
Pacific (*Salix lasiandra*)	1.0	3.0	4.6	2.3	7.2	11.0	2.9	9.0	13.8
Yellow-poplar (*Liriodendron tulipifera*)	1.3	2.4	4.1	3.2	5.7	9.8	4.0	7.1	12.3

[1]These shrinkage values have been taken as one-third the shrinkage to the oven-dry condition as given in the last three columns of this table.

[2]These shrinkage values have been taken as four-fifths of the shrinkage to the oven-dry condition as given in the last three columns of this table.

Table 2.--Recommended moisture content values for various wood items at time of installation

Use of lumber	Moisture content (percentage of weight of ovendry wood) for --					
	Dry southwestern States[1]		Damp southern coastal States[1]		Remainder of the United States[1]	
	Average[2]	Individual pieces	Average[2]	Individual pieces	Average[2]	Individual pieces
	Percent	Percent	Percent	Percent	Percent	Percent
Interior finish woodwork and softwood flooring	6	4-9	11	8-13	8	5-10
Hardwood flooring	6	5-8	10	9-12	7	6-9
Siding, exterior trim, sheathing, and framing[3]	9	7-12	12	9-14	12	9-14

[1] For limiting range, see figure 2.

[2] In general, the moisture content averages have less significance than the range in moisture content permitted in individual pieces. If the moisture content values of all the pieces in a lot fall within the prescribed range, the entire lot will be satisfactory as to moisture content, no matter what its average moisture content may be.

[3] Framing lumber of higher moisture content is commonly used in ordinary construction because material of the moisture content specified may not be available except on special order.

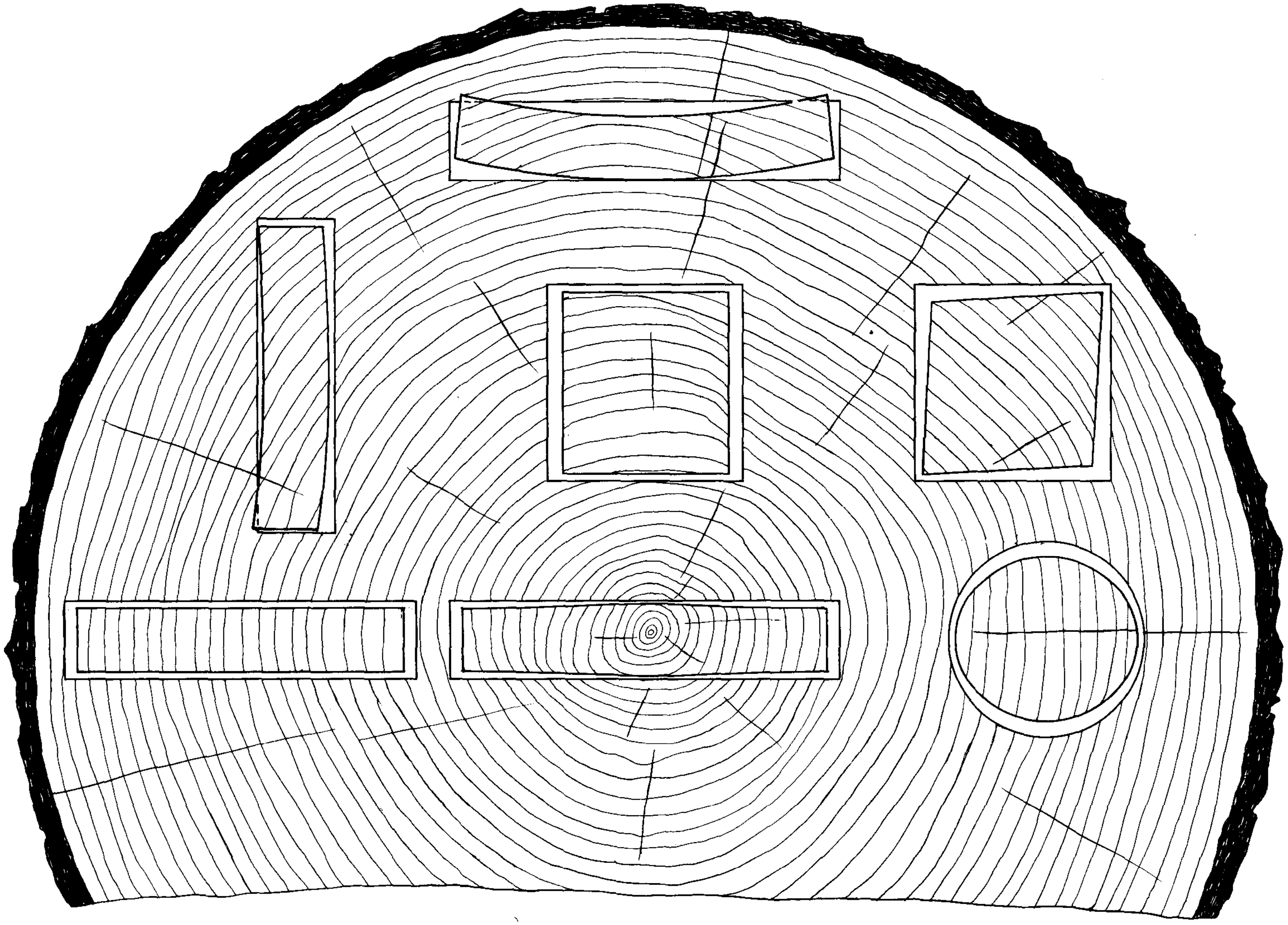

Figure 1.--Characteristic shrinkage and distortion of flats, squares, and rounds as affected by the direction of the annual rings. Tangential shrinkage is about twice as great as radial shrinkage.

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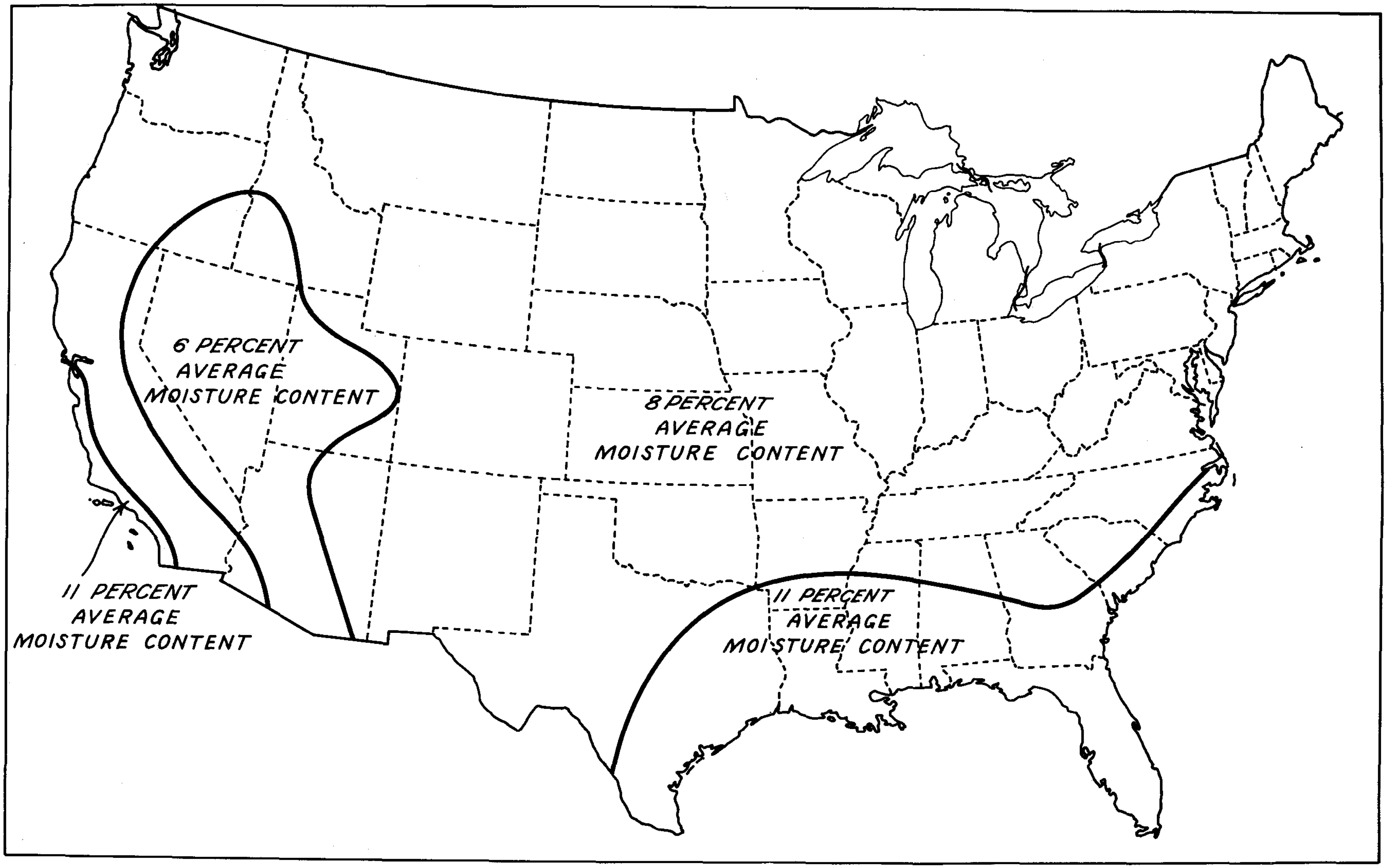

Figure 2.--Recommended moisture content averages for interior-finishing woodwork for use in various parts of the United States.

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