

Wood and Moisture Relationships

J.E. Reeb

Even after being dried, solid wood products shrink and swell as they lose or gain moisture. Loss or gain of moisture also may interfere with paint adhesion and increase susceptibility to stain, decay, and insects. Many of these problems are preventable if the manufacturer or user understands wood and moisture relationships.

Structure of wood cells

Through **photosynthesis**^{*}, a tree produces the sugar glucose. Long chains of glucose form **cellulose**. Cellulose molecules combine to form **elementary fibers**, which in turn are grouped into bundles called **microfibrils**. These microfibrils form the major structural component in cell walls and play an important role in the wood-moisture relationship.

Amount of water in wood

The weight of water in living trees, freshly cut logs, and freshly sawn lumber can exceed the weight of the wood. The total amount of water in a piece of wood is called its **moisture content** (MC). Moisture content is defined as the weight of the water in the wood divided by the weight of the wood. This number is then multiplied by 100 to become a percentage.

If the weight of the water equals the weight of the wood, the MC is 100 percent. If the water weighs more than the wood, the moisture content is greater than 100 percent. Moisture content for freshly cut logs and undried lumber ranges from 45 to greater than 200 percent.

Forms of water in wood

Water in wood takes two forms—free water and bound water (Figure 1). **Free water** exists as liquid and vapor in cell cavities

^{*}Technical terms are printed in bold at their first use and are defined in the glossary (pages 6–7).

(**lumens**). **Bound water** is part of the cell wall materials.

Wood is **hygroscopic**. This means the attraction between dry wood and water is so strong it is impossible to prevent moisture gain. Water easily binds with the cellulose fibers (microfibrils) in the cell wall (Figure 2).

As wet wood dries, free water leaves the lumens (cell cavities) first. Free water resembles liquid in a bucket.

When you dump water out of a bucket, the bucket does not change shape. Similarly, wood does not shrink as it loses free water from the lumen.

After all the free water is gone and only bound water remains, the cell has reached its **fiber saturation point** (fsp). At this point, no water is present in the cell lumen, but the cell wall is completely saturated. It can hold no more water between the microfibrils. You can

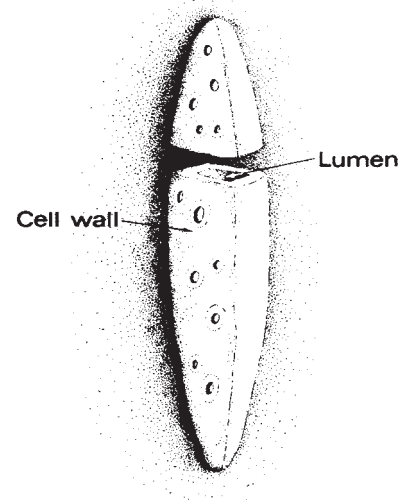


Figure 1.—Free water is found in the cell lumen. Bound water is held between microfibrils in the cell wall.

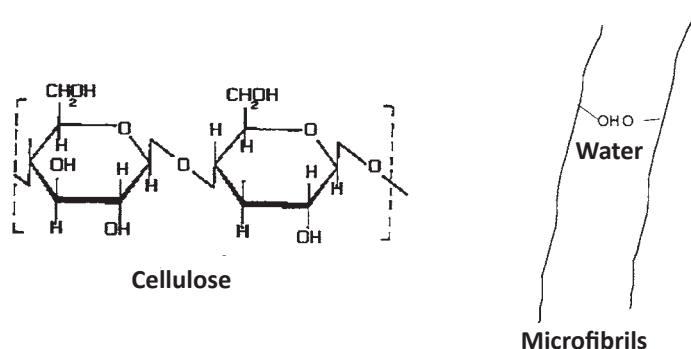


Figure 2.—Bound water is attracted to and held between microfibrils in the cell walls by hydrogen bonding.

remove water from wood cells fairly easily up to the fsp.

Fsp occurs at the cell level. At any given time, some cells in a wood product may be at the fsp while others are not. It would be unreasonable to expect all cells in a large piece of wood to be at their fsp at the same time.

As wood is dried further, bound water leaves the cell wall, and cells start to lose moisture below the fsp. As water leaves and the microfibrils come closer together, shrinking occurs (Figure 3).

When moisture is added to wood, the process is reversed. First, water enters the spaces between the microfibrils in the cell wall. The wood swells as the microfibrils are forced apart.

Once the fsp is reached, excess moisture re-enters the wood lumens and is held like water in a bucket. This water does not force the microfibrils apart since they are as far apart as possible at the fsp. Wood does become heavier as moisture is added above the fsp but it does not swell any further.

Fsp for most wood species falls in the range of 25 to 30 percent MC. Some wood species have higher **extractive** contents (organic compounds in the lumens and between the microfibrils of the cell wall). These woods have lower fsp. For example, redwood has an fsp of about 22 percent, but birch has an fsp as high as 35 percent.

The important thing to remember is that wood shrinks as the moisture content of most cells falls below the fsp. If moisture is added, wood swells until the moisture content of most cells reaches the fsp.

For example, if water is removed from a wood product with an MC of 50 percent, it will not start shrinking until most of its cells are at the fsp or below, probably about 30 percent MC. If water is added to a wood product with an 18 percent MC, it will continue to swell until most of its cells are at the fsp, about 30 percent MC.

Temperature and humidity

Relative humidity is the ratio of the amount of moisture in the air to the total amount of moisture the air can hold at that temperature. **Absolute humidity** is the actual

measure of moisture in a given volume of air (measured in English units of grains/ft³).

Heating air increases its ability to hold moisture. When we heat our home or office, the air can hold more water. Therefore, the relative humidity decreases. Absolute humidity, on the other hand, remains the same; we have not changed the actual amount of moisture in the air.

Cooling air decreases its ability to hold moisture. Therefore, as air cools, absolute humidity remains the same, but relative humidity increases.

Humidity is important because wood products exchange water molecules with the surrounding air according to the level of *relative* humidity.

How wood dries

Wood reaches an **equilibrium moisture content** (EMC) in relation to the relative humidity of its surroundings. The EMC is defined as that MC where the wood neither gains nor loses moisture. As relative humidity increases, the EMC also increases, i.e., more moisture is held in the wood. Table 1 (page 3) shows how relative humidity affects the EMC.

As an example, consider a wood product dried to an MC of 12 percent and then introduced into an environment with relative

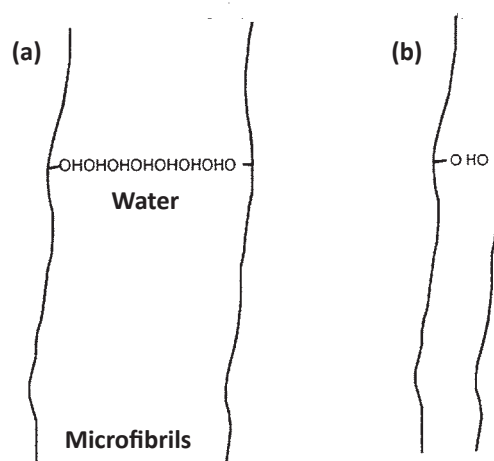


Figure 3.—Two microfibrils: (a) The bound water causes the cell wall to swell. (b) The lack of bound water causes the cell wall to shrink. For illustration, only one chain of water molecules is shown in each illustration. In an actual cell wall, chains would be attached along the length of the microfibrils.

humidity of about 20 percent. The wood eventually will reach an MC of about 4 percent. This means the wood will lose moisture from 12 percent MC to 4 percent MC. Since the wood already is below the fsp, it will shrink.

As wood dries, it shrinks differently in different directions (Figure 4). The greatest shrinkage occurs parallel to the growth rings. This is called the **tangential** surface. Wood shrinks about 8 percent along this surface as it dries from fsp to 0 percent MC. Thus, a 10" wide quartersawn board dried from fsp (assume 30 percent MC) to 15 percent MC would shrink about 0.4" in width. This same board would shrink almost 1" (0.8") in width if dried to 0 percent MC.

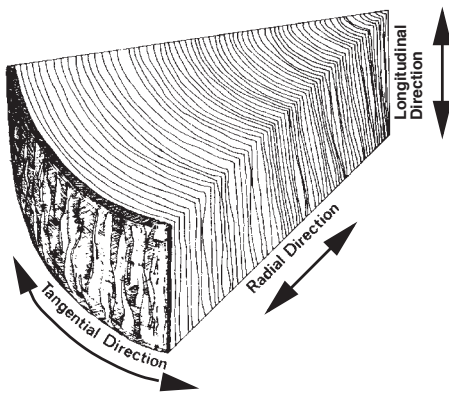


Figure 4.—The greatest shrinking and swelling of wood occurs in the tangential direction. The least shrinking and swelling occurs in the longitudinal direction. An intermediate amount of shrinking and swelling occurs in the radial direction.

An intermediate amount of shrinkage occurs perpendicular to the growth rings. This is called the **radial** surface. Wood shrinks about 4 percent along the radial surface as it dries from fsp to 0 percent MC. A 10" wide flatsawn board dried from fsp (assume 30 percent MC) to 15 percent MC would shrink about 0.2" in width. This board would shrink about 0.4" in width if dried to 0 percent MC.

The least shrinkage occurs along the long axis of the tree, that is, along the grain of the wood product. Wood shrinks about 0.1 percent longitudinally as it dries from fsp to

Table 1.—EMCs at different humidities for 30° to 90°F.

RH	10	20	30	40	50	60	70	80	90
EMC	2–3	4	6	7–8	9–10	10–11	12–13	15–16	20–21

0 percent MC. A 20' board dried from fsp to 0 percent MC would shrink only about 0.24", or less than ¼".

Because wood put in use is not dried to 0 percent MC, there is even less shrinkage. Thus, for most applications, longitudinal shrinkage is negligible.

However, **juvenile wood** (first wood produced in new stems) and **reaction wood** (in leaning trees) can exhibit as much as 2 percent longitudinal shrinkage (up to 20 times that of normal wood). Lumber with juvenile or reaction wood often exhibits **warp**, especially **bow**, **crook**, and **twist**, as it dries or after it is put in use (Figure 5).

Remember, the shrinkage percentages are approximate. They differ somewhat between species and even within the same species. Also, because moisture never is removed completely from wood to be put in use, shrinkage is somewhat less than would occur with drying to 0 percent MC.

Table 2 (page 4) shows shrinkage values for common Oregon species. Only radial and tangential shrinkage values are shown. Longitudinal

shrinkage is minimal unless juvenile or reaction wood is present.

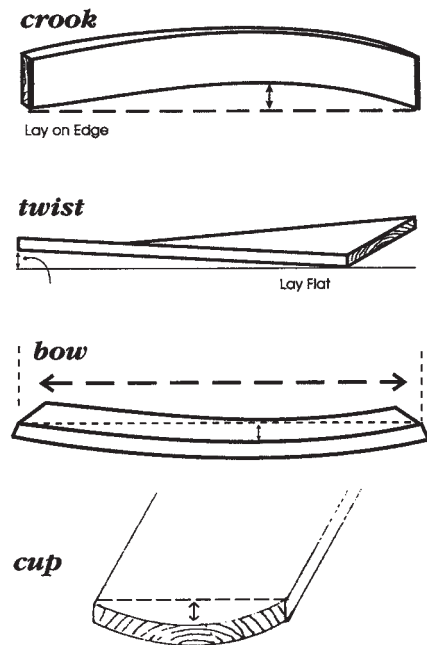


Figure 5.—Various kinds of warp.

How to measure moisture content

The easiest way to determine moisture content is to use a moisture meter. However, the most accurate way is to use the oven-dry method.

Using the oven-dry method

Follow these steps to use the oven-dry method to determine moisture content:

1. Before you dry the wood, weigh a sample to obtain the combined weight of the wood and the water. Record the weight.
2. Dry the sample in an oven at 218°F (103°C). This is just above the boiling point of water. Dry the wood for approximately 24 hours. Be careful not to burn or char the wood.
3. Weigh the wood sample again and record the weight.
4. Repeat steps 2 and 3 until you get the same weight twice in a row. The wood sample now is **oven dry** (OD), sometimes referred to as **bone dry**.
5. Use the following equation to determine the MC percent of the wood:

$$\frac{\text{weight of wood before drying} - 1 \times 100}{\text{oven-dry weight}} = \text{MC\%}$$

For example, if the wood weighs 200 grams before drying and 75 grams after drying, the equation would be:

$$\frac{200 \text{ g} - 75 \text{ g}}{75 \text{ g}} \times 100 = 166.7\%$$

If the water and wood weigh exactly the same, the MC is 100 percent. If the water weighs more than the wood, the MC is greater than 100 percent; if the water weighs less, the MC is less than 100 percent.

Table 2.—Shrinkage values of some Oregon wood species based on their dimensions when green.*

Species	Dried to 20% MC		Dried to 6% MC		Dried to 0% MC	
	Rad	Tang	Rad	Tang	Rad	Tang
Incense Cedar	1.1	1.7	2.6	4.2	3.3	5.2
Port-Orford Cedar	1.5	2.3	3.7	5.5	4.6	6.9
Western Redcedar	0.8	1.7	1.9	4.0	2.4	5.0
Douglas-fir (coast)	1.6	2.5	3.8	6.1	4.8	7.6
Douglas-fir (west)	1.6	2.5	3.8	6.0	4.8	7.5
Douglas-fir (north)	1.3	2.3	3.0	5.5	3.8	6.9
Western Hemlock	1.4	2.6	3.4	6.2	4.2	7.8
Ponderosa Pine	1.3	2.1	3.1	5.0	3.9	6.2
Sugar Pine	1.0	1.9	2.3	4.5	2.9	5.6
Redwood (old growth)	0.9	1.5	2.1	3.5	2.6	4.4
Redwood (second growth)	0.7	1.6	1.8	3.9	2.2	4.9
Red Alder	1.5	2.4	3.5	5.8	4.4	7.3
Oregon Myrtle	1.0	2.8	2.3	6.8	2.9	8.5
Pacific Madrone	1.9	4.1	4.5	9.9	5.6	12.4
Bigleaf Maple	1.2	2.4	3.0	5.7	3.7	7.1
California Black Oak	1.2	2.2	2.9	5.3	3.6	6.6
Tanoak	1.6	3.9	3.9	9.4	4.9	11.7

*Table values are percent.

You can find more information on the oven-dry method in the *Dry Kiln Operator's Manual* (see "For more information," below).

Using a moisture meter

There are two general types of moisture meters—conductance-type and dielectric-type.

Conductance-type meters have prongs that are driven into the wood. They register the wettest point between the prongs.

Many conductance-type meters use insulated-pin electrodes. All but the tips of the prongs are covered with a tough insulating resin. You can start at the surface and take successive readings as you hammer the prongs into the board.

Dielectric-type moisture meters have a flat plate on the bottom. The wood surface is penetrated by an electric field as you run the plate slowly across the board. The average moisture content registers on a meter. Depending on design, different dielectric-type meters read to different depths.

Dielectric-type meters are more accurate for thinner lumber such as 4/4 (1"). In thicker lumber, there can be a wide variation in moisture readings throughout the wood. In these cases, it usually is more important to know the wettest areas than an average. Therefore, a conductance-type meter is more useful for thicker lumber.

The characteristics affecting all moisture meter readings are species, density, moisture distribution, thickness, and temperature. Manufacturers explain how to adjust for these factors based on the meter you use. A partial list of suppliers of moisture meters is listed at the end of this publication.

Some guidelines for working with wood

1. Use wood dried to the proper MC. It should have an MC equal to the EMC where it will be used.
 - For products to be used inside heated buildings, use wood with an MC of about 7 percent.
 - Wood used for framing or other construction purposes should be dried

below 20 percent MC. Wood below 20 percent MC is less susceptible to fungi and insect attack and generally is stronger.

There is a trade-off, however. Drying wood to a lower MC may cause greater shrinkage and, especially if the piece contains juvenile or reaction wood, a greater potential to warp.

2. After manufacturing, protect wood products from gaining or losing moisture while they are stored or shipped.
3. Always finish interior wood products with a good coating of paint or varnish. Although this will not completely stop moisture exchange between the air and the wood, it will slow it considerably and greatly reduce the MC variation. Remember to seal all surfaces, not just the top and sides.
4. After the wood product is put in use, avoid direct sun and precipitation if possible. For outside uses, roof overhangs and adequate foundations are important. If wood will receive direct sun or precipitation, allow for shrinking and swelling in the design of the product.

Unfinished wood exposed to direct sunlight will "weather." The wood turns grayish in color as ultraviolet (UV) rays cause the surface of the wood to break down.

Applying wood finishes and sealers containing UV inhibitors can help prevent this breakdown. For added protection, use a finish that contains UV inhibitors, a fungicide, and a water repellent. These finishes and sealers are sold under several brand names at most home centers.

For more information

- Schniewind, Arno P., ed. *Concise Encyclopedia of Wood and Wood-based Materials* (New York: Pergamon Press, 1989). 354 pp.
- Dry Kiln Operator's Manual* (USDA Forest Service, Forest Products Lab, 1988). 319 pp.
- Panshin, A.J. and C. de Zeeuw. *Textbook of Wood Technology* (San Francisco: McGraw-Hill Book Co., 1970). 705 pp.

William, J.L. *Electric Moisture Meters for Wood*
(USDA Forest Service, Forest Products
Lab, 1988, FPL–GTR–6). 17 pp.

Partial list of moisture meter suppliers

This is only a partial list of suppliers. This list does not mean the Oregon State University Extension Service either endorses these companies' products or intends to discriminate against companies not mentioned.

Bailey's

P.O. Box 550
44650 Hwy 101
Laytonville, CA 95454
Phone: (707) 984-6133
Fax: (707) 984-8115

Delmhorst Instrument Company

51 Indian Lane East
Towaco, NJ 07082
Phone: (201) 334-2557
1-800-222-0638
Fax: (201) 334-2657

Forestry Suppliers, Inc.

205 W. Rankin Street
P.O. Box 8397
Jackson, MS 39284-8397
Phone: 1-800-647-5368
Fax: 1-800-543-4203

Lignomat USA, Ltd.

14345 N.E. Morris Ct.
P.O. Box 30145
Portland, OR 97230
Phone: (503) 257-8957
1-800-227-2105

Valley Products and Design, Inc.

P.O. Box 396
Route 418
Milford, PA 18337
Phone: (717) 296-8009

Wagner Electronic Products

360 Pine Grove Rd.
Rogue River, OR 97537
Phone: (503) 582-0541
Fax: (503) 582-4138

Glossary

Absolute humidity—The actual quantity of moisture in the atmosphere. Often expressed as grains/ft³.

Bound water—Water held within the wood cell wall material. Wood does not shrink until after bound water starts to leave the cells.

Bone dry—Wood at zero moisture content. Not a natural state for wood. As soon as bone-dry wood is exposed to air, it will take in moisture.

Bow—A form of warp. Bow describes a deviation flatwise from a straight line drawn from end to end of a board. If the board is laid flat on a wide face, the ends of the board will be off the ground.

Cellulose—Principal component of wood. Cellulose is made up of long strings (about 10,000 units) of glucose molecules.

Crook—A form of warp. Crook describes a deviation edgewise from a straight line drawn from end to end of a board. If the board is laid on its edge (narrow face), one or both edges will be off the ground.

Cup—A form of warp. Cup describes a trough-like shape with the board edges remaining approximately parallel to each other.

Elementary fibers—The smallest structural organization of cellulose molecules in a wood cell wall.

Equilibrium moisture content—The balance of moisture content wood attains in response to the relative humidity and temperature of the surrounding atmosphere.

Extractives—Chemically diverse organic compounds found in cell lumens and between microfibrils in the cell wall. No one knows exactly how extractives form.

Fiber saturation point—The stage in the drying or wetting of wood when the cell walls are saturated with bound water, and the cell cavities are free of liquid water. Fiber saturation point for most wood species occurs at moisture contents of about 25 to 30 percent.

Free water—Liquid water and water vapor in the cell cavities of wood.

Hygroscopic—A material that exhibits such a strong attraction to water it is impossible to prevent moisture gain. Dry wood is hygroscopic.

Juvenile wood—Wood formed during the first years of tree growth and extending out several rings from the pith. It is related to the age of the cambium layer and not to a certain area of the cross section of the tree. Juvenile wood exhibits more longitudinal shrinkage than mature wood. This natural flexibility allows a young stem to bend rather than to be rigid and possibly break.

Lumen—Cavity of a wood cell where free water is held.

Microfibril—A bundle of cellulose chains joined into a lattice-like structure. It is the smallest natural unit of cell wall structure distinguishable with an electron microscope.

Moisture content (of wood)—The weight of the moisture in wood, usually expressed as a percentage of its oven-dry weight.

Oven dry—See bone dry, above.

Photosynthesis—Manufacture of simple sugars by green plant cells using solar energy. The sugars are formed from carbon dioxide and water. Oxygen is a by-product.

Relative humidity—The ratio of the amount of moisture in the air to the maximum amount of moisture it could hold at that temperature.

Reaction wood—Wood formed in leaning trees. In softwoods, it forms under the lean and is called compression wood. In hardwoods, it forms above the lean and is called tension wood. Reaction wood is formed by the tree to upright itself.

Twist—A form of warp. Twist describes a lengthwise “twisting” of a board in which one corner twists out of the plane of the other three.

Warp—Distortion in lumber and other wood products causing departure from its original plane. Common forms of warp are bow, crook, cup, and twist.