Lumber Stress Grades and Design Properties

An Online Continuing Education Course for Engineers

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Credit: 2 Hours / 2 PDH / 2 CPD

Lumber Stress Grades and Design Properties

Round timbers, ties, and lumber sawn from a log, regardless of species and size, are quite variable in mechanical properties. Pieces may differ in strength by several hundred percent. For simplicity and economy in use, pieces of wood of similar mechanical properties are placed in categories called stress grades, which are characterized by (a) one or more sorting criteria, (b) a set of properties for engineering design, and (c) a unique grade name. The most familiar system is that for lumber. Sorting criteria have also been established for round timbers and ties. This course briefly discusses the stress grades and design properties for lumber, round timber, and ties.

Lumber

The U.S. Department of Commerce American Softwood Lumber Standard PS 20 describes sorting criteria for two stress-grading methods and the philosophy of how properties for engineering design are derived. The derived properties are then used in one of two design formats: (a) the load and resistance factor design (LRFD), which is based on a reference strength at the lower 5th percentile 5-min stress (AF&PA [current edition]), or (b) the allowable stress design (ASD), which is based on a design stress at the lower 5th percentile 10-year stress. The properties depend on the particular sorting criteria and on additional factors that are independent of the sorting criteria. Design properties are lower than the average properties of clear, straight-grained wood.

From one to six design properties are associated with a stress grade: bending modulus of elasticity for an edgewise loading orientation and stress in tension and compression parallel to the grain, stress in compression perpendicular to the grain, stress in shear parallel to the grain, and extreme fiber stress in bending. As is true of the properties of any structural material, the allowable engineering design properties must be either inferred or measured nondestructively. In wood, the properties are inferred through visual grading criteria, nondestructive measurement such as flatwise bending stiffness or density, or a combination of these properties. These nondestructive tests provide both a sorting criterion and a means of calculating appropriate mechanical properties.

The philosophies contained in this course are used by a number of organizations to develop visual and machine stress grades. References are made to exact procedures

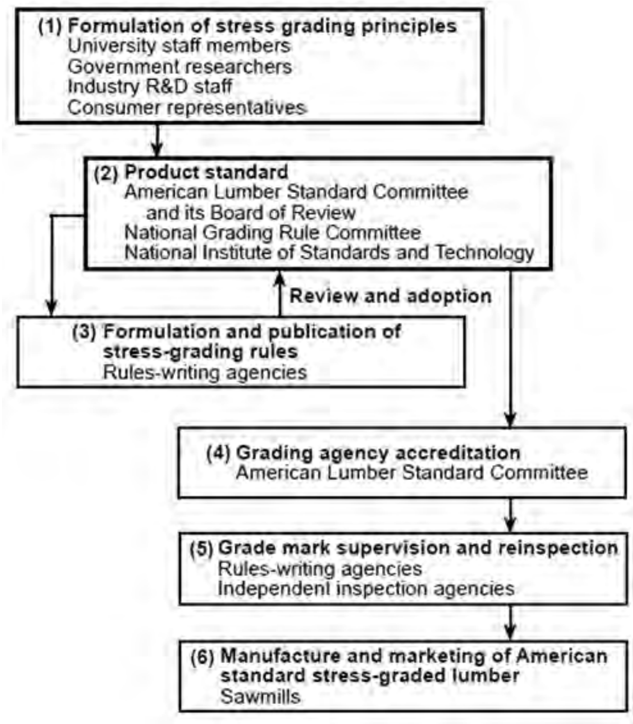

Figure 1. Voluntary system of responsibilities for stress grading under the American Softwood Lumber Standard.

Table 1. Sawn lumber grading agencies[a]

Rules-writing agencies
Northeastern Lumber Manufacturers Association (NeLMA)
Northern Softwood Lumber Bureau (NSLB)
Redwood Inspection Service (RIS)
Southern Pine Inspection Bureau (SPIB)
West Coast Lumber Inspection Bureau (WCLIB)
Western Wood Products Association (WWPA)
National Lumber Grades Authority (NLGA)

Independent agencies
American Institute of Timber Construction
Continental Inspection Agency, LLC
Pacific Lumber Inspection Bureau, Inc.
Renewable Resource Associates, Inc.
Stafford Inspection and Consulting, LLC
Renewable Resource Associates, Inc.
Timber Products Inspection
Alberta Forest Products Association
Canadian Lumbermen's Association
Canadian Mill Services Association
Canadian Softwood Inspection Agency, Inc.
Central Forest Products Association
Council of Forest Industries
MacDonald Inspection
Maritime Lumber Bureau
Newfoundland and Labrador Lumber Producers Association
Quebec Forest Industry Council

[a]For updated information, contact American Lumber Standard Committee, P.O. Box 210, Germantown, MD 20875; alsc@alsc.org; www.alsc.org.

and the resulting design stresses, but these are not presented in detail.

Responsibilities and Standards for Stress Grading

An orderly, voluntary, but circuitous system of responsibilities has evolved in the United States for the development, manufacture, and merchandising of most stress-graded lumber. The system is shown schematically in Figure 1. Stress-grading principles are developed from research findings and engineering concepts, often within committees and subcommittees of ASTM International (formerly the American Society for Testing and Materials).

American Lumber Standard Committee

Voluntary product standards are developed under procedures published by the U.S. Department of Commerce. The Department of Commerce National Institute of Standards and Technology (NIST), working with rules-writing agencies, lumber inspection agencies, lumber producers, distributors and wholesalers, retailers, end users, members of Federal agencies, and others, works through the American Lumber Standard Committee (ALSC) to maintain a voluntary consensus softwood standard, the American Softwood Lumber Standard (PS 20). The PS 20 Standard prescribes the ways in which stress-grading principles can be used to formulate grading rules designated as conforming to the American Lumber Standard. Under the auspices of the ALSC is the National Grading Rule, which specifies grading characteristics for different grade specifications.

Organizations that write and publish grading rule books containing stress-grade descriptions are called rules-writing agencies. Grading rules that specify American Softwood Lumber Standard PS 20 must be certified by the ALSC Board of Review for conformance with this standard. Organizations that write grading rules, as well as independent agencies, can be accredited by the ALSC Board of Review to provide grading and grade-marking supervision and reinspection services to individual lumber manufacturers. Accredited rules-writing and independent agencies are listed in Table 1. The continued accreditation of these organizations is under the scrutiny of the ALSC Board of Review.

Most commercial softwood species lumber manufactured in the United States is stress graded under American Lumber Standard practice and is called American Lumber Standard (ALS) program lumber. Distinctive grade marks for each species or species grouping are provided by accredited agencies. The principles of stress grading are also applied to several hardwood species under provisions of the American Softwood Lumber Standard. Lumber found in the marketplace may be stress graded under grading rules developed in accordance with methods approved by the ALSC or by some other stress-grading rule, or it may not be stress graded. Only those stress grades that meet the requirements of the voluntary American Softwood Lumber Standard system are discussed in this course.

National Grading Rule

Stress grading under the auspices of the ALSC is applied to many sizes and patterns of lumber that meet the American Softwood Lumber Standard provision. However, most stress-graded lumber is dimension lumber (standard 38 mm to 89 mm (nominal 2 to 4 in., actual 1.5 to 3.5 in.) thick) and is governed by uniform specifications under the National Grading Rule. The National Grading Rule provides guidelines for writing grading rules for lumber in this thickness range and specifies grading characteristics for different grade specifications. American Softwood Lumber Standard dimension lumber in this thickness range is required to conform to the National Grading Rule, except for special products such as scaffold planks. Grade rules for other sizes, such as structural timbers (standard 114-mm and larger (nominal 5-in. and larger) thick) may vary between rules-writing agencies or species.

The National Grading Rule establishes the lumber classifications and grade names for visually stress-graded dimension lumber (Table 2). The ALSC Machine Grading Policy provides for the grading of dimension lumber by a combination of machine and visual methods. Visual requirements for this type of lumber are developed by the respective rules-writing agencies for particular species grades.

Table 2. Visual grades described in National Grading Rule

Lumber classification[a]	Grade name	Bending strength ratio (%)
Light framing[b]	Construction	34
	Standard	19
	Utility	9
Structural light framing[b]	Select Structural	67
	1	55
	2	45
	3	26
Stud[c]	Stud	26
Structural joists and planks[d]	Select Structural	65
	1	55
	2	45
	3	26

[a]Contact rules-writing agencies for additional information.
[b]Standard 38 to 89 mm (nominal 2 to 4 in.) thick and wide. Widths narrower than 89 mm (4 in. nominal) may have different strength ratio than shown.
[c]Standard 38 to 89 mm (nominal 2 to 4 in.) thick, ≥38 mm (≥4 in. nominal) wide.
[d]Standard 38 to 89 mm (nominal 2 to 4 in.) thick, ≥114 mm (≥5 in. nominal) wide.

Standards

Table 2 also shows associated minimum bending strength ratios to provide a comparative index of quality. The strength ratio is the hypothetical ratio of the strength of a piece of lumber with visible strength-reducing growth characteristics to its strength if those characteristics were absent. Formulas for calculating strength ratios are given in ASTM standard D 245. The corresponding visual description of the dimension lumber grades can be found in the grading rule books of the rules-writing agencies listed in Table 1. Design properties will vary by size, species, and grade and are published in the appropriate rule books and in the *National Design Specification for Wood Construction* (AF&PA).

Grouping of Species

Most species are grouped together and the lumber from them treated as equivalent. Species are usually grouped when they have about the same mechanical properties, when the wood of two or more species is very similar in appearance, or for marketing convenience. For visual stress grades, ASTM D 2555 contains procedures for calculating clear wood properties for groups of species to be used with ASTM D 245. ASTM D 1990 contains procedures for calculating design properties for groups of species tested as full-sized members. The properties assigned to a group by such procedures will often be different from those of any species that make up the group. The group will have a unique identity, with nomenclature approved by the Board of Review of the ALSC. The identities, properties, and characteristics of individual species of the group are found in the grading rules for any particular species or species grouping. In the case of machine stress grading, the inspection agency that supervises the grading certifies by testing that the design properties in that grade are appropriate for the species or species grouping and the grading process.

Foreign Species

Currently, the importation of structural lumber is governed by two ALSC guidelines that describe the application of the American Lumber Standard and ASTM D 1990 procedures to foreign species. The approval process is outlined in Table 3.

Visually Graded Structural Lumber

Visual Sorting Criteria

Visual grading is the original method for stress grading. It is based on the premise that mechanical properties of lumber differ from mechanical properties of clear wood because many growth characteristics affect properties and these characteristics can be seen and judged by eye. Growth characteristics are used to sort lumber into stress grades. The typical visual sorting criteria discussed here are knots, slope of grain, checks and splits, shake, density, decay, annual ring count and percentage latewood, pitch pockets, and wane.

Knots

Knots cause localized cross grain with steep slopes. A very damaging aspect of knots in sawn lumber is that the continuity of the grain around the knot is interrupted by the sawing process.

In general, knots have a greater effect on strength in tension than compression; in bending, the effect depends on whether a knot is in the tension or compression side of a beam (knots along the centerline have little or no effect). Intergrown (or live) knots resist (or transmit) some kinds of stress, but encased knots (unless very tight) or knotholes resist (or transmit) little or no stress. On the other hand, distortion of grain is greater around an intergrown knot than around an encased (or dead) knot of equivalent size. As a result, overall strength effects are roughly equalized, and often no distinction is made in stress grading between intergrown knots, dead knots, and knotholes.

The zone of distorted grain (cross grain) around a knot has less "parallel to piece" stiffness than does straight-grained wood; thus, localized areas of low stiffness are often associated with knots. However, such zones generally constitute only a minor part of the total volume of a piece of lumber. Because overall stiffness of a piece reflects the character of all parts, stiffness is not greatly influenced by knots.

The presence of a knot has a greater effect on most strength properties than on stiffness. The effect on strength depends approximately on the proportion of the cross section of the piece of lumber occupied by the knot, knot location, and distribution of stress in the piece. Limits on knot sizes are therefore made in relation to the width of the face and location on the face in which the knot appears. Compression members are stressed about equally throughout, and no limitation related to location of knots is imposed. In tension, knots along the edge of a member cause an eccentricity that induces bending stresses, and they should therefore be more restricted than knots away from the edge. In simply supported structural members subjected to bending, stresses are greater in the middle of the length and at the top and bottom edges than at midheight. These facts are recognized in some grades by differing limitations on the sizes of knots in different locations.

Knots in glued-laminated structural members are not continuous as in sawn structural lumber, and different methods are used for evaluating their effect on strength.

Slope of Grain

Slope of grain (cross grain) reduces the mechanical properties of lumber because the fibers are not parallel to the edges. Severely cross-grained pieces are also undesirable because they tend to warp with changes in moisture content. Stresses caused by shrinkage during drying are greater in structural lumber than in small, clear straight-grained specimens and are increased in zones of sloping or distorted grain. To provide a margin of safety, the reduction in design properties resulting from cross grain in visually graded structural lumber is considerably greater than that observed in small, clear specimens that contain similar cross grain.

Table 3. Approval process for acceptance of design values for foreign species

1	Rules-writing agency seeks approval to include species in grading rule book.
2	Agency develops sampling and testing plan, following American Lumber Standard Committee (ALSC) foreign importation guidelines, which must then be approved by ALSC Board of Review.
3	Lumber is sampled and tested in accordance with approved sampling and testing plan.
4	Agency analyzes data by ALSC Board of Review, ASTM D 1990 procedures, and other appropriate criteria (if needed).
5	Agency submits proposed design values to ALSC Board of Review.
6	Submission is reviewed by ALSC Board of Review and USDA Forest Service, Forest Products Laboratory.
7	Submission is available for comment by other agencies and interested parties.
8	ALSC Board of Review approves (or disapproves) design values, with modification (if needed) based on all available information.
9	Agency publishes new design values for species.

Checks and Splits

Checks are separations of the wood that normally occur across or through the annual rings, usually as a result of seasoning. Splits are a separation of the wood through the piece to the opposite surface or to an adjoining surface caused by tearing apart of the wood cells. As opposed to shakes, checks and splits are rated by only the area of actual opening. An end-split is considered equal to an end-check that extends through the full thickness of the piece. The effects of checks and splits on strength and the principles of their limitation are the same as those for shake.

Shake

Shake is a separation or a weakness of fiber bond, between or through the annual rings, that is presumed to extend lengthwise without limit. Because shake reduces resistance to shear in members subjected to bending, grading rules therefore restrict shake most closely in those parts of a bending member where shear stresses are highest. In members with limited cross grain, which are subjected only to tension or compression, shake does not affect strength greatly. Shake may be limited in a grade because of appearance and because it permits entrance of moisture, which results in decay.

Density

Strength is related to the mass per unit volume (density) of clear wood. Properties assigned to lumber are sometimes modified by using the rate of growth and percentage of latewood as measures of density. Typically, selection for density requires that the rings per unit length on the cross section and the percentage of latewood be within a specified range. Some very low-strength pieces may be excluded from a grade by excluding those that are exceptionally low in density.

Decay

Decay in most forms should be prohibited or severely restricted in stress grades because the extent of decay is difficult to determine and its effect on strength is often greater than visual observation would indicate. Decay of the pocket type (for example, *Fomes pini*) can be permitted to some extent in stress grades, as can decay that occurs in knots but does not extend into the surrounding wood.

Heartwood and Sapwood

Heartwood does not need to be taken into account in stress grading because heartwood and sapwood have been assumed to have equal mechanical properties. However, heartwood is sometimes specified in a visual grade because the heartwood of some species is more resi
than is the sapwood; heartw
wood will be exposed to a de
sapwood takes preservative t
heartwood and it is preferable
with preservatives.

Pitch Pockets

Pitch pockets ordinarily have s
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are small and limited in numbe
number of pitch pockets, howev
weakness of bond between annu

Wane

Wane refers to bark or lack of wo
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limitations on wane than does stre
limited in structural lumber on tha

Procedures for Deriving Design

The mechanical properties of visually graded lumber may be established by (a) tests of a representative sample of full-size members (ASTM D 1990 in-grade testing procedure) or (b) appropriate modification of test results conducted on clear specimens (ASTM D 245 procedure for small clear wood). Design properties for the major commercial softwood dimension lumber species given in current design specification and codes in the United States have been derived from full-size member test results. However, design properties for some species of softwood and most species of hardwood dimension lumber (standard 38- to 89-mm (nominal 2- to 4-in.) thick) and all species of structural timbers (standard 114-mm and larger (nominal 5-in. and larger) thick) are still derived using results of tests on small clear samples.

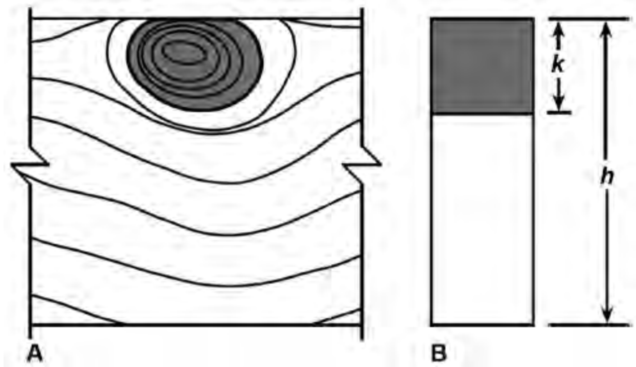
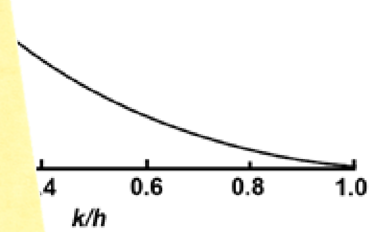


Figure 2. Effect of edge knot: A, edge knot in lum-ber; B, assumed loss of cross section (cross-hatched area).



**bending strength ratio
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al properties of visually graded
historically based on clear wood properties with appropriate modifications for the lumber characteristics allowed by visual sorting criteria. Sorting criteria that influence mechanical properties are handled with "strength ratios" for the strength properties and with "quality factors" for the modulus of elasticity.

Piece to piece variation occurs in both the clear wood properties and the occurrence of growth characteristics. The influence of this variability on lumber properties is handled differently for strength properties than for modulus of elasticity.

Strength Properties—Each strength property of a piece of lumber is derived from the product of the clear wood strength for the species and the limiting strength ratio. The strength ratio is the hypothetical ratio of the strength of a piece of lumber with visible strength-reducing growth characteristics to its strength if those characteristics were absent. The true strength ratio of a piece of lumber is never known