



Mechanical Properties of Wood

An Online Continuing Education Course for Engineers

Course Number: S-4002

Credit: 4 Hours / 4 PDH / 4 CPD

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INTRODUCTION

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

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

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

This course also includes a discussion of the effect of growth features, such as knots and slope of grain, on clear wood properties. The effects of manufacturing and service environments on mechanical properties are discussed, and their effects on clear wood and material containing growth features are compared.

ORTHOTROPIC NATURE OF WOOD

Wood may be described as an orthotropic material; that is, it has unique and independent mechanical properties in the directions of three mutually perpendicular axes: longitudinal, radial, and tangential. The longitudinal axis L is parallel to the fiber (grain); the radial axis R is normal to the growth rings (perpendicular to the grain in the radial direction); and the tangential axis T is perpendicular to the grain but tangent to the growth rings. These axes are shown in Figure 1.

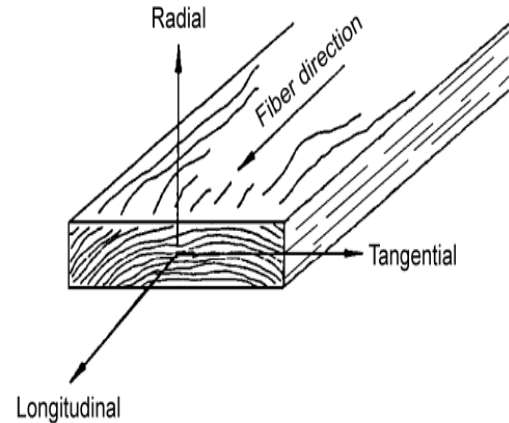


Figure 1. Three Principal Axes of Wood with Respect to Grain Direction and Growth Rings

ELASTIC PROPERTIES

Twelve constants (nine are independent) are needed to describe the elastic behavior of wood: three moduli of elasticity E , three moduli of rigidity G , and six Poisson's ratios μ . The moduli of elasticity and Poisson's ratios are related by expressions of the form

$$\frac{\mu_{ij}}{E_i} = \frac{\mu_{ji}}{E_j}, \quad i \neq j \quad i, j = L, R, T \quad (1)$$

General relations between stress and strain for a homogeneous orthotropic material can be found in texts on anisotropic elasticity.

Modulus of Elasticity

Elasticity implies that deformations produced by low stress are completely recoverable after loads are removed. When loaded to higher stress levels, plastic deformation or failure occurs. The three moduli of elasticity, which are denoted by E_L , E_R , and E_T , respectively, are the elastic moduli along the longitudinal, radial, and tangential axes of wood. These moduli are usually obtained from compression tests; however, data for E_R and E_T are not extensive. Average values of E_R and E_T for samples from a few species are presented in Table 1 as ratios with E_L ; the Poisson's ratios are shown in Table 2. The elastic ratios, as well as the elastic constants themselves, vary within and between species and with moisture content and specific gravity.

The modulus of elasticity determined from bending, E_L , rather than from an axial test, may be the only modulus of elasticity available for a species. Average E_L values obtained from bending tests are given in Tables 3 to 5. Representative coefficients of variation of E_L determined with bending tests for clear wood are reported in Table 6. As tabulated, E_L includes an effect of shear deflection; E_L from bending can be increased by 10% to remove this effect approximately.

Table 1. Elastic Ratios for Various Species at Approximately 12% Moisture Content^a

Species	E_T/E_L	E_R/E_L	G_{LR}/E_L	G_{LT}/E_L	G_{RT}/E_L
Hardwoods					
Ash, white	0.080	0.125	0.109	0.077	—
Balsa	0.015	0.046	0.054	0.037	0.005
Basswood	0.027	0.066	0.056	0.046	—
Birch, yellow	0.050	0.078	0.074	0.068	0.017
Cherry, black	0.086	0.197	0.147	0.097	—
Cottonwood, eastern	0.047	0.083	0.076	0.052	—
Mahogany, African	0.050	0.111	0.088	0.059	0.021
Mahogany, Honduras	0.064	0.107	0.066	0.086	0.028
Maple, sugar	0.065	0.132	0.111	0.063	—
Maple, red	0.067	0.140	0.133	0.074	—
Oak, red	0.082	0.154	0.089	0.081	—
Oak, white	0.072	0.163	0.086	—	—
Sweet gum	0.050	0.115	0.089	0.061	0.021
Walnut, black	0.056	0.106	0.085	0.062	0.021
Yellow-poplar	0.043	0.092	0.075	0.069	0.011
Softwoods					
Baldcypress	0.039	0.084	0.063	0.054	0.007
Cedar, northern white	0.081	0.183	0.210	0.187	0.015
Cedar, western red	0.055	0.081	0.087	0.086	0.005
Douglas-fir	0.050	0.068	0.064	0.078	0.007
Fir, subalpine	0.039	0.102	0.070	0.058	0.006
Hemlock, western	0.031	0.058	0.038	0.032	0.003
Larch, western	0.065	0.079	0.063	0.069	0.007
Pine					
Loblolly	0.078	0.113	0.082	0.081	0.013
Lodgepole	0.068	0.102	0.049	0.046	0.005
Longleaf	0.055	0.102	0.071	0.060	0.012
Pond	0.041	0.071	0.050	0.045	0.009
Ponderosa	0.083	0.122	0.138	0.115	0.017
Red	0.044	0.088	0.096	0.081	0.011
Slash	0.045	0.074	0.055	0.053	0.010
Sugar	0.087	0.131	0.124	0.113	0.019
Western white	0.038	0.078	0.052	0.048	0.005
Redwood	0.089	0.087	0.066	0.077	0.011
Spruce, Sitka	0.043	0.078	0.064	0.061	0.003
Spruce, Engelmann	0.059	0.128	0.124	0.120	0.010

This adjusted bending E_L can be used to determine E_R and E_T based on the ratios in Table 1.

^a E_L may be approximated by increasing modulus of elasticity values in Table 3 by 10%.

Poisson's Ratio

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

Table 2. Poisson's Ratios for Various Species at Approximately 12% Moisture Content

Species	μ_{LR}	μ_{LT}	μ_{RT}	μ_{TR}	μ_{RL}	μ_{TL}
Hardwoods						
Ash, white	0.371	0.440	0.684	0.360	0.059	0.051
Aspen, quaking	0.489	0.374	—	0.496	0.054	0.022
Balsa	0.229	0.488	0.665	0.231	0.018	0.009
Basswood	0.364	0.406	0.912	0.346	0.034	0.022
Birch, yellow	0.426	0.451	0.697	0.426	0.043	0.024
Cherry, black	0.392	0.428	0.695	0.282	0.086	0.048
Cottonwood, eastern	0.344	0.420	0.875	0.292	0.043	0.018
Mahogany, African	0.297	0.641	0.604	0.264	0.033	0.032
Mahogany, Honduras	0.314	0.533	0.600	0.326	0.033	0.034
Maple, sugar	0.424	0.476	0.774	0.349	0.065	0.037
Maple, red	0.434	0.509	0.762	0.354	0.063	0.044
Oak, red	0.350	0.448	0.560	0.292	0.064	0.033
Oak, white	0.369	0.428	0.618	0.300	0.074	0.036
Sweet gum	0.325	0.403	0.682	0.309	0.044	0.023
Walnut, black	0.495	0.632	0.718	0.378	0.052	0.035
Yellow-poplar	0.318	0.392	0.703	0.329	0.030	0.019
Softwoods						
Baldcypress	0.338	0.326	0.411	0.356	—	—
Cedar, northern white	0.337	0.340	0.458	0.345	—	—
Cedar, western red	0.378	0.296	0.484	0.403	—	—
Douglas-fir	0.292	0.449	0.390	0.374	0.036	0.029
Fir, subalpine	0.341	0.332	0.437	0.336	—	—
Hemlock, western	0.485	0.423	0.442	0.382	—	—
Larch, western	0.355	0.276	0.389	0.352	—	—
Pine						
Loblolly	0.328	0.292	0.382	0.362	—	—
Lodgepole	0.316	0.347	0.469	0.381	—	—
Longleaf	0.332	0.365	0.384	0.342	—	—
Pond	0.280	0.364	0.389	0.320	—	—
Ponderosa	0.337	0.400	0.426	0.359	—	—
Red	0.347	0.315	0.408	0.308	—	—
Slash	0.392	0.444	0.447	0.387	—	—
Sugar	0.356	0.349	0.428	0.358	—	—
Western white	0.329	0.344	0.410	0.334	—	—
Redwood	0.360	0.346	0.373	0.400	—	—
Spruce, Sitka	0.372	0.467	0.435	0.245	0.040	0.025
Spruce, Engelmann	0.422	0.462	0.530	0.255	0.083	0.058

Modulus of Rigidity

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

STRENGTH PROPERTIES

COMMON PROPERTIES

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

Modulus of Rupture

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

Work to Maximum Load in Bending

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

Compressive Strength Parallel to Grain

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

Compressive Stress Perpendicular to Grain

Reported as stress at proportional limit. There is no clearly defined ultimate stress for this property.

Shear Strength Parallel to Grain

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

Impact Bending

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

Tensile Strength Perpendicular to Grain

Resistance of wood to tension perpendicular to grain. Values presented are the average of two tests on split a member. Values

Hardness

Generally defined as the load required to make a dent in the wood. Values presented are the average of two tests on a hardness test, measured by Janka hardness test diameter. Values

Tensile Strength Parallel to Grain

Maximum tensile strength on the tensile strength test. Tensile strength values are sufficient tension to rupture of small, clear specimens to be a low or conservative value for lumber). Only a few data are available in Table 7 lists average values. In the absence of test data, values are substituted for tensile strength. The point of rupture is considered for specimens (this is not true for

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