Chapter 4
Grading and Properties of Hardwood Structural Lumber

David W Green

Supervisory Research General Engineer,
USDA Forest Products Laboratory

Structural lumber markets have traditionally been dominated by softwood species. Historically, however, hardwood species have been extensively used forcertain structural products such as timbers for railway and highway bridges, railway ties, mine timbers, and for pallets and containers. In the 1920s, when uniform procedures were first developed for structural grading, allowable properties were assigned to both hardwood and softwood species (Appendix D of Green and Evans 2001). In 1922, the National Lumber Manufacturers' Association (currently the American Forest & Paper Association) produced span tables for joists and rafters for both hardwood and softwood species. Allowable properties for hardwoods were included in the first edition of the *National Design Specification* in 1944, but did not appear in the 1960 edition. In the 1970s and 1980s, studies were published on the technical and economic feasibility of producing 2-inch-thick dimension lumber from several hardwood species including aspen, paper birch, basswood, and yellow-poplar (e.g., Maeglin and Boone 1983,1985; Gerhards 1983; Erickson et al. 1986). In 1988, a number of hardwood species were once again included in the 1988 revision of the *1986 National Design Specification* (DeBonis and Bendtsen 1988). Despite this interest, the only hardwood species occasionally available on a commercial basis was yellow-poplar which was available in dimension lumber and manufactured into trusses. The historic lack of interest in 2-inch-thick structural dimension lumber from hardwood species can largely be attributed to low market acceptance and low profit margins for commodity lumber. In the early 1990s, the National Timber Bridge Initiative and decreased availability of western softwoods resulted in renewed interest in using hardwoods for structural applications. Recently, there has been some interest in producing 2-inch-thick commercial lumber for hardwoods for use in trusses and I-joists. This chapter will summarize the information on the properties and grading of 2-inch-thick dimension lumber resulting from research studies conducted since about 1990.

Visually Graded Dimension Lumber

The American Softwood Lumber Standard, Voluntary Product Standard PS-20, establishes nationally recognized requirements for the grading of lumber (NIST 1999, Green and Hernandez 2000, USDA 1999). The provisions of PS-20 were developed and administered by the American Lumber Standards Committee (ALSC). Grading rules and allowable properties for both softwood and hardwood structural lumber are developed and administered through ALSC's National Grading Rule Committee and Board of Review. Grading rules and designvalues for eastern hardwoods are given in the current edition of the Standard Grading Rules of the Northeastern Lumber Manufacturers' Association (NeLMA 2001). The allowable properties for all species, including hardwoods, are also summarized in the *National Design Specification® (NDS®) for Wood Construction* (AF&PA 2005). For dimension lumber (lumber 4 in. and less in thickness) grades and properties are given for Structural Framing[1] (lumber 2 in. and wider), Stud (lumber 2 in. and wider), and Structural Framing (also 2 in. and wider). Structural Framing grades are Select Structural, No. 1, No. 2, and No. 3. Light Framing grades are Construction, Standard, and Utility. Virtually all of the recent information on yield and properties of hardwood lumber are for Structural Framing grades. These will be the only visual grades discussed in this chapter.

Yield

Studies on hardwood lumber usually express the results either as the total volume of lumber from a given grade that may be obtained from a total volume of log (to be called "recovery" in this chapter) or as the total volume of lumber of a given grade relative to the total volume of all lumber cut from the log or cant (to be called "grade yield" in this chapter). Most of the studies in the literature only report as grade yield.

---

[1] Structural Framing is usually further separated into Structural Light Framing (lumber 2 to 4 in. thick and 2 to 4 in. wide) and Structural Joist and Plank (lumber 2 to 4 in. thick and 6 in. and wider).

Faust (1990) evaluated the grade yield of Structural Light Framing from ungraded sweetgum and yellow-poplar logs. The 12-foot- (3.7-m-) long logs were sawn into nominal 8- by 8-inch cants and then resawn into four 2 by 8's. Two 2 by 4's were produced by ripping one of the 2 by 8's. Several things should be noted about how grade yield for this study is reported in this chapter. The arbitrary selection of one 2 by 8 to be cut into two 2 by 4's makes basing grade yield on the total number of pieces of lumber rather meaningless. Therefore, in **Table 4.1** grade yield is based on the total number of pieces of a given size that were obtained (board feet of lumber was not reported) thus the sum of the grade yields for 2 by 4's (or 2 by 8's) is 100 percent. Also, because of some problems with over drying of the lumber, only the grades based on the maximum strength reducing defects in the piece (such as knots and slope of grain) will be discussed here. Finally, because the lumber was graded following usual prac-

Table 4.1. – Grade yield[a] of hardwood structural lumber from ungraded logs and cants.

		Grade yield (%)				
Species and size	Number of pieces	Select Structural	No. 1	No. 2	No.3	Econ.
Sweetgum						
2 by 4[b]	403	b	18.0	53.5	18.9	9.6
2 by 8[b]	423	b	9.9	41.2	33.1	15.8
Yellow-poplar						
2 by 4[b]	366	b	39.7	37.8	21.8	0.7
2 by 8[b]	362	b	50.9	35.0	13.4	0.7
2 by 4[c]	b	30.4	19.9	38.0	11.7	b
2 by 6[c]	b	24.6	20.7	45.0	9.7	b
2 by 8[c]	b	37.2	11.4	43.0	8.4	b
Hybrid poplar						
2 by 4[d]	243	23.0	23.0	20.2	19.8	14.0
Hard maple						
2 by 6[e]	925	4.2	1.9	41.6	35.4	16.9

[a] Because of the way some studies reported their yield of lumber, all estimates of percent grade yield are based on the board feet (or number of pieces) of lumber of a given size reported in the cited literature. See text for additional discussion.

[b] Faust 1990. For sweetgum and yellow-poplar, Select Structural and No. 1 grades were not separated and would more appropriately be classified as No. 1 and Better.

[c] Moody et al. 1993. Yield of Economy lumber not reported separately from "trim", sawdust, etc. Number of pieces also not reported.

[d] Kretschmann et al. 1999.

[e] Green et al. in progress, b.

tices for grading southern pine dimension lumber, the No. 1 grade reported in the original publication was really a combination of No. 1 and Select Structural and will be called “No. 1 and Better” in this chapter. Table 4.1 shows the grade yield for individual grades and sizes of lumber based on the number of pieces produced. Only the lumber that makes No. 3 or Better grades may be used for structural purposes, and most of the profit comes from lumber that is No. 2 or Better. Some 90 percent of the sweetgum 2 by 4’s and 84 percent of the 2 by 8’s made No. 3 or Better, and 71 percent of the 2 by 4’s and 51 percent of the 2 by 8’s made No. 2 or Better. For yellow-poplar, about 99 percent of both sizes made No. 3 or Better, and 77 percent of the 2 by 4’s and 85 percent of the 2 by 8’s made No. 2 or Better. These high yields for yellow-poplar suggest that the logs may have been very high quality.

Grade yields for visually graded yellow-poplar dimension lumber were also reported as part of a study to develop specifications for hardwood glulam beams (Moody et al. 1993). In this study, logs were obtained from the southwestern part of West Virginia. The trees were 12 to 24 inches (305 to 610 mm) in diameter at breast height and ranged in age from 25 to more than 50 years. Cant sawing was used to obtain a maximum yield from the logs. While recovery of lumber from the logs is reported in the paper, there are some discrepancies in the tabulated numbers. The grade yields discussed here are based on the board foot yield of No. 3 and Better lumber for each size of lumber reported in Table 7 of Moody et al. (1993) after the lumber had been trimmed for maximum grade **(Table 4.1).** To be consistent with the other studies summarized in **Table 4.1,** the grade yields will sum to 100 percent for each individual size? In general, the grade yields, by size, of the yellow-poplar in this study are similar to those reported by Faust (1990), with some allowance made because Economy lumber was not reported separately by Moody et al. (1993). Thus 50.3 percent of the 2 by 4’s in this study would make No. 1 and Better, while 39.7 percent made No. 1 and Better in the study by Faust. For 2 by 8’s the comparisons are 48.6 percent in the Moody et al. study and 39.7 in the Faust study.

Kretschmann et al. (1999) evaluated the grade yield of “Wisconsin-5” hybrid poplar, a variety previously extensively planted in Wisconsin. The material for this study was obtained from three plots of 20-year-old hybrid poplar

---

[2] Grade yields based on the board feet, trimmed, of all sizes sawn from the logs are 2.8,1.9, 3.6, and 1.1 for Select Structural, No. 1, No. 2, and No. 3 2 by 4’s, respectively. For 2 by 6’s, the percentage grade yields based on total board feet of all the sizes are 7.6, 6.4, 13.9, and 3.0 for 2 by 6’s, and 22.2, 6.8, 25.7, and 5.0 for 2 by 8’s.

growing near Hancock, in central Wisconsin. The 50 logs used in this study were about 9 feet (2.7 m) long and had small-end diameters that ranged from 6.75 to 11.5 inches (171 to 292 mm). Recovery was reported in the report for two different sawing patterns, but was not given by lumber grade. Eighty-six percent of the 2 by 4's made No. 3 or Better grade and 66 percent made No. 2 and Better **(Table 4.1).**

Recently a study has been completed on cutting structural lumber from hard maple (Green et al. in progress, b). In this study, 2 by 6 dimension lumber was cut from ungraded hard maple cants obtained from the Upper Peninsula of Michigan. The lumber was dried using a schedule developed for hardwood structural lumber (Simpson et al. 1998) and graded as Structural Joist and Plank by a representative of the Southern Pine Inspection Bureau (SPIB). Grade yield was low in the two upper grades, but was good for No. 2 and No. 3 grades **(Table 4.1).** Thus 83 percent of the lumber made No. 3 or Better, but only 48 percent made No. 2 or Better.

Two studies have evaluated the yield of 2- by 4-inch (51 by 102 mm) structural lumber from USDA Forest Service factory-grade logs; one with red oak and another with red maple. In the first study (McDonald and Whipple 1992), ninety-five 12-foot- (3.7-m-) long logs were obtained from central Wisconsin and sorted into USDA Forest Service standard hardwood log grades F2, F3, and the hardwood Construction grade (Carpenter et al. 1989, Rast et al. 1973, Vaughn et al. 1966). F1 grade oak logs were excluded from the study because those logs are primarily used for veneer. All logs were 10 inches (254 mm) or more in scaling diameter. Logs were sawn by log grade and scaling diameter. The sawing pattern specified a 4-inch (102 mm) cant through the center of each log and 7/4 flitches on each side of the center cant. If possible, another 7/4 flitch was taken outside these flitches, otherwise 4/4 side lumber was sawn. 7/4 lumber was resawn from the center cant. Only the 7/4 lumber was retained for further study. The lumber was kiln-dried to an average moisture content of 15 percent and planed to 1.5 by 3.5 inches (38.1 by 88.9 mm). The 2 by 4's were graded by SPIB Inspector as Structural Light Framing (Chapter 6, USDA 1999).

Grade yield, expressed as a percentage of the total sawn volume of 2 by 4's, is given in **Table 4.2.** The yield of merchantable (No. 3 and Better) lumber from the lower valued Construction grade red oak logs was comparable to the yield from the higher valued F2 grade, with about 50 percent yield of No. 3 or Better. Yield of No. 3 or Better from log grade F3 was only about 25 percent.

Table 4.2. – Grade yield of dry 2 by 4's from factory grade logs.

Species and grade	Grade yield (%) Select Structural	No. 1	No. 2	No. 3	Econ.
Red oak					
F2	11	5	17	18	49
F3	4	1	11	10	75
Const.	5	4	30	14	47
Red maple					
F1	18	1	36	18	27
F2	5	0	22	16	56
F3	3	0	16	18	62

Source: McDonald and Whipple 1992, McDonald et al. 1993.

The second study (McDonald et al. 1993) used procedures very similar to those previously discussed for red oak. In this study, 100 red maple logs were selected from central Vermont. The logs were sorted into USDA Forest Service standard hardwood log grades F1, F2, and F3. Construction grade logs were not available, and therefore not included in the study. Grade yield of red maple are also shown in Table 4.2. With red maple, factory grade F1 logs yielded almost 75 percent No. 3 or Better lumber. With the lower quality F2 and F3 logs, less than half the volume graded as No. 3 or Better.

In both studies an attempt was made to contrast the value of the logs for the production of structural lumber versus their value if the log had been sawn into factory lumber. Because there are no established prices for hardwood structural lumber, and any prices for hardwood lumber would have to be competitive with those of other species, the value of southern pine lumber per thousand board feet (MBF) was used to calculate the value of the oak dimension lumber (Table 4.3). The prices, from 1990, were: $300 per MBF Select Structural, $280 for No. 1, $260 for No. 2, and $150 for No. 3. Thus, for example, the 2,149 board feet for lumber from log grade F2 of red oak was valued at $506 (Table 4.3). In the original publication, however, the volume of lumber that did not make No. 3 was given a value of $0.0. Thus the value of the log was determined as the value of the dimension lumber divided by the entire volume of the log. For grade F2 red oak, this meant that the value of the logs for dimension lumber was listed as $1 19 per MBF, see column 2 in Table 4.4. In retrospect, it seems overly severe to assume that the lumber that did not make No. 3 grade had no value. Even for firewood, dry red oak Economy lumber would have

Table 4.3. – Expected volume and value by log grade for hardwood lumber.

Species and log grade	Log volume	Dimension lumber		Factory lumber	
		Volume	Value	Volume	Value
	(BF)	(BF)	($)	(BF)	($)
Red oak					
F2	4,249	2,149	506	4,130	2,461
F3	2,844	710	157	3,161	1,460
Const.	1,322	701	166	--	--
Red maple					
F1	3,315	2,427	589	3,729	1,225
F2	2,679	1,169	264	3,012	819
F3	1,850	706	149	1,794	407

BF is board foot.
Adapted from McDonald et al. 1992,1993.

Table 4.4. – Value per unit volume for hardwood lumber.

	Value ($) per MBF based on volumes for		
	Structural lumber		
Species and log grade	Log	Dimension lumber	Factory lumber
Red oak			
F2	119	235	596
F3	55	221	462
Const.	126	237	--
Red maple			
F1	178	243	329
F2	99	226	272
F3	81	211	227

MBF is thousand board feet.
Adapted from McDonald et al. 1992, 1993.

some value. An alternative approach would be to evaluate the value of the lumber based only on the volume of the dimension lumber produced, knowing that some market would have to be found for the material that did not make No. 3 lumber grade. On that basis, the value of the F2 red oak logs is $235 per MBF, see column 3 of **Table 4.4.**

The value of the logs for factory lumber could only be approximated. The expected volume of Factory grades was obtained from percent yields tables (Vaughn et al. 1966, Hanks et al. 1980) and published market prices **(Table4.3).**

Note that the volume of No. 3 or Better dimension lumber available from a log was often much less than half the log volume. Thus there are sometimes big differences in the volumes of dimension and Factory grades given in Table 4.3. On this basis, the value of the F2 grade logs from red oak for Factory lumber was estimated as $596 per MBF **(Table 4.4).** In the original publications (McDonald and Whipple 1992, McDonald et al. 1993), the value of the logs for production of dimension lumber never came close to the value for factory lumber ($596 per MBF for F2 red oak factory lumber vs. $199 for dimension lumber). Assuming the value of dimension lumber is based on the volume of dimension lumber produced, it still does not make the value of red oak dimension comparable to the value for oak factory lumber ($235 per MBF for dimension vs. $596 per MBF for factory in Table 4.4). At the time, however, red maple was worth a lot less than oak for factory lumber. Looking at the value of red maple based on the volume of dimension lumber ($243 for log grade F 1, **Table 4.4)** versus the value as factory lumber ($329 for log grade F 1) makes using the maple logs to produce dimension lumber more competitive. In fact, for a grade F3 red maple log, the value of the log for factory lumber was only about 8 percent higher than it was for producing factory lumber, and the value of the lumber that did not make No: 3 lumber grade is not included. Still, these data assume the best (highest value) wood - wood from the outside of the hardwood log–is going into the production of dimension lumber. McDonald et al. (1992,1993) postulated that it might be better to cut clear 1-inch-thick boards from the outside of the log and cut dimension lumber only from the center portion of the log.

Following up on their earlier hypothesis, McDonald et al. (1996) evaluated the potential for producing structural lumber from log heart cants, including graded switch ties and mill run (ungraded) pallet cants. This option could be attractive to mills already producing products from log heart cants. The option of cutting structural lumber from heart centered cants might also be attractive to mills that remove higher quality wood from the outside portion of the log for sale as appearance grade lumber and then use the lower quality inner portion for structural products. A survey of manufacturers in West Virginia found that a range of lumber sizes that could be produced from cants in lumber widths up to 9 inches (229 mm) without incurring a premium price for the cants. The survey also found that a common practice for grading cants was for the buyer to specify species and stipulate only that the cants be “Sound Square Edge” (Railway Tie Association 1993). This specification was used for the “graded switch ties tested in this study. Freshly sawn and graded 7- by 9-inch (178 by 229 mm) switch ties were ripped into nominal 2- by 7-inch (5 1 by 178 mm) pieces of dimension lumber. This process generally yielded four boards per tie. The mill run 6- by 8-inch (1 52 by 203 mm) cants were sawn from logs available at the mill log yard. Four boards were also sawn from each mill run cant.

The lumber from all cants was graded by certified agency graders as Structural Joist and Plank. The results clearly show that the quality of the cants makes a difference (Table 4.5). As would be expected, lumber yield from graded switch ties was higher than that from mill run cants. For all species sampled, yields from graded switch ties of No. 3 or Better lumber exceeded 80 percent. The biggest difference in the yield of No. 3 or Better lumber between graded and ungraded cants was with red maple (39% lower yield with mill run cants than with graded switch ties), while with the oaks there was little difference. Except for the oaks, the graded cants produced more Select Structural and No. 1 grades of lumber, while the grade yield from the ungraded cants shifted to the lower grades.

Properties

Currently nine hardwood species, or species groups, have allowable design strengths for dimension lumber listed in the *National Design Specification®*

Table 4.5. – Yield of green 2 by 6s from heart centered cants.

		Lumber yield (%)				
Species	Source	Select Structural	No. 1	No. 2	No.3	Econ.
Beech	Mill run[a]	8	2	14	41	35
	Switch ties[b]	10	5	31	36	18
Hickory	Mill run[a]	23	2	16	25	34
	Switch ties[b]	25	10	43	17	5
Yellow-poplar	Mill run[a]	10	5	32	26	27
	Switch ties[b]	42	22	25	9	2
Red maple	Mill run[a]	3	4	15	28	50
	Switch ties[b]	16	8	32	33	11
Red oak	Mill run[a]	3	4	15	28	50
	Switch ties[b]	16	8	32	33	11
White oak	Mill run[a]	13	5	25	38	19
	Switch ties[b]	10	5	42	24	19

[a] Ungraded.
[b] Graded by species and specified as "sound square edge."
Source: Table 5 of McDonald et al. 1996.

(NDS®) for Wood Construction (AF&PA 2001). The properties of these species are derived by the "dear wood" procedures of ASTM D2555/D245 (ASTM 2005, Chapter 6 of the *Wood Handbook* [USDA 19991). As with softwood species, most hardwoods are marketed in a grouping of species. With many of these hardwood groupings, it is difficult or impossible to visually identify individual species after the logs have been processed into lumber. For these species groups, allowable properties of the group are controlled by the weakest species in the grouping. For example, as shown in **Table 4.6,** the properties of Mixed Maple are controlled by the properties of silver maple. While this procedure may have validity from marketing and technical perspectives, it may make for inefficient resource utilization.

Recent studies of hardwood properties for visually graded lumber have generally been limited to 2 by 4's and 2 by 6's. These studies have shown that hardwoods have excellent strength and stiffness values. Properties determined from lumber tests often exceed those assigned by the clear wood procedure **(Table 4.7).** For individual species, establishment of properties by the full-size testing procedures of ASTM D1990 (ASTM 2005) might improve hardwood property assignments. However, the inability to identify many individual spe-

Table 4.6. – Mean property values for green, clear wood.

Grouping and species	Modulus of elasticity	Modulus of rupture
	(10^6 lb/in^2)	(10^3 lb/in^2)
Red oak		
Black oak	1.182	8.820
Cherry bark oak	1.790	10.850
Laurel oak	1.393	7.940
Northern red oak	1.353	8.300
Pin oak	1.318	8.330
Scarlet oak	1.476	10.420
Southern red oak	1.141[a]	3.923[a]
Water oak	1.552	8.91 0
Willow oak	1.286	7.400
Mixed maple		
Black maple	1.328	7.920
Sugar maple	1.546	9.420
Red maple	1.386	7.690
Silver maple	0.943[a]	5.820[a]

Source: ASTM 025555,2000.
[a] Species whose properties control the assignment of allowable properties for the group.

Table 4.7. – Comparison of allowable properties assigned to visually graded hardwood lumber to recent test results on structural lumber.

Species and size	Grade[a]	Experimental/Allowable: Modulus of elasticity	Experimental/Allowable: Modulus of rupture	Source
Red maple				
2 by 4	SS	1.07[a]	0.8g[b]	Green and
	No. 2	1.14	1.45	McDonald 1993b
	No. 3	1.27	2.16	
Mixed maple				
2 by 6	SS	1.44	1.72	Green et al.
	No. 1	1.55	1.83	in progress a
	No.2	1.53	1.75	
	No. 3	1.68	1.47	
Red oak				
2 by 4	SS	1.22[b]	1.54[c]	Green and
	No. 2	1.16	1.17	McDonald 1993a
	No. 3	1.22	1.74	
2 by 6	SS	1.42	2.27	Green et al.
	No. 1	1.37	1.89	in progress a
	No. 2	1.45	1.67	
	No. 3	1.53	2.31	
Yellow-poplar				
2 by 4	SS	1.03	1.67	Green and Evans
	No. 2	1.13	1.33	1987
2 by 6	SS	1.08	1.33	Green et al.
	No. 1	1.16	1.56	in progress a
	No. 2	1.22	1.11	
	No. 3	1.19	1.33	
Beech				
2 by 6	SS	1.04	1.26	Green et al.
	No. 1	1.12	1.34	in progress a
	No. 2	1.12	1.31	
	No. 3	1.25	1.67	
Hickory				
2 by 6	SS	1.51	1.99	Green et al.
	No. 1	1.45	1.82	in progress a
	No. 2	1.52	1.92	
	No.3	1.63	3.37	

[a] SS is Select Structural.
[b] Only 46 pieces available.
[c] Only 40 pieces available.

cies in a species grouping would still limit property assignment and lead to inefficient utilization. For most species groupings, more precise property assignments can only be achieved through mechanical grading.

Mechanically Graded Dimension Lumber

Mechanically graded lumber is 2-inch-thick structural lumber evaluated nondestructively by a machine, followed by visual assessment of certain growth characteristics that the machine cannot or may not properly evaluate (USDA 1999, Smulski 1997, Galligan and McDonald 2000). The use of two types of sorting criteria allow more precise sorting of lumber for specific applications in engineered structures such as metal plate connected wood trusses and wood I-joists. Mechanical grading of 2-inch-thick dimension lumber has been conducted commercially for softwood species in the United States since the 1960s. In 1993 research studies evaluated the relationship between bending strength and tensile strength parallel to the grain, and between bending strength and compression strength parallel to the grain for red oak, red maple, and yellow-poplar dimension lumber (Green and McDonald 1993a, 1993b). This research showed that the relationships between lumber strength properties for domestic hardwood species were the same as those used to assign properties to mechanically graded softwood species (ASTM D6570) (ASTM 2005).[3] This research removed remaining technical barriers to the mechanical grading of hardwood structural lumber.

In late 1993, the concept of mechanically grading hardwood was put to the test. With the cooperation of the Northeastern Lumber Manufacturers' Association, the SPIB, the Forest Products Laboratory, and Burke-Parsons-Bowlby Corp., Spencer, West Virginia, 803 pieces of mixed oak 2 by 8 lumber was graded to meet the machine stress rated (MSR) lumber requirements for 1650f-1.4E[4] (Green et al. 1994). The procedures followed were the same as

---

3 Interlocked grain is common in such domestic hardwoods as black gum, sweetgum, cottonwood, sycamore, and tupelo. Research on tropical hardwoods has shown that interlocked grain does not alter the relationship between bending strength (MOR) and tensile strength parallel to the grain (UTS), but does alter the relationship between MOR and compression strength parallel to the grain (UCS) (Green and Rosales 1996). Some property relationships would have to be justified before machine stress rated (MSR) lumber could be produced with species that generally have interlocked grain.

4 Grade names for MSR lumber are given in terms of the allowable bending strength, F_b, and allowable MOE, E, of the grade. Thus 1650f-1.5E MSR lumber has an F_b value of 1,650 psi and an average MOE value of 1.5 million psi.

those used by SPIB to grade southern pine MSR lumber. The results of this certification showed that although only 1 percent of the lumber qualified as Select Structural by visual grading, 36 percent of it could be assigned an MSR grade with properties equal to or greater than those of Select Structural **(Table 4.8).** Thus in ithis instance, the MSR process was able to produce lumber with the properties of Select Tructural grade lumber but with a yield similar to that of No. 2 and Better visual grade. The oak MSR lumber was subsequently used in a timber bridge in Jackson County West Virginia **(Fig. 4.1).** It has subsequently been shown that a similar MSR process is applicable to oak 7 by 9 structural timbers (Kretschmann and Green 1999).

The relationship between modulus of rupture (MOR), also called bending strength, and modulus of elasticity (MOE) is used in the assignment of MSR grades. This is done by establishing a lower tolerance limit on MOE–MORrelationship and using the MOE of the grade to determine the allowable MOR of the lumber **(Fig. 4.2).** Several studies evaluated the relationship between MOE and MOR of hardwood lumber **(Table 4.9).** Two observations may be noted about these results. First, the coefficient of determination on the regression relationship is generally lower for hardwoods than it is for softwoods. This lower coefficient of determination would result in the tolerance limit being further from the mean trend line for hardwoods than it is for softwood **(Fig. 4.2)**. Second, for lumber of equal width the slope of the MOE–MOR relationship is generally steeper for hardwoods than for softwoods **(Fig. 4.3)**. This generally higher slope helps compensate for the lower tolerance limit. Our experience suggests that hardwood MSR lumber can make the same MOR limit for a given

Table 4.8. – Results of machine stress rated (MSR) certification of oak 2 by 8's.

Grade	Yield	Allowable property	
		Bending strength	Modulus of elasticity
	(%)	(lb/in^2)	(10^6 lb/in^2)
Visual			
Select Structural	1	1,350	1.4
No. 1	3	990	1.3
No. 2	33	960	1.2
No. 3	63	540	1.1
MSR			
1650f-1.4E	36	1,650	1.4

Source: Green et al. 1994.

Figure 4.1. – Timber bridge in Jackson County West Virginia containing 1650f-1.4E machine stress rated oak decking.

Figure 4.2. – Conceptual relationship between 5th percentile modulus of elasticity (MOE) and modulus of rupture (MOR) for establishing grades for machine stress rated lumber.

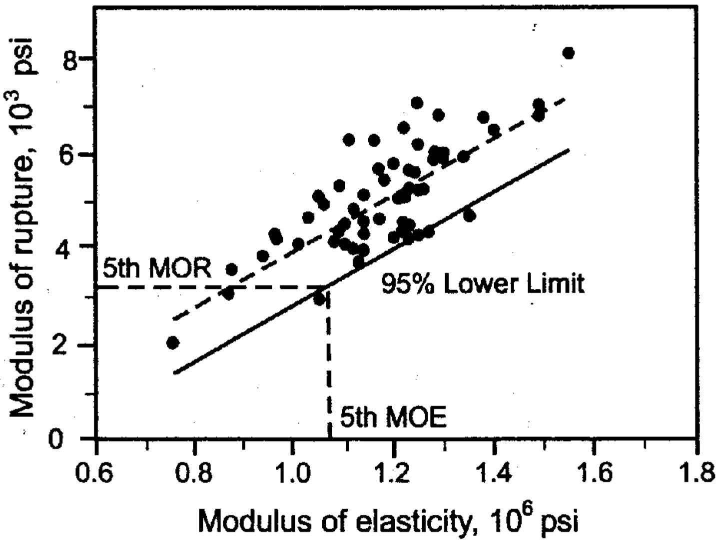

Figure 4.3. – Relationship between modulus of rupture (MOR) and modulus of elasticity (MOE) for dry hardwood and softwood 2 by 4's.

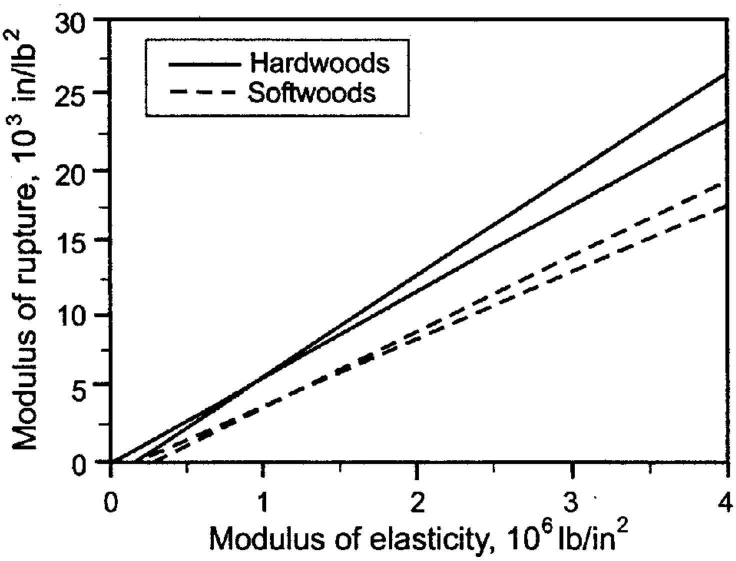

Table 4.9. – Relationship between MOE and MOR for hardwood and softwood lumber at 12 percent moisture content.

Species	Size	Sample size	MOR = A +B(MOE) Slope (B)	Coefficient of determination, r^2	Source
Hardwoods					
Red oak	2 by 4	215	7.009	0.46	a
	2 by 6	229	6.568	0.39	b
Red maple	2 by 4	260	5.840	0.31	c
Mixed maple	2 by 6	220	7.602	0.42	b
Yellow-poplar	2 by 4	126	4.763	0.25	d
	2 by 6	230	7.112	0.22	b
Beech	2 by 6	445	6.248	0.30	b
Hickory	2 by 6	464	5.533	0.33	b
Hybrid poplar	2 by 4	243	5.044	0.42	e
Softwoods					
Southern pine	2 by 4	2,161	4.490	0.52	d
Douglas-fir	2 by 4	2,781	4.593	0.56	d
Hem-fir	2 by 4	903	5.166	0.53	d

[a] Green and McDonald 1993a.
[b] Green et at. in progress a.
[c] Green and McDonald 1993b.
[d] Green and Evans 1987, extracted from data summarized in 1987 report.
[e] Kretschmann et at. 1999.

MOE value as softwood lumber (Green et al. 1994). Additional information on the MOE–MORrelationships for yellow-poplar and sweetgum is presented in Faust et al. (1990). Coefficients of determination for both species are reported at 0.49, unfortunately the data for 2 by 4's and 2 by 8's is combined in their analysis and thus the correlation is not compatible with the data presented in Table 4.9.

For the engineer, the advantage of MSR lumber is a more precise assignment of allowable properties. However, for the producer the advantage is the possibility of achieving higher grade yield for a specified set of allowable properties. As was shown in **Table 4.8** for mixed oak 2 by s's, the yield of a MSR grade having an MOE of 1.4 million psi was only 1 percent for Select Structural visual grade, but was 36 percent when mechanically graded. A recent study (Green et al. in progress, a) shows that for 2 by 6 lumber of several hardwood species where the lumber was cut from graded cants, the yield of MSR lumber runs 10 to 20 percent higher than the visual grade having an equivalent MOE value (Table 4.10). While the latter study was a computer simulation of MSR

Table 4.10. – Allowable properties and grade yield of visually graded hardwood 2 by 6s cut from graded heart centered cants versus that estimated for machine stress rated (MSR) lumber.

	Visual graded as No. 2 and Btr.			MSR		
Species or grouping	Modulus of elasticity	F_b	Grade yield	Modulus of elasticity	F_b	Grade yield
	(10^6 psi)	(10^3 psi)	(%)	(10^6 psi)	(10^3 psi)	(%)
Beech	1.5	1.300	55	1.5	1.650	73
Hickory	1.5	1.300	71	1.5	1.650	99
Mixed maple	1.5	1.180	72	1.5	1.650	90
Red oak	1.2	1.040	77	1.2	1.200	99
Yellow-poplar	1.3	0.910	83	1.3	1.450	94

Source: Green et al. in progress a.

yield, the former study on oak 2 by 8's was from actual production. Thus research to date indicates the possibility of achieving higher yields for a specified set of allowable properties using the MSR process. The challenge for the producer would be to find a market for this material that would pay for the increased cost of mechanical grading.

Because MOE is one of the critical criteria for assigning an MSR grade, the producer of MSR lumber must better control the moisture content (MC) of the lumber than might be required for visually graded structural lumber. A recent study by Green et al. (in progress, b) estimated that the yield of 2100f-2.0E hard maple MSR was reduced from 88 percent at an average MC of 13 percent to 28 percent at an average MC of 23 percent. However, the good relationship between MOE and MC (Green and Evans 1989) presented an opportunity to identify the lumber that was suitable for the production of a high MSR grade based on its green MOE value and visual inspection of growth characteristics. Only those pieces needed to be dried to a lower MC level. The rest of the lumber could be dried to a higher MC level and sold for uses that did not require such high allowable property assignments.

Discussion

Hardwood mills will find that factory lumber and structural lumber differ in many ways.[5] For example, the thicknesses for factory lumber are rough sawn

[5] Much of this discussion is excerpted from McDonald and Whipple (1992). Valuable additional information on the differences in factory lumber and structural lumber is available in this publication.

by quarter-inch classes from 4/4 up to nominal 16/4; structural dimension lumber is usually nominal 2 inches (standard 51 mm) or actual 1.5 inch (38 mm) thickness after drying and planing. Widths are random for factory lumber and vary in 2-inch increments for dimension lumber. Defect limitations allowed on graded products are also much different. More wane and edge knots are accepted in factory lumber than in dimension lumber. Such differences reflect the end use of the grades, and they can produce significant problems to a mill trying to produce both types of products. These problems are further aggravated by different target sizes for green thicknesses and widths. Therefore, getting a stress-graded product on the market involves more than simply providing the means to grade the product. Hardwood logs will have to be sawn like softwood logs to produce a product similar to softwood structural lumber. The simple solution of having one mill saw stress-graded structural lumber is not a likely solution for most hardwood species because of the relatively higher value of factory lumber compared to structural lumber and the efficiency of getting both products from the same logs. The logical solution to the problem is that a portion of the log should be sawn into factory lumber and a portion into dimension lumber.

The results of the studies discussed strongly indicate that success in producing structural lumber will require some sort of sorting scheme. For logs, sorting the logs into groups of those most suitable for production of structural lumber and those most suitable for other (generally higher value) products looks to be essential. The grade of the log was found to have a pronounced effect on grade yield for most species. Not only did higher quality logs produce a higher total yield of structural lumber, but they also tended to produce a better yield in the higher lumber grades. The production of lumber from heart-centered cants seemed particularly attractive for those already purchasing or producing cants, especially if there is a good market for factory lumber for the better quality wood from the outer portions of the log. The results suggest that producing lumber from cants will also require some sort of grading scheme, similar to the grading scheme discussed briefly for railroad ties. In addition, from a mill manager's point of view, the decision to cut structural lumber will involve examining the economic tradeoff between selling cants outright, cutting them into appearance-grade lumber, or cutting them into nominal 2-inch-thick material. For the latter option, the best market will be for lumber that will make No. 2 visual grade or Better.

As in the production of any lumber product, and especially for anyone interested in producing structural lumber from hardwoods, it is critical to understand your markets. Because 2-inch-thick hardwood structural lumber is not currently a generally accepted product, it would be best to establish a relationship with specific buyers prior to beginning production. Those consider-'; ing the production of both mechanically graded and visually graded structural lumber must pay particular attention to the requirements of their buyers.

Another critical factor is kiln-drying. For most structural applications, the lumber must be dried to an average MC of either 12 percent or 15 percent. The typical drying schedule for structural lumber such as southern pine is 1 to 2 days, as opposed to 40 to 90 days for 7/4 oak. The effect of drying degrade on the assignment of structural grades is less restrictive than for most traditional uses of hardwood species, thus drying schedules can generally be accelerated. Recommendations on the drying of hardwood lumber for structural use is discussed in the next chapter.

Literature Cited

American Forest & Paper Association (AF&PA). 2005. National Design Specification" (NDS®) for Wood Construction. AF&PA, Washington, DC.

American Society for Testing and Materials (ASTM). 2005. Annual Book of ASTM Standards. Volume 04.10, Wood. West Conshohocken, PA.

Designation D6570-04. Standard practice for assigning allowable properties for mechanically-graded lumber.

Designation D2555-98. Standard test methods for establishing clear wood strength values.

Designation D245-00 (reapprove 2002). Standard practice for establishing structural grades and related allowable properties for visually graded lumber.

Designation D1990-00 (2002). Standard practice for establishing allowable properties for visually graded dimension lumber from in-grade tests of full size specimens.

Carpenter, RD., D.L. Sonderman, E.R. Rast, and M.J. Jones. 1989. Defects in hardwood timber. USDA Agri. Handb. 678. USDA, Washington, DC. 88 p.

DeBonis, A.L. and B.A. Bendtsen. 1988. Design stresses for hardwood structural grades create new opportunities. In: Executive Summaries from the 43rd Annual Meeting of the Forest Products Society. June 25-29, Reno, NV. Forest Products Society, Madison, WI. pp. 48-50.

Erickson, R.W., H.D. Peterson, T.D. Larson, and R. Maeglin. 1986. Producing studs from paper birch by saw-dry-rip. Res. Pap. FPL-RP-480. USDA Forest Service, Forest Products Laboratory, Madison, WI.

Faust, T.D. 1990. Grade distribution and drying degrade of sweetgum and yellow poplar structural lumber. Forest Prod. J. 40(5): 18-20.

Faust, T.D., R.H. McAlister, and S. J. Zarnoch. 1990. Strength and stiffness properties of sweetgum and yellow poplar structural lumber. Forest Prod. J. 40(10): 58-64.

Galligan, W.L. and K.A. McDonald. 2000. Machine grading of lumber: Practical concerns for lumber producers. Gen. Tech. Rep. FPL-GTR-7. USDA Forest Service, Forest Products Laboratory, Madison, WI.

Gerhards, C.C. 1983. Effect of high-temperature drying on bending strength of yellow poplar 2x4's. Forest Prod. J. 33(2): 61-67.

Green, D.W. and A. Rosales. 1996. Property relationships for tropical hardwoods. In: Proc. of the Intl. Wood Engineering Conf. '96. Oct., New Orleans, LA. V.K.A. Gupu, ed. Louisiana State Univ., Baton Rouge, LA. Vol. 3: 516-521.

Green, D.W. and J.W. Evans. 1987. Mechanical properties of visually graded lumber: Volume I, a summary. Publication 88- 159-389. Dept of Commerce. National Technical Information Service, Springfield, VA, 131 p.

Green, D.W. and J.W. Evans. 1989. Moisture content and the mechanical properties of dimension lumber: Decisions for the future. In: Proc. of the Workshop on In Grade Testing of Structural Lumber. April 25-26, Madison, WI. Proc. 47363, Forest Products Research Society, Madison, WI. pp. 44-55.

Green, D.W. and J.W. Evans. 2001. Evolution of standardized procedures for adjusting lumber properties for change in moisture content. Gen. Tech. Rep. FPL-GTR-127. USDA Forest Service, Forest Products Laboratory, Madison, WI.

Green, D.W. and K.A. McDonald. 1993a. Investigation of the mechanical properties of red oak 2 by 4's. Wood and Fiber Sci. 25(1): 35-45.

Green, D.W. and K.A. McDonald. 1993b. Mechanical properties of red maple structural lumber. Wood and Fiber Sci. 25(4): 365-374.

Green, D.W. and R. Hernandez. 2000. Codes and standards for structural wood products and their use in the United States. North America Forestry Commission. Proc. of the Forest Products Study Group Workshop, Merida, Mexico, June 23,1998. Forest Products Society, Madison, WI. pp. 3-16.

Green, D.W., M.P. Wolcott, and D.C. Hassler. In progress, a. Grading and properties of Appalachian hardwoods from log heart cants. To be submitted to the Forest Prod. J.

Green, D.W., R.J. Ross, and K.A. McDonald. 1994. Production of hardwood machine stress rated lumber. *In:* Proc. of the 9th Int. Symposium on Nondestructive Testing. Sep. 22-24,1993, Madison, WI. Forest Products Society, Madison, WI. pp. 141-150.

Green, D.W., R.J. Ross, J.W. Forsman, and J. Erickson. In progress, b. Mechanical grading options for hard maple structural lumber. To be submitted to the Forest Prod. J.

Hanks, L.F., G.L. Gammon, R.L Brisbin, and E.D. Rast. 1980. Hardwood log grades and lumber grade yields for factory lumber logs. Res. Pap. NE-RP-468. USDA Forest Service, Northeast Forest Research Station, Broomall, PA.

Kretschmann, D.E. and D.W. Green. 1999. Mechanical grading of oak timbers. J. of Materials in Civil Engineering. 11(2): 91-97.

Kretschmann, D.E., J.G. Isebrands, G. Stanosz, J.R. Dramm, A. Olstad, D. Cole, and J. Samsel. 1999. Structural lumber properties of hybrid poplar. Res. Pap. FPL-RP-573. USDA Forest Service, Forest Products Laboratory, Madison, WI.

Maeglin, R.R. and S. Boone. 1983. Manufacturing quality structural lumber from hardwoods using the saw-dry-rip process. In: Proc. of the 9th Annual Hardwood Symposium, Pipestem, VW. Hardwood Research Council, Memphis, TN.

Maeglin, R.R. and S. Boone. 1985. Evaluation of mixed hardwood studs manufactured by the saw-dry-rip process. Res. Note. FPL-RN-0249. USDA Forest Service, Forest Products Laboratory, Madison, WI.

McDonald, K.A. and J.W. Whipple. 1992. Yield of 2 by 4 red oak stress-graded dimension lumber from factory-grade logs. Forest Prod. J. 42(6): 5-10.

McDonald, K.A., C.C. Haler, J.E. Hawkins, and L.P. Timothy. 1996. Hardwood structural lumber from log heart cants. Forest Prod. J. 46(6): 55-62.

McDonald, KA., D.W. Green, J. Dwyer, and J.W. Whipple. 1993. Red maple stress-graded 2 by 4 dimension lumber from factory-grade logs. Forest Prod. J. 43(11/12): 13-18.

Moody, R.C., R. Hernandez, JE Davalos, and S.S. Sonti. 1993. Yellow poplar glulam timber beam performance. Res. Pap. FPL-RP-520. USDA Forest Service, Forest Products Laboratory, Madison, WI.

National Institute of Standards and Technology (NIST). 1999 (or latest edition). American Softwood Lumber Standard. Voluntary Product Standard PS-20. U.S. Dept. of Commerce, Gaithersburg, MD.

Northeast Lumber Manufacturers' Association (NeLMA). 2003. Standard Grading Rules for Northeast Species. NeLMA, Cumberland Center, ME.

Railway Tie Association. 1993. Specifications for timber crossties. St. Louis, month

Rast, E.D., D.L. Sondermann, and G.L. Gammon. 1973. A guide to hardwood log grading. Gen. Tech. Rep. NE-1 (rev.). USDA Forest Service, Northeastern Forest Expt. Sta., Upper Darby, PA. 32 pp.

Simpson, W.T., J.W. Forsman, and R.J. Ross. 1998. Kiln-drying maple structural lumber from log-heart cants. Forest Prod. J. 48(6): 70-76.

Smulski, S. 1997. Machine-graded lumber. Wood Design Focus. 8(2):1-24.

Vaughn, C.L., A.C. Wollin, K.A. McDonald, and E.H. Bulgrin. 1966. Hardwood log grades for standard lumber. Res. Pap. FPL-RP-63. USDA Forest Service, Forest Products Laboratory, Madison, WI.

USDA Forest Service, Forest Products Laboratory (USDA). 1999. Wood Handbook Wood as an Engineering Material. Forest Products Society, Madison, WI.

Undervalued Hardwoods
for Engineered Materials and Components

Robert J. Ross
Project Leader
USDA Forest Products Laboratory
Madison, WI

]ohn R. Erickson
Director (retired)
USDA Forest Products Laboratory
Madison, WI

Forest Products Society
Madison, WI

Northern Initiatives
Marquette, MI

Financial support for the development of this publication was provided to Northern Initiatives through the USDA Forest Service Northeastern Area's Rural Development Through Forestry Program.

ISBN1-892529-32-7

Publication No. 7234

Printed in the United States of America.

0510500