Water and Wood

The problems of a difficult pair

by R. Bruce Hoadley

What is the relative humidity in your workshop? Or in your garage where you are "seasoning" those carving blocks? Or in the spare room where you store your precious cabinet woods? Or for that matter, in any other room in your house or shop?

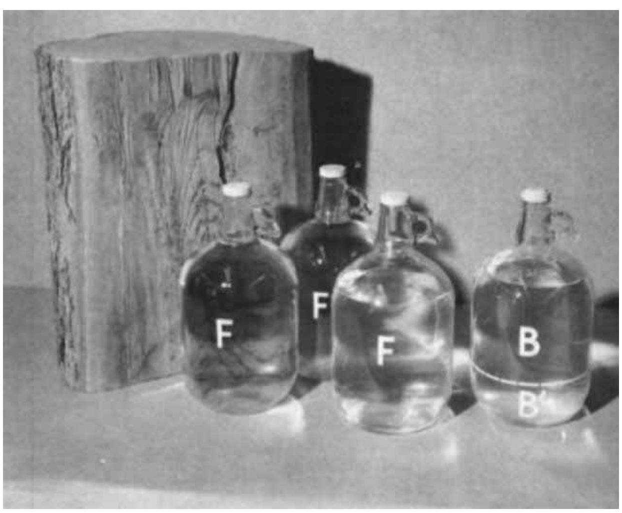
If you're not sure, you may be having problems such as warp, checking, unsuccessful glue joints, or even stain and mold. For just as these problems are closely related to moisture content, so is moisture content a direct response to relative humidity. Water is always present in wood so an understanding of the interrelationships between water and wood is fundamental to fine woodworking. In this article we'll take a look at water or moisture content in wood and its relationship to relative humidity, and also its most important consequence to the woodworker—shrinkage and swelling.

Remember that wood is a cellulosic material consisting of countless cells, each having an outer cell wall surrounding an interior cell cavity (see *Fine Woodworking,* Summer 1976). A good analogy for now is the familiar synthetic sponge commonly used in the kitchen or for washing the car. A sopping wet sponge, just pulled from a pail of water, is analogous to wood in a living tree to the extent that the cell walls are fully saturated and swollen and cell cavities are partially to completely filled with water. If we squeeze the sopping wet sponge, liquid water pours forth. Similarly, the water in wood cell cavities, called free water, can likewise be squeezed out if we place a block of freshly cut pine sapwood in a vise and squeeze it; or we may see water spurt out of green lumber when hit with a hammer. In a tree, the sap is mostly water and for the purposes of wood physics, can be considered simply as water, the dissolved nutrients and minerals being ignored.

Now imagine thoroughly wringing out a wet sponge until no further liquid water is evident. The sponge remains full size, fully flexible and damp to the touch. In wood, the comparable condition is called the fiber saturation point (fsp), wherein, although the cell cavities are emptied of water, the cell walls are fully saturated and therefore fully swollen and in their weakest condition. The water remaining in the cell walls is called bound water. Just as a sponge would have to be left to dry—and shrink and harden—so will the bound water slowly leave a piece of wood if placed in a relatively dry atmosphere. How much bound water is lost (in either the sponge or the board), and therefore how much shrinkage takes place, will depend on the relative humidity of the atmosphere.

A dry sponge can be partially swollen by placing it in a damp location, or quickly saturated and fully swollen by plunging it into a bucket of water. Likewise a piece of dry wood will regain moisture and swell in response to high relative humidity and can indeed be resaturated to its fully

This block of catalpa had a moisture content of 114% and weighed almost 60 pounds when cut. It has been dried to 8% moisture content for carving and now weighs only 30 pounds. The gallon jugs show the actual amount of free water (F) and bound water (B) which were Lost in drying. Some bound water, equivalent to B; still remains in the wood.



Average Moisture Content (Percent) of Green Wood

	HEARTWOOD	SAPWOOD
Ash, white	46	44
Beech	55	72
Birch, yellow	74	72
Maple, sugar	65	72
Oak, northern red	80	69
Oak, white	64	78
Walnut, black	90	73
Douglas fir	37	115
Pine, white	62	148
Pine, sugar	98	219
Pine, red	32	134
Redwood	86	210
Spruce, eastern	41	172

swollen condition. Some people erroneously believe that kiln drying is permanent, but lumber so dried will readsorb moisture. There is a certain amount of despair in the sight of rain falling on a pile of lumber stamped "certified kiln dried"!

It is standard practice to refer to water in wood as a certain percent moisture content. The weight of the water is expressed as a percent of the oven dry wood (determined by placing wood in an oven at 212-221°F until all water is driven off and a constant weight is reached). Thus if a plank weighed 115 pounds originally, but reached a dry weight of 100 pounds in an oven this would indicate 15 pounds of water had been present and the original moisture content would have been 15 ÷ 100 or 15%.

The fiber saturation point averages around 30% moisture content (higher in some species, lower in others). Living trees always have moisture content in excess of this level, although the moisture content (MC) may vary widely. Hardwoods commonly have original moisture contents ranging from 50 to 100%. In softwoods there is usually a noticeable difference between sapwood and heartwood; heartwood moisture content being just over the fiber saturation point whereas the sapwood commonly exceeds 100% moisture content—that is, the sapwood may be more than half water by weight.

When wood dries, all the free water is eventually lost as well as some of the bound water, depending on the relative humidity. When the bound water moisture content is in balance with the atmospheric relative humidity, the wood is said to be at its equilibrium moisture content (emc).

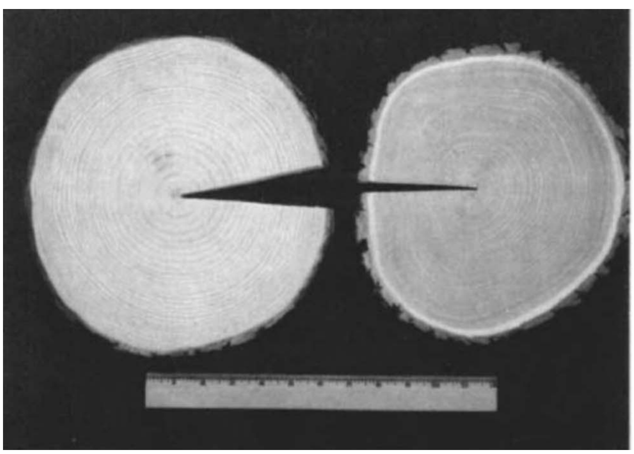
When lumber is left out-of-doors in well-stickered piles, protected from soaking rain and direct sun, it eventually becomes "air-dry". In central New England, the relative humidity (RH) averages around 77%, so air dry lumber will have a moisture content of 13 to 14%.

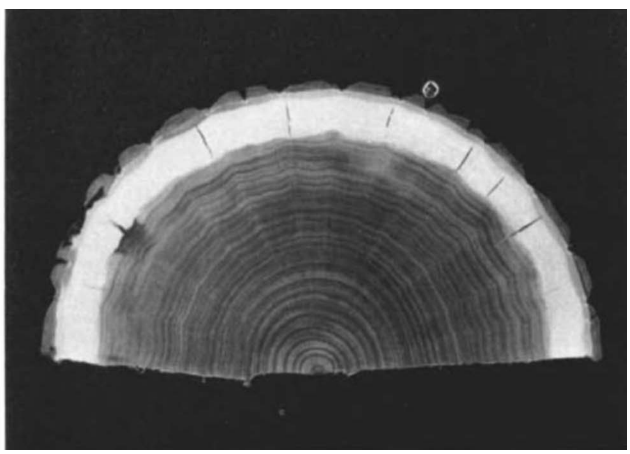
In heated buildings, in coldest winter weather, the relative humidity may drop quite low. The actual moisture content of thin pieces of wood or unprotected wood surfaces may be as low as 2 to 3%, only to return to 10 to 12% in muggy August weather. Therefore, for indoor uses, average moisture content should be attained to begin with. A moisture content of 6 to 8% is usually recommended for furniture manufacture in most northern and central regions of the United States. In the more humid southern and coastal regions the appropriate average equilibrium moisture content might be somewhat higher; in the arid southwest, somewhat lower. The only way commercially to get lumber this dry (that is, below air dry) is to dry it in a kiln; hence "kiln dried" lumber suggests this sufficient degree of drying. The drying can also be accomplished by simply leaving wood exposed indoors until it assumes the proper emc—remembering, of course, that it fluctuates as indoor relative humidity does.

Certain common terms which have been associated with drying are unfortunately misleading. "Curing" lumber suggests the involvement of some chemical reaction as in the

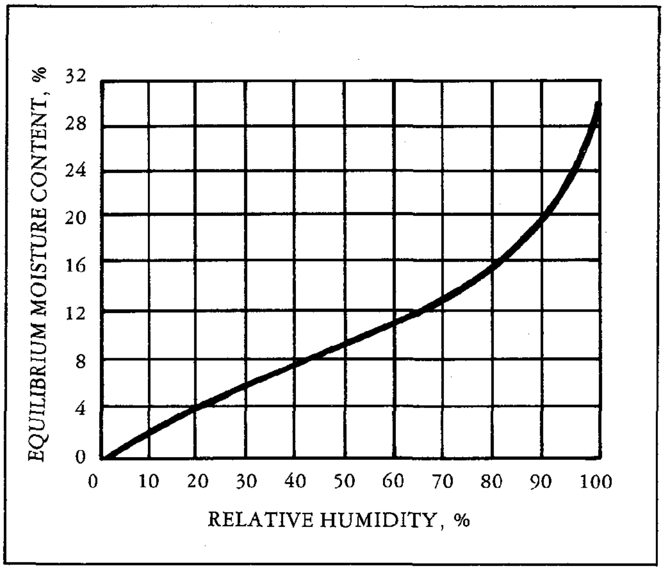
Approximate Shrinkage (as percent of green dimension) from green to oven-dry moisture content

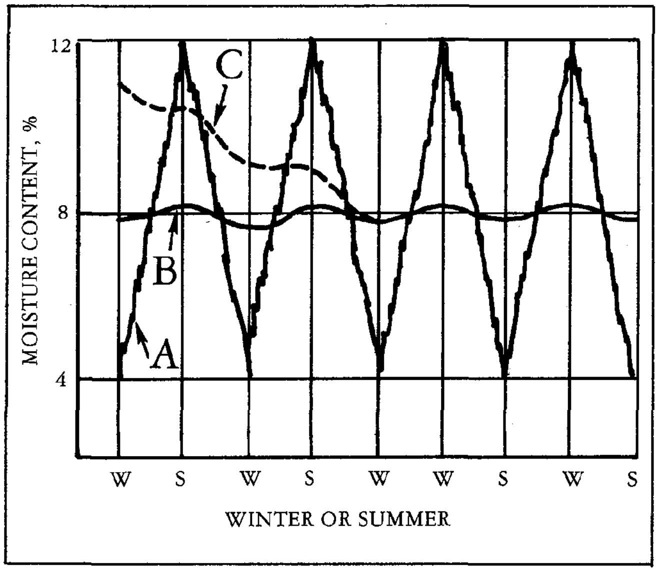
	TANGENTIAL	RADIAL	T/R
HARDWOODS			
Ash, white	7.8	4.9	1.6
Basswood	9.3	6.6	1.4
Beech, American	11.9	5.5	2.2
Birch, yellow	9.5	7.3	1.3
Butternut	6.4	3.4	1.9
Catalpa	4.9	2.5	2.0
Cherry, black	7.1	3.7	1.9
Hickory	11.5	7.2	1.6
Maple, sugar	9.9	4.8	2.0
Oak, northern red	8.6	4.0	2.2
Oak, white	10.5	5.6	1.9
Sycamore	8.4	5.0	1.7
Walnut, black	7.8	5.5	1.4
Mahogany	5.1	3.7	1.4
Teak	4.0	2.2	1.8
SOFTWOODS			
Cedar, northern white	4.9	2.2	2.2
Douglas fir	7.6	4.8	1.6
Hemlock, eastern	6.8	3.0	2.3
Pine, eastern white	6.0	2.3	2.6
Pine, sugar	5.6	2.9	1.9
Pine, red	7.2	3.8	1.9
Redwood	4.4	2.6	1.7
Spruce, red	7.8	3.8	2.1





Cross sectional discs of red pine (left) and catalpa (right) after drying to 6% moisture content. Radial slits were sawn into green discs; width of cracks indicates the relative instability of the two species. At right, the seasoning checks in a butternut half-log illustrates that shrinkage is sometimes greater in sapwood than in heartwood.





SEE ERRATA AT END OF ARTICLE

Curve at left shows the approximate relationship between relative humidity and equilibrium moisture content for most woods. At right, the curves show the seasonal indoor variation of moisture content in wood. A is unfinished thin veneers or wood surfaces, B is furniture of kiln-dried lumber and well coated with finish, and C is furniture of air-dried lumber and well coated with finish.

CALCULATING WOOD SHRINKAGE OR SWELLING

The approximate dimensional change expected in a piece of wood can be estimated by application of the following formula:

$$\Delta D = D_o \times S \times \Delta MC \div fsp$$

where ΔD = Change in dimension
D_o = Original dimension
S = Shrinkage percentage (from tables)
ΔMC = Change in moisture content
fsp = Average value for fiber saturation point, approximately 30%

Example: How much will a 14-inch wide, unfinished colonial door panel attempt to "move" (shrink and swell) if made from flat-sawed Eastern white pine?

Solution: Original dimension (width), D_o is 14 inches.
S (from tables) is 6.0% = 6/100 = 0.06
Assuming the humidity may fluctuate such that moisture content will vary from 4% in winter to 12% in summer, then $\Delta MC = 8\%$.

$$\Delta D = (14 \text{ inches})(0.06)(8\% \div 30\%) = 0.224 \text{ inches}$$

The door panel will thus attempt to change width by nearly a quarter-inch during seasonal humidity changes. Loose framing to allow the panel to move, or finishing with a moisture-impervious finish are therefore recommended.

The formula clearly suggests ways of reducing the consequences of shrinkage and swelling. For example, reducing the dimensions (D_0) of the members: Narrow flooring will surely develop smaller cracks between boards than wide flooring. Choosing a species with a small shrinkage percent (S) can obviously help; e.g. catalpa is obviously more stable than hickory. Reducing the moisture variation is best accomplished by starting with wood of the correct moisture content and giving the completed item a coat of moisture-impervious finish.

setting of resin, or the curing of hides or meat. To some persons, the term "seasoning" suggests the addition of an appropriate chemical or some special aging process to others; it probably originated in connection with certain seasons of the year when natural drying was optimum for efficiency and quality of drying. But in reality, the drying of lumber is basically a water removal operation that must be regulated to control the shrinkage stresses that occur.

The claim that lumber is kiln dried can probably assure only that the lumber has been in and out of a kiln; it does not assure that the lumber has been dried properly (to avoid stresses), that is has been dried to the desired moisture content, or that subsequent moisture regain has not taken place. On the other hand, lumber which has been kiln dried *properly* is unsurpassed for woodworking.

The woodworker's success in dealing with moisture problems depends on being able to measure or monitor either the moisture in the wood directly, or the relative humidity of the atmosphere, or both. Direct measurement of moisture content is traditionally done by placing a sample of known initial weight into an oven (212-221°F) until constant weight is reached (usually about 24 hours for 1-inch cross-sectional wafer). Reweighing to obtain oven-dry weight enables determination of moisture loss and calculation of moisture content (moisture loss ÷ oven-dry weight). By so determining the moisture content of wafers taken from the ends of a sample board, the board moisture content can be closely approximated. Simply monitoring the sample board weight in the future will then indicate changes in moisture content.

An interesting application of this idea is to suspend a wood sample of known (or approximated) moisture content from one end of a rod, horizontally suspended on a string at its balance point. As the wood looses or gains moisture, the inclination of the rod will give a constant picture of changing moisture content. Such an improvisation can be calibrated (by adding known weights) to make a "moisture meter". Of course, there are also commercially made moisture meters, which are surprisingly accurate and simple to operate and will take the guesswork out of measuring moisture content.

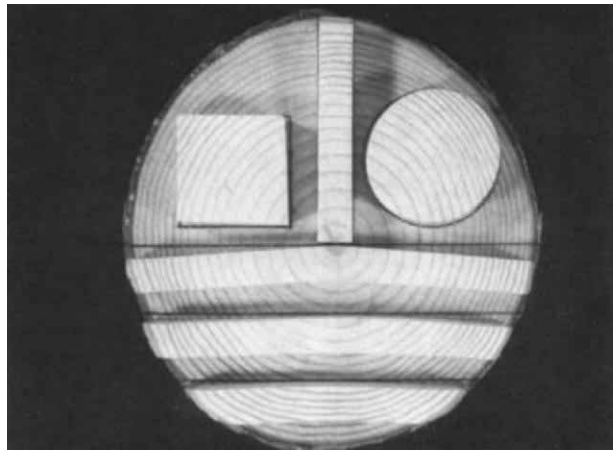
Measuring and controlling relative humidity in the shop can be equally important. Simple and inexpensive wet and dry bulb hygrometers give accurate readings. Common sense will indicate where humidifiers or dehumidifiers (or some improvised means) are necessary to control humidity. One summer I suspected the humidity in my cellar workshop was high. I distributed 1/8-inch thick spruce wafers around and after several days determined their moisture content by the oven-dry technique. To my horror it was up to 21%! I immediately installed a dehumidifier and within a few weeks the emc was lowered to about 9%.

For the woodworker, then it is important either to obtain lumber of proper dryness or to be able to dry it properly (a subject we must leave to the next issue). Further, once having dried wood to the proper moisture content and built something out of it, some consideration must be given to future moisture exchange with the atmosphere. To some extent, design should allow for lumber movement, but usually the principal measure should be that of sealing the finished piece to *prevent* exchange of moisture and avoid the highs and lows of seasonal humidity fluctuation by holding close to the original average. Somehow the notion has prevailed that "wood has to breathe". Unfortunately, the term "breathe"' suggests something positive or even necessary for the well being of the wood, but in reality, depriving wood of its tendency to adsorb and desorb moisture in response to humidity fluctuation is the best course of action.

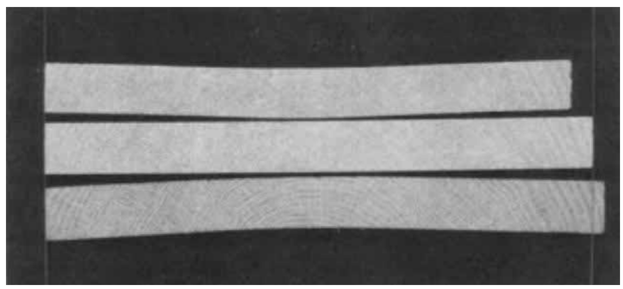
Finishing materials vary widely in their ability to seal off wood surfaces and prevent moisture exchange with the atmosphere. Among the least effective is linseed oil. So-called penetrating oil finishes vary from low to moderate in moisture excluding capability depending on resin content and, as with linseed oil, give improved results when many coats are applied. Shellac is also relatively permeable to moisture. Lacquers are even better, but modern varnishes, such as the urea alkyd or urethane types, offer the best clear-finish protection against moisture adsorption. For end sealing lumber during drying or storage, aluminum paint or paraffin provide the ultimate in moisture barriers, as do commercial end sealing compounds.

Moisture extremes—either too high or too low—sometimes give rise to problems in chemical bonding of adhesives and finishes or high moisture (above 20%) may invite mold, stain or decay. But clearly the most common trouble-maker is the dimensional change—shrinkage and swelling—which accompanies moisture variation over the range below fiber saturation point.

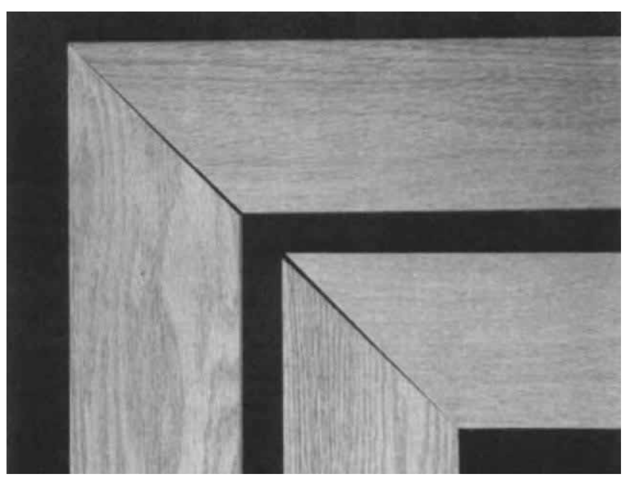
As we begin to unravel the subject of shrinkage, three considerations should be taken into stride: *when* (over what moisture content range), *where* (in what direction relative to cell structure) and *how much* (quantitively in terms of actual dimensions). In the first consideration, as with a sponge, wood shrinks (or swells) as bound water escapes (or is picked up) in seeking its balance with the atmosphere. So only moisture change below fiber saturation point (about 30% MC) results in dimensional change, which is directly proportional to the amount of moisture lost. In considering *where* and *how much,* we must leave our sponge analogy, because a sponge has similar structure and properties in all directions; wood on the other hand, has oriented structure related to the "grain



Various shapes of red pine are shown, after drying, superimposed over their original positions on an adjacent log section. The greater tangential than radial shrinkage causes squares to become diamond shaped, cylinders to become oval. Quarter sawn boards seldom warp but flat-sawn boards cup away from the pith. Camera perspective does not show full extent of shrinkage that occurred.



These three strips of wood were cut in sequence from the end of an air-dry red oak board. As shown by the middle strip, it measured 9-1/2-inch wide at a moisture content of 14 percent. The top strip has been dried to below 4 percent moisture content, the lower strip has been allowed to readsorb to over 20 percent moisture content and thus warps in an opposite direction.



These two red oak frame corners were tightly mitered when originally assembled. The upper one was dried, the lower one dampened. Since wood is stable along the grain, but shrinks and swells across the grain, joints open as shown.

direction" (predominant longitudinal cells) and to the growth rings. Longitudinal shrinkage (i.e., along the grain) is drastically different from shrinkage across the grain; shrinkage across the grain in turn is variable from the radial direction (perpendicular to growth rings) to tangential (parallel to growth rings).

Shrinkage in wood is commonly expressed as a percentage loss in dimension due to loss of bound water, that is, in drying from the fiber saturation point to the oven dry condition. Parallel to the grain, shrinkage is only about 1/10 of one percent, and in most cases can be neglected. However, in juvenile wood (near the pith) or in reaction wood (in limbs and leaning stems) longitudinal shrinkage may be up to ten times the normal amount, and variable—resulting in extreme warp.

The greatest concern is transverse (across-the grain) shrinkage, which averages about 4% radially and 8% tangentially. However, there is considerable variation among species, ranging from 2% to about 12% (see chart).

These values indicate the degree to which some species are apparently "more stable" than others. However, the greatest cause of trouble arises from the difference between radial and tangential shrinkage. As a result, cylinders of wood may become oval, squares may become diamond shaped, and flat sawn boards cup. This shrinkage difference also accounts for wood containing the pith cracking open, as anyone who has tried to dry cross-sectional discs of wood well knows. For it is impossible for wood to shrink more *around* the growth rings than *across* them without the development of stress. We also realize why edge-grain (quarter sawn) boards remain flat and shrink less across the width and are therefore preferable for many uses such as flooring.

Shrinkage in wood tissue results when water molecules leave the microstructure of the cell walls and the cellulosic structure is drawn more closely together. As sapwood transforms into heartwood, molecules of extractives (which usually give heartwood its darker color) may occupy this space and thus reduce total shrinkage. For this reason, woods with high extractive content may tend to be more stable (e.g. redwood, mahogany). At the same time, in a particular piece of wood there may be a troublesome difference between shrinkage of heartwood and sapwood, resulting in noticeable difference in shrinkage or even checking of sapwood.

The woodworker has several options and approaches, which can be applied singly or in combination, for dealing with the instability of wood. First, the wood can be preshrunk, i.e., properly dried to optimum moisture content. And secondly, the subsequent dimensional response to the atmosphere can be reduced or virtually eliminated by proper finishing. Third, sensible design can allow for dimensional change to occur without consequence; the classic example being the traditional feather-edge paneling allowed to move freely within each frame. Fourth, shrinkage and swelling can be overpowered or restrained, as the veneers making up a plywood sheet mutually do, or as the battens on a cabinet door will do. Fifth, chemical treatments may stabilize wood, although this approach is probably least convenient.

Controlling moisture content—and therefore dimensional change—involves an awareness of relative humidity and also the dimensional properties of wood. Understanding and mastering wood/moisture relationships should be looked upon as an integral part of woodworking expertise.

ERRATUM

In Fall '76, p. 22, the legend under the graph showing seasonal variations in moisture content slips out of phase at the third summer. It should continue to alternate winter-summer.