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# How Wood Shrinks and Swells

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**Shrinking and swelling play important roles in the utilization and seasoning of wood. The mechanics of shrinking and swelling and the influence of wood structure are discussed. Emphasis is placed on the variability of shrinking and swelling, and the chief reasons for variability. The effects of shrinking and swelling on wood during seasoning and in use are discussed, along with methods of minimizing these effects.**

## Introduction

WOOD CHANGES IN DIMENSION as its moisture content varies. During the seasoning of green or freshly sawed lumber, there is a decrease in dimension. After the seasoned wood is put in service its dimensions decrease or increase, depending on whether it loses or gains moisture. The dimensional changes in wood are brought about by the shrinking or swelling of the cells, or fibers, of which the wood is composed. Although green wood shrinks slightly as soon as drying starts, shrinking becomes more pronounced after a certain point in drying is reached. Likewise, dry wood swells when taking on water until a certain point is reached, after which little additional swelling occurs. This point, called the fiber-saturation point, is about 30 per cent moisture content for all species of wood.

Shrinkage is the cause of most of the difficulties that arise during seasoning. Both shrinking and swelling may interfere with the most efficient utilization of wood. It is essential in the handling and use of wood, therefore, to consider the primary cause of shrinking and swelling, the shrinking and swelling characteristics of different species and types of wood, the effects of shrinking and swelling, and means by which shrinking and swelling and their effects can be minimized.

## Effect of Structure of Wood Upon Shrinking and Swelling

Wood consists largely of hollow fibers or cells, most of which lie nearly parallel to the axis of the tree trunk. Chief exceptions are the wood-ray cells, which are perpendicular to the axis of the trunk. The walls of the wood cells are crystalline in structure (Fig. 1). In normal wood, most of the crystallites of the cell walls, including those of the wood-ray cells, are oriented nearly parallel to the axis of the tree trunk. The crystallites of the primary layer of the cell wall (Fig. 1) are oriented, however, so that they fall in planes perpendicular to the crystallites of the rest of the cell walls. Since the crystallites are joined end to end, they can approach or move away from each other in the lateral directions only. The crystalline structure of the cell walls, and the opposing directions of the crystallites of the primary and secondary layers of the cell walls, somewhat like cross-banded plywood, com-

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

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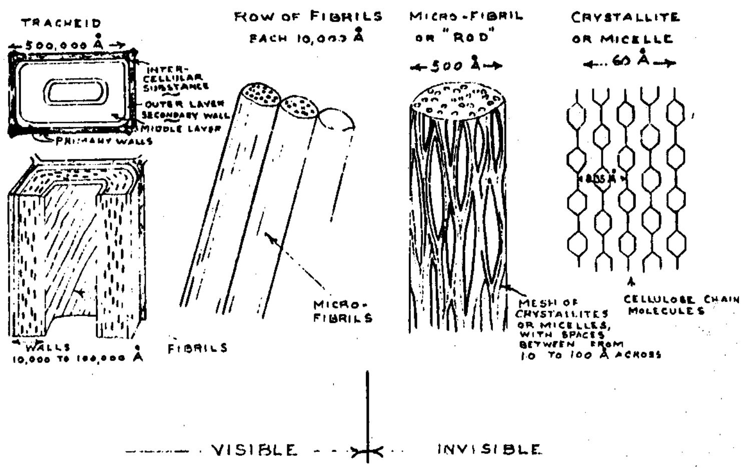

Fig. 1.-Structural details of the cell wall.

plicate the shrinkage and swelling of wood.

The open spaces, or cell cavities, within the wood cells may comprise a considerable percentage of the whole volume. For example, the cell cavities in green magnolia, a relatively lightweight wood, may equal more than 50 per cent of the total volume, while those in a heavier wood like hard maple may equal 40 per cent.

The large quantity of water that most green wood contains may be separated roughly into two parts: that contained as free water in the cell cavities and intercellular spaces of the wood, and that held as asorbed water in the capillaries of the walls of such wood elements as fibers and ray cells. The adsorbed water, which amounts to about 30 per cent moisture content based on the oven-dry weight of the wood, is of primary interest in the consideration of shrinking and swelling, because when the amount of this water is varied, the finer wood elements approach or recede from each other and thereby cause shrinking or swelling.

The crystalline structure of the cell walls of wood and the definite orientation cause most of the shrinking and swelling to occur in a transverse plane, with respect to the axis of the tree, or in tangential and radial directions with respect to the annual growth rings. Since the crystallites of the wood-ray cells are parallel to those in the main body of cells (2, 10),[2] the wood-ray cells shrink and swell principally in the same directions as do the other cells. Although wood does not shrink and swell equally in all directions, the changes in volume could be predicted if the shrinking and swelling of the cell cavities equalled that of the cell walls.

The cell walls are composed principally of two distinct layers, an outer primary layer wrapped around a considerably thicker secondary layer. The crystallites of the secondary layer are roughly parallel to the axis of the tree, while those of the primary layer are approximately perpendicular to it. The structure of the walls of the wood-ray cells is similar, but the crystallites of the secondary layers are in planes perpendicular to the axes of the wood-ray cells, and consequently parallel to the crystallites of the secondary layers of the main wood cells. The crystallites of the primary layers of the wood-ray cell walls are roughly parallel to the long axes of the wood-ray cells. It is evident that, during shrinking or swelling, the primary and secondary walls oppose each other, and the cell cavity therefore does not change in volume like the cell walls. It is also evident that the resistance of the primary walls must be overcome before the shrinking of the secondary walls can accomplish transverse shrinkage of the wood.

Numerous experimenters (1, 9, 12, and 14) have found that the cell-cavity volume tends to remain constant with shrinking or swelling of the cell walls. On this basis, the external shrinkage or swelling of a piece of wood can be determined by its specific gravity and fiber-saturation point. The equation, according to Stamm and Loughborough (13, 15), is

$$S' = df$$

in which *S* is the per cent shrinkage from the green to the oven-dry condition, *d* is the specific gravity of the wood on a dry-weight, green-volume basis, and f is the fiber-saturation point of the wood expressed as the volume of water per unit weight of the wood (in per cent), rather than the common basis of weight of water per unit weight of wood. If the fiber-saturation point is taken to be 30 per cent on a weight basis, equivalent *f* values of 27 per cent for hardwoods and 28 per cent for softwoods are derived for use in the formula, from Stamm's values of 1.115 and 1.071 for the specific gravity of water compressed between the crystallites in hardwoods and softwoods.

The changes in volume of the cell walls bring about changes in the overall dimensions of the piece of wood, thereby causing the wood to shrink or swell. This process is not a simple one, however, because of the presence of the cell cavities. The volume of the cell cavities may decrease, increase, or remain constant during changes in moisture content, and thus alter the relationship between changes in volume of the cell walls and changes in volume of the piece of wood as a whole.

## How Wood Shrinks

When a piece of wood of any appreciable thickness dries, gradients of moisture content are established. That is, surface portions that are exposed to the drying atmosphere become dry before the interior portions. When the moisture content of any portion of the wood falls below 30 per cent, its cell walls shrink and tend to reduce the overall dimension of that portion. Since the relatively dry surfaces are intergrown with the wetter interior parts, however, they are prevented from attaining their full shrinkage. As a result, tensile stresses are set up in the dry surface zones and compressive stresses in the wet interior parts. During this stage, the overall dimensions of the piece decrease slightly, because the dry surface zones shrink and the wet interior is compressed. The tensile stresses in the surface zones, and the compressive stresses in the wet interior, may cause the wood to deform more or less permanently. These deformations, called tension and compression set, complicate shrinkage. Because of set, the tensile stress that was in the surface zones at the start of drying moves progressively inward as drying progresses. At some intermediate stage in drying, both the wet interior and the dry surfaces are in compression. In the final stages of drying, the interior is in tension and the rest of the piece is in compression.

The character of the moisture-content gradients, and the consequent stress patterns set up during drying, depend on the boundary moisture-content conditions, the shrinkage coefficients of the wood, the ease with which the moisture moves through the wood, and the strength properties of the wood in compression and tension perpendicular to the grain. Strength properties are further affected by temperature and moisture content, and the effects vary with species. It is clear that the overall shrinkage of a piece of wood is influenced by the condi-

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[2] Number in parentheses refer to literature cited.

## 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 eliottii*) | 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 |
| 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 |

(CONTINUED)

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 | | | | | | | | | |
| 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 |
| 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 |
| 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 |

tions under which it is dried, and that the primary shrinkage of the cell walls merely sets in operation a series of stresses that, in combination with the resistance offered by the wood, determine the overall change in dimensions.

## Variability of Shrinkage

One of the prominent things about shrinkage is its variability. Shrinkage not only differs among the three directions of grain, tangential, radial, and longitudinal, but also among species. Table 1 gives shrinkage values determined at the Forest Products Laboratory for the wood of numerous species. Values for longitudinal shrinkage are not given because they are usually slight.

Hardwoods shrink considerably more than softwoods. Tangential shrinkage is greater than radial shrinkage, but the ratio between the two varies greatly. Also, woods with a high specific gravity generally shrink the most. Basswood, a light wood, has high shrinkage, however, while black locust, a heavy wood, has moderate shrinkage.

Shrinkage varies widely in material cut from the same species, and even in material cut from the same tree (Fig. 2 and 3). Sapwood generally shrinks less than heartwood. The springwood of an annual ring shrinks less transversely and more longitudinally than the summerwood of the same ring.

Why wood shrinks more tangentially than radially has never been explained satisfactorily. It was thought that the wood-ray cells restricted radial shrinkage because the length of the wood-ray cells lies in a radial direction. It has been found, however, that the structure of the wood-ray cells permits large lengthwise shrinkage (10, 11).

Although the wood-ray cells shrink more lengthwise than the adjacent cells, this shrinkage is less than the radial shrinkage of the other cells (3, 4, 5, and 6). Consequently, the wood-ray cells exert a restraining effect on radial shrinkage. Morschauser (6) isolated the broad rays of red oak and found a relative density factor of 0.76 compared with 1/14 for the other wood fibers. This low density and consequent weakness would tendto diminish the effect of the wood-ray cells in restraining radial shrinkage.

The difference between tangential and radial shrinkage may be caused by the inflection of the crystallites near the pits, since they occur on the radial faces of the wood fibers only (10), or by the position of the bands of

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: | | | | | | | | | |
| 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.

springwood and summerwood. Since the denser summerwood shrinks more than the lighter springwood in both the radial and the tangential direction, the radial shrinkage of the ring is the weighted average of the radial shrinkage of both types of wood. The tangential shrinkage, however, is more nearly equal to the greater tangential shrinkage of the summerwood because the summerwood, which is denser and stronger than the springwood, causes the springwood to Become compressed tangentially and to assume a dimension smaller than it would have if it were allowed to shrink independently. Pentoney (8) states that this theory proposed by Möreth largely explains the difference between tangential and radial shrinkage. Other explanations have been advanced, such as difference between the fibril angles in radial and tangential walls, differences in the thickness of the primary walls in the radial and tangential directions, and difference in the number of cross walls along the radial and tangential axes.

Although shrinkage is variable in normal wood, certain abnormal types of wood contribute to increased variability. Compression wood, which is common to softwoods, shrinks considerably more longitudinally but less transversely than normal wood. The strands of the fiber walls of compression wood make a large angle with the longitudinal axis of the fiber, rather than lying nearly parallel. Tension wood, which is found in hardwoods, also has excessive longitudinal shrinkage, although the reason has not been determined. Particularly lightweight wood of some species has a greater longitudinal shrinkage than heavier wood of the same species. This rule does not apply to light and heavy woods of different species Cottonwood, a light wood, does not shrink appreciably more lengthwise than oak, a heavy wood.

The large void volume that wood contains is subject to change by drying stresses, or possibly by liquid tension. The drying stresses are affected by the manner in which the wood is dried. Wood dried in a dry kiln at relatively high temperatures generally shrinks more than wood seasoned in a yard at relatively low temperatures. When high relative humidity is combined with high temperature, shrinkage is greatest.

Because shrinkage is highly variable, the Shrinkage of any individual piece of a certain species may vary considerably from the average for the species. The shrinkage values given in Table 1, therefore, are more applicable to large numbers of boards cut from a single species rather than to individual boards.

## Effects of Shrinkage and Swelling

Shrinkage starts as soon as any drying takes place. When a tree is felled and cut into logs, the ends and places where the bark has been knocked off begin to dry. As the drying progresses, end and surface checks may develop from the tensile stresses set up, because the shrinkage of the drying surfaces is resisted by the main bulk of the log. If the whole log were to become dry, the end and surface checks would develop into wedge-shaped cracks pointing towards the center, or pith. These cracks would not be the result of drying stresses set up by moisture gradients, but the result of the inherent difference between the tangential and the radial shrinkage of the wood. The size of the cracks that would develop is related to the difference between the tangential and radial shrinkage values for the species. The width of a single crack, at its widest point, can be calculated by the following formula:

$$C_w = \frac{\pi d}{100} (T - R)$$

where

$C_w$ = crack width in inches
d = diameter when green, in inches, or in a rectangular timber, the distance from the faces to the pith
R = radial shrinkage in per cent
T = tangential shrinkage in per cent

Because of the difference between tangential and radial shrinkage, it is difficult to dry a form such as a transverse section of a tree trunk without cracking, because the wood must assume a deformation equivalent to the width of the crack.

When the log is sawed into lumber or other items and the seasoning process starts, shrinkage begins and continues until the seasoning is complete. The width, thickness, and length are reduced from what they were in the freshly sawed state. The reduction in length is generally so slight as to be unimportant. The reduction in thickness will determine the proper setting for sawing the rough lumber to dress

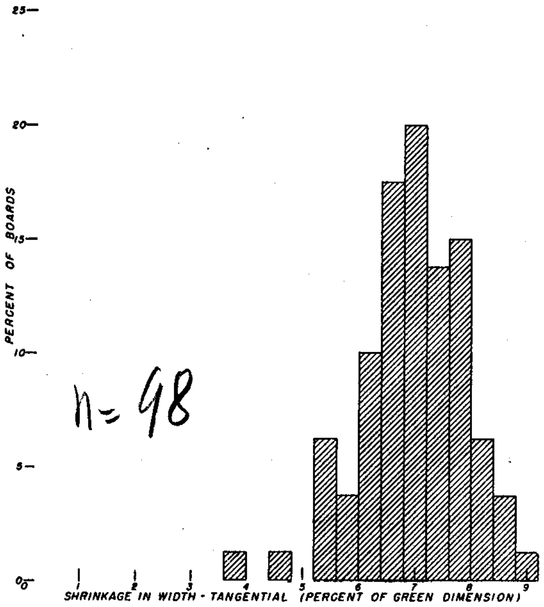

Fig. 2.—Frequency distribution of total tangential shrinkage values far plain sawed boards of longleaf pine heartwood.

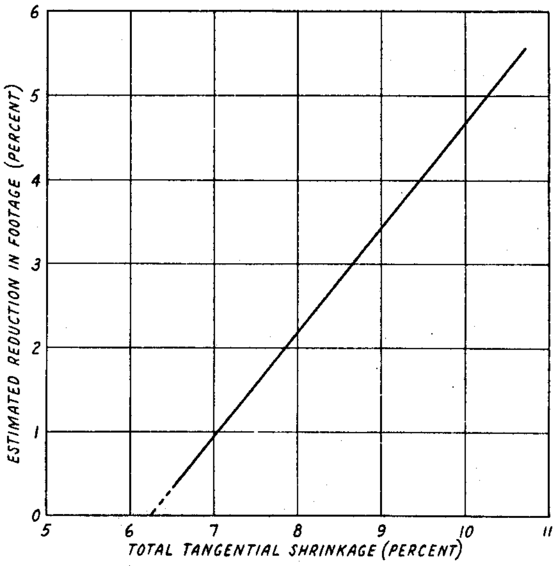

Fig. 4.—Estimated reduction in footage (per cent of air-dried tally) because of tangential shrinkage (per cent of dimension when green) for carload shipments of hardwoods when kiln dried to o moisture content of 5 per cent from an air-dried condition of 18 per cent.

to a certain finished thickness. Since quarter-sawed or edge-grained boards shrink more in thickness than plain- or flat-sawed boards, more allowance should be made for their shrinkage. The decrease in width is important with respect to the loss of footage based on the lumber scale.

Fig. 4 may be used for estimating the loss of footage. The chart is drawn on the basis of a 13 per cent moisture loss. The losses in footage may be prorated for different moisture losses. Under the conditions illustrated by this chart, lumber cut from a species whose total tangential shrinkage is not over 6 per cent should suffer no appreciable loss in footage. Edge-grained or quarter-sawed boards generally will not lose footage. Lumber shipments composed of wide boards will show a greater reduction in footage than shipments made up of narrow boards.

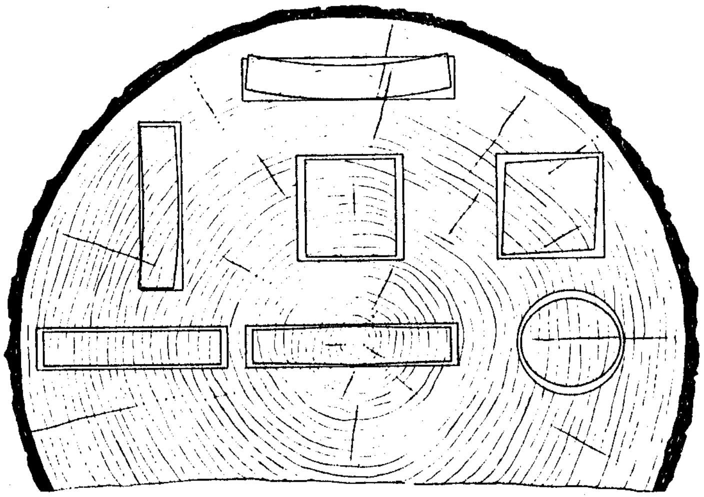

Fig. 5.—Characteristic shrinkage and distortion of flats, squares, and rounds as affected by the direction of the annual rings. The dimensional changes shown are somewhat exaggerated. Tangential shrinkage is about twice as great as radial shrinkage.

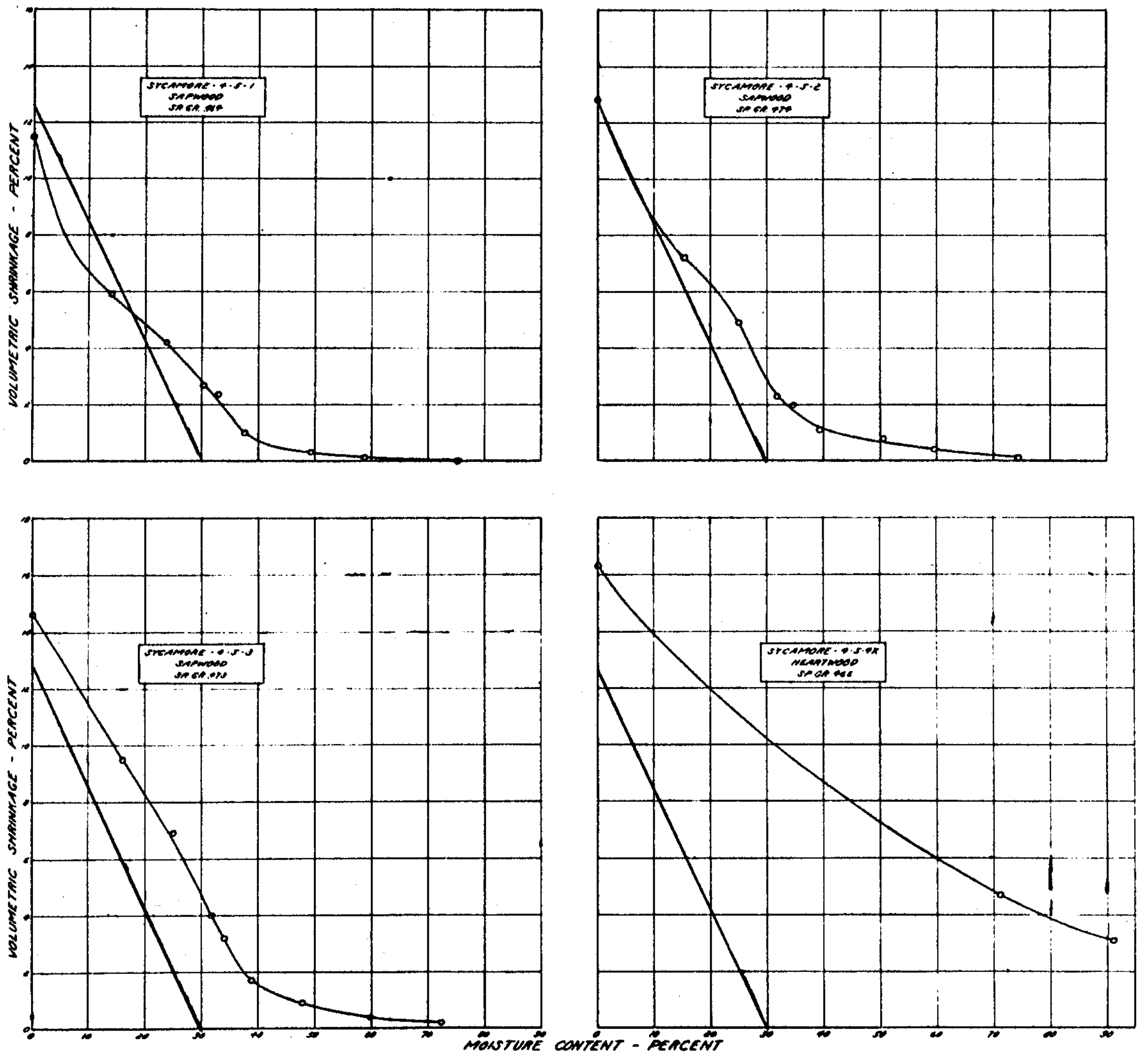

Fig. 3.—Volumetric shrinkage curves for four pieces of sycamore cut from the same radial board. The straight lines represent the calculated shrinkage, based on 30 per cent of water by weight, but 27 per cent by volume. The curved lines represent the actual shrinkage.

Shrinkage during seasoning not only causes a decrease in dimension but also causes changes in cross section and warping. Fig. 5 shows reductions in dimension and changes in cross section for various items with the annual growth rings in different positions with respect to the faces. The changes in the shape of the cross sections are caused by the difference between the tangential and radial shrinkage. Changes in cross section are also caused by set, which is the result of drying stresses. Set may cause a dry board to be thicker at the edges than in the middle, and all faces of a square to be concave.

Warp, which may be divided into cup, bow, crook, and twist, is caused by the difference in shrinkage in the three directions—tangential, radial, and longitudinal. Cup is common in flat-grained or plain-sawed boards, and all such boards would cup if permitted to dry and shrink without restraint. In a plain-sawed board, the position of the annual growth rings with respect to the two faces of the board is not the same. The result is that the outer face has a greater shrinkage potential than the face nearer the pith. Consequently, when the board dries and shrinks, the outer face tends to become concave while the opposite face tends to become convex. The tendency to cup varies inversely with the diameter of the annual rings contained in the board.

The other forms of warp, bow, crook, and twist, may be caused by spiral or diagonal grain, by localized distortions of grain, or by the presence of bands of abnormal wood. Where the wood fibers do not lie parallel or nearly parallel with the faces and edges of a board, a component of transverse shrinkage is developed that acts along the length of the board. The amount and character of warp depends on the position of the zones or areas of cross grain.

Bow, crook, or twist may also be caused by the presence of bands of wood, such as compression wood, that have abnormal longitudinal shrinkage. Wood near the pith often has abnormal longitudinal shrinkage, which is a good reason for “boxing the heart” so that the pith does not fall on one edge or face. Frequently, the wood in the outer portions of mature trees is lighter in weight than that nearer the pith. It will shrink more along the grain, and consequently may cause boards containing both types of wood to warp when they are seasoned.

Shrinkage during drying causes stresses that cause end, surface, and honeycomb checking. A check is a separation of the wood fibers that extends both radially and longitudinally. End checks appear as radiating lines. A honeycomb check is a separation of the fibers similar to an end or a surface check, but it occurs in the interior. It may or may not be a surface or end check that has closed on the surface. All checks are the result of tensile failures perpendicular to the grain. Checks generally originate at a point of weakness in the wood structure, either within the rays or at the junction of the wood-ray cells with the main body of cells, or in a resin duct. Once a check has started, it becomes longer and deeper as drying progresses.

Shakes are not generally classed as a drying defect. Failures within the springwood portion of the annual ring, or at the junction of the springwood and summerwood, are sometimes caused by drying stresses. The primary cause of such failures is radial Shrinkage. This type of failure is most common in softwoods, and principally where there is a strong contrast between springwood and summerwood. Where shakes are present in the green board, they may increase in length when the board is dried. Ring shakes are often present on the ends of logs. If they are not trimmed from the board ends, they lengthen along the board when it dries.

Shrinking and the plasticity of wood are responsible for casehardening. Casehardening is a stressed condition of wood at a low and uniform moisture content throughout its thickness. The surfaces are in compression while the interior is in tension. During the early stages of drying, the surfaces are in tension and the interior is in compression. The surfaces become stretched, in a relative sense, and the wet interior becomes compressed. The dry surfaces become set or fixed, but the compressed interior, which is still wet, retains its ability to shrink. Because of these phenomena, a piece of wood that is completely and uniformly dry may contain considerable stress. The dry wood has lost most of its plasticity and gained in elasticity, so the stresses are within the proportional or elastic limits.

Casehardening can be relieved, because deformed or set wood retains its ability to shrink or swell. The surface zones that are in compression can absorb moisture. With absorption, the plasticity of the wood is restored and a swelling force is generated. The surfaces that were already in compression are subjected to additional compressive stresses. Since the surfaces are now wet and relatively plastic, they are compressed. When they are redried, their dimensions are reduced by the amount that they were compressed. Coincident with this action, the tensile force in the interior is increased and the interior zone may be stretched. The combination of the yielding of the surfaces and the interior eliminates or reduces the stresses and thus relieves casehardening.

Knots, unless they are intergrown with the wood around them, generally loosen during seasoning. A hole drilled in a green board will become smaller laterally as the board dries, but will retain its original dimension longitudinally. The wood that surrounds a knot, however, does not resemble the wood surrounding a drilled hole. The wood fibers surrounding a knot are distorted so that the wood tends to pull away from the knot in the longitudinal direction as it dries and shrinks, but tends to tighten against the knot in the lateral direction. The knot itself shrinks with loss of moisture, thereby contributing to its loosening in the longitudinal direction of the board.

The shrinkage of softwood knots is complicated by the compression wood in the bottom portion. Compression wood shrinks more longitudinally but less laterally than normal wood. Consequently, the knot does not shrink so much laterally, or in diameter, as the wood surrounding it. This helps to keep the knot tight in the lateral direction of the board. The knot does not shrink as much lengthwise as the board shrinks in thickness, however, and it projects above the surfaces of the seasoned boards.

Intergrown knots cannot loosen, because the wood fibers of the knot are continuous with those of the board, although they are turned at a sharp angle. Intergrown knots are likely to check when they dry. The checks radiate from the pith of the knot like heart checks around the central pith of the tree. Also, knots often have bark or pitch, which becomes hard and brittle, between them and the wood of the board. Because of these factors, knots are likely to be knocked out by machining or rough handling.

One of the prime objects in seasoning is to preshrink the lumber. No matter how thoroughly lumber is seasoned, however, some shrinking and swelling in service is inevitable because wood is seldom used under constant atmospheric conditions. Since wood is hygroscopic and responds to changes in relative humidity, its moisture content is constantly changing. Wood in service generally reaches an average moisture content, and changes in relative humidity cause fluctuations about this average. The damage resulting from shrinking and swelling of wood depends on the magnitude of the change in moisture content, the shrinkage coefficients of the species, the character of the use, and the exactness of the requirements.

Large structural timbers are generally installed in a green or partially seasoned condition. The shrinkage that takes place when a large timber reaches an equilibrium moisture content is not usually important unless it causes checking and splitting, and subsequent loosening of fastenings. The shrinkage of inadequately seasoned lighter structural members, such as house framing, is highly important. Many houses are constructed so that the shrinkage of the framing members, particularly the joists, causes the central parts of the building to drop with reference to the outer walls. This may cause plaster cracks in interior partitions, distorted door openings in cross walls, and floors that are not level. Seasonal changes in atmospheric conditions within the building may cause shrinking and swelling that will result in a vertical movement of as much as $^1/_2$ inch at the attic floor level of a two-story house.

The shrinking and swelling of ties, piles, poles, and posts, which are rarely thoroughly seasoned, are generally unimportant unless large cracks or checks occur. If checks or cracks occur after preservative treatment, untreated wood may be exposed, and decay may result. Alternate shrinking and swelling cause checks and cracks to increase in size, and fastenings may then become loose.

The shrinking and swelling of low-grade lumber for rough usage is not highly important, because the conditions under which the lumber is used are not likely to bring the lumber to a low moisture content. However, such lumber should not be used green, but should be air dry. Green lumber may shrink and loosen fastenings and joints. Where wooden containers are stored in heated or dehydrated storage, the moisture content of the lumber should be below that ordinarily attained in air drying.

With furniture, interior finish, flooring, musical instruments, sash and doors, caskets, and so forth, shrinking and swelling in use are highly objectionable because of the exacting use requirements. Shrinkage of parts of furniture may cause warping, opening of joints, and checks and cracks in the finish and in the wood. Highly polished surfaces of large areas may develop depressions and ridges that are conspicuous when viewed in proper light. Shrinking of doors, paneling, or interior finish may expose unfinished wood, while shrinking and swelling may open mitered joints.

Cracks in floors are caused by shrinking and swelling. Swelling causes the flooring to be compressed if the flooring continues to absorb moisture after the cracks have become closed, and when the floor redries, the cracks will be wider than before. Dirt and grit that accumulate in the cracks increase the amount of compression. Swelling also causes floors to bulge and may displace walls and partitions. Shrinking and swelling may loosen nails and cause the floors to squeak.

The sounding boards and backs of instruments like pianos and violins often split or crack, as do the wooden parts of wind instruments.

The strength of joints is seriously affected by the shrinking and swelling of the wooden members. A glued end-to-side joint is stressed when the components shrink or swell because the grain of the two pieces is not aligned and consequently the pieces attempt to shrink or swell by different amounts in the plane of the glue line. Side-to-side glued joints may be stressed when the pieces are of different species, when the grain of the pieces does not match, or when the pieces differ in moisture content at the time of gluing.

Wood-to-metal joints, where a piece of wood is surrounded by metal or where a piece of metal is surrounded by wood, may either loosen or tighten with shrinking or swelling of the wood. A wood handle set into a metal head, such as an ax or hammer, tightens with swelling and loosens with shrinking, while the reverse is true with a metal spike or peg set into a drilled hole in a piece of wood. A driven nail or spike, where the fibers are cut across their length and turned down alongside the nail or spike, loosens with shrinkage on the two sides in contact with the turned fibers, but tightens with respect to the other two sides. A nail or spike driven into end-grain wood becomes tighter as the piece of wood shrinks. No wood-to-metal joints are permanently tight, because when the wood tightens against the metal it may be compressed and become set. When the opposite phase of shrinking or swelling takes place, the joint becomes loose.

A somewhat different type of metal-to-wood joint is represented by a board fastened down by nails. If the board is dry when fastened down, an absorption of moisture will cause the wood of the board to swell against the underside of the nailhead. If the nail holds in the underlying member, the wood of the board may be compressed against the nailhead. If the nail does not hold, it is pulled to a slight extent. This process, combined with the loosening effect of the normal wood-to-metal joint between the nail and the board, contributes to a general loosening and pulling of the nail. Warping also helps loosen the nail. This loosening is all too common, because subflooring often becomes wet during the construction of a building, and it dries and shrinks after the dry finish floor is laid.

In cross-banded construction, where the grain of some parts is usually perpendicular to the grain of others, such as plywood and panels consisting of a core, crossbands, and faces, the components are so placed that they restrict the shrinking and swelling of each other. In plywood, each veneer restrains the shrinking and swelling of adjacent veneers, and its shrinking and swelling are, in turn, restrained by the adjacent veneers. The shrinking and swelling in the two lateral directions are greatly reduced, compared to solid wood, because wood does not shrink or swell much along the grain. A panel of solid lateral-grained pieces with cross-cleats or border strips on the ends resembles plywood in that the grain of some members is perpendicular to the grain of others. Changes in moisture content cause stresses that result in warping unless the construction is finely balanced.

Shrinkage of wood in service is seldom advantageous, but swelling may be. Certain types of structures, such as boats, tanks, or containers, utilize the swelling of wood to obtain tight joints. Once a boat or tank is tightened by swelling, however, drying will cause the seams to open, although the parts may be no drier than they were at the time of assembly. This is because the planks or staves have been compressed to some extent during the swelling process.

The shrinking and swelling properties of wood are used, to a limited extent, in control apparatus. Since wood is hygroscopic, it responds to atmospheric vapor and can be used to control relative humidity. As the relative humidity becomes lower than the setting, the wood element loses moisture to the air, and the resultant shrinkage activates a mechanism to supply moisture to the air. When the relative humidity is raised, the wood element absorbs moisture and swells, thus shutting off the moisture-supply mechanism.

## Minimizing the Effects of Shrinking and Swelling of Wood in Service

The first step in minimizing the effect of shrinking and swelling is to reduce the amount of shrinking and swelling of the wood in service. Although the natural shrinkage of wood can be reduced by certain treatments, these treatments are not practical for wide application. Since a certain amount of shrinkage must be accepted, the wood should be preshrunk before it is put into use. This is accomplished by drying the lumber to a moisture content close to the midpoint of the range between the high and low ex-

Table 2.—ESTIMATED AVERAGE MOISTURE CONTENT OF THE PRINCIPAL INTERIOR WOODWORK IN 13 WIDELY SEPARATED CITIES DURING JANUARY AND JULY

| City | Moisture content of interior woodwork | |
|---|---|---|
| | July<br>Per cent | January<br>Per cent |
| Atlanta, Ga. | 11.5 | 8.5 |
| Albuquerque, N. Mex. | 6.0 | 7.0 |
| Boston, Mass. | 13.0 | 7.0 |
| Dallas, Tex. | 9.0 | 9.0 |
| Duluth, Minn. | 10.5 | 5.0 |
| Madison, Wis. | 10.0 | 6.0 |
| New Orleans, La. | 13.5 | 12.5 |
| New York, N. Y. | 12.5 | 7.0 |
| Portland, Oreg. | 9.5 | 9.0 |
| Salt Lake City, Utah | 4.0 | 7.0 |
| San Francisco, Calif. | 10.5 | 10.5 |
| Seattle, Wash. | 11.0 | 8.5 |
| Washington, D. C. | 11.0 | 8.0 |

Table 3.—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 | | Damp southern coastal States | | Remainder of the United States | |
| | Average*<br>Per cent | Individual pieces<br>Per cent | Average*<br>Per cent | Individual pieces<br>Per cent | Average*<br>Per cent | Individual pieces<br>Per cent |
| 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† | 9 | 7–12 | 12 | 9–14 | 12 | 9–14 |

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*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.

†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.

tremes attained in service. In this manner, the shrinking and swelling will be limited to that brought about by changes in moisture content above and below the midpoint. Since slight swelling is generally less objectionable than slight shrinking, the ideal moisture content at the time of installation is slightly below the midpoint of the expected moisture-content range.

The moisture-content range of wood in service depends on the exposure conditions. Temperature, relative humidity, and wetting affect the moisture-content, and relative humidity is normally the most important of the three. Table 2 gives the results of a study of the moisture content of woodwork within houses (7). The data in Table 2 provide a basis for the recommended moisture content values for house construction items (Table 3).

Although it is not always known beforehand where a product is to be used, a moisture content of about 8 per cent is suitable for interior uses in most regions of the United States. Lumber for the manufacture of products that have exacting use requirements should be kiln-dried to a moisture content of 5 to 8 per cent. Lumber that is thoroughly air seasoned to a moisture content of 12 to 15 pet cent is suitable for rough construction and noncritical use. House framing members, such as joists and studs, and subflooring and sheathing are generally air seasoned. Such items, however, will lose moisture when the house is heated, and the resultant shrinkage may cause difficulties.

In addition to proper seasoning, shrinking and swelling difficulties can be minimized by the selection of species that have a low coefficient of shrinkage. Also, quartersawed boards shrink less in width than plain-sawed boards. Therefore, a floor made from quartersawed or edge-grain material develops narrower cracks than one made from plain-sawed material.

Shrinking and swelling difficulties may be minimized by proper construction features. Plywood panels represent the ultimate in the reduction of shrinkage or swelling in the lateral directions, but not in thickness, where they shrink and swell somewhat more than solid wood. The lateral shrinkage and swelling is nearly equal in the two directions with respect to the grain of the face plies. However, the shrinkage or swelling in length along the grain of the face ply is greater than along the length of a solid board of normal wood., Boats planked with plywood sometimes develop bulges or hollows between the frames, because the plywood swells somewhat in the lengthwise direction, where strip planking laid fore and aft remains smooth.

The furniture panel, with its core, crossbands, and face veneers, represents a member in which lateral shrinking and swelling are reduced greatly, although not quite so much as in ply wood. Where pieces of wood are assembled in such a way that the grain directions of some are at right angles to each other, the connections should be made to accommodate shrinking and swelling wherever possible. Cleats should be fastened by screws in slots, rather than in tight holes, or by clips inserted into grooves. The ability of the fastenings to permit some slippage, while still holding firmly, will relieve stresses that would otherwise cause warping.

Wood is exposed to fluctuating conditions, and protective coatings and finishes of good moisture resistance reduce the range in moisture content through which the wood goes. The shorter the duration of the damp and dry periods the more effective are the coatings. During a continuous exposure to constant conditions, all protective coatings lose their effectiveness. When coatings or finishes are used, as on a table top for example, both the top and bottom should receive the same protection. If this is not done, a difference in the rate of moisture loss or pickup between the two faces may cause warping. The end-grain surfaces of items such as doors, should receive a protective coating, even though they are invisible. Likewise, interior finish and trim should be back-painted to retard changes in moisture content with changing conditions.

Wood exposed to rain and sunshine or occasional immersion in water should be protected from weathering by coatings of paint. The paint protects the surface of the wood from rapid wetting and drying. Rapid wetting and drying in succession, with the accompaying swelling and shrinking, tend to cause many minute surface checks to form, which contribute greatly to the process called weathering.

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