Wood

This is one of the oldest and the most widely used structural material. It is a composite of strong and flexible cellulose fibers (linear polymer) surrounded and held together by a matrix of lignin and other polymers. The properties are anisotropic and vary widely among types of wood. Wood is ten times stronger in the axial direction than in the radial or tangential directions.

Mechanical Properties of Wood

Orthotropic Nature of Wood

Wood may be described as an orthotropic material; that is, it has unique and independent mechanical properties in the directions of three mutually perpendicular axes: longitudinal, radial, and tangential. The longitudinal axis L is parallel to the fiber (grain); the radial axis R is normal to the growth rings (perpendicular to the grain in the radial direction); and the tangential axis T is perpendicular to the grain but tangent to the growth rings.

Elastic Properties

Twelve constants (nine are independent) are needed to describe the elastic behavior of wood: three moduli of elasticity E, three moduli of rigidity G, and six Poisson's ratios. General relations between stress and strain for a homogeneous orthotropic material can be found in texts on anisotropic elasticity.

Modulus of Elasticity

Elasticity implies that deformations produced by low stress are completely recoverable after loads are removed. When loaded to higher stress levels, elastic deformation or failureoccurs. The three moduli of elasticity, which are denoted by EL, ER, and ET, respectively, are the elastic moduli along the longitudinal, radial, and tangential axes of wood. These moduli are usually obtained from compression tests; however, data for ER and ET are not extensive. Average values of ER and ET for samples from a few species are presented in Table 4–1 as ratios with EL; the Poisson's ratios are shown in Table 4–2. The elastic ratios, as well as the elastic constants themselves, vary within and between species and with moisture content and specific gravity. The modulus of elasticity determined from bending, EL, rather than from an axial test, may be the only modulus of elasticity available for a

species. Average *EL* values obtained from bending tests are given in Tables 4–3 to 4–5. Representative coefficients of variation of *EL* determined with bending
tests for clear wood are reported in Table 4–6. As tabulated, *EL* includes an effect of shear deflection; *EL* from bending can be increased by 10% to remove this effect approximately. This adjusted bending *EL* can be used to determine *ER* and *ET* based on the ratios in Table 4–1.

Poisson's Ratio

When a member is loaded axially, the deformation perpendicular to the direction of the load is proportional to the deformation parallel to the direction of the load. The ratio of the transverse to axial strain is called Poisson's ratio. The Poisson's ratios are denoted by □*LR*, □*RL*, □*LT*, □*TL*, □*RT*, and □*TR*. The first letter of the subscript refers to direction of applied stress and the second letter to direction of lateral deformation. For example, □*LR* is the Poisson's ratio for deformation along the radial axis caused by stress along the longitudinal axis. Average values of Poisson's ratios for samples of a few species are given in Table 4–2. Values for □*RL* and □*TL* are less precisely determined than are those for the other Poisson's ratios. Poisson's ratios vary within and between species and are affected by moisture content and specific gravity.

Radial

Tangential

Longitudinal

Fiber direction

Modulus of Rigidity

The modulus of rigidity, also called shear modulus, indicates the resistance to deflection of a member caused by shear stresses. The three moduli of rigidity denoted by *GLR*, *GLT*, and *GRT* are the elastic constants in the *LR*, *LT*, and *RT* planes, respectively. For example, *GLR* is the modulus of rigidity based on shear strain in the *LR* plane and shear stresses in the *LT* and *RT* planes. Average values of shear moduli for samples of a few species expressed as ratios with *EL* are given in Table 4–1. As with moduli of elasticity, the moduli of rigidity vary within and between species and with moisture content and specific gravity.

Strength Properties

Common Properties

Mechanical properties most commonly measured and represented as “strength properties” for design include modulus of rupture in bending, maximum stress in compression parallel to grain, compressive stress perpendicular to grain, and shear strength parallel to grain. Additional measurements are often made to evaluate work to maximum load in bending, impact bending strength, tensile strength perpendicular to grain, and hardness. These properties, grouped according to the broad forest tree categories of hardwood and softwood (not correlated with hardness or softness), are given in Tables 4–3 to 4–5 for many of the commercially important species. Average coefficients of variation for these properties from a limited sampling of specimens are reported in Table 4–6.

Modulus of rupture—Reflects the maximum loadcarrying capacity of a member in bending and is proportional to maximum moment borne by the specimen.
Modulus of rupture is an accepted criterion of strength, although it is not a true stress because the formula by which it is computed is valid only to the elastic limit.

Work to maximum load in bending—Ability to absorb shock with some permanent deformation and more or less injury to a specimen. Work to maximum load is a measure of the combined strength and toughness of wood under bending stresses.

Compressive strength parallel to grain—Maximum stress sustained by a compression parallel-to-grain specimen having a ratio of length to least dimension of less than 11.

Compressive stress perpendicular to grain—Reported as stress at proportional limit. There is no clearly defined ultimate stress for this property.

Shear strength parallel to grain—Ability to resist internal slipping of one part upon another along the grain.
Values presented are average strength in radial and tangential shear planes.

Impact bending—In the impact bending test, a hammer of given weight is dropped upon a beam from successively increased heights until rupture occurs or the beam deflects 152 mm (6 in.) or more. The height of the maximum drop, or the drop that causes failure, is a comparative value that represents the ability of wood to absorb shocks that cause stresses beyond the proportional limit.

Tensile strength perpendicular to grain—Resistance of wood to forces acting across the grain that tend to split a member. Values presented are the average of radial and tangential observations.

Hardness—Generally defined as resistance to indentation using a modified Janka hardness test, measured by the load required to embed a 11.28-mm (0.444-in.) ball to one-half its diameter. Values presented are the average of radial and tangential penetrations.

Tensile strength parallel to grain—Maximum tensile stress sustained in direction parallel to grain. Relatively few data are available on the tensile strength of various species of clear wood parallel to grain. Table 4–7 lists average tensile strength values for a limited number of specimens of a few species. In the absence of sufficient tension test data, modulus of rupture values are sometimes substituted for tensile strength of small, clear, straightgrained pieces of wood. The modulus of rupture is considered to be a low or conservative estimate of tensile strength

for clear specimens (this is not true for lumbe

Mechanical Properties of Wood

The mechanical properties presented in this chapter were obtained from tests of small pieces of wood termed “clear” and “straight grained” because they did not contain characteristics such as knots, cross grain, checks, and splits. These test pieces did have anatomical characteristics such as growth rings that occurred in consistent patterns within each piece. Clear wood specimens are usually considered “homogeneous” in wood mechanics.
Many of the mechanical properties of wood tabulated in this chapter were derived from extensive sampling and analysis

procedures. These properties are represented as the average mechanical properties of the species. Some properties, such as tension parallel to the grain, and all properties for some imported species are based on a more limited number of specimens that were not subjected to the same sampling and analysis procedures. The appropriateness of these latter properties to represent the average properties of a species is uncertain; nevertheless, the properties represent the best information available.

Variability, or variation in properties, is common to all materials. Because wood is a natural material and the tree is subject to many constantly changing influences (such as moisture, soil conditions, and growing space), wood properties vary considerably, even in clear material. This chapter provides information, where possible, on the nature and magnitude of variability in properties.

This chapter also includes a discussion of the effect of growth features, such as knots and slope of grain, on clear wood properties. The effects of manufacturing and service environments on mechanical properties are discussed, and their effects on clear wood and material containing growth features are compared. Chapter 6 discusses how these research results have been implemented in engineering standards.

Orthotropic Nature of Wood

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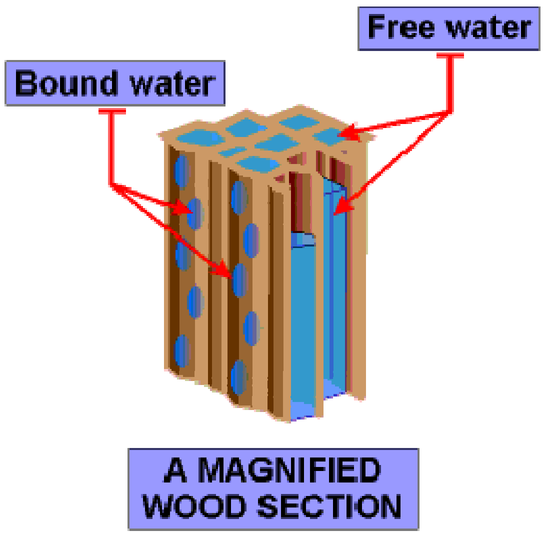
the tangential axis *T* is perpendicular to the grain but tangent to the growth rings. These axes are shown in Figure 4–1.

MOISTURE & WOOD

Moisture in wood exists in two forms:

1. *Free water*, liquid filling the wood cell cavities

2. *Bound water*, liquid or vapor chemically bound by hydrogen bonding to the cellulose of the wood cell walls



As wood dries, the free water in the cell cavities is drawn away first. Once the free water is removed, the bound water is gradually released from the cell walls.

FIBER SATURATION POINT

Fiber saturation point (FSP): The moisture content at which all of the free water is removed - the cell cavities are empty - but the cell walls are still completely saturated.

This is a key concept in wood design since moisture affects the physical and mechanical properties of wood differently depending on whether the MC% is above or below the FSP.

- *MC% above FSP*: physical and mechanical properties of wood remain constant as MC% changes
- *MC% below FSP*: physical and mechanical properties of wood change as MC% changes

The FSP varies for different species of wood, but is typically around 30%. Table M-1 lists FSP values for various wood species. The rate of change of physical properties is also dependent on wood species.

Table M-1: Fiber Saturation Point

At Room Temperature

Species	FSP(%)
Ash, white	24.0
Birch, yellow	27.0
Douglas fir	26.0
Hemlock, western	28.0
Larch, western	28.0
Pine, loblolly	21.0
Pine, longleaf	25.5
Pine, red	24.0
Spruce, red	27.0
Spruce, Sitka	28.5

The following demonstration is based on the properties of Douglas fir.

▪

- *Lumber Deformation*. Shrinkage distortion typical for three cuts of lumber is illustrated in this log cross section. Note the curvature of the annual rings in each cut and how that affects the distorted shape.

Drying causes not only cross sectional distortion, but may also result in warping along the length of lumber. Various types of warp are due to discontinuities such as knots as well as the annual ring orientations.

Moisture Content

The weight of moisture contained in a piece of wood expressed as a percentage of its oven dry weight is almost universally referred to as its moisture content. Expressed mathematically

$$mc = \frac{(W_g - W_o)}{W_o} \cdot 100\%$$

where mc = moisture content

W_g = green weight of the wood

W_o = oven dry weight of the wood

By oven dry weight is meant the quasi-constant weight attained by wood samples dried at 105 C^o (221 F^o). As pointed out by MacLean (1952; Stamm, 1964) it is advantageous to define moisture content in terms of the oven dry weight of the wood since the oven dry weight is a constant value that may be determined at any time. This factor is of considerable value in numerous experiments where to initially oven dry a sample to determine its moisture content would irrevocably alter its characteristics and prevent its subsequent experimental use. Furthermore, expressed as a percentage of oven dry weight, moisture content is readily envisaged since it represents the amount of moisture contained in the wood as parts by weight of water to 100 parts of wood substance. Finally, the equilibrium moisture content of many wood species at a given temperature and relative humidity is nearly the same regardless of their density or specific gravity. If moisture content were placed on some other basis such as the green weight of wood, this extremely useful approximate relationship would be lost.

Example(1)

The green weight of a specimen of red oak is 136 grams. Its oven dry weight is 100 grams. What is its moisture content?

Ans:

W_g= the green weight = 136 grams

W_o= the oven dry weight = 100 grams

Therefore,

$$mc = \frac{(136\,g - 100\,g)}{100\,g} \cdot 100\% = 36\%$$

When the moisture content of a piece of wood has been determined by some means other than the oven drying method, its oven dry weight can nonetheless be found by calculation. If, for example, the weight of a green sample is known to be 600 grams and its moisture content 50 percent, the oven dry weight can be calculated from the definition formula, i.e.,

$$mc = \frac{(600\,g - W_o)}{W_o} \cdot 100\% = 60\%$$

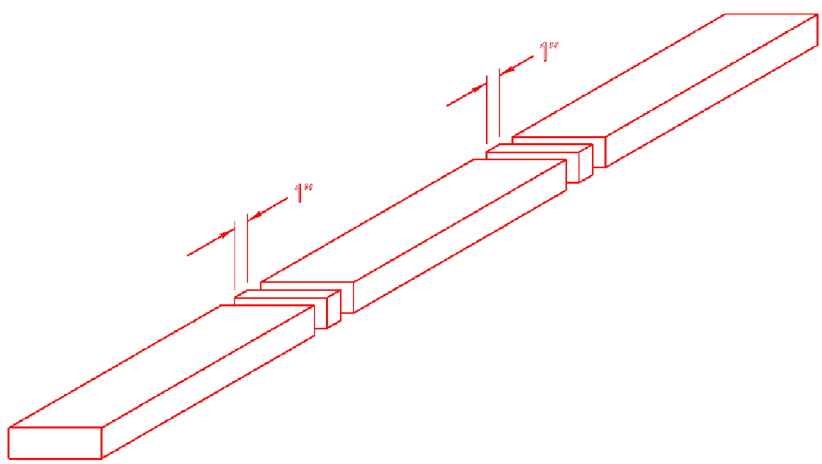
or,

W_o= 375 grams.

This method is particularly useful for determining the oven dry weight of large specimens. Frequently small moisture samples can be cut from a board without ruining it for subsequent test uses. These samples can be oven dried to determine their moisture content, and from this information, the oven dry weight of the entire board can be found.

Example(2)

Two sample moisture sections one inch thick along the grain, were cut from a 1 x 4 inch by twelve foot long green sugar maple board, Figure 1. The first sample had a green weight of 68 grams and an oven dry weight of 40 grams while the second had green and oven dry weights of 72 and 43 grams, respectively. The total weight of the three remaining four foot sections of the board was 18 pounds. What was the average oven dry weight of each of these four foot lengths?



Ans:

The moisture content of the first sample was

$$mc_1 = \frac{(68g - 40g)}{40g} \cdot 100\% = 70\%$$

and the second

$$mc_2 = \frac{(72g - 43g)}{43g} \cdot 100\% = 67.4\%$$

The average of these two values is

$$mc_{avg} = \frac{(70\% + 67.4\%)}{2} = 68.7\%$$

Each of the three-four foot sections weighs

W_g= 18 lbs/3 = 6 lbs

or, in grams

W_g= 6 lbs x 454g/lb = 2724g

The oven dry weight of each specimen is thus given by

$$\frac{(2724\,g - W_o)}{W_o} \cdot 100\% = 68.7\%$$

or,

W_o= 1614.7g , or, 3.56 lb

Density and Specific Gravity

Confusion often results over the meaning of the two terms, density and specific gravity. By density is meant concentration of matter, measured as mass per unit volume (Hodgman, 1950), or,

$$\rho = \frac{m}{V}$$

where p' is used to represent density, m represents mass, and V represents volume. By definition, therefore, densities can only be expressed as grams per cubic centimeter, kilograms per cubic meter, or slugs per cubic foot. In wood seasoning work, however, an engineering interpretation of density is typically used; that is, weight per unit volume, or

$$\rho = \frac{W}{V}$$

where W is the weight of a material. When defined in this way, ρ should be referred to as "weight density" to distinguish it from the physicist's "mass density." This notational precision is seldom observed, however, and which of the two terms is meant is usually left to the reader's judgment.

Weight density is unconsciously used in everyday speech. The density of water, for example, is spoken of as 62.4 pounds per cubic foot or 8.33 pounds per gallon. Frequently, however, a person will simply say, "water weighs 62.4 pounds per cubic foot." The density of wood is usually stated in pounds per cubic foot. If, for example, the weight of one board foot of green red oak is 5 pounds, then its weight density is

$$\rho = \frac{5\ lb}{bd\ ft} \cdot \frac{12\ bd\ ft}{ft^3} = \frac{60\ lb}{ft^3}$$

The density of wood is, of course, not a fixed value but depends upon the moisture content of the wood. Wood density varies greatly from species to species. According to Brown, et al. (1952) the lightest species weigh about 2-1/2 pounds per cubic foot when oven dry compared to 87 pounds per cubic foot for the heaviest. Balsa, the fourth or fifth lightest species in the world (Warring, 1966; Chudnuff, 1984) has a density as low as 4 pounds per cubic foot up to 25 pounds per cubic foot or more.

Specific gravity is defined as the ratio of the density of a material to the density of pure water, or, expressed mathematically

$$Sp.Gr. = \frac{\rho_x}{\rho_w}$$

where ρ_x refers to the density of the material in question and ρ_w to the density of pure water (usually taken at 4 C^o.). It has been pointed out (Sears and Zemansky, 1952) that the term "specific gravity" is a poor one since it has nothing to do with gravity. A more descriptive term would perhaps be "relative density."

The specific gravity of a wood specimen may be calculated by means of the formula

$$Sp.\,Gr. = \frac{weight\ of\ the\ specimen}{weight\ of\ equal\ volume\ of\ water}$$

If, for example, an ovendry rectangular sugar maple specimen measures 1 centimeter along each face and weighs 0.68 grams, its sp. gr. is

$$S_o = \frac{\frac{0.68g}{1cm^3}}{\frac{1g}{1cm^3}} = 0.68$$

Although the weight of wood is almost universally taken as its oven-dry weight, the volume may be measured when the moisture content of the specimen is at any desired arbitrary value. The specific gravity of a piece of wood is not, therefore, a single-valued constant but depends instead upon the circumstances under which it was determined. Specific gravity values are highest when based upon oven dry volume measurements and least when based upon green volume measurements. As previously mentioned it is convenient to base wood-moisture and specific gravity calculations on the oven-dry weight of the wood since it is an extreme, reproducible, constant condition that can be determined at any time. For the same reasons, specific gravity determinations are most conveniently made with either green or oven dry specimens. In the United States specific gravity values are usually based on green volume measure, but in Europe they are typically based on oven dry dimensions.

Example(3)

The oven dry weight of a sugar maple specimen is 100 grams. Its green volume, volume at 15% m.c., and oven-dry volume are 178, 161, and 147 cubic centimeters respectively. What are the specific gravity values corresponding to these conditions?

Ans.

$$S_g = \frac{100}{178} = 0.56$$

$$S_{15} = \frac{100}{161} = 0.62$$

$$S_o = \frac{100}{147} = 0.68$$

where S_g, S_{15}, and S_o refer to specific gravity values based on volumes measured when the sample was green, at 15% m.c., and oven dry.

In wood seasoning research it is often desirable to convert specific gravity values from one volume basis to another. To do this we make use of the fact that the volumetric shrinkage and therefore the sp. gr. of many

wood species is proportional to the change in moisture content (expressed as weight) below the fiber saturation point; that is, $dV = k \cdot dW$, where dV refers to the change in volume, dW refers to the change in weight of moisture contained in the sample, and k is a constant of proportionality. When a specimen dries below the fiber saturation point (f.s.p. nge in weight, dW, is given by the expression

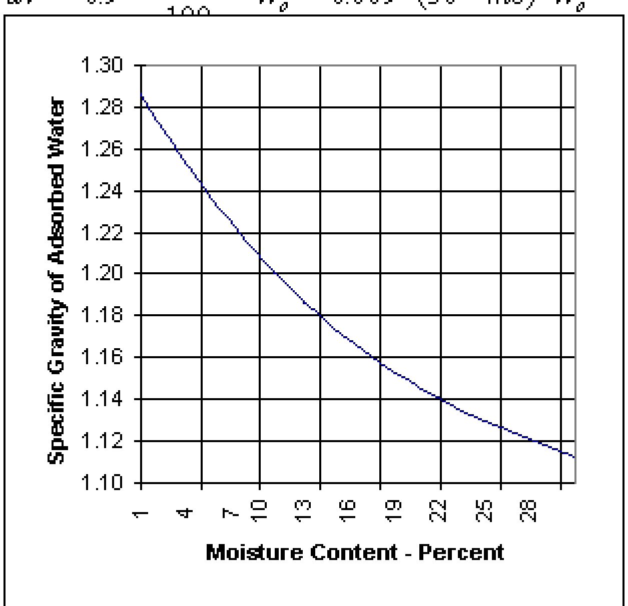
$$dW = \frac{30 - mc}{100} \cdot W_o$$

where W_o refers to the oven dry weight of the wood and the fiber saturation point is assumed to be 30 percent. In the centimeter gram second (cgs) system of units, we might expect the volume of water lost to be numerically equal to the weight lost since 1 cm^3 of water weighs about 1 gram. When water is absorbed into wood, however, it does not retain its original volume, but is slightly compressed. As shown in Figure 2 (MacLean, 1952), the specific gravity of the water imbibed into wood at the f.s.p. is 1.115 (Skaar, 1972). The specific volume of this water is

$$Sp.Vol. = \frac{1}{Sp.Gr.} = \frac{1}{1.115} = 0.9$$

so that the corresponding volumetric shrinkage of the wood where $k = 0.9$

$$dV = 0.9 \cdot \frac{30 - mc}{100} \cdot W_o = 0.009 \cdot (30 - mc) \cdot W_o$$



Reducing this to a unit volume change gives

$$dv = 0.009 \cdot \frac{W_o}{V_g} \cdot (30 - mc)$$

where V_g refers to the green volume of the specimen. Finally,

since

$$S_g = \frac{W_o}{V_g}$$

this expression can be written

$$dv = 0.009 \cdot S_g \cdot (30 - mc)$$

Given the green volume of the wood, V_g, the sp. gr., S_x at some lower moisture content can then be found from the expression

$$S_x = \frac{W_o}{V_g - dV}$$

Substituting the appropriate expression for dV into the above expression gives

$$S_x = \frac{W_o}{V_g - 0.009 \cdot W_o \cdot (30 - mc)}$$

Dividing top and bottom by V_g and substituting S_g for W_o / V_g gives

$$S_x = \frac{S_g}{1 - 0.009 \cdot S_g \cdot (30 - mc)}$$

Example (4)

The sp. gr., S_g, of red oak is 0.57. What is its specific gravity based on oven dry volume?

Ans.

$$S_o = \frac{0.57}{1 - 0.009 \cdot (0.57)(30)} = 0.675$$

Similarly, to calculate S_x values from specific gravities based on oven-dry volumes, dV must be added, and the following expression results

$$S_x = \frac{S_o}{1 + 0.009 \cdot S_o \cdot mc_x}$$

Example (5)

The sp. gr., S_o, of red oak is 0.68. What is the specific gravity based on green volume?

Ans.

$$S_g = \frac{0.68}{1 + 0.009 \cdot (0.68)(30)}$$

To determine the sp. gr., S_x, based on volume at moisture content, mc_x, when the sp. gr., S_y, corresponding to some other moisture content, mc_y, is known, the following general formula may be used:

$$S_x = \frac{S_y}{1 + 0.009 \cdot S_y \cdot (mc_x - mc_y)}$$

Finally, when S_o and S_g, are both known, S_x may be found by a simple proportion

$$S_x = S_o - (S_o - S_g)(mc_x) / 30$$

Table (1) gives the specific gravity of a number of wood species based on both green and oven-dry volume.

Void Volume of Wood

Void Volume of Oven-Dry Wood

When wood is seasoned to prepare it for subsequent treatment with preservatives or other chemicals, it is important to know how much water must be removed from the wood before the desired amount of solution can be injected into it. As an example, a gallon of water weighs approximately 8.3 pounds and occupies 0.1337 cubic feet. If we wish to treat a charge of material with an aqueous solution and obtain a retention of 8 pounds per cubic foot, the wood must have in it an unoccupied space equal to about 13.37% of the total volume of the wood. MacLean (1952) points out, however, that even with small easily penetrated specimens, about 5 to 10 percent of the air space in the wood remains unfilled. He further states that it is usually not practical to obtain net retentions using the full cell method of treatment that fill more than 80 to 85 percent of the available air space. Using this information it can be seen that the required void volume is 16 to 20 percent greater than calculated above.

To calculate this unoccupied space, which is usually referred to as void volume and is expressed as a fraction of the total specimen volume, it is first necessary to calculate the fractional volume of solid wood substance present. If, for convenience, we accept 1.50 as the specific gravity of oven-dry wood substance, the maximum density of a completely solid wood specimen devoid of pores would be 1.50g/cm^3.

Wood, as it occurs naturally, is porous, however, and contains many void spaces. Because of its porosity, the oven dry density of a unit cube of natural wood will be less than the density of pure wood substance. Since such a unit cube of natural wood contains essentially nothing more than wood substance and air, the fractional amount of solid wood substance present in the cube is given by the ratio of the oven-dry density of the natural wood to the oven-dry density of pure wood substance. Algebraically, the solid volume, v_s, can be calculated as

$$v_s = \frac{W_o}{W'_o} = \frac{S_o}{S'_o} = \frac{S_o}{1.50}$$

where W_o = the oven dry weight of a unit cube of dry wood, and W'_o = the oven dry weight of a unit cube of dry wood substance = 1.50 grams (as long as cgs units are used since specific gravity and density are numerically equal in this system of units). If we now consider an actual wood specimen such as sugar maple which has an oven-dry density of 0.68g/cm^3, we find that the fractional solid volume is

$$v_s = \frac{0.68}{1.50} = 0.453$$

or, expressed as a percentage, we may say that solid wood substance occupies 45.3 percent of the total volume of oven-dry sugar maple.

If the solid volume of oven-dry wood is given by the ratio $S_o / 1.50$, then the void volume, v_v, must be given by the expression

$$v_v = 1 - \frac{S_o}{1.50}$$

where 1 is the total volume of a unit cube. Referring to the example above, since the fractional solid volume of oven-dry sugar maple is 0.453, it follows that its fractional void volume is 1 - 0.453, or 0.547. In other words, 54.7 percent of the total volume of oven dry sugar maple is made up on void space.

Example (6)

If the sp. gr., Sg, of red oak is .57, what is its fractional void volume in the oven-dry condition?

Ans.

To solve the problem we must first calculate, S_o, the oven-dry sp. gr. of the red oak. Applying the expression previously derived gives

$$S_o = \frac{0.57}{1 - 0.009 \cdot (0.57)(30)} = 0.67$$

The fractional void volume of the wood may then be calculated as follows:

$$v_v = 1 - \frac{0.67}{1.50} = 0.55$$

Void Volume of Wood at Any Moisture Content

Whereas determining the fractional void volume of oven-dry wood is a relatively straightforward procedure, calculating void volumes at other moisture content levels is more complex since the effects of the included water must be considered. The included water has two effects. Firstly, it causes the wood to swell, and secondly, it adds its volume to the volume of wood substance present. As was previously shown, that part of the water which is absorbed into the cell walls is compressed. Three different contributions to solid volume (where solid volume now includes the water present) must thus be appraised:

1) the space occupied by cell wall substance

2) the space occupied by imbibed water

3) the space occupied by free water

The fractional volume, v_1, of cell wall wood substance present in wood at some moisture content level, mc_x, is given by the expression

$$v_1 = \frac{S_x}{1.50}$$

where S_x is the sp. gr. of the wood sample based on volume measured at a specific moisture content level. Note that S_x rather than S_o is required in this expression.

Next, consider a unit cube of wood which has a moisture content of mc_x percent. The amount of cell wall substance in this cube is given by the oven-dry weight, and the solid volume is then given by the ratio of the oven-dry weight of the cell wall substance contained in this unit cube to the weight of a unit volume of solid cell wall substance. The weight of the imbibed water, W_x, is

$$W_x = \frac{S_x \cdot mc_x}{100}$$

The absolute fractional volume is then calculated by dividing W_x by the density of the water, ρ_x, so that the volume occupied by the imbibed water, v_2, is

$$v_2 = \frac{S_x \cdot mc_x}{100\rho_x}$$

where mc_x equals the current moisture content which is equal to or less than the f.s.p., and ρ_x is the density of the imbibed water as shown in Figure 2.

The fractional volume of free water present, v_3, is equal to

$$v_3 = \frac{S_x \cdot mc_y}{100}$$

where mc_y is the moisture content above f.s.p. That is, if a specimen had a moisture content of 53%, mc_y would equal 23% (assuming f.s.p is 30%). This water is not compressed, and hence its volume is taken the same as that of pure water.

The total fractional volume, v_T , of materials in a unit cube of wood at some moisture content mc_x, is, therefore, equal to the sum of the partial volumes, i.e.,

$$v_T = v_1 + v_2 + v_3$$

It follows, as before, that the remaining fractional void volume is 1 minus this quantity, i.e.,

$$v_v = 1 - (v_1 + v_2 + v_3)$$

Substituting the previously derived expressions for partial volumes into this equation and simplifying yields

$$v_v = 1 - S_x \cdot \left[\frac{1}{1.50} + \frac{mc_x}{100\rho_x} + \frac{mc_y}{100}\right]$$

When the moisture content is substantially above f.s.p., compression of the imbibed water can usually be neglected. The above formula may then be simplified to

$$v_v = 1 - S_x \cdot \left[\frac{1}{1.50} + \frac{mc}{100}\right]$$

where mc is the total moisture content.

Example (7)

What is the void volume of red oak at 60% m.c.?

Ans.

The sp. gr., S_g, of green red oak is 0.57; similarly, the sp. gr. of the imbibed water is 1.115. Therefore,

$$v_v = 1 - 0.57 \cdot \left[\frac{1}{1.50} + \frac{0.3}{1.115} + 0.3\right] = 0.296.$$

Let us now compare this with the value obtained using the second expression

$$v_v = 1 - 0.57 \cdot \left[\frac{1}{1.50} + 0.6\right] = 0.278$$

This latter value differs from the first by only 7.32 percent.

Example (8)

What is the void volume of basswood at 10% m.c.?

Ans.

The S_o of basswood equals 0.40 and S_g equals 0.32. Using a straight line approximation,

$$S_x = 0.40 - \left[\frac{10}{30}\right] \cdot (0.40 - 0.32) = 0.373$$

From Figure 2 it is seen that $\rho_{10} = 1.20 g/cm^3$. Thus,

$$v_v = 1 - 0.373 \cdot \left[\frac{1}{1.50} + \frac{0.1}{1.2}\right] = 0.72$$

If the previous calculations appear somewhat confusing, an alternative approach, based upon the sp. gr. of wood substance at current m.c. rather than oven-dry conditions, may be of help in visualizing and calculating void volume and maximum moisture content. It is first necessary to calculate the sp. gr. of wood substance at current m.c.

The weight of moisture absorbed by an oven-dry cube of wood substance is given by the expression

$$dW'_x = \frac{mc_x W'_o}{100} \quad mc_x \le 30$$

where dW'_x is the weight of water, W'_o is the oven-dry weight of the wood substance, and mc_x is the current m.c. Reducing this to unit volume and unit weight, dw'_x, gives

$$dw'_x = \frac{mc_x}{100} \cdot \frac{W'_o}{V_o} = \frac{mc_x}{100} \cdot S'_o = \frac{1.50 \cdot mc_x}{100}$$

where dw'_x is weight per unit volume of the water, V_o is the oven-dry volume, and S'_o is the sp. gr. of oven-dry wood substance, i.e., S'_o= 1.50. If the absorbed water were not compressed, the change in volume of a unit cube owing to the moisture would be given by $dv = dw'$. Since it is compressed, however, we must account for the reduced volume, either by dividing dw'_x by an average value of density for imbibed water, 1.115, or by an exact value for density taken from the graph shown by MacLean. Thus,

$$dv_x = \frac{1.50}{\rho_x} \cdot \frac{mc_x}{100}$$

where dv_x is change in volume adjusted to current m.c. on a unit basis and ρ_x is the density of imbibed water at the current m.c. The volume of the original unit cube of oven dry wood substance is thus increased to

$$v = 1 + dv = 1 + \left[\frac{1.50}{\rho_x} \cdot \frac{mc_x}{100} \right]$$

and the new sp. gr. of the wood substance is

$$S'_x = \frac{W'_o}{v} - \frac{1.50}{1 + \left[\frac{1.50}{\rho_x} \cdot \frac{mc_x}{100} \right]}$$

where S'_x is the sp. gr. of wood substance at the current m.c.

Example (9)

What is the sp. gr. of green wood substance?

Ans.

In the green state, mc_x, as here defined, is taken to be 30%; S'_o as before has a value of 1.50, and ρ_x = 1.115 at 30 percent moisture content. Therefore,

$$S'_g = \frac{1.50}{\left[1 + \frac{1.50}{1.115} \cdot \frac{30}{100} \right]} = \frac{1.50}{1 + 0.404} = 1.069$$

Example (10)

What is the sp. gr. of wood substance at 10% m.c.?

Ans.

At 10% m.c. the density of the imbibed water (read from the graph) is 1.20. Therefore,

$$S'_{10} = \frac{1.50}{\left[1 + \frac{1.50}{1.20} \cdot \frac{10}{100}\right]} = \frac{1.50}{1 + 0.125} = 1.333$$

If we now define solid volume V'_s to include both wood

substance and imbibed water, then the fractional solid volume of a cube of wood below the fiber saturation point can be expressed as

$$V'_s = \frac{S_x}{S'_x}$$

and the fractional void volume, V'_v, up to the fiber saturation point as

$$V'_s = 1 - \frac{S_x}{S'_x}$$

Above the fiber saturation point, void volume must be reduced by the amount of free water present; therefore

$$V'_v = 1 - \frac{S_x}{S'_x} - \frac{mc - 30}{100} \cdot S_x$$

or,

$$V'_v = 1 - \frac{S_x}{S'_x} - \frac{mc_y S_x}{100}$$

where $mc_y = mc - 30$. Rearranging terms gives

$$V'_v = 1 - S_x \cdot \left[\frac{1}{S'_x} + \frac{mc_y}{100} \right]$$

This void volume expression, V'_v, is identical in form to the previously derived one, V_v, except that the first two terms inside the parenthesis of the expression for V_v have been replaced by $1 / S'_x$. It follows therefore, that

$$\frac{1}{S'_x} = \frac{1}{S'_o} + \frac{mc_x}{100\rho}$$

or,

$$S'_x = \frac{100 \cdot \rho \cdot S'_o}{100 \cdot \rho + mc_x \cdot S'_o} = \frac{S'_o}{1 + \left[\frac{mc_x \cdot S'_o}{100 \cdot \rho} \right]} - \frac{1.50}{1 + \left[\frac{1.50 \cdot mc_x}{100\rho} \right]}$$

as was previously shown.

Example (11)

What is the void volume of yellow birch, S_o = .66, at 10% m.c.?

Ans.

The sp. gr. of yellow birch at 10% m.c. is

$$S_{10} = \frac{1}{1 + \left[\frac{0.66}{1.20} \cdot \frac{10}{100}\right]}$$

where the density of imbibed water at 10% m.c. is 1.20g /cm^3. Solving gives

$$S_{10} = \frac{0.66}{1 + 0.055} = 0.626$$

From the previous example, $S_{10} = 1.333$. Therefore,

$$V'_v = 1 - (0.626 / 1.33) = 1 - 0.470 = 0.530$$

Had we worked this in the previous way

$$V_v = 1 - 0.626 \cdot \left[\frac{1}{1.50} + \frac{10}{1.2 \cdot (100)}\right]$$

or,

$$V_v = 1 - 0.626 \cdot (0.667 + 0.835) = 1 - 0.626(0.751) = 1 - 0.470 = 0.530$$

as before.

Maximum Moisture Content of Wood

Since the void volume of wood is zero when it is completely saturated with water, the above equations can be solved for maximum moisture content simply by setting V_v equal to zero. Solving the second expression for mc_{max} with $V_v = 0$ and $S_x = S_g$ gives

$$mc_{max} = \left[\frac{1}{S_g} - \frac{1}{1.50}\right] \cdot 100\%$$

or,

$$mc_{max} = \left[\frac{1.50 - S_g}{1.50 \cdot S_g}\right] \cdot 100\%$$

Example (12)

What is the maximum possible m.c. of Eastern white pine?

Ans.

The S_g of white pine equals 0.34. Therefore,

$$mc_{max} = \left[\frac{1.50 - 0.34}{1.50 \cdot 0.34}\right] \cdot 100\% = \frac{1.16}{0.51} \cdot 100\% = 227\%$$

Properties of wood

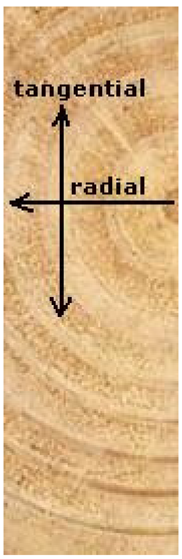
Rev. 3 — page content was last changed July 21, 2005 [small changes to the final draft to improve readability]

Content

3.1 Hardwoods and softwoods

The botanical terms *softwoods* and *hardwoods* indicate the basic cellular structure of the wood *(hardwood structures are more complex)* and how moisture moves within the living tree. They do not indicate the softness or hardness of particular timbers. Softwoods generally come from the coniferous species *(pines, firs and spruces for example)* and the timber is generally fine textured but not particularly light. All the hardwoods *(for example eucalypts and oaks, even balsa which at around 160 kg/m³ is the lightest and softest commercial timber)* have broad leaves and the texture of the wood ranges from fine to coarse.

(If you wish to learn more about the microstructure of trees copy and paste the terms 'tracheid parenchyma rays vessels' *into the Google search engine.)*

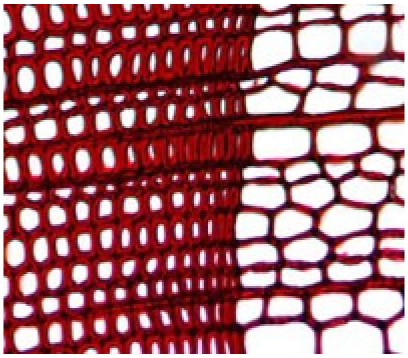


3.2 Grain and growth rings

Imagine a growing tree as a composite structure chiefly composed of elongated, hollow, water-filled cells (roughly 1 mm long in hardwoods and 5 mm long in softwoods) glued together in bundles (like drinking straws) with the lay of the cellulose fibres generally running parallel to the outer surface of the trunk. This is the grain direction but it will vary, sometimes substantially, due to growth abnormalities. The term **grain** encompasses both the direction of the fibres and the texture of the wood, i.e. the size and arrangement of the cell structures. *(Grain in a sawn board may be described as straight, wavy, spiral, interlocked, sloping and others. The terms edge, end and face grain refer to the grain aspect as displayed in a board.)*

Trees expand their trunks by addition of new peripheral growth layers. In softwoods this expansion growth can generally be discerned on the end surfaces of a cut log as a series of concentric annual **growth rings**. Each ring may display the growth as a lighter colour representing the faster growth during the earlier growing season [early wood], with a darker colour indicating slower, denser growth during the less favourable part of the growing season [late wood].
Environmental events will also affect growth rings. Because of

favourable year round conditions the rings in tropical, and possibly sub-tropical, trees may not exist, or may be difficult to discern, the same applies to eucalypts from Australia's warm temperate climate areas.



The honeycomb-like cross-section photomicrograph [100×] shows the band of thin walled, large cavity early wood cells of one season on the right, with the stronger, thick walled, small cavity cells of the prior season's late wood on the left. The timber from a fast grown tree will not be as strong as that from a slow grown tree of the same species, on the other hand the timber from a tree that has grown too slowly will not be as strong as that from the optimally grown tree.

The **rate of growth** is shown by the width of the annual rings, or the number of growth rings per 25 mm. Generally for those softwoods typically used in aircraft construction the number of radial growth rings appearing in the end of sawn boards, or on the face, should be at least six, possibly eight, per 25 mm but less than 15 to 18; and with a high percentage [50%?] of the stronger late wood. *(If the tree is too slow grown the strong late wood bands are too narrow; if too fast grown the weaker early wood bands are too wide [in softwoods], or the late wood cell walls are too thin [in hardwoods].)*

One aspect to note is that moisture and minerals extracted from the soil by the roots are delivered to the crown of the trees through a form of capillary attraction within the cells. When seasoned wood is used for mechanical structures a similar action will draw adhesive away from end grain joint surfaces unless appropriate application methods are used. See "Wood joints and adhesives".

When looking at the machined faces of a board visible lines from the growth rings may indicate the direction of the board grain. For aircraft grade timber straight grain is vital [see 'strength and stiffness' below] so the general lines of the grain along the longitudinal axis of the board should be reasonably straight and the

maximum grain slope on all sides should not deviate from parallelism with the long axis by more than 25 mm in 400 mm, i.e. a ratio around 1:16, or 1:20 if the timber is for wing spars. *(Sloping grain has many causes; spiral growth, growth around knots or just the sawmilling process.)* Wood will split along the lay of the fibres so splitting a sample length is accepted as a normal method of detecting grain slope but there are other less destructive methods.

Two distinct zones can often be seen in the cross-section of a cut log. The inner darker zone, possibly more than 70% of the surface area, is the **heartwood** which provides structural strength and the outer zone is the **sapwood** which provides for the tree's nutrient storage and sap flow. As the trunk expands the inner sapwood cells are gradually converted to thicker-walled heartwood. Seasoned sapwood is not as dense as heartwood and the nutrients contained make it more prone to insect attack.

3.3 Sawmilling of timber

Various sawing patterns and combinations are used to convert logs into boards, 'live sawing' is mainly used to produce cheaper 'ready-for-use' material, 'back sawing' or 'flat sawing' produces boards with the faces tangential [see the growth rings image above] to the growth rings and 'quarter sawing' produces an often highly figured edge grain on the face of the board consequently such boards may be referred to as 'edge grain' boards. Quarter-sawn boards are the most expensive to produce.

In Australia boards are classed as 'back-sawn' if the growth rings lie at an angle less than 45° to the longer cross section dimension or 'quarter-sawn' if the rings lie at an angle greater than 45° to the longer dimension. In the image above you can see that all boards, from the log on the right, would be quarter-sawn when cut this way. However if quarter-sawn boards are specified by the aircraft designer the expectation may be that the rings are 90° to the longer cross section dimension plus/minus 10°. Quarter-sawn boards are less likely to distort or crack during the drying process and are more stable in service. An advantage with quarter sawn softwood is that the rate of growth is readily seen when selecting boards.

3.4 Moisture content and density

Timber as felled has considerable moisture content [MC] present as 'free' moisture within the cell cavities and 'bound' or 'combined' moisture saturating the cell walls. The freshly sawn lumber will lose perhaps 50% of its total weight, shrink somewhat and become much stronger, harder and more durable during the seasoning [drying and stabilising] process. The seasoning process also improves timber workability and the bonding of adhesives and surface finishes. The target MC for the process is normally 12% (i.e. weight of water compared to weight of totally dry wood) but it may vary between 10% and 15% in temperate climate conditions; at these levels only bound moisture remains. See effects of humidity and heat below. Timber with MC between 15% and 25 % is sometimes regarded as partially seasoned.

In the drying process the wood first loses the free moisture to reach the **fibre saturation point** [FSP] where no moisture is contained in the cell cavities but the cell walls are still saturated with bound moisture. The FSP occurs at 30–35% MC in hardwoods and 25–30% MC in softwoods. Timber does not shrink during drying until the FSP is reached then it begins to shrink at a roughly proportionate rate until an equilibrium MC is attained. Board shrinkage from FSP to 12% MC is usually insignificant longitudinally, quite significant in the tangential direction along the rings [6% to 8%] but not so much in the radial direction, maybe half the tangential shrinkage. However there are some timbers that do not conform with that generalised statement; Australian hoop pine for example, where the tangential shrinkage from FSP to 12% MC is only about 3.5% and the radial shrinkage is around 2.5%.

The specific gravity of the cell wall material is about the same in most timbers *(about 1.5 which is 50% heavier than water)* but the density [mass per unit volume] of seasoned wood is chiefly governed by the relationship between cell wall and the cell cavity volume – cavities lack mass – so **density is an indicator of strength and stiffness**. A single density value for a particular species is often quoted in the literature but there is a considerable variation in the density of boards from the same species, which varies according to the maturity of the tree, the part of the trunk [base or top, inner or outer] from which the board is cut, the growth conditions and whether it is plantation or naturally grown – the latter generally being more dense.

(If the apparent specific gravity of a particular wood is stated then multiply that by 1000 to obtain the density in kg/m³. For example apparent specific gravity 0.55 density = 550 kg/m³.)

Measuring density: the only way to really determine the density of a particular seasoned board is to cut a piece from the board, carefully measure both volume and weight and convert to kg/cubic metre. If you dry it in the microwave for 20 or 30 minutes before measuring and weighing you will have the density at 0% MC and the density at 12% MC will be about 6% greater. When drying perhaps it may be better if you check the weight after 15 minutes in the microwave then every five minutes or so until the weight stops reducing. To check MC see below.

Density classification: the density of seasoned timber is usually measured — for classification purposes — at 12% air-dry MC.

- exceptionally light — under 300 kg/m³
- light — 300 to 450 kg/m³
- medium — 450 to 650 kg/m³
- heavy — 650 to 800 kg/m³
- very heavy — 800 to 1000+ kg/m³

Aircraft weight restraints mandate the use of wood having low weight but ample strength and such timber is most likely contained in the lower band of the medium density classification; excepting perhaps timber for propellers. For 90 years top quality North American Sitka spruce (average density perhaps 440 kg/m³) has been the aircraft designer's timber of choice for most of the airframe, and regarded as the benchmark for comparison purposes.

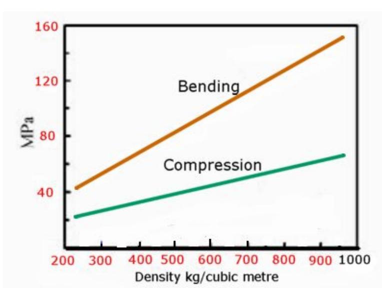
An aircraft like Leo Pownings Jodel D18, requires around 0.15 m³ of wood, so if built from Sitka spruce it might contain 66 kg of timber. Hoop pine [at left] is the preferred Australian timber but at an average 510 kg/m³ at 12% MC it is about 15% heavier than Sitka spruce, although stiffer and generally stronger and somewhat stabler. The difference in empty aircraft weight between Sitka spruce and hoop pine (using material of the same dimensions) in the Jodel would be about 10 kg, equivalent to nearly 14 litres of fuel – not an insignificant weight increase when there is a legally imposed upper limit to ultralight aircraft MTOW and there might be a slight change in cg position. However, although heavier, hoop pine is probably a superior timber for home builder construction – in weight and strength it is similar to Douglas fir but easier to work.

For a comparison of the strength properties of hoop pine, Sitka spruce and Douglas fir see ' Comparison of three recommended softwoods'.

3.5 Strength and stiffness

The most important considerations for an aircraft designer/builder is the weight, strength and stiffness of particular timbers. *(Secondary considerations would include workability, stability, steam bendability, gluability, impact resistance and ease of surface finishing.)* Strength and stiffness are allied to density and as the density of boards from an individual species varies considerably so does the strength. One aspect of **strength** is the load carrying capacity of a length of timber, usually expressed as ‘modulus of rupture in static bending’ [MR] — 'modulus' means 'measure' so it's a measure of the maximum load-carrying capacity when that load is applied slowly at the centre point of a beam. **Stiffness** describes a length of timber's resistance to deflection under load and 'modulus of elasticity in static bending' [ME] is the measure.

Both MR and ME are expressed in units of pressure – MPa [= N/mm^2]; to convert pounds per square inch to megapascals multiply by 0.007.



The graph is an approximation of compressive strength and stiffness relative to the density of seasoned wood.

Other aspects of wood strength generally considered are:

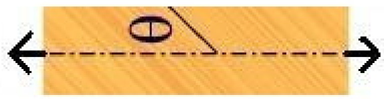
- tensile — resistance to forces trying to pull the fibre structure apart
- compressive — resistance to squeezing or crushing forces both parallel and perpendicular to the grain
- shear — resistance to shearing forces that might lead to fibre separation along/across a plane.
- impact — ability to absorb shock loads.

For more information on the terms and tests used in determining strength values see 'Basic strength and elastic properties of wood'. Other considerations on aspects of strength and stiffness can be found in the 'wood beams in aircraft' module.

Commercial strength groups: laboratories ascertain the mechanical properties of species by testing large numbers of 'clear' specimens (i.e. free of sloping grain and other defects) with standard dimensions — possibly 50 mm × 50 mm × 300 mm for the MR test — and generally at 12% MC and in a 20 °C environment. Like density the mechanical properties of defect free material of the same species vary considerably, so you must be wary when the MR or ME of a particular species is published as a single value. That value may be the mean value of all tests or it could be the '5th percentile' value, meaning that 95% of the samples tested had an MR or ME higher than that value, or it could be any other of the standard deviation values associated with the normal distribution curve.

To overcome this problem of strength definition when there is so much variation within species it is convenient to assign timber within strength groups. In the Australian standard grading for seasoned structural timber, each species is allocated a ranking of SD1 (strongest) to SD8 (weakest) according to the following values.

Minimum values for strength groups (units are MPa = 145 lb/sq.inch)



Strength group	Modulus of rupture	Modulus of elasticity	Maximum crushing strength
SD1	150	21500	80
SD2	130	18500	70
SD3	110	16000	61
SD4	94	14000	54
SD5	78	12500	47
SD6	65	10500	41
SD7	55	9100	36
SD8	45	7900	30

3.6 Effect of grain slope on strength

Wood is not like aluminium or steel whose physical properties are mostly independent of direction. For example, the tensile strength of timber varies with grain direction and is at a maximum parallel to the grain and at a minimum perpendicular to the grain.

The diagram at left shows a board under tension (the load is trying to stretch it) and the angle of the grain to the axis of the load is about 45°. At this angle the tensile/compressive strength of the board is probably reduced to less than 25% of its available strength at the 0° angle, i.e. when the grain is parallel to the long axis of the board and to the load.

In softwoods grain angles greater than a few degrees produce a markedly disproportionate reduction in tensile/compressive strength — maybe 25% reduction at just 15° and 50% reduction at 30°. The decrease in stiffness is even greater. Hence, as stated previously, the need to use boards that allow all structural members cut from them to have a *maximum grain slope* better than 1:15 [4°], or perhaps 1:20 [3°] for critical structures, throughout the component. (The structural member can be sawn from the board in a manner that produces minimum grain slope within that member.)

3.7 Effects of humidity and heat

Within a board moisture moves from wetter to drier zones until the MC is more or less constant throughout. Wood is hygroscopic so the MC of seasoned wood will adjust to the relative humidity of its environment — either absorbing water vapour from the atmosphere or evaporating moisture into it — until the wood reaches an MC that is in equilibrium with the atmosphere [the EMC]. Read the 'atmospheric moisture' section in the meteorology guide and note vapour partial pressure and how relative humidity changes with temperature.

So although the components of a fully seasoned wooden structure may have 12% MC when in the temperate coastal zone of Australia, the same structure's MC might fall to 7–8% in dry inland conditions or rise to 18–20% in monsoonal conditions in northern Australia.

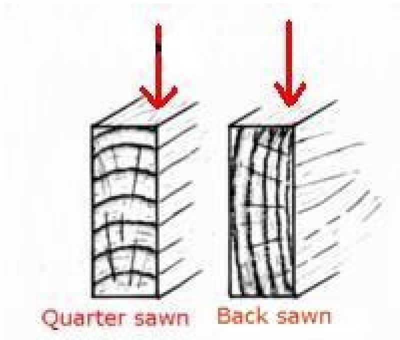
The density of wood changes by about 0.5% for each percentage point variation from 12% MC; i.e. a board at 18% MC will be 3% heavier than when at 12%.

The strength of wood is inversely proportional to the temperature; if the temperature of wood at 12% MC is increased from 20 °C to 40 °C the modulus of rupture will decrease by around 15%. *(Rule of thumb: about a 1% reduction in the ultimate strength and stiffness values for each 1 °C increase in wood temperature and the converse for temperature decrease.)* Short term heat soaking will not permanently affect strength but long periods at high temperatures will reduce the ultimate MR and ME values.

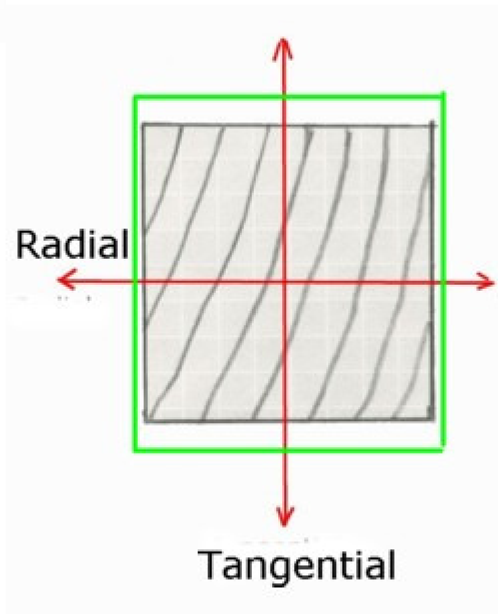
(The colour of the surface finish has a very significant effect on the temperature of aircraft surfaces: in 40° C ambient temperature the temperature of a white surface can reach 68° C, light green 84° C, red 100° C and black 110° C. Aluminium finish is about 75° C, so best paint your aircraft white. The figures are from an aircraft maintenance publication that was specifically referring to fibre reinforced polymer surfaces.)

If long term MC exceeds 20% the wood's susceptibility to decay/ dry rot is greatly increased, particularly so in warmer temperatures and in conditions where free moisture is trapped within the structure and oxygen can be absorbed from the atmosphere. MC changes also affect strength; a change from 12% MC to 18% MC will decrease the modulus of rupture by perhaps 25%.

Increasing bendability: plasticization [softening] of wood can be achieved chemically, by microwave irradiation, by steaming or by boiling; the latter methods are the most appropriate for the home workshop. If pieces of wood of smaller cross sections are soaked in a home made steam bath, or near-boiling water, for sufficient time for the wood to reach an internal temperature of 90° — 95° C and MC of 18% — 20%, the piece becomes ductile and thus able to be bent into a permanent shape without fracturing. If then clamped in a shaped form, of the desired curve, the piece will maintain somewhere near that bend after cooling and drying out — a very useful property when forming wing rib cap strips and similar curved components. *(By experimenting with an exaggerated bending form profile it is possible to compensate for the springback and achieve the exact curve after release).*



Stability: unless all surfaces and joints are coated with an impermeable barrier the absorption or release of water vapour will prompt dimensional **movement** [swelling/contraction] in structural members which, in effect, changes tension/compression in the structure.



Remember from the preceding section concerning moisture content and density that movement is insignificant longitudinally but generally quite significant in the tangential dimension [along the rings] – that often being more than twice the movement in the radial dimension, so it is important to align the cross-section grain of a structural member so that the extra tangential movement causes the least stress. The green rectangle in the image shows expansion due to moisture intake, though greatly exaggerated. If it is desirable that minimum all round movement should occur then the longest dimension of a rectangular section member should be aligned in the radial direction. Howwever the tangential movement in hoop pine is much less than the norm for aircraft softwoods and only about 40% more than the radial movement, thus the overall dimensional movement in a quarter sawn hoop pine board will be quite small.

The timber for solid beams should normally be back sawn, particularly in softwoods, as the strength of the growth rings when roughly parallel to the beam depth provides additional bending resistance. However stability considerations would dictate the reverse as the movement in the tangential dimension along the rings may be about twice the movement in the radial dimension, as explained above, thus solid aircraft spars are normally quarter sawn though with hoop pine one might opt for a back sawn spar because of the relatively small difference in radial/tangential movement.

An online wood shrinkage and expansion calculator is available at www.woodbin.com/calcs/shrinkulator.htm. If you input the initial MC [say 8%] and the EMC [say 16%] plus a nominal dimension [say 100] the calculator will provide the expansion radially and tangentially.

Painting, varnishing, epoxy coating or other moisture barriers slow the rate of adjustment to the environment and the wood takes some time to adjust to EMC, so daily humidity changes probably have no significant effect but seasonal changes certainly will. Moisture is more readily absorbed through end grain because of the capillary action provided so special measures may need to be taken to minimize that absorption. When constructing an aircraft it is important to ensure that no spaces within the structure are completely sealed off from the atmosphere; not just to ensure moisture movement but also to ensure that all compartments/cells readily adjust to in-flight atmospheric pressure changes.

Measuring MC: you can measure the MC of a board by cutting off a sample, weighing it carefully and immediately, then microwave it for sufficient time to completely dry the sample. Weigh it again then calculate the initial MC% which will be:

([initial weight – dry weight] / dry weight) × 100

for example: initial weight 87 grams, dry weight 77 grams:

$$([87 - 77] / 77) \times 100 = 13\% \text{ MC}$$

Effects of fuel and other liquids. Avgas, kerosene and most lubricating oils do not react with wood and have no significant effect on strength. However alcohols [as contained in mogas] and ethylene glycol [antifreeze] will cause wood to swell and will reduce strength while present, about the same effect as water absorption.