U.S. DEPARTMENT OF AGRICULTURE • FOREST SERVICE
FOREST PRODUCTS LABORATORY • MADISON, WIS.
In Cooperation with the University of Wisconsin

USDA FOREST SERVICE
RESEARCH NOTE
FPL - 0230
August 1975

MECHANICAL PROPERTIES OF 23 SPECIES OF EASTERN HARDWOODS[1]

By

B. ALAN BENDTSEN, Forest Products Technologist
and
ROBERT L, ETHINGTON, Assistant Director

Summary

Important mechanical properties of clear, straight-grained wood of 23 species are tabulated, along with coefficients of variation. These property estimates can be used to match up species with kind of material needed for a specific job, or to search for substitutes for a presently used species. Some of the species appear, with allowable properties, in two published plywood manuals. There are no similar hardwood lumber stress grades, but standard methods exist for generating them, should interest develop.

Introduction

Eastern hardwoods constitute a major timber resource, reportedly as much as 200 billion cubic feet according to Sternitzke (26). The stands run heavily to small, poor-quality stems that are underutilized. Projected wood fiber needs suggest that it is important to develop methods for using these hardwoods. This paper offers a compendium of information on mechanical properties of 23 species, as essential information for encouraging more effective use.

[1] This report was prepared in support of symposium, "Utilization of Hardwoods Growing on Southern Pine Sites." Two additional species were of interest, blackjack oak (*Quercus marilandica*) and Shumard oak (*Quercus shumardii*). No property information was found for either,

Fundamental Mechanical Properties

Tests of small specimens free of strength-reducing growth characteristics and processing defects such as knots, cross grain, shake, splits, checks, and wane are used to measure fundamental strength and elastic properties of wood. The "small clear" mechanical properties, probably more than any other physical characteristic, are used to guide the multitude of native species into end-use products for which they are most suited.

A summary of the common mechanical properties and specific gravity of clear, straight-grained wood of 23 species is given in table 1. Values are presented for the green and air-dry moisture condition. The basic reference documents for table 1 are the Wood Handbook (29) and USDA Technical Bulletin No. 479 (12). Other sources are indicated by footnotes to the table.

Table 1 values are estimates of mean property values for each species. However, some caution is suggested in their use. The values were obtained by methods outlined in ASTM D 143 (3). When the standard was developed there was limited ability to achieve representative sampling. Consequently, the tabulated averages are based on tests of samples from a few subjectively selected trees, mostly from forests as they existed 50 to 60 years ago.

The limitations of the early sampling method preclude making reliable estimates of property variation by species. However, average coefficients of variation of 50 species presented in table 2 can be used to estimate the, spread of property values associated with table 1 values. The properties of approximately 95 pct of the material of a species can be expected to fall in the range of the average value plus or minus twice the product of the coefficient of variation and the average.

A number of tests of mechanical properties of lesser importance than those in table 1 are sometimes conducted on small, clear specimens: Tension parallel to grain, toughness, torsion, rolling shear, fatigue, and creep. Except for toughness and tension parallel to grain, tests of these minor properties on species covered in this paper are too isolated or insignificant to tabulate. Other references, listed at the end of the report include some minor properties and properties of individual species when used for a particular product. Toughness and tension-parallel-to-grain values for species where data were available are given in tables 3 and 4.

Literature provides information on property variation, on the relation between mechanical properties and wood anatomy, and on such diverse things as the relationship between strength and chemical composition, the bending radii of Tanalith-treated gum and hickory, and the effect of nitrogen fertilizer on properties of several species. It is not possible to concisely summarize the work, nor are many species involved. However, the reader interested in great detail regarding a particular species may find useful information in the references.

Eastern Hardwoods in Structural Application

Stress-graded plywood can be manufactured from sweetgum and yellow-poplar in conformance with U.S. Product Standard PS 1-74 (16), and allowable properties are given in Plywood Design Specification, APA Report Y-510 (2). Plywood from white ash, pecan, American elm, hackberry, sweetgum, red maple, yellow-poplar, and tupelo can be manufactured according to Design Guide HP-SG-71 (9) for interior use only, and allowable properties are given for it.

Currently, allowable design properties are not assigned to hardwood lumber in the United States (aspen, cottonwood, and red alder excepted) in any nationally recognized document. Yet it is clear (from table 1) that hardwoods have the mechanical properties that normally characterize structural materials. Furthermore, hardwoods are used in numerous structural applications: Furniture parts, striking tool handles, bowling pins, baseball bats, parallel bars, stairs and stair railings, highway guardrail posts, and pallets. They are also used on a local basis, but sometimes rather extensively, where we might expect stress-graded lumber to be appropriate-- railroad bridges, sheet piling, and shoring. This usually happens where there is a strong tradition of use or where no regulation of the construction takes place.

If hardwoods are a suitable structural material, why are they not stress-graded? At the 1974 annual meeting of the Forest Products Research Society in Chicago, W. L. Galligan presented a paper that gave some insight to this question. Two principal reasons were suggested: (1) Lack of unified market demand, and (2) a lack of understanding of the stress-grading system and how to develop a market for the stress-graded product.

Galligan discussed in detail a four-stage approach for achieving stress grading of hardwoods: (1) Identify the market, (2) define the grades, (3) assign allowable properties, and (4) provide for acceptance of the system and product. That paper takes the first big step in defining the problem and offering solutions.

On the other hand, it is not likely that the action required by Galligan's approach will be accomplished in the near future. Until that action occurs, can southern hardwoods be used in structural applications normally reserved for stress-graded softwoods? Perhaps not where building codes or regulatory authorities govern. However, throughout the eastern United States thousands of farm houses and outbuildings constructed of hardwoods testify that light-frame construction is feasible. Design was commonly based upon good sense, tradition, and "seat of the pants" techniques. Occasionally beams or rafters sagged, but more frequently the structures performed adequately and may well have contained more wood than necessary for good performance.

If an owner is willing to assume full responsibility for the integrity of a structure and he is not subject to regulatory control, the nondesigned structure may still be practical today. However, if desired, a degree of sophistication beyond the "seat of the pants" technique is also possible. A hardwood species can be visually graded under the National Grading Rule for Softwood Lumber (given, for example, in "Standard Grading Rules for Southern Pine Lumber" published by the Southern Pine Inspection Bureau) providing the species is capable of producing lumber to match the rule description. Allowable properties can be calculated using the principles of ASTM D 245 (4) and ASTM D 2555 (5). If ASTM D 2555 does not list the species of interest, clear-wood mechanical properties must be supplied from some other source, such as table 1 of this paper.

This procedure probably would not be sanctioned by the American Lumber Standards Committee, nor meet with approval of building inspectors or code authorities without considerable scrutiny. Nevertheless, for a person building a structure for himself and who is willing to accept responsibility, it provides some basis for design and a means of reducing his risks..

ASTM D 2915 (6), "Evaluating Allowable Properties for Grades of Structural Lumber," offers still another opportunity for stress-grading hardwoods. This standard may be particularly applicable when the market for a specific product, such as bridge stringers or timbers for powerline towers, is sufficiently large. Under the standard, allowable properties could be assigned to grade descriptions written specifically for the products of interest.

References

1. Ali, Mohammed Omar.
   1968. Strength-chemical composition relationships of yellow-poplar (Liriodendron tulipifera). Ph. D. thesis, North Carolina State Univ.

2. American Plywood Association.
   1974. Plywood design specification. APA Rep. Y-510.

3. American Society for Testing and Materials.
   1974. Standard methods of testing small, clear specimens of timber. ASTM Desig. D 143-72.

4. ______.
   1974. Standard methods for establishing structural grades and related allowable properties for visually graded lumber. ASTM Desig. D 245-70.

5. ______.
   1974. Standard methods for establishing clear wood strength values. ASTM Desig. D 2555-73.

6. ______.
   1974. Evaluating allowable properties for grades of structural lumber. ASTM Desig. D 2915-74.

7. Finnorn, W. J., and R. A. Holcombe.
   1959. Bending radii of three thicknesses of Tanalith-treated black gum and dense and nondense Tanalith-treated hickory. Timber Engineering Company, for Bureau of Ships, Contract No. NOBS 77018.

8. Forest Service, USDA.
   1973. The outlook for timber in the United States. For. Resour. Rep. No. 20.

9. Hardwood Plywood Manufacturers Association.
   1971. Structural design guide for hardwood plywood. HPMA Design Guide HP-SG-71.

10. Luxford, R. F., and L. W. Wood.
    1944. Survey of strength and related properties of yellow-poplar. U.S. For. Prod. Lab. Rep. No. 1516. Madison, Wis.

11. Markwardt, L. J.
    1941. Comparative properties of woods for crossties. Oct. 31, 1930. Railway Eng. and Maint. 27(1):48-49. Jan. 31, 1941.

12. _______, and T.R.C. Wilson.
1935. Strength and related properties of woods grown in the U.S. USDA Tech. Bull. 479.

13. McBurney, R. S., D. V, Doyle, and J. T. Drow.
1946. The elastic properties of wood. Young's moduli, Poisson's ratios, and modulus of rigidity of sweetgum at approximately 11 percent moisture content. U.S. For. Prod. Lab. Rep. Nos. 1528-F, -G, Madison, Wis.

14. Mitchell, H. L.
1972. Effect of nitrogen fertilizer on the growth rate and certain wood-quality characteristics of sawlog size red oak, yellow-poplar, and white ash. Proc. of Symp. on the Effect of Growth Acceleration on the Properties of Wood, U.S. For. Prod. Lab.

15. Myer, J. Edson.
1930. The structure and strength of four North American woods as influenced by range, habitat, and position in the tree. Bull. of New York State Coll. of For., vol. 3, No. 2B.

16. National Bureau of Standards.
1974. Prod. Stand. PS l-74 for Construction and Industrial Plywood.

17. Nearn, William T.
1952. Strength properties of laminated yellow-poplar beams tested green and air dry. Pa. State For. School Res. Pap. 18. 8p., illus.

18. Paul, B. H.
1930. Lightweight ash from butt swelled trees should be segregated in shipping ash lumber. Wood Constr. 16(4):3. Feb. 15. Clipped.

19. _______.
1959. Second-growth oak. South. Lmbrmn. J. and Build. Mater. Dealer.

20. _______, and N. A. Norton.
1936. Variations in the wood of yellow-poplar from the southern Appalachian region. J. For, 34(10):936-942.

21. Peck, E. C.
1951. Kiln temperature: Effect on yellow-poplar core stock. Woodwork. Dig. 180-183. Aug.

22. Pillow, M. Y.
1939. Characteristics of ash from southern bottomlands. South. Lmbrmn. 159(2009);131-136.

23. ______.
1939. White ash and green ash: Their wood structure and properties as influenced by growth conditions. Ph. D. thesis, Univ. of Wisconsin-Madison.

24. ______.
1950. Guides for selecting tough ash. South. Lmbrmn. 181(2264):42-52.

25. Stem, E. G.
1944. Strength properties of yellow-poplar from Virginia. Bull. Va. Polytech. Inst. 38(2). (Eng. Sta. Ser. No. 59).

26. Stemitzke, H. S.
1974. Eastern hardwood resources: Trends and prospects. For. Prod. J. 24(3):13-16.

27. Tang, R. C., S. F. Adams, and R. E. Mark.
1971. Modulus off rigidity and torsional strength of scarlet oak related to moisture content. Wood Sci. 3(4):238-244.

28. Taylor, Fred W.
1966. A study of the natural variation of certain properties of the wood of yellow-poplar within trees, between trees, and between geographic areas. Ph. D. thesis, Univ. of North Carolina.

29. U.S. Forest Products Laboratory.
1974. Wood Handbook. U.S. Dep. of Agr., Agr. Handb. No. 72.

Table 1. Mechanical properties[1] of 23 eastern hardwoods commonly associated with southern pines

Common and botanical name of species	Specific gravity[2]	Static bending: Modulus rupture	Static bending: Modulus of elasticity	Static bending: Work to maximum load	Impact bending-height of drop causing complete failure	Crushing strength parallel to grain	Compression perpendicular to grain stress at proportional limit	Shear strength parallel to grain	Tensile strength perpendicular to grain	Side hardness
		Psi	10^6 psi	In.-lb/in.^{3}	In.	Psi	Psi	Psi	Psi	Lb
Ash:										
Green	0.53	9,500	1.40	11.8	35	4,200	730	1,260	590	870
(Praxinus pennsylvanica)	.56	14,100	1.66	13.4	32	7,080	1,310	1,910	700	1,200
white	.55	9,600	1.44	16.6	38	3,990	670	1,380	590	960
(F. americana)	.60	15,400	1.74	17.6	43	7,410	1,160	1,950	940	1,320
Elm:										
American	.46	7,200	1.11	11.8	38	2,910	360	1,000	590	620
(Ulmus americana)	.50	11,800	1.34	13.0	39	5,520	690	1,510	660	830
Winged[3]	.60	9,200	1.21	21.7	73	3,700	630	1,300	850	1,140
(U. alata)	.66	14,800	1.65	23.1	69	6,780	1,020	2,370	1,210	1,540
Hackberry	.49	6,500	.95	14.5	48	2,650	400	1,070	630	700
(Celtis occidentalis)	.53	11,000	1.19	12.8	43	5,440	890	1,590	580	880
Hickory, true:										
Mockernut	.64	11,100	1.57	26.1	88	4,480	810	1,280	--	[4]1,440
(Carya tomentosa)	.72	19,200	2.22	22.6	77	8,940	1,730	1,740		1,970
Pignut	.66	11,700	1.65	31.7	89	4,810	920	1,370	--	[4]1,520
(C. glabra)	.75	20,100	2.26	30.4	74	9,190	1,980	2,150		2,140
Shagbark	.64	11,000	1.57	23.7	74	4,580	840	1,520	--	[4]1,460
(C. ovata)	.72	20,200	2.16	25.8	67	9,210	1,760	2,430	--	1,880
Shellbark	.62	10,500	1.34	29.9	104	3,920	810	1,190	--	[4]1,670
(C. laciniosa)	.69	18,100	1.89	23.6	88	8,000	1,800	2,110	--	1,810
Maple, red	.49	7,700	1.39	11.4	32	3,280	400	1,150	--	700
(Acer rubrum)	.54	13,400	1.64	12.5	32	6,540	1,000	1,850	--	950
Oak, red:										
Black	.56	8,200	1.18	12.2	40	3,470	710	1,220	--	1,060
(Quercus velutina)	.61	13,900	1.64	13.7	41	6,520	930	1,910	--	1,210
Cherrybark	.61	10,800	1.79	14.7	54	4,620	760	1,320	800	1,240
(Q. falcata var. pagodaefolia)	.68	18,100	2.28	18.3	49	8,740	1,250	2,000	840	1,480
Laurel	.56	7,900	1.39	11.2	39	3,170	570	1,180	770	1,000
(Q. laurifolia)	.63	12,600	1.69	11.8	39	6,980	1,060	1,830	790	1,210

(Page 1 of 2)

Table 1. Mechanical Properties [1] of 23 eastern hardwoods commonly associated with southern pines --continued

Common and botanical name of species	Specific gravity[2]	Static bending: Modulus of rupture	Static bending: Modulus of elasticity	Static bending: Work to maximum load	bending-height of drop causing complete failure	Crushing strength parallel to grain	Compression perpendicular to grain stress at proportional limit	Shear strength parallel to grain	Tensile strength perpendicular to grain	Side hardness
		Psi	10^6 psi	In.-lb /in.^{3}	In.	Psi	Psi	Psi	Psi	Lb
Oak, red: --continued										
Northern red	0.56	8,300	1.35	13.2	44	3,440	610	1,210	750	1,000
(*Quercus rubra*)	.63	14,300	1.82	14.5	43	6,760	1,010	1,780	800	1,290
Scarlet	.60	10,400	1.48	15.0	54	4,090	830	1,410	700	1,200
(*Q. coccinea*)	.67	17,400	1.91	20.5	53	8,330	1,120	1,890	870	1,400
southern red	.52	6,900	1.14	8.0	29	3,030	550	930	480	860
(*Q. falcata*)	.59	10,900	1.49	9.4	26	6,090	870	1,390	510	1,060
Water	.56	8,900	1.55	11.1	39	3,740	620	1,240	820	1,010
(*Q. nigra*)	.63	15,400	2.02	21.5	44	6,770	1,020	2,020	920	1,190
Oak. white:										
Post	.60	8,100	1.09	11.0	44	3,480	860	1,280	790	1,130
(*Q. stellata*)	.67	13,200	1.51	13.2	46	6,600	1,430	1,840	780	1,360
White	.60	8,300	1.25	11.6	42	3,560	670	1,250	770	1,060
(*Q. alba*)	.68	15,200	1.78	14.8	37	7,440	1,070	2,000	800	1,360
Sweetbay[4]	.45	6,900	1.29	9.2	28	3,120	360	850	--	480
(*Magnolia virginiana*)	.47	10,900	1.64	9.2	26	5,680	560	1,680	--	690
Sweetgum	.46	7,100	1.20	10.1	36	3,040	370	990	540	600
(*Liquidamber styraciflus*)	.52	12,500	1.64	11.9	32	6,320	620	1,600	760	850
Tupelo, black	.46	7,000	1.03	8.0	30	3,040	480	1,100	570	640
(*Nyssa sylvatica*)	.50	9,600	1.20	6.2	22	5,520	930	1,340	500	810
Yellow-poplar	.40	6,000	1.22	7.5	26	2,660	270	790	510	440
(*Liriodendron tulipifera*)	.42	10,100	1.58	8.8	24	5,540	500	1,190	540	540

[1] Values in the first line for each species are from tests of green material; those in the second line are from tests of air-dry material with results adjusted to 12 pct moisture content.

[2] Based on ovendry weight volume green or at 12 pct moisture content.

[3] All data for species from 1955 edition of U.S. Forest Products Laboratory, Wood Handbook. U.S. Dep. Agr., Handb. No. 72.

[4] All data for species from FPL files; data not previously published.

Table 2. Average coefficient of variation for specific gravity and mechanical properties in Table 1[1]

Property	Coefficient of variation
	Pct
Specific gravity	10
Modulus of rupture	16
Modulus of elasticity	22
Work to maximum load	34
Impact bending	25
Crushing strength parallel	18
Compression perpendicular	28
Shear strength	14
Tension perpendicular	25
Side hardness	20

[1]Values given are based on tests of green wood of approximately 50 species. Values for wood adjusted to 12 pct moisture content may be assumed to be approximately the same magnitude.

Table 3. Average toughness[1] values for a few species of wood

Species	Moisture content	Specific gravity[2]	Toughness
	Pct		In.-lb
Elm, winged	Green	0.60	670
	11	.68	500
Hickory:			
Mockernut	Green	.64	940
	12	.72	790
Pignut	Green	.66	1,020
	12	.75	860
Shagbark	Green	.64	840
	12	.72	680
Shellbark	Green	.62	1,010
	12	.69	1,020
Oak:			
Scarlet	11	.66	480
Overcup	Green	.56	700
	13	.62	330
Sweetbay	Green	.44	210
	11	.47	170
Sweetgum	Green	.48	340
	13	.51	260
Yellow-poplar	Green	.43	310
	12	.45	220

[1]Average radial and tangential toughness of specimens 2 cm square and 28 cm long.

[2]Based on ovendry weight and volume at moisture content indicated.

Table 4. Average tension-parallel-to grain strength for several species[1]

Species	Specific gravity[2]	Tensile strength
		Psi
Elm, winged	0.68	[3]27,000
Oak, overcup	.57	11,300
	.63	14,700
Sweetgum	.46	13,600
	.52	17,300
Yellow-poplar	.42	15,900
	.46	22,400

[1]First line for each species are results of tests on green material; second are results of tests of air-dried material adjusted to 12 pct moisture content.

[2]Based on ovendry weight and volume green or at 12 pct moisture content.

[3]Air-dry material only tested for winged elm.