Moisture Content and Wood Shrinkage

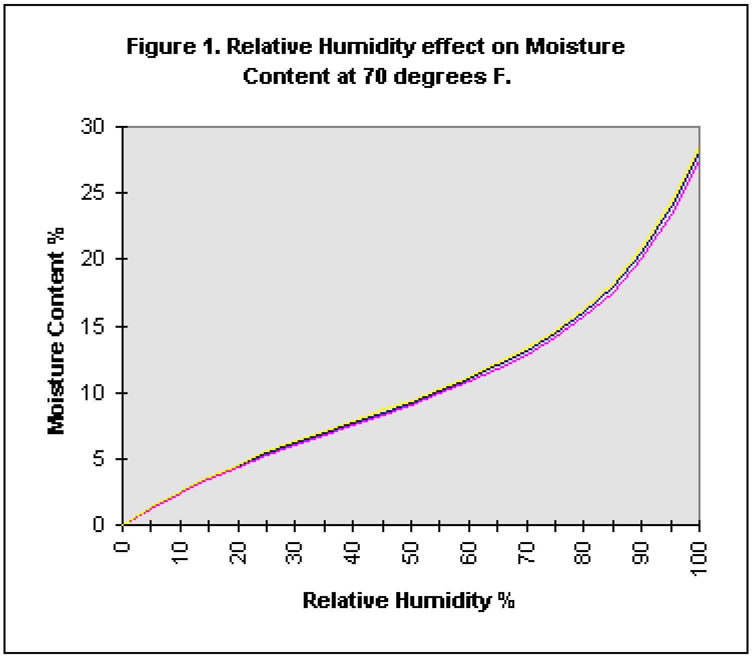
I've had these wood shrinkage tables in my "future YMMV" folder for some time, but Paul Fennell's September MCW demonstration brought them to the forefront. Last month he talked about how he deals with wood shrinkage and showed us a drying chart for a small hollow form, as well as a histogram of the T/R ratios for a large number of American hardwoods. What's that again? T/R? What's a histogram? This is the perfect lead-in to a more in-depth article on the general topics of moisture content and shrinkage in wood. Note: Drying turnings is a multifaceted and sometimes contentious topic (microwaving, alcohol soaking, soap soaking, boiling, etc.) that I won't be getting into in this article.

To talk about drying wood, we first have to understand a little bit about the internal structure of wood and about how moisture is held in wood. Visualize a handful of straws. In a living tree, the walls of the tubes, the wood fibers, are saturated with moisture, and "free" water, used to move nutrients within the tree, partially or fully fills the cavities (lumens). Technically, wood is defined as "green" when the cell wall fibers are completely saturated with water. Green wood usually contains additional free water in the lumens. Have you ever attended a turning demo where the first couple of rows got drenched? Now that's what I call green wood! That water being slung out is the "free" water.

The "moisture content" (*MC*) for a given piece of wood is defined as the weight of water held in the wood divided by the weight that piece of wood would have if it were oven dry, expressed as a percentage. In equation form, this can be written as $MC = (w - w_{od})/w_{od}$, where w is the weight of the wood with its moisture, and w_{od} is the oven-dry weight (i.e., with no moisture). In living trees, the moisture content ranges from around 30% to more than 200%. For much of the United States, the minimum moisture content of thoroughly air-dried lumber is 12-15%. Kiln-dried hardwood will usually be less than 10%.

As the moisture is reduced, the moisture content at which the cell wall fibers are completely saturated, but the cell cavities contain no water, is called the "fiber saturation point." For further drying, the loss of moisture occurs more slowly than the loss of free water and also results in a reduction in the size of the cell walls, which causes the timber to shrink in size. The fiber saturation point of wood averages around 28 percent moisture content at room temperature, but values for individual species, and individual pieces of wood, may vary significantly beyond these values, with values from 22-38% reported.

Below the fiber saturation point, the moisture content of wood is a function of the relative humidity and the temperature of the surrounding air. The "equilibrium moisture content" (EMC) is the moisture content at which the wood is neither gaining nor losing moisture -- a dynamic equilibrium that changes with ambient relative humidity and temperature. If wood is placed in an environment at an arbitrary air temperature and relative humidity, its moisture content will change until it reaches equilibrium with its surroundings. This new moisture content is the EMC of the wood for that temperature and relative humidity. If a piece of wood is dried to the oven-dry point and then exposed to a moist atmosphere, it will eventually return to the EMC for that environment. For a table of EMC as a function of air temperature and relative humidity, valid for most any wood, see www.woodbin.com/ref/wood/emc.htm. A cut from this table, showing the effect of relative humidity on moisture content at a 70-degree Fahrenheit air temperature, is seen here in Figure 1. You can see, for example, that if the relative humidity of the surrounding air is 50 percent and the temperature is 70 degrees F, the MC of the wood will be 9.2%.

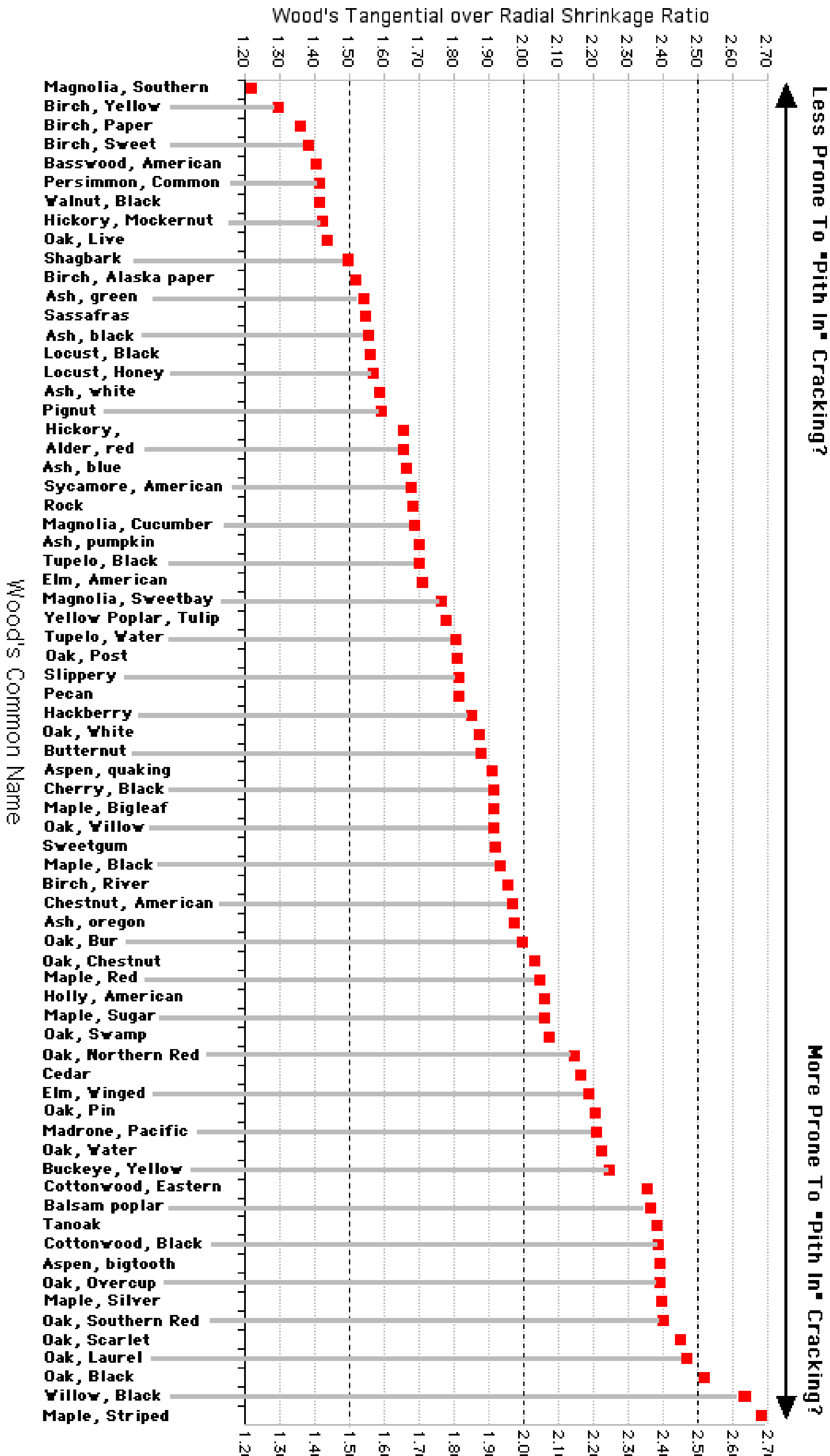


The “fiber saturation point” (FSP) is often considered as that moisture content below which the physical and mechanical properties of wood begin to change as a function of reduced moisture content. Wood is dimensionally stable when the moisture content is above the fiber saturation point. Below that point, wood shrinks when losing moisture from the cell walls and swells when gaining moisture into the cell walls. Once the FSP has been reached in the drying process, the wood will shrink in an almost linear fashion down to the point where it will no longer shrink.

Wood is an anisotropic (not homogeneous in terms of directionality) material in shrinkage characteristics. It shrinks most in the direction along, or tangential to the annual growth rings (“tangentially”). It shrinks about one-half as much across the rings (radially), because radial shrinkage is partly restrained by rays (fibers that run perpendicular to the growth rings). “Longitudinal” shrinkage, along the grain, is very small and virtually negligible. The effects of shrinkage vary, depending upon the species, thickness of the timber, the part of the log from which the member was cut, the initial moisture content, the rate of change of moisture, and the environment in which the timber is placed. As a piece of wood dries, the combined effects of this differential radial and tangential shrinkage may result in warping, checking, splitting, or performance problems that detract from the wood’s usefulness.

The shrinkage of wood is affected by species and a number of other variables such as the size and shape of the wood, the temperature, the rate of drying, and more. For some applications, the absolute tangential shrinkage (T) and radial shrinkage (R) values are important (as in sizing the rim thickness of a rough-turned bowl). One of the most important factors, however, is the species-dependent ratio of T/R. This is where we came in – with Paul Fennell’s T/R histogram last month. An ordered display of T/R ratios, for a selected set of woods, is presented in Fig. 2. Woods with low values, near the top of the chart, tend to be more dimensionally stable upon drying, while one might expect some cracking problems with the ones near the bottom.

Figure 2.



Wood's Tangential over Radial Shrinkage Ratio
1.20
1.30
1.40
1.50
1.60
1.70
1.80
1.90
2.00
2.10
2.20
2.30
2.40
2.50
2.60
2.70
Wood's Common Name
Magnolia, Southern
Birch, Yellow
Birch, Paper
Birch, Sweet
Basswood, American
Persimmon, Common
Walnut, Black
Hickory, Mockernut
Oak, Live
Shagbark
Birch, Alaska paper
Ash, green
Sassafras
Ash, black
Locust, Black
Locust, Honey
Ash, white
Pignut
Hickory,
Alder, red
Ash, blue
Sycamore, American
Rock
Magnolia, Cucumber
Ash, pumpkin
Tupelo, Black
Elm, American
Magnolia, Sweetbay
Yellow Poplar, Tulip
Tupelo, Water
Oak, Post
Slippery
Pecan
Hackberry
Oak, White
Butternut
Aspen, quaking
Cherry, Black
Maple, Bigleaf
Oak, Willow
Sweetgum
Maple, Black
Birch, River
Chestnut, American
Ash, oregon
Oak, Bur
Oak, Chestnut
Maple, Red
Holly, American
Maple, Sugar
Oak, Swamp
Oak, Northern Red
Cedar
Elm, Winged
Oak, Pin
Madrone, Pacific
Oak, Water
Buckeye, Yellow
Cottonwood, Eastern
Balsam poplar
Tanoak
Cottonwood, Black
Aspen, bigtooth
Oak, Overcup
Maple, Silver
Oak, Southern Red
Oak, Scarlet
Oak, Laurel
Oak, Black
Willow, Black
Maple, Striped
Less Prone To "Pith In" Cracking?
More Prone To "Pith In" Cracking?

It is not practical, for our purposes, to go into all aspects of what this differential wood shrinkage factor means to the woodworker, but let it just be said that T/R is often used to determine the propensity of a species to distort (woods with the larger ratios will distort more than those with smaller ratios), and it is important in understanding wood behavior before, during, and after assembly. Paul Fennell pointed out that he likes to work with mesquite because its T/R ratio is around 1.1, and its T and R values are quite small, so it doesn't shrink or distort much.

Paul works mostly with vessels in the end-grain orientation where they exhibit less distortion. Note that a bowl turned in the side-grain orientation will *always* distort because one of its diameters is longitudinal, and the other is radial. The longitudinal shrinkage from green to oven-dry condition is so small, that it can usually be ignored (only 0.1-0.2 percent for most species), while typical values of radial shrinkage, as seen in the following table, average around 5%. The combined affects of radial and tangential shrinkage may result in an even greater change in the smaller diameter.

The attached Wood Shrinkage Chart provides values of T, R, and T/R for a large number of North American hardwoods. (Similar tables for softwoods and imported exotics can be found at www.woodbin.com/ref/wood/shrink_table.htm.) The data in these tables comes originally from the USDA Forest Products Laboratory in Madison, Wisconsin. It should be noted that these values are averages, from many pieces of wood, that have been developed in laboratory testing, sometimes over many years. It is not possible to predict accurately the movement of a single piece of wood. The average of a quantity is much more predictable, and averages can be applied to most practical situations.

The Wood Shrinkage Chart for hardwoods follows on the next two pages.

Always use common sense. Things that work in one situation may not work in another. Follow all Safety Rules. If it feels wrong, it probably is; stop and rethink. ***Y****our* ***M****ileage* ***M****ay* ***V****ary*

Source: U.S. Forest Products Laboratory

Wood Species	% Radial Shrinkage	% Tangential Shrinkage	Tangential/ Radial Ratio
U. S. Hardwoods			
Alder, Red	4.4	7.3	1.7
Ash, Black	5.0	7.8	1.6
Ash, Blue	3.9	6.5	1.7
Ash, Green	4.6	7.1	1.5
Ash, Oregon	4.1	8.1	2.0
Ash, White	4.9	7.8	1.6
Aspen, Bigtooth	3.3	7.9	2.4
Aspen, Quaking	3.5	6.7	1.9
Basswood	6.6	9.3	1.4
Beech, American	5.5	11.9	2.2
Birch, Alaska Paper	6.5	9.9	1.5
Birch, Paper	6.3	8.6	1.4
Birch, River	4.7	9.2	2.0
Birch, Sweet	6.5	9.0	1.4
Birch, Yellow	7.3	9.5	1.3
Buckeye, Yellow	3.6	8.1	2.3
Butternut	3.4	6.4	1.9
California-laurel	3.0	9.0	3.0
Catalpa, Northern	2.0	5.0	2.5
Cherry, Black	3.7	7.1	1.9
Chestnut, American	3.4	6.7	2.0
Cottonwood, Balsam Poplar	3.0	7.1	2.4
Cottonwood, Black	3.6	8.6	2.4
Cottonwood, Eastern	3.9	9.2	2.4
Dogwood, Flowering	7.0	12.0	1.7
Elm, American	4.2	9.5	2.3
Elm, Cedar	4.7	10.2	2.2
Elm, Rock	4.8	8.1	1.7
Elm, Slippery	4.9	8.9	1.8
Elm, Winged	5.3	11.6	2.2
Hackberry	4.8	8.9	1.9
Hickory, Pecan	4.9	8.9	1.8
Hickory, Mockernut	7.7	11.0	1.4
Hickory, Pignut	7.2	11.5	1.6
Hickory, Shagbark	7.0	10.5	1.5
Hickory, Shellbark	7.6	12.6	1.7
Holly, American	4.8	9.9	2.1
Honeylocust	4.2	6.6	1.6
Hophornbeam	9.0	10.0	1.1
Horse Chestnut	2.0	3.0	1.5
Locust, Black	4.6	7.2	1.6
Madrone, Pacific	5.6	12.4	2.2
Magnolia, Cucumbertree	5.2	8.8	1.7

Magnolia, Southern	5.4	6.6	1.2
Sweetbay	4.7	8.3	1.8
Maple, Bigleaf	3.7	7.1	1.9
Maple, Black	4.8	9.3	1.9
Maple, Red	4.0	8.2	2.1
Maple, Silver	3.0	7.2	2.4
Maple, Striped	3.2	8.6	2.7
Maple, Sugar	4.8	9.9	2.1
Mesquite	2.2	2.6	1.1
Oak, Black	4.4	11.1	2.5
Oak, Laurel	4.0	9.9	2.5
Oak, Northern Red	4.0	8.6	2.2
Oak, Pin	4.3	9.5	2.2
Oak, Scarlet	4.4	10.8	2.5
Oak, Southern Red	4.7	11.3	2.4
Oak, Water	4.4	9.8	2.2
Oak, Willow	5.0	9.6	1.9
Oak, Bur	4.4	8.8	2.0
Oak, Chestnut	5.3	10.8	2.0
Oak, Live	6.6	9.5	1.4
Oak, Overcup	5.3	12.7	2.4
Oak, Post	5.4	9.8	1.8
Oak, Swamp Chestnut	5.2	10.8	2.1
Oak, White	5.6	10.5	1.9
Persimmon,Common	7.9	11.2	1.4
Sassafras	4.0	6.2	1.6
Sweetgum	5.3	10.2	1.9
Sycamore, American	5.0	8.4	1.7
Tanoak	4.9	11.7	2.4
Tupelo, Black	5.1	8.7	1.7
Tupelo, Water	4.2	7.6	1.8
Walnut, Black	5.5	7.8	1.4
Willow, Black	3.3	8.7	2.6
Yellow-poplar	4.6	8.2	1.8