Strength and stiffness properties of sweetgum and yellow-poplar structural lumber

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Abstract

The forest resource base in the Southeast is rapidly changing. Dwindling reserves of high quality pine sawlogs will provide incentives to utilize low-density hardwoods such as yellow-poplar and sweetgum for structural lumber. Inventories of sweetgum *(Liquidambar styraciflua* L.) and yellow-poplar *(Liriodendron tulipifera* L.) are currently high and growth is exceeding removals. The mechanical properties of dimension lumber produced from sweetgum are relatively unknown. The objective of this study was to establish strength and stiffness data on sweetgum dimension lumber in bending, tension, and compression modes. The relationship between these strength modes was also investigated. Results indicate that sweetgum equals or exceeds yellow-poplar in strength and stiffness overall, and on a grade-by-grade basis. Correlations between bending, tension, and compression strength and stiffness were lower than correlations established for pine.

The forest resource base in the Southeast is rapidly changing. It has been projected that plantation-grown pine, which now provides about 20 percent of the softwood resource, will provide over 50 percent of the softwood by the year 2000 (15). Plantation-grown pine has a high percentage of juvenile wood, which lowers its utility for traditional uses such as structural lumber and plywood. Projections indicate that the demand for pine timber will exceed the available supply, resulting in rising prices for pine and increased incentives for using low-density hardwood species such as yellow-poplar *(Liriodendron tulipifera* L.) and sweetgum *(Liquidambar styraciflua* L.) (14). Yellow-poplar structural lumber has been accepted by the American Lumber Standards Committee and the design values are published by the National Forest Products Association (9).

The growth of low-density hardwood species currently exceeds the volume cut. This availability, plus the generally lower stumpage prices for mixed hardwoods (oak, poplar, sweetgum, etc.) compared to pine, has created interest in the use of hardwoods for structural framing. Grading rules for hardwood structural lumber have been proposed for several species such as aspen, alder, cottonwood, and yellow-poplar (11,12). It seems likely that on a price basis alone, suitable hardwood species will be accepted for structural applications in the near future.

Over the past several years, there has been an increase in the use of machine stress rated (MSR) lumber for critical structural applications such as laminating stock, scaffold planks, and light-frame wood trusses. It seems likely that the trend toward MSR grading of lumber will also apply to hardwood structural lumber. The basis for the use of MSR lumber is the relationship of the plank bending modulus of elasticity (MOE) to the bending, compression, and tensile strength of a given structural member (adjusted for visual defects). Although the relationships between stiffness, strength, and visual defects for softwood structural lumber have been developed over the past 20 years, there has been little comparable research on these relationships for hardwoods (5-8). Because the characteristics of growth for low-density hardwoods are so different from pine with regard to the persistence of branches, size of knots, interlocked and spiral grain, etc., it is unlikely that these relationships would be the same for hardwoods.

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TABLE 1. – Summary of study variables.

Variable	Level
Independent	
Species	Yellow-poplar
	Sweetgum
Size	Nominal 2 by 4's by 12 ft.
	Nominal 2 by 8's by 12 ft.
Defect grade (pine rules)	Grade 1
	Grade 2
	Grade 3
Covariate	
Specific gravity	Continuous
Dependent variables	
Static bending	
MOR	Continuous
MOE	Continuous
Tension	
MOR	Continuous
MOE	Continuous
Compression	
MOR	Continuous
MOE	Continuous

Objectives

Sweetgum cannot be efficientlv utilized and marketed for structural purposes until the various mechanical properties of full-sized lumber and the relationship of these properties are understood. The objectives of this study were to determine: 1) the bending, tensile, and compressive strength and MOE in bending for sweetgum and yellow-poplar structural lumber; and 2) the correlation coefficients between MOE and tensile and bending strength for sweetgum and yellow-poplar structural lumber.

Materials and procedures

The study consisted of an analysis of covariance for a completely randomized design defined as a 2 × 2 × 3 factorial with one covariate. The 12 factorial treatment combinations, formed from 2 species, 2 widths, and 3 defect classes, were adjusted with specific gravity (SG) as a covariate. Table 1 summarizes the design.

Yellow-poplar and sweetgum timber were selected randomly, representing average woods-run material from one location in North Carolina Piedmont hardwood stands. The structural lumber was cut at a modern hardwood sawmill in the same area. The logs were cut into pith-centered nominal 8-inch square cants 12 feet long. The hardwood cants were then broken down on a resaw in the same way that pine cants would be processed. Figure 1 illustrates the breakdown pattern. The 2 by 8's were cut first, followed by the 2 by 4's, to facilitate sorting and stacking. The hardwood 2 by 4's and 2 by 8's were graded by defect and warp grades according to Southern Pine Inspection Bureau rules by a certified lumber grader (12). The rough-sawn hardwood structural lumber (approximately 22 thousand board feet (MBF)) was then shipped to a mill in South Carolina for kiln-drying.

The yellow-poplar and sweetgum structural lumber was dried on an 8/4 redgum (trade name for sweetgum heartwood) schedule. The final moisture content (MC) was targeted to be 12 to 15 percent. However, the yellow-poplar lumber was overdried because it was dried in the same kiln charge with the sweetgum. Both the yellow-poplar and the sweetgum came out of the kiln at an MC less than

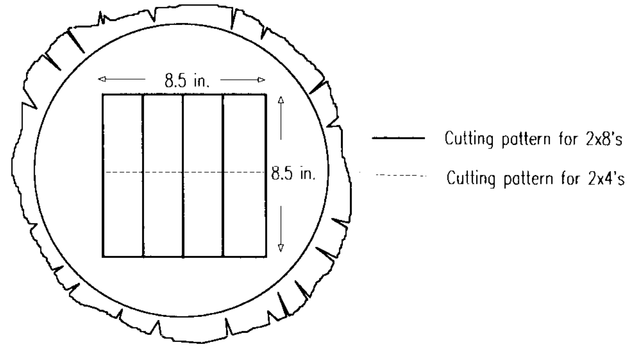

Figure 1. — Diagram of log breakdown for producing sweetgum and yellow-poplar structural lumber.

12 percent. MC measured by moisture meter showed a range of 7 to 12 percent and an average of 9 percent. However, MC by the ovendry method showed the yellow-poplar averaged about 6 to 7 percent MC with end trim measuring as low as 4.5 percent. The sweetgum lumber averaged around 11 percent MC with end trim as low as 7 percent MC. No stress relief nor equalization of the lumber were performed due to scheduling problems. The grading marks were transferred from the face of the individual pieces to the end of the pieces just prior to planing. The top left corner of the specimen on the grading chain remained the top left corner for all subsequent test procedures.

The material was then dressed on the faces and edges to 1.5 by 3.5 inches for the nominal 2 by 4's and 1.5 by 7.25 inches for the nominal 2 by 8's. Some problems related to overdrying and shrinkage were noted at this stage. Some of the sweetgum 2 by 8's tended to be slightly less than 7.25 inches wide and less than 1.5 inches thick. Thus, the sweetgum showed some skip after dressing. This is not surprising because sweetgum has a volumetric shrinkage of up to 15 percent, while yellow-poplar has a volumetric shrinkage of about 12.5 percent, the same as loblolly pine (13). Greater allowances for green dimensions should be made for sweetgum to avoid skip. The yellow-poplar 2 by 8's were slightly cupped and brittle due to their lower MC. Pressures from planer feed rolls caused many of the yellow-poplar 2 by 8's to split due to the low MC and the fact that many boards were pith-centered. The lumber was regraded for warp, crook, and splits immediately after planing.

The dressed hardwood structural lumber was processed through a Metriguard Model 7100 Continuous Lumber Tester (CLT) to obtain an average plank bending MOE value. The CLT used in this study has been certified by an independent testing agency to accurately grade MSR lumber. The CLT was calibrated immediately prior to use with a standard aluminum calibration bar. The data were collected using a computer-based data acquisition system. A custom-developed software program scanned the load transducers every 0.3 milliseconds (22 data points per lineal inch) and recorded 5 stiffness parameters. The average MOE of each board was also displayed on the control panel of the CLT and was manually recorded.

The hardwood structural lumber was shipped to Athens, Ga., for laboratory testing. The tension tests were run first, followed by the static bending and compression tests. Photographs of each board, front and back, were taken before the destructive test procedure to record visual lumber defects.

The tensile strength tests were conducted according to the provisions of ASTM D 198 (1) run on a Metriguard Model 412 Tension Tester with a capacity of 100,000 pounds. The tensile load was applied at a rate such that the average time to failure was approximately 10 minutes. The test span between the grips was constant at 96 inches. Specimen elongation was measured with a linear variable differential transformer (LVDT) over a gauge length of 86 inches. Tensile load was measured with an electronic load cell incorporated in one of the gripping heads. Tensile load and elongation were recorded at l-second intervals using the computer-based data acquisition system. The test machine and the computer-based data acquisition system were calibrated at least twice a month. Two MC/SG specimens were cut from each specimen immediately after failure.

The static bending tests were conducted using a BLH-120 (120,000-lb. capacity) universal test machine and were conducted according to the provisions of ASTM D 198 (2). The test span was set at 138 inches with the load applied at third points. Load and deflection data were recorded at l-second intervals during the test using the computer-based data acquisition system. The loading rate was adjusted so that the average time to failure was approximately 10 minutes. An MC/SG specimen was cut from each specimen immediately after failure.

A clear, straight-grained, compression parallel-to-grain test specimen, 9 inches long, was cut from an undamaged end of each static bending specimen and was tested according to the general provisions of ASTM D 143 (2). The standard length for compression specimens is 8 inches. However, the particular LVDT used in this study required the extra length for clearance. No buckling failures were noted. The compression specimens were tested on the BLH-120 universal test machine. The deflections were determined over a gauge length of 6 inches with an LVDT mounted in a compressometer. Measurements of load and deflection transducers were taken each second during the test. The loading rate was adjusted so that the average time to failure was approximately 10 minutes. Each specimen was measured for MC and SG following specimen failure.

Results and discussion

The strength and stiffness testing was accomplished over a 6-month period. There were no facilities for storing the specimens under controlled temperature and relative humidity conditions prior to testing. The MC of each specimen at time of test was determined from a sample wafer by the ovendry method.

The computer-based automatic data collection hardware and software permitted accurate and unbiased testing of all specimens. The only problem noted was with the compression parallel-to-grain test data. The compressometer for measuring compressive strain over a 6-inch gauge length was designed for the standard specimen size of 2 by 2 by 8 inches, as specified in ASTM D 143-78 (2). The compression specimens used in this study (1.5 by 7.25 by 9 in.) did not always deform evenly across their width. In retrospect, a second compressometer should have been installed on the other edge of the nominal 2- by 9-inch specimens and the readings averaged. This system of two compressometers will be incorporated in any future compression tests of wide specimens. Detailed analysis of grading data, plank bending, and MSR data will be presented in subsequent reports.

The data for the laboratory tests were analyzed using the SAS statistical package (10) on a personal computer. Calculation of MOE and modulus of rupture (MOR) from the raw test data was done using Lotus 1-2-3 (version 2.01) and a custom-written macro program that displayed stress/strain diagrams and chose data used in the MOE calculations.

Summary statistics of bending, tensile, and compressive strength and stiffness values by species and specimen width are presented in Table 2. The sweetgum specimens (grade and MC not considered) were consistently higher than the yellow-poplar specimens in strength and stiffness. Note that the ratio between tensile and compressive strength and stiffness is slightly lower for sweetgum than for yellow-poplar. This indicates that the mode of failure in bending between the two species may be slightly different (4). This difference may be due to the interlocked grain found in sweetgum.

Analysis of study variables

An analysis of covariance was performed using PROC GLM to assess the effects of species, width, and defect and their interactions on the strength and stiffness properties after adjusting for the covariate of SG. MC was accounted for in the analysis by adjusting the strength and stiffness values to a constant 12 percent using the procedures and factors outlined in ASTM D 2915-84 (3).

The analysis of three-way factorial experiments is often complex when interactions are present. Therefore, the philosophy used in this study needs to be explained. The simplest situation is when interactions are nonsignificant but one or more of the main effects are significant. Here, each significant factor was analyzed separately by all possible pairwise comparisons on the factor level means to determine which were significantly different. However, when interactions were present, the effects of these factors could not be analyzed separately because, by definition of interaction, the effect of a level of one factor depends on the level of the other. Thus, all pairwise comparisons were performed on the treatment means formed by all combinations of the interacting factors.

Because the analysis was unbalanced (unequal replication) and utilized a covariant (SG), least squares means (LSMEANS) were used for pairwise comparisons when the typical F-tests on main effects and/or interactions were significant. LSMEANS are desirable in this situation because they are estimators of the means that would be expected had the design been balanced and with all covariates at their mean value. In addition, the use of the Bonferroni approach (10) for all pairwise comparisons was used to ensure a maximum experimentwise error rate of 0.05. This was accomplished by using a smaller error rate for individual comparisons defined as "0.05 / *s*" where *s* is the number of pairwise comparisons within a partic-

TABLE 2. – *Average stiffness and strength for hardwood structural lumber.*

	No. of specimens	SG[a]	MC[b]	Bending MOR Average	Bending MOR SD[c]	Bending MOE Average	Bending MOE SD
			(%)	(psi)		(psi × 10^6)	
Sweetgum							
2 by 4	138	0.591	9.03	6,551	2,468	1.76	0.31
2 by 8	137	0.565	10.08	5,851	1,832	1.61	0.52
Combined	275	0.578	9.55	6,202	2,210	1.69	0.43
Yellow-poplar							
2 by 4	142	0.431	7.55	6,963	2,467	1.66	0.24
2 by 8	105	0.438	8.49	4,784	2,258	1.53	0.59
Combined	247	0.434	7.94	6,028	2,613	1.60	0.43
Species combined	522	0.510	8.79	6,120	2,409	1.65	0.43
				Average	SD	Tensile MOE Average	Tensile MOE SD
				(psi)		(psi × 10^6)	
Sweetgum							
2 by 4	105	0.591	9.02	4,664	2,636	1.76	0.51
2 by 8	107	0.565	10.89	4,158	1,760	1.62	0.28
Combined	212	0.578	9.95	4,409	2,246	1.69	0.42
Yellow-poplar							
2 by 4	139	0.435	6.90	4,818	2,467	1.64	0.27
2 by 8	101	0.435	6.55	3,214	1,810	1.54	0.36
Combined	240	0.435	6.75	4,143	2,348	1.60	0.31
Species combined	452	0.501	8.25	4,268	2,302	1.64	0.37
				Compressive strength Average	Compressive strength SD	Compressive MOE Average	Compressive MOE SD
				(psi)		(psi × 10^6)	
Sweetgum							
2 by 4	133	0.591	8.87	7,096	946	1.86	0.49
2 by 8	120	0.582	9.34	7,056	940	2.39	1.02
Combined	253	0.587	9.10	7,075	940	2.11	0.83
Yellow-poplar							
2 by 4	136	0.452	8.41	5,577	944	1.74	0.46
2 by 8	105	0.442	9.03	6,146	739	1.94	0.60
Combined	241	0.448	8.68	5,825	904	1.83	0.53
Species combined	494	0.519	8.89	6,465	914	1.97	0.71

	Tensile/compressive ratio Strength	Tensile/compressive ratio Stiffness
Sweetgum	0.62	0.80
Yellow-poplar	0.71	0.87

[a]SG measured on green volume basis at percent MC indicated.
[b]MC at time of test.
[c]SD = standard deviation.

TABLE 3. — *Significance probabilitiss for study variables and interactions.* [a]

Source	DF[b]	Static bending MOR Pr > F	Static bending MOE Pr > F	Tension MOR Pr > F	Tension MOE Pr > F	Compression MOR Pr > F	Compression MOE Pr > F
Species	1	0.6571	0.2438	0.0825	0.4402	0.0011**	0.6693
Width	1	0.0001**[c]	0.0001**	0.0001**	0.0756	0.0002**	0.0001**
Defect	2	0.0001**	0.0001**	0.0001**	0.0001**	0.0005**	0.0613
Species × Width	1	0.0060**	0.6883	0.1327	0.7857	0.0001**	0.0903
Species × Defect	2	0.6567	0.3577	0.0725	0.6146	0.0099**	0.1706
Width × Defect	2	0.5420	0.7094	0.3413	0.4879	0.4831	0.1892
Species × Defect × Width	2	0.1738	0.9950	0.5797	0.5888	0.8859	0.5086
SG	1	0.0132*	0.0001**	0.0908	0.0001**	0.0001**	0.0054**

[a]Properties are adjusted values to 12 percent MC per ASTM D 2915-84. Probabilities (Pr) are for type III sums of squares.
[b]DF = degrees of freedom.
[c]* = significant at the 0.05 level; ** = significant at the 0.01 level.

ular experiment. Obviously, fewer individual pairwise comparisons will be judged significant, but the probability of making an error for all the comparisons together will be controlled at 0.05. This gives protection against finding significance that don't really exist but appear significant because numerous "a posteriori" tests were performed. Static bending, tension, and compression tests were considered separately. The significance probabilities from the analysis are shown in Table 3. Results for each test will be discussed separately.

Static bending (edgewise)

The analysis of static bending (edgewise) MOR revealed statistically significant effects for width, defect grade, and SG with a significant species × width interaction. Due to this interaction, the main effect of width is difficult to analyze separately. Therefore, pairwise comparisons were performed on the four treatment LSMEANS (Table 4). The results show that 2 by 4's are significantly stronger than 2 by 8's, regardless of species. Sweetgum 2 by 8's are significantly stronger than yellow-poplar 2 by 8's, while yellow-poplar 2 by 4's are stronger than sweetgum 2 by 4's. The effect of defect was assessed by performing pairwise comparisons of the factor level LSMEANS and showed that all grades were significantly different with a logical downward progression from Grade 1 to Grade 3.

Static bending MOE showed statistically significant effects due to width, defect grade, and SG (Table 3). The pairwise comparison of LSMEANS (Table 4) showed that the 2 by 4's were significantly stiffer than the 2 by 8's. The pairwise comparisons for defect show a logical downward progression from Grade 1 to Grade 3. However, Grade 2 was not significantly stiffer than Grade 3. These results are consistent, in a relative sense, with the published allowable design values for yellow-poplar (9,10).

TABLE 4.– *Static bending pairwise comparisons at the 0.05 experimentwise error rate. Values adjusted to 12 percent MC.*[a]

	Bending MOR (strength)						
			Pair-wise comparisons[b]				
Species × Width	LSMEAN	SE		1	2	3	4
Sweetgum (2 by 4)	5,938	238	1	.	*		*
Sweetgum (2 by 8)	5,217	230	2	.	.	*	
Yellow-poplar (2 by 4)	6,340	235	3	.	.	.	*
Yellow-poplar (2 by 8)	4,507	276	4	.	.	.	.
			Pairwise comparisons[c]				
Defect grade	LSMEAN	SE		1	2	3	
1	6,470	160	1	.	*	*	
2	5,442	131	2	.	.	*	
3	4,589	219	3	.	.	.	
	Bending MOE (stiffness)						
			Pair-wise comparisons[d]				
Width	LSMEAN	SE		1	2		
2 by 4	1,610,000	19,300	1	.	*		
2 by 8	1,450,000	22,800	2	.	.		
			Pairwise comparisons[c]				
Defect grade	LSMEAN	SE		1	2	3	
1	1,620,000	24,800	1	.	*	*	
2	1,520,000	19,500	2	.	.		
3	1,450,000	32,629	3	.	.	.	

[a]* = significant pairwise comparisons; blank space = nonsignificant differences; . = redundant or no pairwise comparison.
[b]Alpha = 0.05/6 = 0.00833 for each individual comparison.
[c]Alpha = 0.05/3 = 0.0167 for each individual comparison.
[d]Alpha = 0.05/1 = 0.05 for each individual comparison.

Tension

The analysis of tensile strength showed significant effects for width and defect grade. Pairwise comparisons for tensile strength (Table 5) show that 2 by 4's are stronger in tension than 2 by 8's. There is a logical downward progression in tensile strength from Grade 1 to Grade 3.

Tensile MOE showed significant effects for defect grade and SG. Table 5 shows the logical downward progression of tensile MOE from Grade 1 to Grade 3. Grade 3 is not significantly lower in MOE than Grade 2. This was also the case for static bending MOE.

Compression

The analysis of compressive strength revealed extremely complex relationships. Species, width, defect grade, and SG were statistically significant main effects. The species × width and species × defect interactions were also significant. Because there were 2 significant interactions, pairwise comparisons were performed on all 12 treatment LSMEANS (Table 6). Yellow-poplar 2 by 4's were significantly lower in compressive strength than sweetgum 2 by 4's for grades 1 and 2 only. However, there was no significant difference in compressive strength for the 2 by 8's of the two species. Sweetgum showed a downward progression in strength from Grade 1 to Grade 3, although few of the differences were statistically significant. Yellow-poplar showed very little difference in compressive strength due to defect grade. This is not surprising because the compression specimens were essentially defect free.

For compressive MOE, only width and SG showed significant effects. The pairwise comparison (Table 6) shows that 2 by 4's have significantly lower compressive MOE than 2 by 8's.

Strength and stiffness relationships

The study objective of determining the relationship between MOE and strength was addressed by calculating the correlation coefficients, r, for the various measures

TABLE 5.– *Tension pairwise comparisons at the 0.05 experimentwise error rate. Values adjusted to 12 percent MC.*[a]

	Tensile MOR (strength)					
			Pair-wise comparisons[b]			
Width	LSMEAN	SE		1	2	
2 by 4	4,205	142	1	.	*	
2 by 8	3,224	154	2	.	.	
			Pairwise comparisons[c]			
Defect	LSMEAN	SE		1	2	3
1	4,439	165	1	.	*	*
2	3,682	157	2	.	.	*
3	2,795	214	3	.	.	.
	Tensile MOE (stiffness)					
			Pairwise comparisons[c]			
Defect	LSMEAN	SE		1	2	3
1	1,610,000	26,900	1	.	*	*
2	1,500,000	25,600	2	.	.	
3	1,410,000	34,900	3	.	.	.

[a]* = significant pairwise comparisons; blank space = nonsignificant differences; . = redundant or no pairwise comparison.
[b]Alpha = 0.05/1 = 0.05 for each individual comparison.
[c]Alpha = 0.05/3 = 0.01667 for each individual comparison.

TABLE 6.– *Compression pairwise comparisons at the 0.05 experimentwise error rate. Values adjusted to 12 percent MC.*[a]

		Compressive MOR (strength)														
					Pairwise comparisons[b]											
Species	Defect	LSMEAN	SE		1	2	3	4	5	6	7	8	9	10	11	12
Sweetgum (2 by 4)	1	6,191	172	1	.						*	*	*			
Sweetgum (2 by 4)	2	5,871	115	2	.	.					*	*				
Sweetgum (2 by 4)	3	5,604	119	3	.	.	.	*								
Sweetgum (2 by 8)	1	6,329	147	4	.	.	.	.		*	*	*	*			
Sweetgum (2 by 8)	2	5,820	101	5	.	.	.	.	.		*	*				
Sweetgum (2 by 8)	3	5,484	175	6	.	.	.	.	.	.						
Yellow-poplar (2 by 4)	1	5,124	102	7	.	.	.	.	.	.	.			*	*	
Yellow-poplar (2 by 4)	2	5,159	114	8	.	.	.	.	.	.	.	.		*	*	
Yellow-poplar (2 by 4)	3	5,146	187	9	.	.	.	.	.	.	.	.	.	*		
Yellow-poplar (2 by 8)	1	5,676	117	10	.	.	.	.	.	.	.	.	.	.		
Yellow-poplar (2 by 8)	2	5,737	129	11	.	.	.	.	.	.	.	.	.	.	.	
Yellow-poplar (2 by 8)	3	5,680	236	12	.	.	.	.	.	.	.	.	.	.	.	.

	Compressive MOE (stiffness)				
				Pairwise comparisons[c]	
Width	LSMEAN	SE		1	2
2 by 4	1,700,000	43,500	1	.	*
2 by 8	2,050,000	49,800	2	.	.

[a]* = significant pairwise comparisons; blank space = nonsignificant differences; = redundant or no pairwise comparison.
[b]Alpha = 0.05/66 = 0.00076 for each individual comparison.
[c]Alpha = 0.05/1 = 0.05 for each individual comparison.

TABLE 7. – *Relationship between strength and stiffness properties* for *hardwood structural lumber.*

	CLT-MOE	Bending MOR_{12}[a]	Bending MOE_{12}	Bending MOE	Tension MOR_{12}	Tension MOE_{12}	Tension MOE
Sweetgum correlation matrix, values of *r*.							
CLT-MOE	1	.434	.737	.752	.450	.583	.614
Bending MOR_{12}		1	.489	.487	- -[b]	--	--
Bending MOE_{12}			1	.991	--	--	--
Bending MOE				1	--	--	--
Tension MOR_{12}					1	.463	.459
Tension MOE_{12}						1	.985
Tension MOE							1
Yellow-poplar correlation matrix, values of *r*.							
CLT-MOE	1	.428	.517	.526	.376	.653	.650
Bending MOR_{12}		1	.490	.497	--	--	--
Bending MOE_{12}			1	.998	--	--	--
Bending MOE				1	--	--	--
Tension MOR_{12}					1	.500	.484
Tension MOE_{12}						1	.998
Tension MOE							1
Combined species correlation matrix, values of *r*.							
CLT-MOE	1	.434	.613	.625	.418	.615	.630
Bending MOR_{12}		1	.494	.497	--	--	--
Bending MOE_{12}			1	.993	--	--	--
Bending MOE				1	--	--	- -
Tension MOR_{12}					1	.486	.479
Tension MOE_{12}						1	.965
Tension MOE							1

[a]Properties with subscript 12 are adjusted values to 12 percent MC per ASTM D 2915-84.
[b]No correlation data.

of stiffness (MOE) and specimen strength (MOR). The strength values used in the correlation analysis were those adjusted to 12 percent MC. The results are shown in Table 7. The *r* values for stiffness/strength relationships are between 0.500 and 0.737. The correlations between the CLT-MOE[1], static bending, and tensile MOE indicate that some relationship exists between these measures of MOE. The values seem low. However, different orientations are being measured with the CLT and the static tests.

[1]Average MOE calculated by the E computer of the Metriguard 7100 CLT.

The relationship between the CLT/MOE and the static bending MOE are shown graphically for yellow-poplar (Fig. 2) and sweetgum (Fig. 3).

Summary and conclusions

The primary objective of this study was to define strength and stiffness characteristics of sweetgum in the form of structural lumber. Strength properties of yellow-poplar structural lumber have already been investigated and therefore were included as a study control. Properties of tension, compression, and bending (edgewise and plank) were measured in laboratory tests on sweetgum and yellow-poplar 2 by 4's and 2 by 8's 12 feet long. In all, about 1,200 pieces of lumber were tested. In addition,

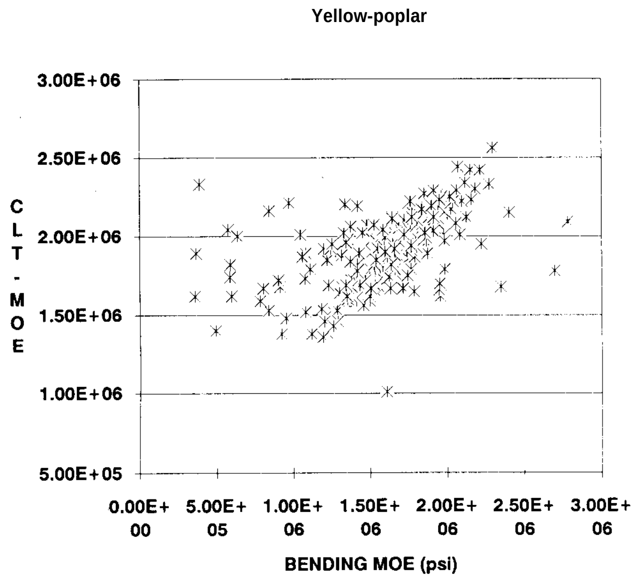

Figure 2. — Scatter diagram of CLT measure of MOE and static bending MOE for yellow-poplar.

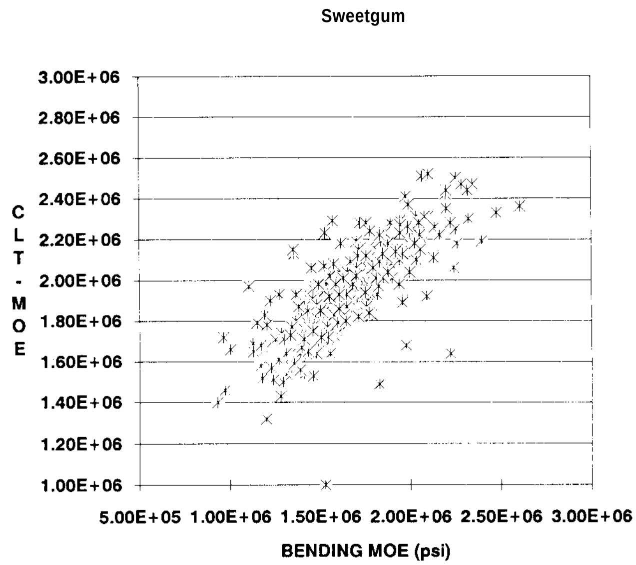

Figure 3. — Scatter diagram of CLT measure of MOE and static bending MOE for sweetgum.

about 1,600 pieces of lumber were graded for defects and warp (before and after drying). All lumber was machine stress rated using a CLT to evaluate plank bending stiffness under production conditions.

The conclusions from the analysis of results maybe summarized as follows:

1. Sweetgum structural lumber appears to be as strong and stiff as yellow-poplar structural lumber overall and on a grade-by-grade basis. There appears to be no reason why sweetgum structural lumber could not be used in general construction once allowable design stresses have been determined.

2. Correlations between average MOE and bending, tensile, or compressive strength were low. This may be a result of the more complex structure of the hardwood material.

3. National grading rules do not always indicate the relative strength or stiffness of sweetgum. A modified set of grading rules may need to be developed for sweetgum to account for the characteristic interlocked grain pattern.

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