43 Wood as a Construction Material

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43.1 Introduction

This brief introduction to wood as a material is written primarily to inform the practicing civil engineer about what wood is; its cellular makeup; and, therefore, how it may be expected to react under various loading conditions. Space limitations preclude much detail; instead, references are given to lead the reader to detailed cause-effect relationships. Emphasis is placed on those items and relationships that most often lead to wood misuse or problems of proper wood use in structural applications and that may provide useful, practical guidelines for successful wood use.

What Is Wood?

Next to stone, wood is perhaps the building material used earliest by humans. Despite its complex chemical nature, wood has excellent properties which lend themselves to human use. It is readily and economically available; easily machinable; amenable to fabrication into an infinite variety of sizes and shapes using simple on-site building techniques; exceptionally strong relative to its weight; a good heat and electrical insulator; and—of increasing importance—it is a renewable and biodegradable resource. However, it also has some drawbacks of which the user must be aware. It is a “natural” material and, as such, it comes with an array of defects (**knots**, irregular grain, etc.); it is subject to decay if not kept dry; it is flammable; and it is anisotropic.

Definitions

In order to understand how best to use wood as a structural material, a few terms must be understood. A tree is a marvel of nature; it comes in a variety of species, sizes, shapes, and utilization potentials. However, all trees have some basic characteristics in common:

Growth ring: The portion of wood of a tree produced during one growing season. In the temperate zones this is also called an *annual ring*.

Earlywood: The portion of a growth ring that is formed early in the growing season. It normally contains larger cells with thinner walls. Earlywood is relatively low in **density** and is followed by latewood as the growing season progresses.

Latewood: The portion of a growth ring that is formed later in the growing season. Cells tend to be smaller in size and have thicker, denser cell walls.

Heartwood: The innermost growth rings of a tree; may be darker in color than the outermost growth rings (called sapwood). Contains phenolic compounds that in some species impart decay resistance to the heartwood.

Sapwood: The outermost growth rings of a tree; always light brown to cream-colored in all species; never decay- or insect-resistant. Sapwood and heartwood together make up the "wood" of commercial use.

Bark: The outside covering of a tree, which protects the tree from invasion by insects, disease, and decay. The bark is separated from the wood of a tree by a thin layer of cells, the *cambium,* which is able to produce new cells annually to increase a tree in diameter as an annual ring is added.

Hardwood: Trees that are deciduous, i.e., trees whose leaves are broad and are generally shed each year in the temperate zones. Typical hardwoods include oaks, maples, and poplar. It is important to realize that not all hardwoods are "hard"; balsa is a hardwood, for example. The major use of hardwoods is in furniture and cabinet manufacture.

Softwood: Typically "evergreen" trees with needle-like leaves. Includes Douglas fir, pines, spruces, cedars, and hemlock. Traditionally softwoods have been used primarily for structural timbers and are graded specifically for this purpose. The wood of softwoods ranges from soft to quite hard.

Wood cells: Long, thin, hollow units that make up wood. Most cells are oriented with their long axis roughly parallel to the axis of the tree. However, cell orientation may vary, as around a tree branch to form a knot in a board cut from a tree, and some cells are in groups called **wood rays**, which are oriented horizontally and radiate outward from the center of the tree.

Wood rays: A band of cells radiating outward from the center of the tree toward the bark. The long axis of these ray cells is horizontal; ray cells are used for food storage and horizontal translocation of fluids in a tree.

Wood Chemistry and Anatomy

Chemically, wood of all species is composed of five basic components: **cellulose**, in the form of long-chain molecules in large groups that make up threadlike structures called **microfibrils**; **hemicellulose**; **lignin**; *extractives*; and *ash*. Cellulose gives the wood its strength, particularly along the microfibrillar direction, and constitutes 40 to 50% of the wood by volume, depending upon species. Hemicellulose is about 20 to 35% of the wood of a tree by volume and is a more readily soluble form of cellulose; it is a polysaccharide often referred to as "fungi food." Lignin is the natural adhesive that glues the cellulose molecules and wood cells together to give the wood its rigidity and its viscoelastic and thermoplastic properties. Extractives typically constitute about 1 to 5% of the wood, and while they have little or no effect on wood strength, they impart resistance to decay and insects to those species that are termed durable. Extractives may also impart color to the heartwood. It is important to note that while all species probably contain some amount of extractives in the heartwood portion of a tree, they do not necessarily create a coloration different from that of the sapwood, nor do they necessarily impart any degree of durability or toxicity to insects and fungi to the heartwood. Ash is normally about 1% of the volume of wood.

The microfibrils are oriented at 5 to 30° to the cell axis; it is their orientation within a cell, as well as their very small shrinkage along their length as wood dries compared to their relatively large shrinkage between adjacent microfibrils, that is directly responsible for two major characteristics of wood: disparate strength properties and shrinkage properties along and across the grain, i.e., wood's anisotropic nature. Wood's cellular orientation, with most of the cells oriented longitudinally (approximately parallel to the axis of the tree) and bands of ray cells oriented radially, produces wood properties that are generally taken as *orthotropic:* longitudinal, radial, or tangential (tangent to the growth rings and perpendicular to the wood rays). From a practical point of view, radial and tangential properties are of a similar order of magnitude; thus, wood is usually viewed as having properties "along the grain" and "across the grain." A study of compression strength values in Table 43.1 will emphasize the fact that wood is widely variable in its properties and is generally much stronger along the grain than it is across the grain.

Wood species differ one from another, despite the fact that all wood is made up of basically the same chemical components. Inter- and intraspecies differences may be accounted for by several factors:

1. *Different cell types.* Softwoods have primarily one cell type: an all-purpose cell called a *tracheid,* which is responsible for both wood strength and vertical translocation of fluids. Hardwoods, on the other hand, have a number of different cell types with more specialized functions. Wood strength reflects those different cell types. Likewise, particularly in hardwoods, the proportions, or mix, of cell types also affect wood properties.
2. *Proportion of wood ray cells and size of wood rays.* In general, the softwood species tend to have small, narrow wood rays. Hardwoods, on the other hand, have rays that range in size from too small to be easily seen with the eye (buckeye, willow, cottonwood) to large (oak species). Ray size and appearance, along with more distinctive heartwood coloration, have led to the preference for hardwoods in furniture and panel manufacture as well as to species strengths and use differences.
3. *Site.* This may broadly include numerous aspects of tree growth: wet vs. dry site, low vs. high elevation (differences in water and temperature), weather cycles, shaded vs. sunny site, fertile vs. less fertile site, etc. These factors in turn affect the length of a tree's growing season and, hence, the width of the growth rings. The width of an annual growth ring tends to affect overall wood density and, thereby, species and individual tree properties. As a rough rule of thumb, softwoods with wider-than-normal growth rings (say, less than four rings per inch as seen on a tree cross-section) tend to be low in density and have lower strength properties. Hardwoods in general tend to have normal or higher-than-normal strength properties as growth ring width increases.

Wood strength properties also vary from the center (pith) of the tree outward toward the bark. The innermost growth rings for most species studied (particularly for softwood species) tend to be lower in density, weaker, and more prone to **warp** in product form than the outer rings. Although this characteristic varies between species, it is generally limited to the first 10 to 20 growth rings from the pith, with those nearest the pith being generally weakest and gradually increasing in strength as rings are added. Since these innermost rings contain the most knots, they also tend to become relegated to the lower grades of lumber and do not usually end up in structurally critical members. Their warpage characteristics also tend to relegate them to nonstructural uses. (One exception to this, however, is sometimes found in the use of pith-centered, nominal 4-by-4s used as concrete formwork.)

43.2 Wood Defects as They Affect Wood Strength

The major problems that arise in wood use may be attributed either to the effects of grain distortions (cell orientation or alignment), to the effects of excess moisture, or to defects that occur as a result of the drying process. The specific defects taken into account in the grading of lumber products include

TABLE 43.1 Clear Wood Strength Values (Metric Units) Unadjusted for End Use and Measures of Variation for Commercial Species of Wood in the Unseasoned Condition[a]

	Modulus of Rupture[b]		Modulus of Elasticity[c]		Compression Parallel to Grain, Max. Crushing Strength		Shear Strength		Compression Perpendicular to Grain: Fiber Stress at Proportional Limit		Compression Perpendicular to Grain: Mean Stress at 0.04 in. Deformation[d,e]	Specific Gravity	
	Avg. MPa	Standard Deviation MPa	Avg. MPa	Standard Deviation MPa	Avg. MPa	Standard Deviation MPa	Avg. MPa	Standard Deviation MPa	Avg. MPa	Standard Deviation MPa	MPa	Avg.	Standard Deviation
Cedar													
Western red	35.74	5.25	6474	1.54	19.13	3.40	5.32	0.79	1.68	0.45	2.96	0.31	0.027
Douglas fir[f]													
Coast	52.85	9.08	10,756	2.17	26.09	5.06	6.23	0.90	2.63	0.74	4.83	0.45	0.057
Interior West	53.18	9.11	10,432	2.23	26.70	5.51	6.45	0.94	2.88	0.81	4.87	0.46	0.58
Interior North	51.28	8.02	9715	1.89	23.92	4.15	6.53	0.87	2.45	0.69	4.61	0.45	0.049
Interior South	46.77	6.26	8012	1.38	21.46	3.37	6.57	1.05	2.32	0.65	3.99	0.43	0.045
Fir													
Balsam fir	38.04	3.81	8625	0.99	18.14	1.95	4.56	0.57	1.29	0.21	2.34	0.32	0.025
Subalpine fir	33.78	4.58	7253	1.25	16.49	2.50	4.80	0.71	1.32	0.30	2.40	0.31	0.032
Pine													
Eastern White	33.99	5.44	6853	1.51	16.82	3.03	4.67	0.66	1.50	0.42	2.68	0.35	0.035
Lodgepole	37.85	6.05	7419	1.63	18.00	3.24	4.72	0.66	1.74	0.49	3.05	0.39	0.039
Ponderosa	35.37	5.66	6874	1.51	16.89	3.04	4.85	0.68	1.94	0.54	3.39	0.39	0.039
Sugar	33.74	4.57	7115	1.33	16.95	2.66	4.95	0.72	1.48	0.30	2.63	0.34	0.027
Western White	32.32	4.78	8225	1.77	16.78	2.80	4.67	0.68	1.32	0.32	2.40	0.35	0.034

Redwood													
Old Growth	51.71	8.29	8115	1.79	29.03	5.23	5.54	0.77	2.92	0.82	4.94	0.39	0.039
Second-Growth	40.82	6.53	6584	1.45	21.44	3.86	6.16	0.86	1.85	0.52	3.24	0.34	0.034
Spruce													
Englemann	32.44	4.77	7095	1.43	15.03	2.94	4.39	0.44	1.36	0.34	2.47	0.033	0.033
Sitka	39.02	6.25	8481	1.87	18.41	3.32	5.22	0.73	1.92	0.54	3.35	0.38	0.038
Hickory													
Shagbark	75.98	12.16	10,797	2.37	31.58	5.68	10.48	1.47	5.81	1.63	9.53	0.64	0.064
Maple													
Sugar	64.95	10.39	10,659	2.34	27.72	4.99	10.10	1.41	4.45	1.25	7.36	0.57	0.057
Oak Red													
Northern	57.23	9.16	9329	2.05	23.72	4.27	8.37	1.17	1.13	1.19	6.81	0.56	0.056
Southern	47.71	7.63	7867	1.73	20.89	3.76	6.44	0.90	3.77	1.05	6.29	0.53	0.053
Oak, White													
Live	82.25	13.16	10,859	2.39	37.44	6.74	15.24	2.13	14.06	3.94	22.63	0.81	0.081
White	57.23	9.16	8591	1.89	24.55	4.42	8.61	1.21	4.63	1.30	7.65	0.60	0.060
Swamp	67.98	10.88	10,983	2.41	30.06	5.41	8.94	1.25	5.27	1.48	8.66	0.64	0.064

[a] *Source:* Adapted from Tables 1 and 2, ASTM. 1992. *Standard Practice for Establishing Clear Wood Strength Values, ASTM Designation D2555-88.* American Society for Testing and Materials, Philadelphia, PA.

[b] Modulus of rupture values are applicable to material 51 mm (2 in.) in depth.

[c] Modulus of elasticity values are applicable at a ratio of shear span to depth of 14.

[d] Based on a 51 mm (2 in.) wide steel plate bearing on the center of a 51 mm (2 in.) wide by 51 mm (2 in.) thick by 152 mm (6 in.) long specimen oriented with growth rings parallel to load.

[e] A coefficient of variation of 28% can be used as an approximate measure of variability of individual values about the stresses tabulated.

[f] The regional description of Douglas fir is that given on pp. 54–55 of U.S. Forest Service Research Paper FPL. 27, "Western Wood Density Survey Report No. 1."

Knots: The result of cutting across a branch in lumber manufacture. If the branch is cut perpendicular to its axis, the knot is round or oblong and presents a miniature aspect of a tree with visible growth rings. Knots may be *live* (cut through a living branch with intact tissue) or *dead* (cut through a dead branch stub with loose bark, usually resulting in a knothole). If the saw is oriented so as to cut along the length of a branch, the knot is greatly elongated and is termed a *spike knot*. Due to the obvious grain distortion around knots, they are areas of severe strength reduction. The lumber grading process takes this into account by classifying lumber grade by knot size, number, type, and location within the member. Knots located along the edge of a piece are, for example, restricted in size more than are knots located along the centerline of the member.

Slope of grain: A deviation of cell orientation from the longitudinal axis of the member. Slope of grain may be a natural phenomenon wherein the grain is at some angle to the tree axis (termed *spiral grain*), or it may be the result of sawing the member nonparallel to the tree axis. Slope of grain has a negative effect upon wood strength properties. A slope of 1:20 has minimal effect, but a slope of 1:6 reduces strength to about 40% in bending and to about 55% in compression parallel to the grain. Tensile strength is even more adversely affected.

Wane: Lack of wood. Wane occurs whenever a board is sawn so as to intersect the periphery of the tree, resulting in one edge or portion of an edge of a board being rounded or including bark. Limited amounts of wane are permitted, depending upon lumber grade. The effect of wane on wood strength or nailing surface is obvious.

Shake: A lengthwise separation of the wood, which usually occurs between or through the annual growth rings. Shakes are limited in grading since they present a plane of greatly reduced shear strength. Shake may occur as a result of severe wind that bends a tree to produce an internal shear failure, or as a result of subsequent rough handling of the tree or its products.

Splits and cracks: Separations of the wood cells along the grain, most often the result of drying stresses as the wood shrinks. Cracks are small, whereas splits extend completely through the thickness of a piece. Splits at the ends of the member, particularly along the central portion of a beam, are limited in grading.

Insect attack: Insect attack may range from small blemishes that do not affect strength to large voids or extensive damage in the wood as the result of termite or other insect infestation. Insect attack is usually treated as equivalent to the effect of similarly sized knotholes.

Decay: Decay, caused by wood-destroying fungi, is precluded from wood use except for certain species in lower grades because the strength-reducing effects of fungal attack are quite significant even before visible evidence (wood discoloration, punkiness) appears. It is important to note that decay organisms require moisture to live and grow; hence, the presence of active decay or mold implies access to a source of moisture. Moist wood will *always* decay, unless the wood is **preservative**-treated or is of a very durable species.

43.3 Physical Properties of Wood

The practicing civil engineer should be knowledgeable about several important physical properties of wood:

Specific Gravity (SG)

As a general rule, specific gravity (SG) and the major strength properties of wood are directly related. SG for the major native structural species ranges from roughly 0.30 to 0.90. The southern pines and Douglas fir are widely used structural species that are known to exhibit wide variation in SG; this is taken into account in the lumber grading process by assigning higher allowable design values to those pieces having narrower growth rings (more rings per inch) or more dense latewood per growth ring and, hence, higher SG.

Moisture Content (MC) and Shrinkage

Undoubtedly, wood's reaction to moisture provides more problems than any other factor in its use. Wood is *hygroscopic*; that is, it picks up or gives off moisture to equalize with the relative humidity and temperature in the atmosphere. As it does so, it changes in strength; bending strength can increase by about 50% in going from green to a **moisture content (MC)** found in wood members in a residential structure, for example. Elasticity values can also increase, but only about 20%, over a similar moisture change range. Wood also shrinks as it dries, or swells as it picks up moisture, with concomitant warpage potential. Critical in this process is the **fiber saturation point (fsp)**, the point (about 25% moisture content, on **oven-dry** basis) below which the hollow center of the cell has lost its fluid contents, the cell walls begin to dry and shrink, and wood strength begins to increase. The swelling and shrinkage processes are reversible and approximately linear between fiber saturation point and 0% MC. Due to its chemical and cellular makeup, wood shrinks along the grain only about 0.1 to 0.2%. Shrinkage across the grain may range from about 3 to 12% in going from *green* (above fiber saturation point) to 0% MC, depending not only on species but also on grain orientation (radial vs. tangential). Wood decay or fungal stain do not occur when the MC is below 20%.

There is no practical way to prevent moisture change in wood; most wood finishes and coatings only slow the process down. Thus, vapor barriers, adequate ventilation, exclusion of water from wood, or preservative treatment are absolutely essential in wood construction. The *National Design Specification for Wood Construction®* (NDS®) (American Forest and Paper Association, 1991) contains explicit guidelines for the treatment of wood moisture content in regard to various structural design modes, including fastener design.

Moisture content is defined by the equation

$$\mathrm{MC}(\%) = \frac{\text{Wet weight} - \text{Oven-dry weight}}{\text{Oven-dry weight}} \times 100 \qquad (43.1)$$

The MC of wood may be in excess of 200% as it is cut from a log, particularly in species that are low in SG and contain thin-walled cells. It is important to note that a wood member dries most rapidly from the ends and that as it dries below fsp, shrinkage stresses may result in cracks, checks, splits, and warpage. These defects are limited in stress-grades of lumber.

Thermal Properties/Temperature Effects

Although wood is an excellent heat insulator, its strength and other properties are affected adversely by exposure for extended periods to temperatures above about 100°F. Refer to NDS (American Forest and Paper Association, 1991). The combination of high relative humidity or MC and high temperatures, as in unventilated attic areas, can have serious effects on roof sheathing materials and structural elements over and above the potential for attack by decay organisms. Simple remedies and caution usually prevent any problems. At temperatures above 220°F, wood takes on a *thermoplastic* behavior. This characteristic, which is rarely encountered in normal construction, is an advantage in the manufacture of some reconstituted board products, where high temperatures and pressures are utilized.

Durability

Although design texts classify various species as nondurable, moderately resistant to decay, or resistant to decay, it is best to note that only the heartwood of a species may be resistant to decay and of the readily available species, only a few are effectively resistant in their natural state (redwood, cypress, western red cedar, and black locust). On the other hand, many structural softwood species are made very durable against fungal and insect attack when properly preservative-treated with creosote, pentachlorophenol, chromated copper arsenate (CCA), or ammoniacal copper arsenate (ACA).

Chemical Effects

Wood is relatively chemically inert. Although, obviously, wood will deteriorate when in contact with some acids and bases, some species have proven very useful for food containers (berry boxes and crates) because they are nontoxic and impart no taste to the foods contained therein. Wood structures have also found widespread use as storage facilities for salt and fertilizer chemicals.

43.4 Mechanical Properties of Selected Species

Major Engineering Properties

As stated before, wood strength depends on several factors unique to wood as a material; these factors include species (and associated inherent property variability), wood (properties parallel or perpendicular to the grain), MC at time of use, **duration of load**, and lumber grade (reflective of type and degree of defects present). Tables 43.1 and 43.2 present average strength property values for selected structural species. It is important to note that these values are for wood that is straight-grained, defect-free, and at a green MC (i.e., above fsp). The data are best used for property comparisons between species. These basic properties are modified to arrive at allowable design properties (refer to Section 43.7 and to [ASTM, 1992] and [ASTM, 1988]) following a general format of

$$F = \frac{\left(\bar{X} - 1.645\ \mathrm{SD}\right)}{F_{\mathrm{ADJ}}}\left(F_{\mathrm{MC}}\right)\left(F_{\mathrm{SIZE}}\right)\left(F_{\mathrm{DENS}}\right)\left(F_{\mathrm{SR}}\right)$$

where F = allowable design stress

$\bar{X}$ = average property value, green MC

SD = standard deviation for the property; this reduction of 1.645 standard deviations from the mean establishes a 95% lower exclusion value on the mean. Design values for E and compression perpendicular to the grain, considered to be non-life-threatening properties, are derived directly from mean values, however, with no adjustment for property variability.

F_{MC} = a factor to correct for an increase in property value if the product is dried. The factor applies only to members of nominal 4 in. or less in least dimension. (Larger members are not dried prior to installation, and subsequent drying defects in large sizes may act to nullify much of the strength increase due to drying.)

F_{SIZE} = a correction for member size. Test observation shows that larger-depth beams fail at lower stress levels than smaller beams, and allowable bending stress values are corrected by a factor of $(2/d)^{1/9}$, where d = member depth in inches.

F_{DENS} = a density correction factor for southern pine or Douglas fir members that are slow-grown and of a high density.

F_{SR} = a "strength ratio" factor for lumber grade (defects). Current grades for visually graded structural lumber are Select Structural (SR 65), No. 1 (SR 55), No. 2 (SR 45), and No. 3 (SR 26). The SR value, as a percentage, expresses the ratio of the strength of a member with its permitted defects to the strength it would have if defect-free.

F_{ADJ} = an adjustment factor to convert table values from short-time duration of load to "normal" duration (assumed to be an accumulated 10-year period of full design load) plus a factor of safety.

The reader is referred to the ASTM documents (ASTM, 1988, 1992) and the lumber grade rules manuals for stress grading details and for the factors that apply to related products, such as scaffold plank, etc.

TABLE 43.2 Clear Wood Strength Values (English Units) Unadjusted for End Use and Measures of Variation for Commercial Species of Wood in the Unseasoned Condition[a]

	Modulus of Rupture[b]		Modulus of Elasticity[c]		Compression Parallel to Grain, Max. Crushing Strength		Shear Strength		Compression Perpendicular to Grain: Fiber Stress at Proportional Limit		Compression Perpendicular to Grain: Mean Stress at 0.04 in. Deformation[d,e]	Specific Gravity	
	Avg. (psi)	Standard Deviation (psi)	Avg. (ksi)	Standard Deviation (ksi)	Avg. (psi)	Standard Deviation (psi)	Avg. (psi)	Standard Deviation (psi)	Avg. (psi)	Standard Deviation (psi)	(psi)	Avg.	Standard Deviation
Cedar													
Western red	5184	761	939	223	2774	493	771	115	244	65	430	0.31	0.027
Douglas fir[f]													
Coast	7665	137	1560	315	3784	734	904	131	382	107	700	0.45	0.057
Interior West	7713	1322	1513	324	3872	799	936	137	418	117	707	0.46	0.058
Interior North	7438	1163	1409	274	3469	602	947	126	356	100	669	045	0.049
Interior South	6784	908	1162	200	3113	489	953	153	337	94	578	0.43	0.045
Fir													
Balsam fir	5517	552	1251	143	2631	283	662	83	187	31	340	0.32	0.025
Subalpine fir	4900	664	1052	182	2391	363	696	103	192	44	348	0.31	0.032
Pine													
Eastern White	4930	789	994	219	2440	439	678	95	218	61	389	0.35	0.035
Lodgepole	5490	878	1076	237	2610	470	685	96	252	71	443	0.39	0.039
Ponderosa	5130	821	997	219	2450	441	704	99	282	79	491	0.39	0.039
Sugar	4893	663	1032	193	2459	386	718	105	214	43	382	0.34	0.027
Western White	4688	693	1193	257	2434	406	677	98	192	46	348	0.35	0.034
Redwood													
Old Growth	7500	1202	1177	259	4210	758	803	112	424	119	716	0.39	0.039
Second-Growth	5920	947	955	210	3110	560	894	125	269	75	470	0.34	0.034

TABLE 43.2 (continued) Clear Wood Strength Values (English Units) Unadjusted for End Use and Measures of Variation for Commercial Species of Wood in the Unseasoned Condition[a]

	Modulus of Rupture[b]		Modulus of Elasticity[c]		Compression Parallel to Grain, Max. Crushing Strength		Shear Strength		Compression Perpendicular to Grain: Fiber Stress at Proportional Limit		Compression Perpendicular to Grain: Mean Stress at 0.04 in. Deformation[d,e]	Specific Gravity	
	Avg. (psi)	Standard Deviation (psi)	Avg. (ksi)	Standard Deviation (ksi)	Avg. (psi)	Standard Deviation (psi)	Avg. (psi)	Standard Deviation (psi)	Avg. (psi)	Standard Deviation (psi)	(psi)	Avg.	Standard Deviation
Spruce													
Englemann	4705	692	1029	207	2180	427	637	64	197	50	358	033	0.033
Sitka	5660	906	1230	271	2670	481	757	106	279	78	486	0.38	0.038
Hickory													
Shagbark	11,020	1763	1566	344	4580	824	1520	213	843	236	1382	0.64	0.064
Maple													
Sugar	9420	1507	1546	340	4020	724	1465	205	645	181	1067	0.57	0.057
Oak, Red													
Northern	8300	1328	1353	298	3440	619	1214	170	164	172	987	0.56	0.056
Southern	6920	1107	1141	251	3030	545	934	131	547	153	912	0.53	0.053
Oak, White													
Live	11,930	1909	1575	346	5430	977	2210	309	2039	571	3282	0.81	0.081
White	8300	1328	1246	274	3560	641	1249	175	671	188	1109	0.60	0.060
Swamp	9860	1578	1593	350	4360	785	1296	181	764	214	1256	0.64	0.064

[a] *Source:* Adapted from Tables 1 and 2, ASTM. 1992. *Standard Practice for Establishing Clear Wood Strength Values, ASTM Designation D2555-88.* American Society for Testing and Materials, Philadelphia, PA.

[b] Modulus of rupture values are applicable to material 51 mm (2 in.) in depth.

[c] Modulus of elasticity values are applicable at a ratio of shear span to depth of 14.

[d] Based on a 51 mm (2 in.) wide steel plate bearing on the center of a 51 mm (2 in.) wide by 51 mm (2 in.) thick by 152 mm (6 in.) long specimen oriented with growth rings parallel to load.

[e] A coefficient of variation of 28% can be used as an approximate measure of variability of individual values about the stresses tabulated.

[f] The regional description of Douglas fir is that given on pp. 54–55 of U.S. Forest Service Research Paper FPL. 27, "Western Wood Density Survey Report No. 1."

Note that while this format is still in use and indicates major factors considered in lumber grade-strength assessment, it has been largely replaced for some properties by "in-grade testing" data, described in Section 43.7.

Strengths and Weaknesses

Wood in bending is amazingly strong for its weight; however, in many applications beam size is limited more by deflection criteria than by strength. Young's modulus (E) values for native species will range from about 3450 MPa (0.5 million psi) to about 17,250 MPa (2.5 million psi). Wood in tension parallel to the grain is exceedingly strong; however, it is readily affected by wood defects, particularly by knots and slope of grain. For this reason tensile allowable design properties are taken as 0.55 • bending values. Also, tension perpendicular to the grain properties are very weak, and fracture in this mode is abrupt; design for this mode of possible failure is not acceptable (a singular exception to this rule is made for laminated arches, haunched frames, and similar members where shear stress is unavoidable; allowable design values in these cases are in the range of only 0.10 MPa to 0.20 MPa (15 to 30 psi).

Wood strength in compression necessarily must consider grain angle since compressive strength varies inversely with grain angle from 0° (parallel to the grain) to 90° (perpendicular to the grain). This relationship is described by Hankinson's formula:

$$N = \frac{C_{\parallel} \times C_{\perp}}{\left(C_{\parallel}\right)\left(\sin^2 \phi\right) + C_{\perp}\left(\cos^2 \phi\right)} \tag{43.2}$$

where N = normal stress on a surface
$C_{\parallel}$ = compressive strength parallel to the grain
$C_{\perp}$ = compressive strength perpendicular to the grain
ϕ = grain angle measured in degrees from parallel to the member long axis

This relationship is also used in the design of fasteners in a joint where members converge from different angles or where eccentric bearing occurs.

Stability must be taken into account for columns with a ratio of column length to least cross-sectional dimension greater than around 10. Column stability is a function of compressive strength, E, end fixation, and manufacture (sawn lumber vs. round piles vs. **glu-lam**) (American Forest and Paper Association, 1991). Wood is very strong in shear across the grain, but very weak and variable in shear along the grain; for this reason horizontal shear stress over supports in bending beams is often a critical design consideration, particularly for short, deep beams. The designer of wood structures must at all times be aware of wood species, grade, grain angle in localized areas, and MC effects.

Recent design criteria for bending beams (American Forest and Paper Association, 1991) take beam stability into account. As in column design, beam strength, elasticity, and other factors enter in. In cases where combined stresses occur (tension or compression combined with bending, as in roof or ceiling loads applied to timber trusses), possible two-dimensional bending is also taken into account.

In general, structures made of stress-graded material do not fail; their performance record is excellent. Several reasons may account for this. Wood tends to be resilient; members also tend to "share" their loads. Load-sharing design factors (called *repetitive member factors*) may be applied, but they are considered to be conservative. Three or more bending members fastened together and stabilized, as by flooring over joists, in sizes limited to nominal 2 to 4 in. thick may be termed **repetitive member use**, and allowable bending design stresses may be increased by a conservative 15%. In addition, allowable design stresses are, in general, also conservative; there are several built-in safety factors in the derivation process. The visual grading process for structural lumber is predicated upon setting an upper limit on permissible defect sizes and number; most pieces within a grade have defects somewhat less in size or degree than is permitted in the grade, resulting in an additional margin of safety. Wood structural failure is most often attributed to poor design or failure of the fasteners.

TABLE 43.3 Frequently Used Load Duration Factors for Wood Construction[a]

Load Duration	Factor	Typical Design Load
Permanent	0.9	Dead load
10 years	1.0	Occupancy live load
2 months	1.15	Snow load
7 days	1.25	Construction load
10 minutes	1.6[b]	Wind/earthquake load
Impact	2.0	Impact load

[a] *Source:* Taken from Table 2.3.2, NDS. 1991. *National Design Specification for Wood Construction.* American Forest and Paper Association, Washington, D.C.
[b] The 1.6 factor was 1.33 in previous editions of NDS; some code agencies may not accept the new value.

Duration of Load Effects

Wood is one of those materials that exhibits duration of load (DOL) effects; it will withstand higher loads at failure if the load is applied over a shorter period of time as opposed to a longer time to create failure. All strength properties show this effect except E and compression perpendicular to the grain. For design purposes, **normal duration of load** for full design load is taken as 10 years; other load durations are accounted for by multiplier factors, given in Table 43.3. There is some evidence indicating, however, that for lower grades of material the limiting defect (a large knot, for example) is the major factor in determining failure and that for low-grade lumber the DOL factors for short DOLs should be ignored or applied with caution.

Wood, due to its plastic nature, creeps under load. A safety factor is recommended in designing where deformation is important. In beam design, a general rule of thumb is that instantaneous bending deflection under load is about half that which will result over the normal life of the structure. For long columns subject to buckling, a safety factor of 3 for E is recommended. An increasing rate of creep deformation is indicative of impending failure; measurement of beam deflection over time, for example, may be used to indicate potential problems (as in flat roof ponding) and required reinforcement.

Strength Variability

As a biological material, wood is variable in all its properties. Variability is measured by coefficient of variation values, Table 43.4, where the values listed are broad species values.

A property variability effect is also imposed by the presence of minor defects within the wood (small grain deviations near knots; rapid growth in some annual rings of conifers, which tend to lower density; very slow growth in any species; or wood in close proximity to the pith, which is inherently low in density and has a propensity to shrink excessively). Generally this is taken into account mathematically in the design stress determination and grading processes; however, caution must be used whenever load situations require the loading of single members, as in scaffolding.

TABLE 43.4 Coefficient of Variation (COV) Values for Wood Properties[a]

Property	COV
SG	0.10
Modulus of Rupture	0.16
E	0.22
Compression, parallel	0.18
Compression, perpendicular	0.28
Shear	0.14

[a] *Source:* Adapted from Table 4-5, Forest Products Laboratory. 1987. *Wood Handbook: Wood as an Engineering Material.* Agricultural Handbook 72, USDA, Washington, D.C.

Age Effects

If wood in use is kept dry and free from mechanical and insect damage, it will remain nearly unchanged in its properties over time. Timbers removed from old structures may be reused. The only cautionary action is to have any structural members regraded to account for any increase in cracks or splits due to the continued drying of a piece in use. Most wood members will be in the range of 12 to 20% MC at time of installation. They may, over time, dry to as low as 5 to 7% MC, depending on their ambient conditions. Although wood strength may be expected to increase as the MC decreases, defects that occur due to the drying process tend to offset or nullify strength increases. This is particularly evident in large, heart-centered members, which may develop large cracks from the outer surface of the piece to the center (pith) of the piece. Shear strength may be affected in beams, and column strength/stability may also be affected.

43.5 Structural Products and Their Uses

Beginning with small trees and limbs, then lumber and plywood, structural uses of wood have evolved slowly into "artificial" products, such as wood composite beams and laminated veneer lumber, which have greatly expanded the architectural design capabilities of wood structures as well as conserving a valuable natural resource through more complete utilization. Thin-kerf saws, improved veneer production techniques, better adhesives, and extensive research and development on modern timber products have led not only to new products but also to the efficient utilization of more of the tree and of a much wider range of species.

The simplest form of wood for use is the *pole* or *piling*. This is merely a delimbed and debarked tree. Common species used for this purpose are the southern pines and Douglas fir, both of which must be preservative-treated prior to use. Western red cedar is also used extensively but does not need to be treated. Poles are often **incised** (surface perforated to permit deeper, more uniform preservative penetration) before treatment. Poles have wide usage in farm structures, in the utility field, and to obtain a rustic appearance in restaurants and residential construction. Piling is, of course, used in marine structures or as foundation supports when driven into the ground. Piling has been known to have been used for several decades, removed, inspected, and reused; the exclusion of oxygen underground essentially eliminates the danger of decay except at ground level. For this reason poles and piling should be inspected regularly for signs of deterioration at any point where wood, moisture, and oxygen meet for any significant period of time and where the ambient temperature lies between 15° and 35°C. In dealing with poles and piling (long columns) it is essential that lateral stability and adequate bracing against buckling be carefully considered.

Lumber is the most common wood construction material. Allowable design stresses for the many softwood species and grades of lumber are available; refer to NDS (American Forest and Paper Association, 1991) or to lumber grade rules books. Some hardwood species have assigned design stresses; however, stress-graded hardwoods are virtually nonexistent in most areas. Paradoxically, hardwoods have long been used in the East and Midwest regions for farm structures, but as general construction lumber, not with allowable stress ratings. The reason for this is because most hardwoods are valued for their esthetic appearance and, therefore, command considerably higher prices in the furniture trade than most softwoods do in the structural markets.

Structural lumber comes in several grades and is manufactured in 2-foot increments of length. It is important to note that structural lumber (synonymous with the term *stress-graded lumber*) is graded to be used as single, unaltered members. Cutting the piece along its length or across its width essentially nullifies any grade marking.

Since lumber is purchased in discrete lengths by grade and by width and thickness (2-by-6, etc.), the stocking and marketing of a vast multitude of different sizes, lengths, and grades has necessitated species grouping. Species of similar properties and uses have been grouped (via specific procedures outlined in ASTM D-2555 [ASTM, 1988]) for marketing ease. For example, "southern pine" consists of a mixture of as many as eight distinct hard pines; "hem-fir" is made up of western hemlock combined with several fir species. The allowable design values are derived to reflect the mix of species, with limits imposed by the species with the lowest average property values. Lumber is also categorized by size and use classes as

TABLE 43.5 American Standard Lumber Sizes for Structural Lumber[a]

	Thickness (in.)			Face Width (in.)		
Item	Nominal	Minimum Dry	Dressed Green	Nominal	Minimum Dry	Dressed Green
Dimension	2	1½	1⁹⁄₁₆	2	1½	1⁹⁄₁₆
	2½	2	2¹⁄₁₆	3	2½	2⁹⁄₁₆
	3	2½	2⁹⁄₁₆	4	3½	3⁹⁄₁₆
	3½	3	3¹⁄₁₆	6	5½	5⅝
	4	3½	3⁹⁄₁₆	8	7¼	7½
	4½	4	4¹⁄₁₆	10	9¼	9½
				12	11¼	11½
				14	13¼	13½
Timbers	5 and larger	—	½ in. less than nominal	5 and larger	—	½ in. less than nominal

[a] Adapted from Table 5-6, Forest Products Laboratory. 1987. *Wood Handbook: Wood as an Engineering Material*. Agricultural Handbook 72, USDA, Washington, D.C.

1. dimension lumber (often referred to as "joists and planks"): nominal 2 in. or 4 in. thick and nominal 2 in. or more in width; graded primarily for edgewise or flatwise bending
2. beams and stringers: nominal 5 in. and thicker with a width at least 5 cm (2 in.) greater than nominal thickness; graded for strength in bending when loaded on the narrow face
3. posts and timbers: pieces of square or nearly square cross-section, 5 in. by 5 in. nominal thickness or larger; graded primarily for use as posts or columns
4. stress-rated boards: lumber less than 2 in. in thickness and 2 in. or wider

These classes do not preclude use for other purposes; e.g., post and timber grades also have allowable bending stresses assigned to them.

Lumber is purchased by its **nominal size**, e.g., 2-by-6; its actual size is somewhat less. The nominal size represents the member as it would be before reduction in size due to the removal of saw kerf, shrinkage due to drying, and reduction in size due to planing smooth after drying. Nominal and actual green and dry sizes are given in Table 43.5.

Plywood was the first of a large number of wood panel products produced for structural purposes. It is made of an odd number of layers of veneer; each alternate layer is laid with the grain at right angles to adjacent layers. The odd number of layers ensures that the panel is "balanced" in terms of strength and shrinkage about the panel neutral axis. Obviously, this necessitates that the grain on the face plies be placed so as to utilize the panel's strength along the grain. Plywood is manufactured in several standard thicknesses; 0.64 cm to 3.8 cm (¹/4 to 1¹/₂ in.) are common thicknesses. The most common species used on the outermost plies for structural purposes are southern pine and Douglas fir; however, dozens of different species may be used for the interior, or core, plies. Only the face plies are required to be of the designated species. Plywood is typically manufactured in 122 cm ¥ 244 cm (4 ft by 8 ft) panels, but special sizes are available. Plywood is typically used as floor underlayment and roof sheathing, but it has been largely replaced by other panel products for these uses. It is also widely used for concrete forming where special, surface-treated panels are available. Plywood is produced in several grades in regard to glueline durability. Panels may be rated as *interior* (for interior use only; the glueline is not to be exposed to moisture) or *exterior*. Exterior panels are classed as Exposure 1, which has a fully waterproof bond and is designed for applications where long construction delays may be expected or where high moisture conditions may be encountered in service; or Exposure 2, which is intended for protected construction applications where only moderate delays in providing protection from moisture may be expected. Structural plywood panels are grade-stamped with glueline type and recommended span rating. A special grade, *marine plywood*, is also available; it has improved durability and a higher grade of veneer in the inner plies. Consult the American Plywood Association for technical advice on plywood design and use (*American Plywood Association,* 1992a,b).

TABLE 43.6 Ranges of Physical and Mechanical Property Values for Commercially Available Flakeboard[a]

Type of Flakeboard	Density kg/m³	Density pcf	Modulus of Rupture MPa	Modulus of Rupture psi	Modulus of Elasticity MPa	Modulus of Elasticity ksi
Waferboard	608.70–720.83	38–45	13.79–20.68	2000–3000	3.10–4.48	450–650
Oriented strand board						
Parallel to alignment	608.70–800.92	38–50	27.58–48.26	4000–7000	5.17–8.96	750–1300
Perpendicular to alignment	—	—	10.34–24.13	1500–3500	2.07–3.45	300–500

Type of Flakeboard	In-Plane Shear Strength MPa	In-Plane Shear Strength psi	Internal Bond MPa	Internal Bond psi
Waferboard	8.27–12.41	1200–1800	0.34–0.69	50–100
Oriented strand board				
Parallel to alignment	6.89–10.34	1000–1500	0.48–0.69	70–100
Perpendicular to alignment	—	—	—	—

[a] Excerpted from Table 22-5, Forest Products Laboratory. 1987. *Wood Handbook: Wood as an Engineering Material*. Agricultural Handbook 72, USDA, Washington, D.C.

Whereas lumber is sawn from a log with a considerable waste factor for slabs and sawdust, and plywood is made from thin sheets of veneer peeled from higher-quality logs, other panel products have been developed from technology that permits the conversion of entire logs into particles, chips, or carefully sized flakes with insignificant waste factors, and subsequently into panels with predictable engineering properties and a wide array of marketable sizes and thicknesses. **Particleboard**, the oldest of these products, is made from particles bonded under pressure with, usually, a urea-formaldehyde adhesive. Its intended use is as a substrate for overlaid sheet materials or as underlayment. Strength properties are relatively low. A majority of the particleboard produced is utilized by the furniture and related industries. Like all panel products, its properties depend upon the material input and process: species, size and shape of the particles or flakes, orientation of the flakes, adhesive used, density of the finished product, thickness of the panel, and pressure and temperature at which the panels are formed. Particleboards are not generally considered as "structural" materials because of lower levels of strength and use of a nondurable adhesive.

However, as a subset of generic particleboard, composites made from large flakes and exterior-grade/waterproof adhesives have evolved into structural-use panels. They may be "engineered" for a specific purpose by varying the pressing temperature, pressure, adhesive amount, and flake orientation. Board strength may be designed into the product. However, unlike lumber and most materials where bending strength and E tend to be properties of primary importance, panel products need to be evaluated as well for their internal bond strength, shear properties, and fastener strength. This has resulted in a wide variety of panel products with properties patterned toward specific end uses. Oriented-strand board (OSB) is one of the most recent such products; its flakes are mechanically oriented to align them to be closely parallel to the long axis of the panel on the outer faces of the panel in order to attain properties more closely resembling those of plywood in bending, while still maintaining relatively low density and the economic advantage of maximum resource use and low cost. Panel weight can be varied by producing a layered product with the inner portion of the panel made up to have different properties than the faces. Typical uses of OSB panels are roof sheathing, floor sheathing, and web material in composite wood I-beams or in shear walls. Physical and mechanical property values for various flakeboard types are given in Table 43.6; note that the tabled values are *not* design allowable values, and manufacturers' specifications should be referred to.

Glued-laminated beams (glu-lam) have been in use for decades and have the distinct advantage of being able to be produced in nearly any size or shape desired. The only practical limitation is the difficulty in transporting large structural beams or arches to the building site. Glu-lam is made by gluing thin boards, usually 1 or 2 in. (2.5 or 5.1 cm) thick lumber, together over forms to achieve the desired size and shape of a solid member. All the boards used are dried prior to lay-up of the member to greatly reduce drying defects associated with large, sawn timbers, and by using thin layers, natural defects are evenly distributed throughout the beam. Current technology in this field is centered on methods to combine accurate grade separation of high-quality lumber with computerized design placement of high-strength outer laminations balanced against lower-strength and lower-grade material in the inner laminations to achieve maximum material utilization at economical cost. The boards used in glu-lam, particularly for outer laminations, are a specialty grade with special grading criteria. Laminating grades of L1, L2, and L3 are graded with additional restrictions on permitted defects and growth rates over the normal visual grades. "Standard" beam lay-up configuration and sizes, as well as design criteria, are available from the American Institute of Timber Construction. Lumber used in glu-lam manufacture is generally of a softwood species, although glu-lam from hardwoods is available. Manufacture is in conformance with ANSI/AITC A190.1-1983. Finished beams come in three appearance grades: Industrial, Architectural, and Premium. Beams may be preservative-treated if necessary. Sizes and shapes will vary, but "standard" widths are 6.3 cm (2½ in.), 7.9 cm (3⅛ in.), 13.0 cm (5⅛ in.), 17.1 cm (6¾ in.), 22.2 cm (8¾ in.), and 27.3 cm (10¾ in.); number of laminations and depth of member can be as many as 50 or more laminations and several feet in depth. The American Institute of Timber Construction has a technical staff to aid in glu-lam design.

A new breed of product, **structural composite lumber** (SCL), has appeared recently on the market; it is a panel product made of thin layers of veneer or of wood strands mixed with a waterproof adhesive. The veneered product, termed **laminated-veneer-lumber** (LVL), is a miniature glu-lam. The strand products are known as *parallel-strand-lumber* (PSL) and *laminated-strand-lumber* (LSL); the latter, being the newest, evolved directly from the oriented-strand board-manufacturing process. SCL products are generally produced in flat panels or *billets* (of selected species) 122 cm to 244 cm (4 to 8 ft) wide, 3.8 cm (1½) in. or more thick, and up to 12.3 m (40 ft) long. These products are available in larger sizes than sawn lumber and tend to be significantly stronger than lumber of equal size (due to redistribution and minimization of defects), but, due to the stringent manufacturing process, they also tend to be somewhat more expensive. They are normally used for purposes requiring high strength or stiffness in both residential and light industrial/commercial construction. Table 43.7 lists design stress values for building code-approved LVL products.

With the plethora of engineered specialty products, it is no surprise that a vast array of structural composite products has also become available. Solid lumber structural members, while still preferred for many traditional uses, particularly in residential construction, are being replaced by wood I-beams with LVL flanges and OSB webs. Metal bar webs and lumber or LVL flanges are common. Toothed, stamped metal plate connectors are used as fasteners for a myriad of structural frames, trusses, and components. Design software has kept pace with these trends and is able to factor into a design the various decisions on temperature effects, moisture effects, duration of load, and combined stress situations as well (Triche and Suddarth, 1993).

TABLE 43.7 Design Stress Values for Code-Approved LVL Products[a]

Design Stress	MPa	Range psi
Flexure	15.17–28.96	2200–4200
Tension parallel-to-grain	11.03–19.31	1600–2800
Compression parallel-to-grain	16.55–22.06	2400–3200
Compression perpendicular to grain:		
Perpendicular to glueline	2.76–4.14	400–600
Parallel to glueline	2.76–5.52	400–800
Horizontal shear:		
Perpendicular to glueline	1.38–2.07	200–300
Parallel to glueline	0.69–1.38	100–200
Modulus of elasticity	12,410–19,310	1.8 ¥ 10^6–2.8 ¥ 10^6

[a] *Source:* Forest Products Laboratory. 1987. *Wood Handbook: Wood as an Engineering Material.* Agricultural Handbook 72, USDA, Washington, D.C., pp. 10–13.

TABLE 43.8 Preservative Retention Level–Use Recommendations

Retention Level (lbs/cu. ft)	Use/Exposure
0.25	Above ground
0.40	Ground contact/fresh water
0.60	wood foundation
2.50	Salt water

43.6 Preservatives

For all practical purposes only a few native species are truly immune to fungal deterioration, and then, as stated earlier, only the heartwood portion of the wood is decay-resistant. Availability and economy usually dictate that where decay resistance is required, preservative treatment is a must. Any structural component that is in contact with the ground, subject to periodic wetting (leakage or rain), or in a high-relative-humidity atmosphere for extended time periods, may be expected to decay.

There are several preservatives available; degree of exposure and the use of the member will indicate which specific preservative to use. In all cases a pressure treatment is required; dip treating, soaking, or painting the surface with a preservative solution are only temporary deterrents at best and are not recommended where structural integrity is required. Creosote, one of the oldest and most effective treatments, is used primarily for treating utility poles and marine piling. It is an oilborne preservative of high toxicity and is not recommended where human contact is anticipated. A number of arsenic-containing treatments are commonly used. CCA (chromated copper arsenate) is used with dimension lumber, particularly with southern pine, and ACA (ammoniacal copper arsenate) is also commonly used. Both CCA and ACA are waterborne preservatives that are pressure-impregnated into dry (below fsp) lumber; the chemicals become permanently bonded to the wood as the wood becomes redried after treatment. It is very important to know that until the wood has become dry again after treatment, it is dangerous to handle. Resawn wood that is wet on the inside of the piece, even if it appears dry on the outside, can produce arsenic poisoning. It is also important to know that even under high impregnation pressures, the depth of penetration of the preservative into the wood may be incomplete. Resawing may expose untreated wood to decay; treatment after cutting or boring members to final size is recommended. CCA and ACA treatments are commonly used for foundations, decks, and greenhouses. Dry CCA- and ACA-treated lumber is approved for human contact use. Under no circumstances are wood scraps of CCA- or ACA-treated wood to be burned in the open air; this will ultimately release poisonous arsenic and chromium compounds into the air.

Borate compounds are effective wood preservatives and are economical and nontoxic to humans and animals. Unfortunately, they also leach out of the wood rather readily when subjected to rain or wet conditions. Research on these and other compounds may result in a new family of leach-resistant, nontoxic-to-humans preservatives for wood in the future.

Preservative-treated structural lumber is available in several grades, depending upon intended use and retention level. Table 43.8 lists desired use-retention levels; retention levels are part of the information given on the grade stamp of treated lumber.

43.7 Grades and Grading of Wood Products

Lumber stress-grading procedures for structural purposes are under the jurisdiction of the American Lumber Standards Committee and follow guidelines given in several ASTM documents. Although several rules-writing agencies publish grading rules with grade descriptions, they all conform to ALSC guidelines and restrictions and, therefore, the common grades are identical for American and Canadian producers. There are currently two grading methodologies: visual grading and machine stress rating (MSR). Visual grading is accomplished by skilled graders who visually assess the size and location of various defects and other characteristics on all four faces of a board. The main defects assessed include slope of grain, knots (size, number, and location relative to the edges of the piece), wane, checks and splits, decay (not permitted except for "white speck" in some grades), and low density for the species. Strength reductions for various defects are termed **strength ratio** (SR) values and are applied to strength values representing a statistical 95% lower confidence limit on mean strength for the property and species. Strength ratio factors delimit the grades as Select Structural (SR = .65), No. 1 (SR = .55), No. 2 (SR = .45), No. 3 (SR = .26). Because E and compression perpendicular to the grain are not considered to be life-threatening properties, their use is treated differently. The SR value for all grades of lumber for compression perpendicular to the grain is 1.00. E values do not use an SR term; instead "quality factors" are used. Quality factors, dictated by ASTM standard (ASTM, 1992), are less severe than SR factors. Special dense grades (Dense Select Structural, etc.) are assigned to slow-growing, dense pieces of southern pine and Douglas fir.

Structural lumber is produced in three MC categories: S-GRN (surfaced in the green MC condition, above 19% MC); S-DRY (surfaced in the dry condition, maximum MC of any piece is 19%); and MC-15 (surfaced at a maximum MC of 15%). Southern pine grade rules have additional designations of KD for kiln-dried material and AD for air-dried material; drying lumber in a kiln is accomplished at temperatures high enough to effectively kill insects and to dry areas of accumulated pitch. Southern pine may be labeled MC-15AD, MC-15KD, MC-19AD, etc. Pieces over nominal 4 in. in thickness are normally sold S-GRN.

The various strength characteristics, as outlined in ASTM documents, including an appropriate safety factor, are applied to each board by the grader to arrive at a relatively conservative assessment of a grade. Every stress-graded piece is required to have a grade stamp on it; the grade stamp contains five pieces of information: producing mill number; grading association under which the grade rules have been issued; species or species group; moisture content at time of grading (e.g., S-DRY); and lumber grade.

For the most common softwood species and a few hardwood species used in construction, the recently completed, and very extensive, in-grade testing program has brought about some shifting of the allowable design stress values. These tests of numerous grades of lumber in various species and across most nominal 2-by and 4-by sizes were conducted to ascertain whether the design stresses accurately represented what was in the marketplace. Up-to-date knowledge of within-grade variability in property values and information on the presence or absence of basic forest resource quality shifts were also obtained. After careful analysis, many of the design values were reassigned; some species-size-grade categories warranted an increase while others were reduced. Fewer species groups are now marketed. More realistic values have resulted across the board, leading to improved reliability in wood structures.

The machine stress rating (MSR) grading process relies on a statistical relationship between a nondestructively determined E value and the bending strength of the piece. Thus, each piece is rapidly flexed flatwise in a machine to obtain an average E for the piece and a low-point E; the average E is then statistically, by species, used to assign a bending stress value, with the low-point E serving as a limiting factor in the process of assigning a grade. The MSR process lends itself to more accurate strength/E evaluation and also to closer quality control programs because it makes an actual piece-by-piece test for one property. In general, this process has been limited to identifying higher-quality material for use in specialized industries, e.g., truss and wood I-beam manufacture. The MSR grading process has an added advantage in that lumber graded by this process is grade-stamped with a combination bending stress and E value; e.g., $2100F_b$-$1.8E$. Different combinations may easily be selected to meet special market demands. Currently over a dozen grade categories are available, ranging from $900F_b$-$1.0E$ to $2850F_b$-$2.3E$. Although the MSR grading process is somewhat capital-intensive, it has definite advantages in terms of grading accuracy and reliability.

Panel products are produced and graded in close relationship to quality control (QC) program results. That is, panels are produced according to strict manufacturing parameters, and quality is monitored via regular production line QC test procedures. The reader is referred to APA documents or manufacturer's specifications for the many various grades and uses of panel products such as siding, sheathing, structural plywood, OSB products, etc. (American Plywood Association, 1992a, 1992b).

43.8 Wood Fasteners and Adhesives

Fasteners come in a wide variety of sizes, shapes, and types. Nails are the most common fastener used in construction. Design loads for nails depend upon type of nail (common wire, threaded hardened steel, spike, coated, etc.), wood species or density, thickness of the members being fastened together, nail diameter and length, depth of penetration of the point into the main member, and failure mode. Various failure mode criteria have been incorporated into fastener design in the 1991 edition of NDS. Fastener design for bolts, lag screws, and shear connectors have similar design considerations. Most wood fasteners used in construction tend to have rather large safety factors incorporated into their design and tend to form tenacious joints; however, small deformations of fasteners at a joint also tend to result in serious deformations and structural deficiency over time. Inadequate or inappropriate joint design is a common cause of building problems that are often mistakenly attributed to "wood failure." For all fastener designs the following aspects must be kept in mind: DOL (shorter term loads allow higher design values per fastener); MC factors for dry, partially seasoned, or wet conditions at time of fabrication or in subsequent service; service temperature; group action (a reduction of design load for a series of fasteners in a row); the effect of having a metal side plate in lieu of a wood side plate; and whether the fastener is loaded in lateral or withdrawal mode. In general, placing fasteners into the end grain of wood is to be avoided, certainly so in a withdrawal mode.

Metal plate connectors are also commonly used; they are almost universally used in truss fabrication for residential and light frame construction. Although accurate plate placement is critical, their performance has proven their utility for decades, and numerous computer software packages are available to design structural frames or components that integrate metal plate fasteners into the design. Various types of joist hangers and heavier metal fixtures are also readily available and tend to speed construction of larger structures, particularly where modular components can be fabricated on site. Various fastener manufacturers provide engineering specifications for use of their specific products.

There are several wood-to-wood adhesives which produce joints stronger than the wood itself; however, their use is generally restricted to controlled factory conditions where temperature, adhesive age and formulation, press time, pressure, and adequate QC can be carefully monitored. Wood-to-wood bonds that are well made perform satisfactorily, but they require adequate, uniform pressure on smooth, clean, well-mated surfaces with an even glue spread. A waterproof adhesive is strongly recommended if adhesives are used as a fastener for wood in construction; phenol-resorcinol-formaldehyde is one that is waterproof (it is also widely used for plywood and panel product manufacture). Field gluing is generally to be avoided; however, the use of epoxy resins, particularly for repair work, is practiced successfully.

43.9 Where Do Designers Go Wrong? Typical Problems in Wood Construction

Wood and wood products are relatively simple engineering materials, but the conception, design, and construction process is fraught with problems and places to err. In using wood in its many forms and with its unique inherent characteristics, there are problem areas which seem to present easily overlooked pitfalls. As gentle reminders for caution, some of these areas are discussed below.

Wood and water do not mix well — Wood is hygroscopic and, unless preservative-treated, rots when its MC rises above 20%. It must be protected in some way. Minor roof leakage often leads to pockets of decay, which may not be noticed until severe decay or actual failure has occurred. Stained areas on wood siding or at joints may indicate metal fastener rust associated with a wet spot or decay in adjoining, supporting members. In many cases what appears to be a minor problem ends up as major and sometimes extensive repair is required. Improper installation or lack of an adequate vapor barrier can result in serious decay in studs within a wall as well as paint peel on exterior surfaces. Ground contact of wood members can lead to decay as well as providing ready access to wood-deteriorating termites. Placement of preservative-treated members between the ground and the rest of the structure (as a bottom sill in a residence) is usually a code requirement. Timber arches for churches, office buildings, and restaurants are usually affixed to a foundation by steel supports; if the supports are not properly installed, they may merely form a receptacle for rain or condensation to collect, enter the wood through capillary action, and initiate decay. Once decay is discovered, major repair is indicated; preservative treatment to a decayed area may prevent further decay, but it will not restore the strength of the material. Elimination of the causal agent (moisture) is paramount. Visible decay usually means that significant fungal deterioration has progressed for 1 to 2 feet along the grain of a member beyond where it is readily identifiable.

Pay attention to detail — In an area that has high relative humidity, special precautions should be taken. A structure that is surrounded by trees or other vegetation or that prevents wind and sun from drying action, is prone to high humidity nearly every day, particularly on a north side. Likewise, if the structure is near a stream or other source of moisture, it may have moisture problems. Home siding in this type of atmosphere may warp or exhibit heavy mildew or fungal stain. Buildings with small (or nonexistent) roof overhangs are susceptible to similar siding problems if the siding is improperly installed, allowing water or condensation to enter and accumulate behind the siding. Inadequate sealing and painting of a surface can add to the problem. In a classic example, a three-story home on a tree-shaded area next to a small stream and with no roof overhang had poorly installed siding, which subsequently warped so badly that numerous pieces fell off of the home. Poor architecture, poor site, poor construction practice, and poor judgment combined to create a disaster. This type of problem becomes magnified in commercial structures, where large surfaces are covered with wood panel products that tend to swell in thickness at their joints if they are not properly sealed and protected from unusual moisture environments. If properly installed, these materials provide economical, long-term, excellent service.

Wood is viscoelastic and will creep under load — This has created widespread problems in combination with clogged or inadequate drains on flat roofs. Ponding, with increasing roof joist deflection, can lead to ultimate roof failure. In situations where floor or ceiling deflection is important, a rule of thumb to follow is that increased deflection due to long-term creep may be assumed to be about equal to initial deflection under the design loading. In some cases the occupants of a building will report that they can hear wood members creaking, particularly under a snow load or ponding action. This is a good indication that the structure is overstressed and failure, or increasing creep deformation with impending failure, is imminent. Deflection measurements over a several-week period can often isolate the problem and lead to suitable reinforcement.

Repair structural members correctly — Epoxy resin impregnation and other techniques are often used to repair structural members. These methods are said to be particularly effective in repairing decayed areas in beams and columns. Removal of decayed spots and replacement by epoxy resin is acceptable only if the afflicted members are also shielded from the original causal agent—excess moisture or insect attack. Likewise, if a wood adhesive must be used as a fastener in an exposed area, use a waterproof adhesive; "water-resistant" or carpenter's glue won't do. Although several wood adhesives will produce a wood-to-wood bond stronger than the wood itself, most of these adhesives are formulated for, and used in, furniture manufacture, where the wood is dry (about 6 to 7% MC) at time of fabrication and is presumed to be kept that way. Structural-use adhesives (unless they are specially formulated epoxy or similar types) may be used where the wood is not above about 20% MC. Structural-use adhesives must also be gap-fillers; i.e., they must be able to form a strong joint between two pieces of wood that are not always perfectly flat, close-fitting surfaces. In addition, the adhesive should be waterproof. The most common and readily available adhesive that meets these criteria is a phenol-resorcinol-formaldehyde adhesive, a catalyzed, dark purple-colored adhesive which is admirably suited to the task.

Protect materials at the job site — Failure to do so has caused plywood and other panel products to become wet through exposure to rain so that they delaminate, warp severely, or swell in thickness to the point of needing to be discarded. Lumber piled on the ground for several days or more, particularly in hot, humid weather, will pick up moisture and warp or acquire surface fungi and stain. This does not harm the wood if it is subsequently dried again, but it does render it esthetically unfit for exposed use. To repeat, wood and water do not mix.

Take time to know what species and grades of lumber you require, and then inspect it — Engineers and architects tend to order the lumber grade indicated by mathematical calculations; carpenters use what is provided to them. Unlike times past, no one seems to be ultimately responsible for appropriate quality until a problem arises and expensive rework is needed. Case in point: a No. 2 grade 2-by, which is tacitly presumed to be used in conjunction with other structural members to form an integrated structure, is not satisfactory for use as scaffolding plank or to serve a similar, critical function on the job site where it is subjected to large loads independent of neighboring planks.

Inspect the job site — Make sure that panel products, such as plywood, OSB, or flakeboard, are kept under roof prior to installation. Stacked on the ground or subjected to several weeks of rainy weather, not only will these panels warp, but they may lose their structural integrity over time. "An ounce of prevention," etc.

Be aware of wood and within-grade variability due to the uniqueness of tree growth and wood defects — It is often wise to screen lumber to cull out pieces that have unusually wide growth rings or wood that is from an area including the pith (center) of the tree. This material often tends to shrink along its length as much as ten times the normal amount due to an inherently high microfibrillar angle in growth rings close to the pith. In truss manufacture this has resulted in the lower chords of some trusses in a home (lower chords in winter being warmer and drier) to shorten as they dry, while the top chords do not change MC as much. The result is that the truss will bow upward, separating by as much as an inch from interior partitions — very disconcerting to the inhabitants and very difficult to cure. A good component fabricator is aware of this phenomenon and will buy higher-quality material to at least minimize the potential problem. Conversely, avoid the expensive, "cover all the bases" approach of ordering only the top grade of the strongest species available.

Inspect all timber connections during erection — Check on proper plate fasteners on trusses and parallel chord beams after installation; plates should have sufficient teeth fully embedded into each adjoining member. Occasionally in a very dense piece the metal teeth will bend over rather than penetrate into the wood properly. A somewhat similar problem arises if wood frames or trusses are not handled properly during erection; avoid undue out-of-plane bending in a truss during transport or erection since this will not only highly stress the lumber but may also partially remove the plates holding the members together. Bolted connections must be retightened at regular intervals for about a year after erection to take up any slack due to subsequent lumber drying and shrinkage.

Perhaps one of the major causes of disaster is the lack of adequate bracing during frame erection — This is a particularly familiar scenario on do-it-yourself projects, such as by church groups or unskilled erection crews. Thin, 2-by lumber is inherently unstable in long lengths; design manuals and warning labels on lumber or product shipments testify to this, yet the warnings are continually disregarded. Unfortunately, the engineer, designer, or architect and materials supplier often are made to share the resulting financial responsibility.

Be aware of wood's orthotropicity — A large slope of grain around a knot or a knot strategically poorly placed can seriously alter bending or compressive strength and are even more limiting in tension members. Allowable design values for tension parallel to the grain are dictated by an ASTM standard (ASTM, 1992) as being 55% of allowable bending values because test results have indicated that slope of grain or other defects greatly reduce tensile properties. Different orthotropic shrinkage values, due to grain deviations or improper fastening of dissimilar wood planes, can lead to warpage and subsequent shifts in load-induced stresses. Care must be taken when using multiple fasteners (bolts, split rings, etc.) to avoid end splits as wood changes MC, particularly if the members are large and only partially dried at the time of installation. When installing a deep beam that is end-supported by a heavy steel strap hanger, it is often best to fasten the beam to the hanger by a single bolt, installed near the lower edge of the beam. This will provide the necessary restraint against lateral movement, whereas multiple bolts placed in a vertical row will prevent the beam from normal shrinkage in place and often induce splits in the ends of the beam as the beam tries to shrink and swell with changes in relative humidity. Not only are the end splits unsightly, but they also reduce the horizontal shear strength of the beam at a critical point. In addition, if the beam has several vertically aligned bolts and subsequently shrinks, the bolts will become the sole support of the beam independent of the strap hanger, as shrinkage lifts the beam free of the supporting strap hanger.

Use metal joist hangers and other fastening devices; they add strength and efficiency in construction to a job — Toe-nailing the end of a joist may restrain it from lateral movement, but it does little to prevent it from overturning if there is no stabilizing decking. Erection stresses caused by carpenters and erection crews standing or working on partially completed framework are a leading cause of member failure and job site injury.

In renovating old structures, as long as decay is not present, the old members can be reused — However, because large sawn timbers tend to crack as they dry in place over a period of time, the members must be regraded by a qualified grader. The dried wood (usually well below 19% MC) has increased considerably in strength, perhaps counterbalancing the decrease in strength due to deep checking and/or splitting. End splits over supports should be carefully checked for potential shear failure.

Wood and fire pose a unique situation — Wood burns, but in larger sizes—15 cm (6 in.) and larger—the outer shell of wood burns slowly and, as the wood turns to charcoal, the wood becomes insulated and ceases to support combustion. Once the fire has been extinguished, the wood members can be removed, planed free of char, and reused, but at a reduced section modulus. Smaller members can also be fire retardant–treated to the degree that they will not support combustion. However, treating companies should be consulted in regard to any possible strength-reducing effects due to the treatment, particularly where such members are to be subjected to poorly ventilated areas of high temperature and high relative humidity, as in attic spaces. In recent years newly developed fire retardant treatments have reacted with wood when in a high temperature–high relative humidity environment to seriously deteriorate the wood in treated plywood or truss members. These chemicals, presumably withdrawn from the marketplace, act slowly over time, but have contributed to structural failure in the attics of numerous condominium-type buildings. Preventive measures where such problems may be anticipated include the addition of thermostatically controlled forced-air venting (the easiest and probably most effective measure); the addition of an insulation layer to the underside of the roof to reduce the amount of heat accumulation in the attic due to radiant heat absorption from the sun; and the installation of a vapor barrier on the floor of the attic to reduce the amount of water vapor from the underlying living units.

In using preservative-treated wood it is always best—certainly so when dealing with larger members—to make all cuts to length, bore holes, cut notches, etc., prior to treatment. Depth of preservative treatment in larger members is usually not complete, and exposure of untreated material through cutting may invite decay. Determination of the depth of penetration of a preservative by noting a color change in the wood is hazardous; penetration may be more or less than is apparent to the eye. Deep checking as a large member dries will often expose untreated wood to fungal organisms or insects. Periodic treatment by brushing preservative into exposed cracks is highly recommended. This is particularly true for log home–type construction. Modern log home construction utilizes partially seasoned materials with shaped sections, which not only increase the insulative quality of the homes but also tend to balance, or relieve, shrinkage forces to reduce cracking. Treated or raised nonwood foundations are recommended.

Wood is an excellent construction material, tested and used effectively over the years for a myriad of structural applications—provided one takes the time to understand its strengths and weaknesses and to pay appropriate attention to detail. Knowing species and lumber grade characteristics and how a member is to be used, not only in a structure but also during erection, can go a long way toward trouble-free construction.

43.10 Wood and the Environment

Trees are nature's only renewable resource for building materials. Trees use energy from the sun and carbon dioxide to create cellulose while cleansing the atmosphere and giving off oxygen. Wood is a significant "storehouse" for carbon, and it does all this with little or no input from people. Converting trees into useful products requires much less energy than is needed for other construction materials. Considering any other structural material in terms of production costs to the environment and use through recycling and ultimate disposal, wood is certainly the most environmentally benign material in use today. It is renewable, available, easily converted into products, recyclable, and biodegradable with no toxic residues.

What is the current status of the forest resource? What are the factors affecting the resource and its use? The answers seem to depend upon whom you ask, because there are no explicit, easy answers. Environmental concerns and the "green movement" have resulted in national policy shifts regarding forest use. Large acreages have been set aside as wilderness areas to remain totally unavailable for timber management and harvest. Harvesting on national timberlands has been drastically curtailed. This will necessarily shift harvesting pressure more to industrial and private commercial forestland. While commercial forestland, which is held by numerous wood products companies, is quite productive and provides more product per acre than other sources, privately held timberlands tend to be the least managed of the nation's forested acres. Thus, even though a valid argument can be made for sequestering national timberlands or reducing their production of timber products, shifting the nation's demand for wood to the private, noncommercial sector may not be wise in the long run. On a brighter note, in many traditional timber states, regulations require that cut areas be properly and promptly restocked and waste greatly reduced. It has been estimated that in several western states six trees are planted for each one that is harvested (but under normal forest growth patterns only one or two of the six survive to reach maturity). In most regions of the U.S. increases in tree growth significantly exceed harvest and mortality due to fire, old age, and disease. In other words, there is more timber being produced annually than is being harvested by a significant margin. But that is not the whole story. Average tree diameter has been steadily declining as we have harvested the biggest, best, and most economically available trees. Likewise, individual tree quality has been decreasing, and many forested areas are inaccessible or uneconomical for harvesting operations. Balanced against these factors is the impact of advancing technology. Such products as structural composite lumber, LVL, OSB, glu-lam, and other products, as well as improved grading and strength assessment techniques, have stretched the resource remarkably. We use nearly 100% of the tree for useful products; waste has been significantly reduced. Lesser-known species are being utilized; for example, aspen, a "junk tree" species not long ago, is now the mainstay for many OSB plants in the upper Midwest because of its low density, availability in large quantities, and desirable panel properties. Thin-kerf saws, improved kiln-drying technology, environmentally friendly preservatives, waste conversion to fuel energy (modern integrated paper mills may be over 90% energy self-sufficient, paper industry average energy self-sufficiency value is 56%), and more reliable product grading and QC programs are just a few successful resource-stretching innovations.

New technologies have made tremendous strides and old technologies are being updated. In some areas it is predicted that by the turn of the century wood will be a significant fuel source. Fast-grown tree plantations of hardwoods represent an economical fuel source that does not require mining and is there when the sun is not shining or the wind is not blowing. Wood chips added to coal significantly reduce sulfur and carbon emissions. Over 1000 wood-burning plants are in operation, and their combined output is reputed to be the equivalent of three large nuclear reactors (Anonymous, 1993). Wood waste from manufacturing operations and demolition refuse may become a valuable, environmentally acceptable fuel source.

Although controversy regarding just how we are to allocate the nation's timber resource to provide for endangered species, increased demand for "wild" areas, and increasing numbers of products made from wood will certainly continue, it is possible to retain many of the "natural" aspects of forests and still obtain products from this remarkable resource on a sustainable basis if attention is paid to proper management and skillful utilization. Current (1990s) controversy over environmental policies will lead to acceptable compromise in time. However, the nature of trees and all the wood products derived from them will assure wood a prominent place as a highly preferred, environmentally desirable, and economically competitive building material.

Defining Terms

Bark — The outside covering of a tree which protects the tree from invasion by insects, disease, and decay.

Cellulose — A long-chain molecule that constitutes the major building block of plant material. Cellulose is the element responsible for wood's strength along the grain.

Check — Often referred to as a "seasoning check"; a separation of the wood cells as a result of shrinkage during drying. Checks tend to reduce shear strength.

Decay — Results from fungal attack of wood. Fungi may attack either the wood cellulose and hemicellulose or the lignin; in either case even the early stages of decay seriously reduce wood strength and make it unsuitable for any structural purpose.

Density — Weight per unit volume of wood. The weight is always in the oven-dry condition (i.e., 0% MC); the volume, however, may be measured at any stated MC (most often green, 12%, or oven-dry). Since wood shrinks as it dries, density values vary, and the MC base must be stated as, for example, "volume measured at 12% MC." Similarly, specific gravity values will vary depending on the MC at which volumetric measurements are made.

Duration of load (DOL) — The ability of wood members to sustain larger loads for shorter periods of time without failure than they can sustain without failure for longer periods of time. Structures that will have design loads imposed upon them for shorter than "normal" DOL are permitted to have an increase in allowable design stresses in bending, compression parallel to the grain, tension parallel to the grain, and shear. Normal DOL is defined as a 10-year cumulative loading duration.

Earlywood — The portion of a growth ring that is formed early in the growing season. It normally contains larger cells with thinner walls. Earlywood is relatively low in density and is followed by latewood as the growing season progresses. See **Latewood**.

Fiber saturation point (fsp) — A point (about 25% MC, depending on species) in the drying of wood at which the hollow centers of the wood cells have lost their moisture, leaving the cell walls fully saturated. Wood does not begin to shrink until its MC has dropped below fsp.

Flat-sawn — Lumber that has its wide face in a tangential plane (i.e., cut approximately tangent to the annual growth rings); also called plain-sawn. See **Quarter-sawn**.

Glu-lam — A structural product made by gluing structural boards together; the grain of all pieces is oriented along the long axis of the member. Glu-lam may be manufactured into a variety of curved beams, arches, or irregular shapes. See also **Laminated-veneer-lumber**.

Growth ring — The portion of wood of a tree produced during one growing season. In the temperate zones this is also called an annual ring.

Hardwood — Trees that are deciduous; that is, trees whose leaves are broad and are generally shed each year in the temperate zones. Typical hardwoods include oaks, maples, and poplar.

Heartwood — The innermost growth rings of a tree; may be darker in color than the outermost growth rings (called *sapwood*). Contains phenolic compounds that in some species impart decay resistance to the heartwood.

Hemicellulose — A long-chain molecule similar to cellulose, but more easily soluble in dilute acid or basic solutions.

Incising — Perforation of the surface of a pole or wood member by a series of chisel-like knives prior to preservative treatment to permit deeper and more uniform infusion of the preservative into the wood.

Knots — The result of a branch having been cut in the manufacture of a board. If the branch is cut at a right angle to its length, the knot appears as a branch cross-section; if the branch is cut along its length, appearing to go across the face of a board, it is termed a spike knot.

Laminated-veneer-lumber (LVL) — A board product made by gluing pieces of thin lumber or veneer together to make a larger member, usually formed into long flat panels suitable for remanufacture into common lumber sizes. The grain of all pieces is oriented along the long axis of the panel. See also **Glu-lam** and **Plywood**.

Latewood — The portion of a growth ring that is formed later in the growing season. Cells tend to be smaller in size and have thicker, denser cell walls than in earlywood. See **Earlywood**.

Lignin — A highly complex molecule that acts as an adhesive to bond wood cellulose units together. Although plastic in nature, especially at elevated temperatures, lignin gives wood its rigidity.

Microfibrils — Groups of cellulose or hemicellulose molecules that form long, threadlike macro-molecules. Layers of microfibrils form the wood cell walls and are ultimately responsible for wood's anisotropic properties.

Moisture content (MC) — The amount (weight) of water in a piece of wood, expressed as a percent of the weight of an oven-dry (0% MC) piece.

Nominal size — A convenient size nomenclature that approximates the size of a member in a log prior to being sawn into lumber; a nominal 2-by-4, when sawn, dried, and surfaced, has an actual, usable size of 1½ ¥ 3½ in., for example.

Normal duration of load — Ten years, cumulative, of the load for which a member or structure has been designed. Allowable design stresses may be modified for shorter or longer load periods.

Oriented-strand board (OSB) — A flat board product made from wood flakes that are long and narrow and are oriented along the length of the panel, and a waterproof adhesive, so that the properties and characteristics resemble those of solid lumber.

Oven-dry weight — The weight of a piece of wood at 0% MC; normally determined by drying a small block of wood at 103°C until repeated weighings indicate that all moisture has been removed from the block.

Particleboard — A flat board product made from wood particles or flakes mixed with an adhesive and formed under pressure and elevated temperature. Not sold for structural use. See also **Oriented-strand board**.

Preservative — A chemical, usually in solution form, that is forced into wood (usually under pressure) to preserve the wood from attack by insects and decay organisms.

Plywood — A flat glued panel made from thin sheets of veneer with alternate plies having grain directions oriented 90 degrees to adjacent plies.

Quarter-sawn — Lumber that has its wide face in a radial plane (i.e., cut approximately parallel to the wood rays). Lumber is quarter-sawn to accentuate the wood figure due to the large wood rays in some species. See **Flat-sawn**.

Repetitive member use — A structural situation wherein three or more bending members in sizes of 2 to 4 in. in nominal thickness (as for floor joists) are fastened together and stabilized, as by flooring, to form an interactive unit. Repetitive members are permitted a 15% increase in allowable bending stress.

Sapwood — The outermost growth rings of a tree; always light brown to cream-colored in all species; never decay- or insect-resistant. Sapwood and heartwood together make up the "wood" of commercial use.

Shake — A lengthwise separation of the wood that may occur between or through annual growth rings.

Slope of grain — A deviation of cell orientation from the longitudinal axis of a member; measured as rise/run (as in 1 in 10). Slope of grain may be a growth phenomenon (as when grain deviates around a knot) or a manufacturing defect caused by failure to cut a member "along the grain."

Softwood — Typically "evergreen" trees with needle-like leaves. Includes Douglas fir, pines, spruces, cedars, and hemlock.

Specific gravity (SG) — The ratio of the density of a material to that of an equal volume of water. See **Density**.

Split — A separation of wood cells along the grain; splits are deeper and more serious than cracks or checks in that splits penetrate completely through the thickness of a member. Splits most often occur at the ends of a member and reduce shear strength.

Strength ratio (SR) — A factor applied in lumber stress grading to account for wood defects. It represents a ratio of the strength of a piece with all its defects to the strength the piece would have if no defects were present.

Structural composite lumber (SCL) — A panel product made of thin layers of veneer or wood strands mixed with a waterproof adhesive. See **LVL**.

Wane — A lack of wood that occurs in lumber manufacture when the edge of a member intersects the periphery (bark) of a tree so that the edges are not "square."

Warp — Any deviation from a true or plane surface, including bow, crook, cup, and twist. *Bow* is a deviation flatwise from a straight line drawn from end to end of a piece. *Crook* is a deviation edgewise from a straight line drawn from end to end of a piece. *Cup* is a deviation in the face of a piece from a line drawn from edge to edge of a piece. *Twist* is a deviation flatwise, or a combination flatwise and edgewise, of a piece, resulting in the raising of one corner of a piece while the other three corners remain in contact with a flat surface.

Wood cells — Long, thin, hollow units that make up wood. Most cells are oriented with their long axis roughly parallel to the axis of the tree.

Wood rays — Groups of cells whose long axes are oriented horizontally and that radiate outward from the center of a tree. Wood rays are responsible for horizontal translocation of fluids in a tree and are partially responsible for the difference in radial vs. tangential shrinkage and swellage in wood.

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