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Analysis of Glulam Timber Beams with Mechanically Graded (E-rated) Outer Laminations

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Abstract

An analysis of results of bending tests on 771 glued–laminated timber (glulam) beams indicated that bending strength is predictable based on the mechanical grade (E-grade) of the outer laminations. This result was found to be applicable to glulam beams made from various species of hardwood and softwood lumber with balanced or unbalanced modulus of elasticity and visual grade requirements in the outer laminations. Data from this analysis will provide information that will be helpful in developing standards.

Keywords: Glued–laminated timber (glulam), E-rated lumber, mechanically graded lumber, bending strength

Introduction

The system for grading structural lumber in many countries relies on identification of the lumber species and classification by certain visual characteristics. In North America, this visual grading system has proven to be extremely effective for major markets, the leading market being residential construction. With the trend toward more highly engineered components for residential and commercial construction, many producers and secondary manufacturers are using mechanical grading as a means of better identifying the structural capabilities of lumber.

One advantage of mechanical grading is that species identification becomes less important in characterizing important design properties such as stiffness and design stresses in both bending and tension. Mechanical grading systems presently used in many counties directly measure lumber stiffness and, through established correlation with both bending and tensile strength properties, infer other design properties. With the possibility of more international trade in logs and cants, mechanical grading will likely increase in importance because many species are difficult to identify once the trees are cut and the logs sawn into lumber.

Mechanical grading of lumber for use in engineered wood products has been both researched and practiced to some extent for several years. In North America, producers of prefrabricated I-joists, metal-plate connected trusses and structural glued-laminated timber (glulam) have utilized mechanical grading to both broaden their raw material base and improve the reliability of their products.

Objectives

The primary objective of this report is to describe the technical basis for improving the structural utilization of lumber by mechanical grading in the manufacture of structural glulam timber. The secondary objective is to demonstrate that glulam timber beams made from a variety of species have similar strength properties, provided the same criteria are used to grade the lumber and manufacture the beams.

Methods

Bending test data from research reports on glulam timber beams made with mechanically graded lumber used in the outer tension and compression laminations were analyzed. Beams manufactured using similar grades in the outer laminations were adjusted to a common basis and analyzed.

Sources of Data

Fourteen research reports were used as sources of data (Appendix). Three of these sources describe beams made with Canadian lumber (Aplin 1983; Littleford 1974; and Yeh 1992), one with Norwegian lumber (Falk et al. 1992), and the remainder with U.S. lumber.

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Species

The study included five groups of softwood species and three groups of hardwood species (Appendix). The softwood groups were Douglas Fir–Larch, Southern Pine, Hem–Fir, Spruce–Pine–Fir (SPF), and Norway spruce. Southern Pine includes four U.S. species with similar properties. Hem–Fir is a group of six species from western North America. SPF is a group of eight or nine North American species, the exact grouping depending upon the grading agency in the United States or Canada. The hardwood groups were Red Maple, Yellow Poplar, and Red Oak. Red Oak is a group of nine species with similar properties.

Species are marketed as groups because of their similar strength properties and growing ranges. Not all of the species listed in each group were included in the study beams. In some instances, it was not possible to determine the specific species. For example, it was not possible to differentiate between lumber from the four Southern Pine species after processing. Also, Hem–Fir includes several species that are difficult to differentiate in lumber form. Based on a review of the reports and knowledge of the source of the material, the species most likely represented are highlighted in the list in the Appendix.

Description of Beams

The lumber used to manufacture the beams ranged in finished thickness from about 33 mm (1.3 in.) to 38 mm (1.5 in.). Table A in the Appendix shows the lumber grades used in the beam layups in terms of the number of laminations in five zones: outer and inner tension, core, and inner and outer compression. The layup is described from the bottom to top (tension to compression) of a normally loaded simple beam. Typically, mechanically graded lumber used in the outer tension and compression zones of beams is denoted by the nominal modulus of elasticity (MOE), followed by a number that indicates the maximum edge-knot size permitted in the lumber grade; e.g. 6 = 1/6, 4 = 1/4, 3 = 1/3, and 2 = 1/2. Table A (Appendix) shows the actual MOE values taken from the original references, and the edge-knot criteria, when available, are shown as a superscripted value.

The glulam beams fell into three layup categories: (a) beams with outer tension and compression laminations that were balanced with respect to MOE and visual grade criteria (b) beams with outer tension and compression laminations that were balanced with respect to MOE, but unbalanced with respect to visual grade criteria, and (c) beams with outer tension and compression laminations that were unbalanced with respect to both MOE and visual grade criteria.

Data Adjustments

Strength and stiffness data were adjusted to a common basis to remove the major effects of moisture content, dimensions, and method of loading.

Moisture Content – Nearly all the beams were evaluated at moisture contents between 10 and 16 percent; the data for these beams were not adjusted to account for these slight differences. An exception was data source 13 (see Appendix), which reported beams that had been soaked in water. These beams were adjusted to dry conditions using the dry dimensions and the adjustment factors of 1.25 for modulus of rupture (MOR) and 1.2 for MOE (AITC 1993).

Volume Effect – Beams ranged from 80 mm wide, 280 mm deep, and 4.9 m long to 180 mm wide, 610 mm deep, and 12.2 m long. Because analyses have shown that the calculated bending stress at failure (MOR) is dependent upon the volume of a beam, all beams were adjusted to a standard size using U.S. design practice. The standard size selected was 80 mm by 300 mm by 6.4 m. The MOR values were adjusted to this size using the following U.S. practice (AITC 1993):

$$MOR_s = [153{,}500/wdl]^x \, MOR$$

where MOR_s = MOR at standard conditions
w = width of beam, mm
d = depth of beam, mm
l = length of beam, m
x = exponent of 0.1 for all species except Southern Pine
= 0.05 for Southern Pine
MOR = MOR for beams from research reports, dead load stresses included

Method of Loading Effect – *Most* beams were loaded using two symmetrically placed load points spaced about one-fifth of the span apart, which closely approximates the effect of a uniform load. Those beams loaded with the load points placed at the third point of the span would be expected to have slightly lower strength values than those tested with one-fifth span between load points and were adjusted using a 1/0.96 factor (AITC 1993).

Layup Effect – Even though MOR values were adjusted to a standard size beam, there were nevertheless differences as a result of the variation in the beam layup. Using the actual lumber MOE properties (Appendix, Table A), a ratio for each beam

group was calculated that transformed the MOR properties to an outer fiber stress on the tension side at failure. This allowed comparison of beams that may have a homogeneous layup of lumber grades and beams that may have an extreme imbalance of lumber grades. This adjustment ratio consisted of a transformed section factor (T), which adjusts the moment of inertia of a rectangular beam cross-section to a transformed cross-section that accounts for different stiffness zones. The adjustment ratio also accounts for the shift in the neutral axis from the geometic center of the beam (d/2) to the transformed section neutral axis (z). The ratios (Td/2z) for each beam group are given in Table A. This type of adjustment was discussed in detail by Moody (1974).

Results

The data sources provided a total of 771 glulam beam test results. A total of 422 beams met the category (a) layup criterion, 242 beams the category (b) layup criterion, and 107 beams the category (c) layup criterion.

Figure 1 shows outer fiber stress versus MOE of the outer tension lamination for all sources combined. Note that the general trend is an increase in outer fiber stress with increase in tension lamination (TL) MOE. The lines through the data represent the average (top line) and fifth percentile (bottom line) outer fiber stress values for groups of beam results categorized by

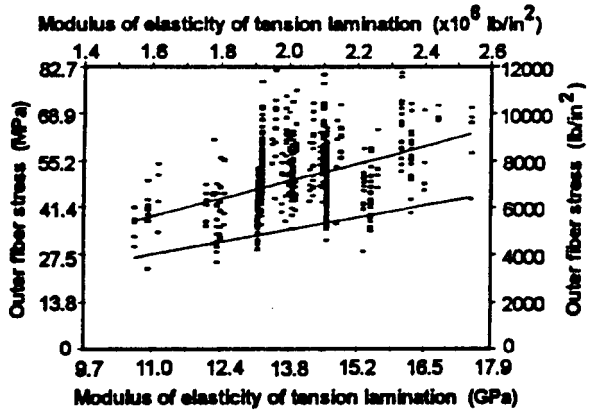

Figure 1—Outer fiber stress versus MOE of outer tension laminations for all glulam beams made with mechanically graded outer laminations. (Top line, average regression; bottom line, fifth percentile regression).

TL MOE in 690-MPa (100,000 lb/in^2) increments. Statistics for each group of beams within the specified increments are provided in Table 1.

Discussion

Species Effects

The increase in outer fiber stress with increase in TL MOE was expected (Fig. 1). Although differences due to species were not separated in this figure, the important fact is that there were no distinct differences between beam groups for a particular TL MOE level.

Table 1—Properties for all beam groups

TL MOE			Outer fiber stress						
			Average			5th percentile		5th/2.1	
(GPa)	(x10^6 lb/in^2)	Beams (no.)	(MPa)	(x10^3 lb/in^2)	COV (%)	MPa	(x10^3 lb/in^2)	MPa	(x10^3 lb/in^2)
11.0	(1.6)	22	39.6	(5.75)	17.8	27.8	(4.03)	13.2	(1.92)
12.4	(1.8)	43	40.0	(5.80)	20.5	27.0	(3.92)	12.9	(1.87)
13.1	(1.9)	195	47.0	(6.82)	18.4	33.8	(4.90)	16.1	(2.33)
13.8	(2.0)	116	54.7	(7.93)	17.7	39.6	(5.74)	18.8	(2.73)
14.5	(2.1)	281	50.6	(7.34)	16.7	37.6	(5.45)	17.9	(2.60)
15.2	(2.2)	54	46.9	(6.80)	19.7	32.3	(4.69)	15.4	(2.23)
15.9	(2.3)	25	61.3	(8.89)	14.8	45.9	(6.65)	21.8	(3.17)
16.5	(2.4)	29	57.4	(8.33)	15.3	42.7	(6.19)	20.3	(2.95)
17.2	(2.5)	6	62.9	(9.12)	18.5	40.3	(5.84)	19.2	(2.78

For example, the combined group of 116 beams made with 13.8 GPa (2.0×10^6 lb/in^2) tension laminations had a calculated design outer fiber stress of 18.8 MPa (2.73×10^3 lb/in^2) (Table 1). For comparison, glulam beam configurations that meet a 16.5-MPa (2.4×10^3 lb/in^2) design bending stress level commonly have a 13.8 GPa (2.0×10^6 lb/in^2) TL MOE level. The ratio between the design bending stress and design outer fiber stress is 0.88, which is smaller than any of the Td/2z values found in Table A. This means that most common beam configurations with a 13.8-GPa TL MOE level would meet this design bending stress level. Moreover, this beam group consisted of three types of softwoods (Hem–Fir, SPF, and Southern Pine), three types of hardwoods (Red Maple, Red Oak and Yellow Poplar), and lumber that originated from two countries (United States and Canada).

This result is significant in that the design properties assigned to visually graded lumber from these species are quite different; it indicates that mechanical grading with appropriate visual restrictions provides a means for grading lumber that greatly reduces the effect of species.

Unbalancing Effects

Visual Grade – The effect of using lower quality lumber in the compression-side laminations was evaluated by comparing the results of category (a) and (b) glulam beams.

Figure 2 shows the outer fiber stress versus TL MOE plots for category (a) and (b) beams. A regression line was fit to all the data only as a quantitative representation of the average trend. Inspection of Figure 2 indicates that there was no significant difference in glulam beam performance when lower quality lumber was used on the compression side of the glulam beams, as long as the MOE of the outer laminations was balanced. Thus, these two groups are combined in Figure 3 for comparison with category (c) glulam beams.

MOE – The effect of using an imbalance of both visual and MOE characteristics of tension- and compression-side laminations was evaluated by comparing the results of category (c) beams to the combined group of category (a) and (b) beams (Fig. 3). Note that the TL MOE levels of the first three distinct groups of category (c) beams (11.0 GPa (1.6×10^6 lb/in^2), 12.4 GPa (1.8×10^6 lb/in^2), and 13.8 GPa (2.0×10^6 lb/in^2)) appear to follow the average regression line. The remaining distinct group

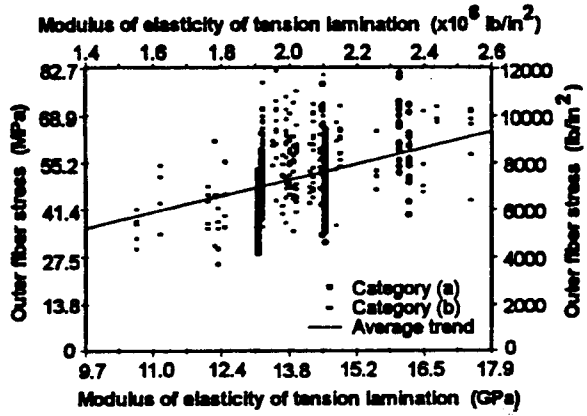

Figure 2—Outer fiber stress for category (a) and (b) glulam beams versus TL MOE. Regression line represents average of both groups.

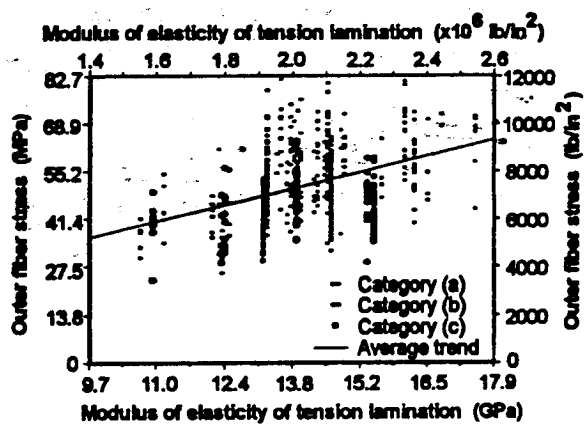

Figure 3—Outer fiber stress for category (a), (b), and (c) glulam beams versus TL MOE. Regression line represents average of category (a) and (b) groups.

of category (c) beams at the 15.2-GPa (2.2×10^6 lb/in^2) TL MOE level appears to fall below that trend. Thus, based on the approach used to observe the relative trends between glulam beams that were balanced and unbalanced with respect to the MOE of the outer laminations, it appears that unbalanced glulam beam configurations did not significantly affect their overall performance. The reason for the discrepancy of the 15.2-GPa (2.2×10^6 lb/in^2) TL MOE beams cannot be explained.

A previous analysis of beams from only a few of the sources formed the basis for unbalanced beams now permitted in AITC 117 (AITC 1993). The analysis in

this report confirms the previous analysis and indicates that beams can be unbalanced with respect to both MOE and visual grade criteria and yield acceptable strength levels. Unbalancing has the advantage of providing for efficient utilization of material that is high in stiffness but has knots or other characteristics that may lower its tensile strength to a level that is not acceptable for the outer tension zone of a beam.

Stress Classes – The trend of increasing fifth percentile outer fiber stress provides support for a "stress class" system for glulam timber. This type of system is currently being considered for both European and Japanese glulam standards.

Conclusions

Data from 14 studies of a total of 771 glulam beams made with mechanically graded (E-rated) lumber in the outer laminations were analyzed. The results are as follow:

1. As expected, there appeared to be a trend of incease in outer fiber stress with increase in modulus of elasticity (MOE) of outer tension zone laminations.

2. The relationship between tension lamination (TL) MOE and outer fiber stress was similar for beams with balanced and unbalanced outer lamination visual grade characteristics. This result has implications for the utilization of lumber that has high stiffness but not correspondingly high tensile strength.

3. The relationship between TL MOE and outer fiber stress for beams with unbalanced outer lamination MOE properties appeared to follow the same overall trend found for balanced beams.

These observations led to the following conclusions:

- Species, species group, and country of origin of the lumber have a minimum effect on glulam beam strength properties.

- The mechanical grade of the outer tension zone as the indicator of bending strength properties appears to be an effective way to classify glulam beams.

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Appendix. Data Sources, Species Groups, and Beam Properties

Sources of Data for Glulam Beam Analysis

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Species Groups

Species groups were taken from Design Values for Wood Construction, 1991, National Design Specification Supplement, American Forest and Paper Association, Washington, DC. Species shown in bold and italics are those likely used to manufacture the test beams.

Species group	Species included in group
Douglas Fir–Larch	***Douglas-fir*** Western larch
Hem–Fir	California red fir ***Grand fir*** ***Noble fir*** ***Pacific silver fir*** ***Western hemlock*** White fir
Southern Pine	***Loblolly pine*** ***Longleaf pine*** ***Shortleaf pine*** ***Slash pine***
SPF (U.S.)	Balsam fir Black spruce ***Engelmann spruce*** Jack pine ***Lodgepole pine*** Norway (red) pine ***Red spruce*** Sitka spruce ***White spruce***
SPF (Canada)	Alpine fir Balsam fir ***Black spruce*** ***Engelmann spruce*** Jack pine ***Lodgepole pine*** Red spruce White spruce
Red Maple	***Red Maple***
Yellow Poplar	***Yellow Poplar***
Red Oak	Black Oak Cherrybark Oak Laurel Oak ***Northern Red Oak*** Pin Oak Scarlet Oak Southern Red Oak Water Oak Willow Oak

Table A—Properties of E-rated beams[a]

		Beam		Nominal dimensions			Modulus of elasticity of laminations (10^6 lb/in^2)[b]					
							Tension side			Compression side		
Ref.	Species group	ID	(no.)	Width (in.)	Depth (in.)	Length (ft)	Outer	Inner	Core	Inner	Outer	Td/2z
(1)	SPF (Canada)	1-5,7-8 A&B[c]	(14)	5	12	16	$1@2.1^{4}$	$1@1.8^{3}$	$3@1.55^{L3}$	$1@1.8^{3}$	$1@2.1^{4}$	0.939
		D2-8[d]	(7)	5	24	33	$2@2.1^{4}$	$3@1.8^{3}$	$5@1.55^{L3}$	$3@1.8^{3}$	$2@2.1^{3}$	0.939
		E2,E4-8[d]	(6)	5	24	33	$2@2.1^{4}$	$3@1.8^{3}$	$5@1.55^{L3}$	—	$5@1.8^{3}$	0.913
(2)	Norway spruce	LH40[c]	(112)	3.5	12	20	—	—	9@2.11	—	—	1.000
		LC38[c]	(96)	3.5	12	20	2@2.11	—	5@1.91	—	2@2.11	0.984
		LH35[c]	(104)	3.5	12	20	—	—	9@1.91	—	—	1.000
(3)	Southern Pine	4.01-20[c]	(19)	3	14	24	$1@2.33^{4}$	$2@2.08^{N1D}$	$4@1.68^{N2M}$	$2@2.08^{N1D}$	$1@2.33^{4}$	0.934
		6.01-20[c]	(19)	5	23	40	$2@2.36^{4}$	$3@2.07^{N1D}$	$7@1.75^{N2M}$	$3@2.07^{N1D}$	$2@2.32^{4}$	0.930
(4)	Red Maple	RM01-15[d]	(15)	5	18	30	$2@2.10^{6}$	$1@1.79^{3}$	$6@1.68^{N3}$	$1@1.79^{3}$	$2@2.02^{3}$	0.922
(5)	Hem–fir	H01-03[d]	(3)	5	24	40	$1@2.15^{6}$	$2@2.04$/ $2@1.75$	$6@1.42^{L3}$	$2@1.75$/ $2@2.00$	$1@2.15$	0.923
		H04-06[d]	(3)	5	24	40	1@2.44	$2@2.23$/ $2@2.08$	6@1.70	$2@2.07$/ $2@2.13$	1@2.18	0.902
		W01-03[d]	(3)	5	24	40	$1@1.95^{6}$	$2@1.76$/ $1@1.55$	$8@1.39^{L3}$	$1@1.56$/ $2@1.76$	1@1.95	0.901
		W04-06[d]	(3)	5	24	40	1@2.36	$2@1.92$/ $1@1.87$	8@1.65	$1@1.95$/ $2@1.95$	1@2.10	0.847
(6)	Hem–fir	H19-24[d]	(6)	5	24	40	$2@2.09^{6}$	$2@1.81^{4}$	$8@1.40^{L3}$	$2@1.81^{2}$	$2@2.09^{2}$	0.919
		H25-30[d]	(6)	5	24	40	$2@1.81^{6}$	$2@1.53^{4}$	$8@1.26^{L3}$	$2@1.53^{2}$	$2@1.81^{2}$	0.916
	D-fir	D01-06[d]	(6)	5	24	40	$2@2.54^{6}$	$2@2.04^{6}$	$8@1.50^{L3}$	$2@2.04^{2}$	$2@2.54^{2}$	0.890
		D07-12[d]	(6)	5	24	40	$2@2.06^{6}$	$2@1.78^{4}$	$8@1.46^{L3}$	$2@1.78^{2}$	$2@2.06^{2}$	0.923
	HF/DF	HDF13-18[d]	(6)	5	24	40	$2@2.15^{6}$	$2@1.79^{4}$	$8@1.50^{L3}$	$2@1.79^{2}$	$2@2.15^{2}$	0.912
	Southern Pine	S01-06[d]	(6)	5	24	40	$2@1.98^{6}$	$2@1.78^{4}$	$8@1.45^{N2}$	$2@1.78^{2}$	$2@1.98^{2}$	0.936
		S07-12[d]	(6)	5	24	40	$2@2.26^{6}$	$2@1.80^{4}$	$8@1.44^{N2}$	$2@1.80^{3}$	$2@2.26^{3}$	0.894
	SPF (U.S.)	LP31-36[d]	(6)	5	24	40	$2@1.76^{4}$	$2@1.54^{3}$	$8@1.07^{L3}$	$2@1.54^{2}$	$2@1.76^{2}$	0.914
		LP37-42[d]	(6)	5	24	40	$2@1.55^{3}$	$2@1.27^{3}$	$8@1.22^{L3}$	$2@1.27^{2}$	$2@1.55^{2}$	0.920
(7)	SPF (Canada)	1,2 A&B[d]	(4)	3	11	16	$1@1.62^{6}$	$1@1.55^{4}$	$4@1.02^{L3}$	$1@1.46^{2}$	$1@1.64^{2}$	0.940
		3,4 A&B[d]	(4)	3	11	16	$1@2.00^{6}$	$1@1.75^{4}$	$4@1.29^{L3}$	$1@1.84^{2}$	$1@1.99^{2}$	0.920
		5,6 A&B[d]	(4)	3	11	16	$1@1.78^{6}$	$1@1.43^{4}$	$4@1.18^{L3}$	$1@1.61^{2}$	$1@1.79^{2}$	0.906
		7,12 A&B[d]	(4)	5	16	24	$1@2.14^{6}$	$2@1.80^{4}$	$6@1.29^{L3}$	$2@1.81^{2}$	$1@2.18^{2}$	0.881
		8,10 A&B[d]	(4)	5	16	24	$1@1.99^{6}$	$2@1.80^{4}$	$6@1.30^{L3}$	$2@1.75^{2}$	$1@1.99^{2}$	0.910
		9,11 A&B[d]	(4)	5	16	24	$1@2.40^{6}$	$2@1.98^{6}$	$6@1.26^{L3}$	$2@1.97^{2}$	$1@2.38^{2}$	0.860
(8)	Red Maple	4.01-15[d]	(15)	3	12	20	$1@1.99^{6}$	$1@1.72^{3}$	$4@1.80^{N2}$	$1@1.72^{3}$	$1@1.96^{3}$	0.953
	Red Maple	6.01-15[d]	(15)	5	18	30	$1@1.92^{6}$	$2@1.74^{3}$	$6@1.73^{N2}$	$2@1.74^{3}$	$1@1.92^{3}$	0.945
	Red Maple	8.01-15[d]	(12)	7	24	40	$1@1.96^{6}$	$1@1.93^{6}$/ $2@1.74^{3}$	$9@1.69^{N2}$	$1@1.74^{3}$	$2@1.90^{3}$	0.938
(9)	D-fir	E[e]	(15)	3	12	20	$1@2.24^{6}$	$1@2.08^{6}$	$6@2.02^{L3}$	—	$1@2.08^{2}$	0.948
	Southern Pine	F[e]	(15)	3	12	20	$1@2.01^{6}$	$1@1.79^{6}$	$6@1.53^{N2}$	—	$1@1.79^{3}$	0.899
	Hem-fir	G01-15[e]	(15)	3	12	20	$1@2.22^{6}$	$1@1.88^{6}$	$5@1.20^{L3}$	—	$2@1.88^{2}$	0.853
	SPF (U.S.)	H01-15[e]	(15)	3	12	20	$1@1.80^{6}$	$1@1.49^{4}$	$5@1.20^{L3}$	—	$2@1.49^{2}$	0.864
(10)	Yellow Poplar	4.01-15[d]	(15)	3	11	20	$1@2.01^{6}$	$1@1.80^{3}$	$4@1.83^{N2}$	$1@1.80^{3}$	$1@1.99^{3}$	0.956
	Yellow Poplar	6.01-15[d]	(15)	5	16	30	$1@2.07^{6}$	$2@1.84^{3}$	$6@1.88^{N2}$	$2@1.84^{3}$	$1@2.03^{3}$	0.936
	Yellow Poplar	8.01-15[d]	(15)	7	23	40	$2@2.02^{6}$	$2@1.69^{3}$	$9@1.85^{N2}$	$2@1.69^{3}$	$2@2.02^{3}$	0.938
(11)	Red Oak	RO4.01-18[d]	(18)	3	12	20	$1@1.92^{6}$	$1@1.77^{3}$	$4@1.56^{N2}$	$1@1.77^{3}$	$1@1.94^{3}$	0.955
	Red Oak	RO6.01-12[d]	(12)	5.125	27	40	$2@2.00^{6}$	$2@1.74^{3}$	$10@1.76^{N2}$	$2@1.74^{3}$	$2@1.95^{3}$	0.936
(12)	SPF (U.S.)	K01-07[d]	(7)	5	12	20	$2@1.79^{4}$	—	$5@1.43^{N2}$	—	$2@1.79^{3}$	0.966
	SPF (U.S.)	K08-12[e]	(5)	5	18	20	$3@1.79^{4}$	—	$8@1.43^{N2}$	—	$2@1.79^{3}$	0.961
	E.Hemlock	M01-07[e]	(7)	5	12	20	$1@1.59^{4}$	$1@1.40^{2}$	$5@1.24^{N2}$	—	$2@1.40^{2}$	0.885
	E.Hemlock	M08-12[e]	(5)	5	18	20	$1@1.59^{4}$	$2@1.40^{2}$	$8@1.24^{N2}$	—	$2@1.40^{2}$	0.893
(13)	D-fir	E[e]	(15)	3	12	20	$1@2.24^{6}$	1@2.08	$6@2.02^{L3}$	—	$1@2.08^{2}$	0.948
	Southern Pine	F[e]	(15)	3	12	20	$1@2.01^{6}$	$1@1.79^{6}$	$6@1.53^{N2}$	—	$1@1.79^{3}$	0.899
(14)	SPF (Canada)	31-50[c]	(18)	5.125	12	18	$1@1.92^{6}$	—	$7@1.45^{2}$	—	$1@1.92^{6}$	0.885
	SPF (Canada)	1-3,13-18, A&B[c]	(20)	2.5	18	27	$1@1.92^{6}$	$1@1.67^{3}$	$9@1.45^{2}$	$1@1.67^{3}$	$1@1.92^{6}$	0.883
	SPF (Canada)	4-9,11-12,19-30[c]	(20)	5.125	18	27	$1@1.92^{6}$	$1@1.67^{3}$	$9@1.45^{2}$	$1@1.67^{3}$	$1@1.92^{6}$	0.883

[a]Conversion factors: 1-in. = 25.4 mm; 1 ft = 0.3048 m; 10^6 lb/in^2 = 6.895 GPa.
[b]Superscript values indicate visual grade; number signifies maximum allowable edge-knot size as fraction of cross section (e.g., 6 = 1/6).
[c]Beams with outer laminations balanced with respect to MOE and visual grade criteria.
[d]Beams with outer laminations balanced with respect to MOE only.
[e]Beams with outer laminations unbalanced with respect to MOE and visual grade criteria.