POTENTIAL UTILIZATION OF SWEETGUM AND YELLOW-POPLAR FOR 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 incentive 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

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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.

INTRODUCTION

The forest resource base in the Southeast is rapidly changing. It has been projected that plantation grown pine, which now provides about twenty percent of the softwood resource, will provide over fifty percent of the softwood by the year 2000 (USDA, 1988). Plantation grown pine has a high percentage of juvenile wood which lowers its utility for such traditional uses as structural lumber and plywood. Projections (USDA, 1977) indicate that the demand for pine timber will exceed the available supply, resulting in rising prices for pine and incentive for the use of low-density hardwood species such as yellow-poplar (Liriodendron tulipifera, L.) and sweetgum (Liquidambar styraciflua, L.) . Yellow-poplar structural lumber has been accepted by the American Lumber Standards Committee and the design values are published by National Forest Products Association (NFPA, 1982).

The growth of the 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 (Southern Pine Inspection Bureau, 1977; Softwood Inspection Bureau, 1982) . 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 towards the 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 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 (Galligan et al, 1980; Green, 1983; Green et al, 1984; Evans et al, 1984), there has been little comparable research on these relationships for hardwoods. Since the habit of growth for the low density hardwoods is so different from pine with regard to persistence of branches, size of knots, interlocked and spiral grain etc., it is unlikely that these relationships would be the same for hardwoods.

OBJECTIVES

Sweetgum cannot be efficiently utilized and marketed for structural purposes until the various mechanical properties of full-sized lumber and the relationship of these properties is understood. The objectives of this study were to determine:

1. bending, tensile and compressive strength and modulus of elasticity in bending for sweetgum and yellow-poplar structural lumber.

2. the correlation coefficients between modulus of elasticity 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 x 2 x 3 factorial with one covariate. The twelve factorial treatment combinations, formed from two species, two widths and three defect classes, were adjusted with specific gravity 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 2x8's were cut first, followed by the 2x4's to facilitate sorting and stacking. The hardwood 2x4's and 2x8's were graded by defect and warp grades according to the National grading rule (SPIB, 1977) by a certified lumber grader. The rough-sawn hardwood structural lumber (approximately 22 MBF) was then shipped to a mill in South Carolina for kiln-drying.

The yellow-poplar and sweetgum structural lumber was dried on a 8/4 redgum (trade name for sweetgum heartwood) schedule. The final moisture content (MC) was targeted to be 12% to 15%. However, the yellow-poplar lumber was over-dried since it was dried in the same kiln charge with the sweetgum. Both the yellow-poplar and the sweetgum came out of the kiln at a moisture content less than 12%. Moisture content as measured by moisture meter showed a range of 7% to 12% and an average of 9%. However, moisture content by the ovendry method showed that the yellow-poplar averaged about 6% to 7% MC with end trim measuring as low as 4.5%. The sweetgum lumber averaged around 11% MC with end trim as low as 7% MC. No stress relief or equalization of the lumber was performed due to scheduling problems. The grading marks were transferred from the face of the individual pieces to the end of

Table 1
Summary of Study Variables

Independent Variables	Levels
Species	Yellow-poplar Sweetgum
Size	nominal 2x4's x 12 ft nominal 2x8's x 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

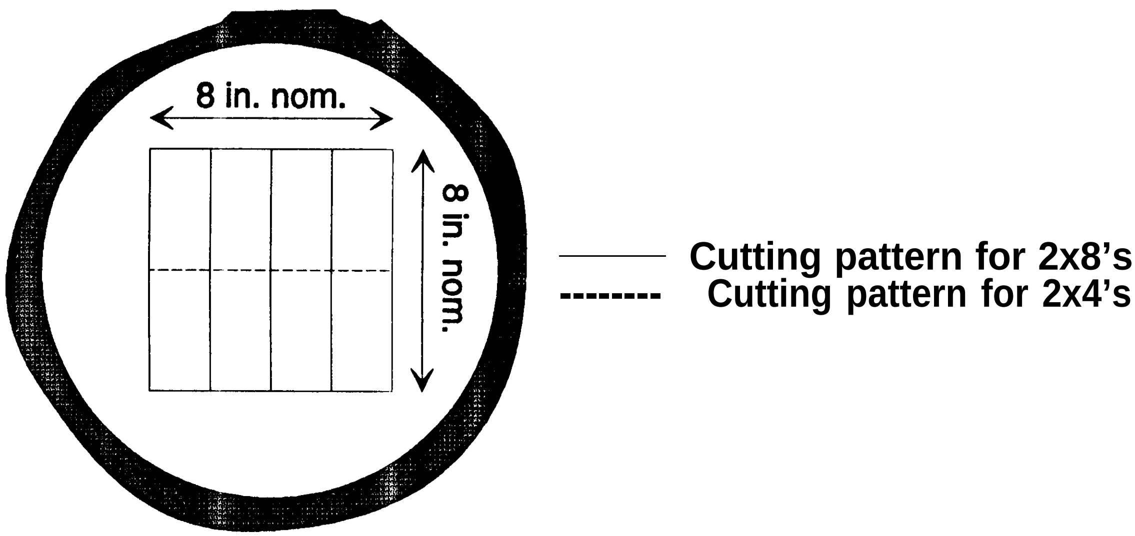

Figure 1: Diagram of log breakdown for producing sweetgum and poplar structural lumber.

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 x 3.5 inches for the nominal 2x4's and 1.5 x 7.25 inches for the nominal 2x8's. Some problems related to over-drying and shrinkage were noted at this stage. Some of the sweetgum 2x8'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 since 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 (USDA, 1974). Greater allowances for green dimensions should be made for sweetgum to avoid skip. The yellow-poplar 2x8's were slightly cupped and brittle due to their lower moisture content. Pressures from planer feed rolls caused many of the 2x8 yellow-poplar to split due to the low moisture content 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 modulus of elasticity value. The CLT used in this study has been certified to grade MSR lumber by an independent testing agency. The CLT was calibrated immediately prior to use with a standard aluminum calibration bar. The data was 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, Georgia for laboratory testing. The tension tests were run first, followed by the static bending and the 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 (ASTM, 1980a) 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 an LVDT (linear variable differential transformer) over a gauge length of 86 inches. Tensile load was measured with an electronic load cell incorporated in one of the gripping heads. The tensile load and elongation were recorded at one second intervals using the computer-based data acquisition system. The test machine and the computer-based data acquisition system were calibrated at least twice per month. Two moisture content/specific gravity specimens were cut from each specimen immediately after failure.

The static bending tests were conducted using a BLH-120 (120,000 pound capacity) universal test machine and were conducted according to the provisions of ASTM D-198 (ASTM, 1980b). The test span was set at 138 inches with the load applied at third points. Load and deflection data were recorded at one 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. A moisture content/specific gravity specimen was cut from each specimen immediately after failure.

A clear, straight-grained compression parallel to the grain test specimen, 9 inches long, was cut from an undamaged end of each static bending specimen and were tested according to the general provisions of ASTM D-143 (ASTM, 1980b). 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 once per 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 moisture content and specific gravity following specimen failure.

RESULTS AND DISCUSSION

The strength and stiffness testing was accomplished over a six month period. There were no facilities for storing the specimens under controlled temperature and relative humidity conditions prior to testing. The moisture content 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 allowed for 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 six inch gauge length was designed for the standard 2 by 2 by 8 inch specimens specified in ASTM D-143-78 (2). The 1.5 by 7.25 by 9 inch compression specimens in this study 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 was analyzed using the SAS statistical package (12) on a PC. Calculation of MOE and MOR from the raw test data was done using Lotus 1-2-3 Ver. 2.01 and a custom-written macro program to display stress/strain diagrams and choose 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 moisture content 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 (Buchannan, in press ASCE Journal). 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 specific gravity. Moisture content 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 (4).

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 non-significant 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 since, 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.

Since the analysis was unbalanced (unequal replication) and utilized a covariant (specific gravity), least squares means (LSMEANS) was used for pairwise comparisons when the typical F-tests on main effects and/or interactions were significant. LSMEANS are desirable in this situation since 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 (12) for all pairwise comparisons was used to ensure a maximum experimentwise error rate of 0.05. This is 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 particular 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 which don't really exist but appear significant since numerous "a posterior" 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.

Table 2
Average Stiffness and Strength for Hardwood Structural Lumber

	n	SpGr[1]	MC%[2]	Bending MOR Average (psi)	Bending MOR Std.Dev.	Bending MOE Average (million psi)	Bending MOE Std.Dev.
Sweetgum							
2x4's	138	0.591	9.03	6,551	2,488	1.76	0.31
2x8's	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							
2x4's	142	0.431	7.55	6,963	2,467	1.66	0.24
2x8's	105	0.438	8.49	4,764	2,258	1.53	0.59
Combined	247	0.434	7.94	6,028	2,613	1.60	0.43
Species Cabined	522	0.510	8.79	6,120	2,409	1.65	0.43

	n	SpGr[1]	MC%[2]	Tensile Strength Average (psi)	Tensile Strength Std.Dev.	Tensile MOE Average (million psi)	Tensile MOE Std.Dev.
Sweetgum							
2x4's	105	0.591	9.02	4,664	2,636	1.76	0.51
2x8's	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							
2x4's	139	0.435	6.90	4,818	2,467	1.64	0.27
2x8's	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

	n	SpGr[1]	MC%[2]	Compressive Strength Average (psi)	Compressive Strength Std.Dev.	Compressive MOE Average (million psi)	Compressive MOE Std.Dev.
Sweetgum							
2x4's	133	0.591	8.87	7,096	946	1.86	0.49
2x8's	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							
2x4's	136	0.452	8.41	5,577	944	1.74	0.46
2x8's	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	Stiffness
Sweetgum	0.62	0.80
Yellow-poplar	0.71	0.87

1 Specific gravity measured on green volume basis at MC% indicated.

2 Moisture content at time of test.

Table 3
Significance probabilities for study variables and interactions.[1]
(Probabilities are for Type III Sums of Squares)

Source	DF	Static Bending MOR Pr > F[2]		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	**	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	
SPEC*DEF*WIDTH	2	0.1738		0.9950		0.5797		0.5888		0.9959		0.5086	
SpGr	1	0.0132	*	0.0001	**	0.0908		0.0001	**	0.0001	**	0.0054	**

1 Properties are adjusted values to 12% moisture content per ASTM D2915-84.

2 An "*" denotes significance at the 0.05 level while "**" denotes significance at the 0.01 level.

Static Bending (edgewise)

The analysis of static bending (edgewise) MOR revealed statistically significant effects for width, defect grade and specific gravity with a significant species x 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 4a.). The results show that yellow poplar 2x4's are significantly stronger than yellow-poplar 2x8's. The sweetgum 2x4's are significantly stronger than the sweetgum and yellow-poplar 2x8'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 significantly effects due to width, defect grade and specific gravity. The pairwise comparison of LSMEANS (Table 4a.) showed that the 2x4's were significantly stiffer than the 2x8'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 (11, 12).

Tension

The analysis of tensile strength showed significant effects for width and defect grade. Pairwise comparisons for tensile strength (Table 4b.) show that 2x4's are stronger in tension than 2x8'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 specific gravity. Table 4b. 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 specific gravity were statistically significant main effects. The species x width and species x defect interactions were also significant. Since there were two significant interactions, pairwise comparisons were performed on all 12 treatment LSMEANS (Table 4c.). Yellow- poplar 2x4's were significantly lower in compressive strength than sweetgum 2x4's for grades 1 and 2 only. However, there was no significant difference in compressive strength for the 2x8'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

Table 4a

Static bending pairwise comparisons at the 0.05 experimentwise error rate[1]

(values adjusted to 12% moisture content).

Bending MOR (Strength)

SPECIES X WIDTH		LSMEAN	S.E.	Pairwise Comparisons[2]	1	2	3	4
Sweetgum	2x4	5,938	238	1	.	*	*	
Sweetgum	2x8	5,217	230	2	.	.	*	
Yellow-poplar	2x4	6,340	235	3	.	.	.	*
Yellow-poplar	2x8	4,507	276	4	.	.	.	.

DEFECT GRADE	LSMEAN	S.E.	Pairwise Comparisons[3]	1	2	3
1	6,470	160	1	.	*	*
2	5,442	131	2	.	.	*
3	4,589	219	3	.	.	.

Bending MOE (Stiffness)

WIDTH	LSMEAN	S.E.	Pairwise Comparisons[4]	1	2
2x4	1,610,000	19,300	1	.	*
2x8	1,450,000	22,800	2	.	.

DEFECT GRADE	LSMEAN	S.E.	Pairwise Comparisons[5]	1	2	3
1	1,620,000	24,800	1	.	*	*
2	1,520,000	19,500	2		.	
3	1,450,000	14,500	3			.

1 Significant pairwise comparisons are denoted by "*" in the table while nonsignificant differences are represented with a blank. A "." denotes a redundant or no pairwise comparison at that entry.

2 Alpha = 0.05/6= 0.00833 for each individual comparison.

3 Alpha = 0.05/3 = 0.0167 for each individual comparison.

4 Alpha = 0.05/1 = 0.05 for each individual comparison.

5 Alpha = 0.05/3 = 0.0167 for each individual comparison.

Table 4b
Tension pairwise comparisons at the 0.05 experimentwise error rate[1] (values adjusted to 12% moisture content).

Tensile MOR (Strength)

WIDTH	LSMEAN	S.E.	Pairwise[2]	1	2
2x4	4,205	142	1	.	*
2x8	3,224	154	2		.

DEFECT	LSMEAN	S.E.	Pairwise[3]	1	2	3
1	4,439	165	1	.	*	*
2	3,682	157	2		.	*
3	2,795	214	3			.

Tensile MOE (Stiffness)

DEFECT	LSMEAN	S.E.	Pairwise[4]	1	2	3
1	1,610,000	26,900	1	.	*	*
2	1,500,000	25,600	2		.	
3	1,410,000	34,900	3			.

1 Significant pairwise comparisons are denoted by "*" in the table while nonsignificant differences are represented with a blank. A "." denotes a redundant or no pairwise comparison at that entry.

2 Alpha = 0.05/1 = 0.05 for each individual comparison.

3 Alpha = 0.05/3 = 0.01667 for each individual comparison.

4 Alpha = 0.05/3 = 0.01667 for each individual comparison.

Table 4c
Compression pairwise comparisons at the 0.05 experimentwise error rate[1] (values adjusted to 12% moisture content).

Compressive MOR (Strength)

SPECIES	WIDTH	DEFECT	LSMEAN	S.E.	Pairwise Comparisons[2]												
						1	2	3	4	5	6	7	8	9	10	11	12
Sweetgum	2x4	1	6,191	172	1	.						*	*	*			
Sweetgum	2x4	2	5,871	115	2	.	.					*	*				
Sweetgum	2x4	3	5,604	119	3	.	.	.	*								
Sweetgum	2x8	1	6,329	147	4	.	.	.	.		*	*	*	*			
Sweetgum	2x8	2	5,820	101	5	.	.	.	.	.		*	*				
Sweetgum	2x8	3	5,484	175	6	.	.	.	.	.	.						
Yellow-poplar	2x4	1	5,124	102	7	.	.	.	.	.	.	.			*	*	
Yellow-poplar	2x4	2	5,159	114	8	.	.	.	.	.	.	.	.		*	*	
Yellow-poplar	2x4	3	5,146	187	9	.	.	.	.	.	.	.	.	.	*		
Yellow-poplar	2x8	1	5,876	117	10	.	.	.	.	.	.	.	.	.	.		
Yellow-poplar	2x8	2	5,737	129	11	.	.	.	.	.	.	.	.	.	.	.	
Yellow-poplar	2x8	3	5,680	236	12	.	.	.	.	.	.	.	.	.	.	.	.

Compressive MOE (Stiffness)

WIDTH	LSMEAN	S.E.	Pairwise Comparisons[3]		
				1	2
2x4	1,700,000	43,500	1	.	*
2x8	2,050,000	49,800	2		.

1 Significant pairwise comparisons are denoted by “*” in the table while nonsignificant differences are represented with a blank. A “.” denotes a redundant or no pairwise comparison at that entry.

2 Alpha = 0.05/66 = 0.00076 for each individual comparison.

3 Alpha = 0.05/1 = 0.05 for each individual comparison.

little difference in compressive strength due to defect grade. This is not surprising since the compression specimens were essentially defect free.

For compressive MOE, only width and specific gravity showed significant effects. The pairwise comparison (Table 4c.) shows that 2x4's have significantly lower compressive MOE than 2x8'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 of stiffness (MOE) and specimen strength (MOR). The strength values used in the correlation analysis were those adjusted to 12 percent moisture content. The results are shown in Table 5. The r values for stiffness/strength relationships are between 0.479 and 0.500. The correlations between the CLT-MOE[2], 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.

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

Estimated Allowable Stresses

The Weibull distribution was fitted to the bending, tension and compression strength data using a maximum likelihood estimator algorithm (Bailey, 1974). The $L_{.05}$ values for the Weibull[3] and Normal[4] were also calculated. Table 6 shows the calculated estimate for allowable stress values for bending, tension and compression based on the $L_{.05}$ values for the three-parameter Weibull and the normal distribution. The allowable stress values were determined using the following formula adapted from ASTM D-2555-78 (ASTM, 1980d) and ASTM D-2915-74 (ASTM, 1980e):

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2 Average MOE calculated by the E computer of the Metriguard 7100 CLT.

3 $L_{.05} = \hat{a} + \hat{b}\,(-\ln(1-0.05))^{1/\hat{c}}$ where $\hat{a}$, $\hat{b}$ and $\hat{c}$ are estimates of the Weibull parameters and in is the natural logarithm.

4 $L_{.05}$ = Average Strength - ($t_{.05}$ X Std. Dev.), where $t_{.05}$ = Student's "t" for 95% probability.

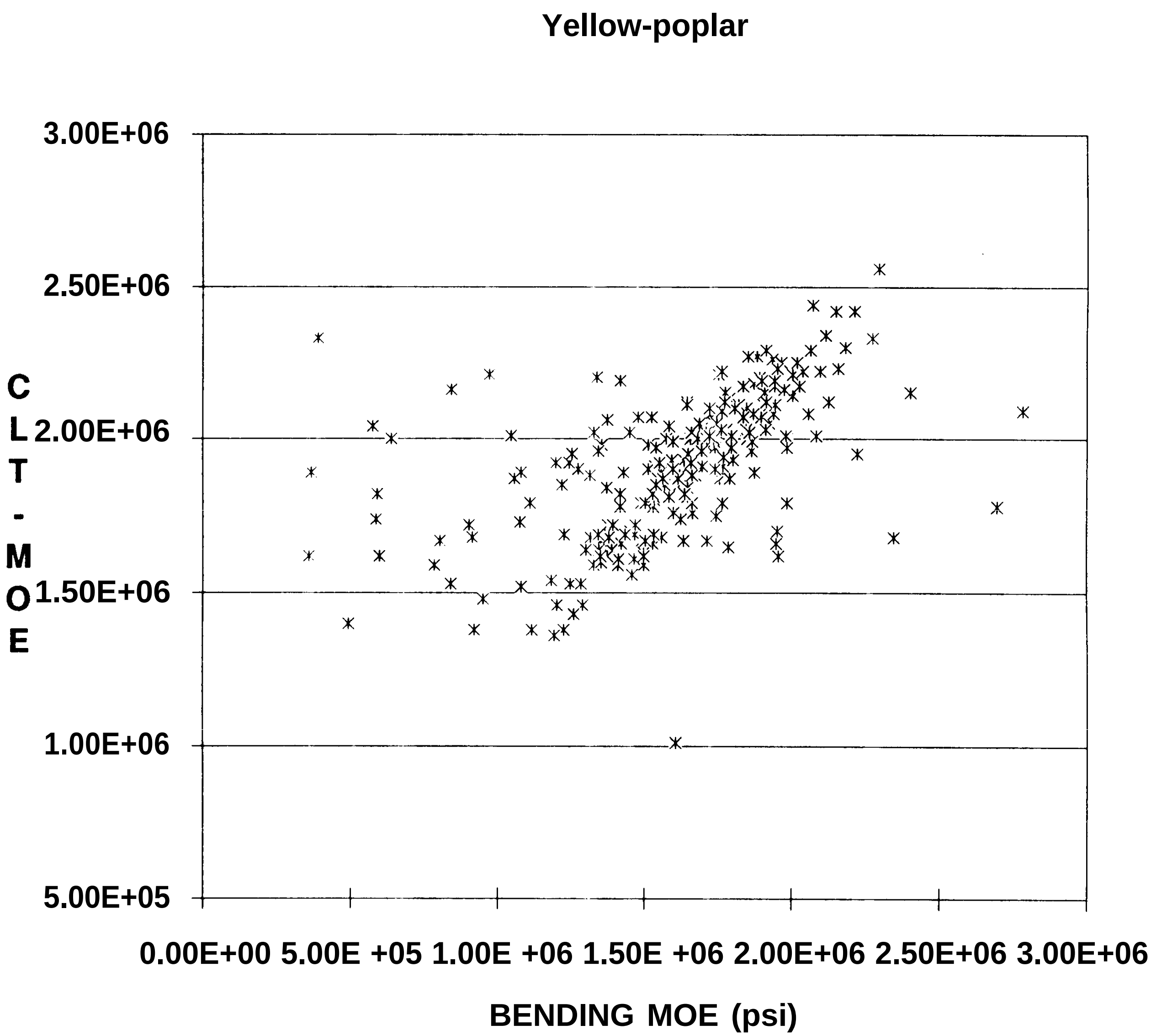

Figure 2: Scatter diagram of CLT measure of MOE and static bending MOE for yellow-poplar.

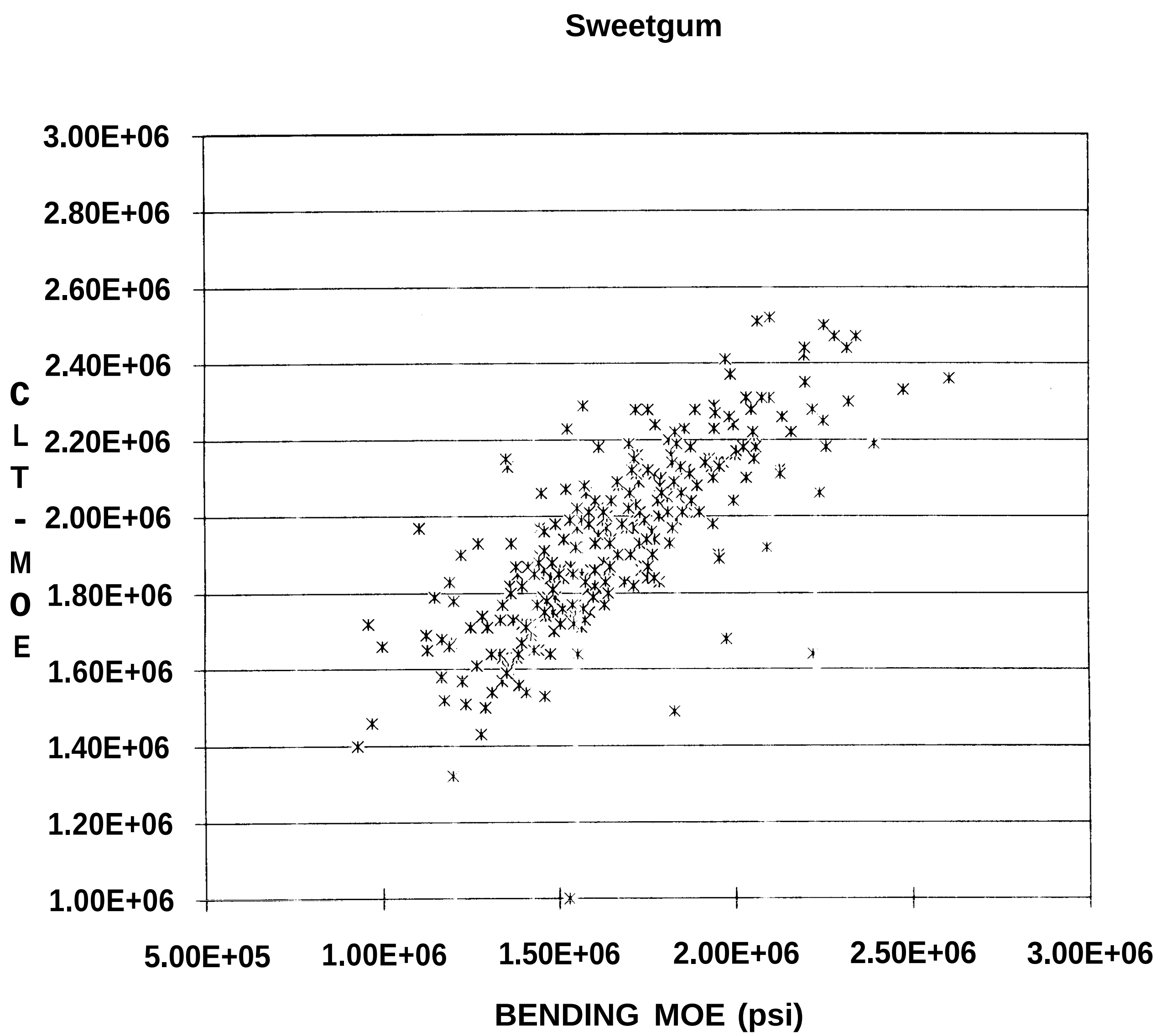

Figure 3: Scatter diagram of CLT measure of MOE and static bending MOE for sweetgum.

Table 5
Relationship between strength and stiffness properties for hardwood structural lumber

Sweetgum Correlation Matrix, values of r.

	CLT-MOE	Bending MOR_{12}[1]	Bending MOE_{12}	Bending MOE	Tension MOR_{12}	Tension MOE_{12}	Tension MOE
CLT-MOE	1	.434	.737	.752	.450	.583	.614
Bend MOR_{12}		1	.489	.487	x[2]	x	x
Bend MOE_{12}			1	.991	x	x	x
Bend MOE				1	x	x	x
Tens MOR_{12}					1	.463	.459
Tens MOE_{12}						1	.985
Tens MOE							1

Yellow-poplar Correlation Matrix, values of r.

	CLT-MOE	Bending MOR_{12}	Bending MOE_{12}	Bending MOE	Tension MOR_{12}	Tension MOE_{12}	Tension MOE
CLT-MOE	1	.428	.517	.526	.378	.653	.650
Bend MOR_{12}		1	.490	.497	x	x	x
Bend MOE_{12}			1	.998	x	x	x
Bend MOE				1	x	x	x
Tens MOR_{12}					1	.468	.479
Tens MOE_{12}						1	.985
Tens MOE							1

Combined Species Correlation Matrix, values of r.

	CLT-MOE	Bending MOR_{12}	Bending MOE_{12}	Bending MOE	Tension MOR_{12}	Tension MOE_{12}	Tension MOE
CLT-MOE	1	.434	.613	.625	.418	.615	.630
Bend MOR_{12}		1	.494	.497	x	x	x
Bend MOE_{12}			1	.997	x	x	x
Bend MOE				1	x	x	x
Tens MOR_{12}					1	.486	.479
Tens MOE_{12}						1	.985
Tens MOE							1

1 Properties with subscript "12" are adjusted values to 12% moisture content per ASTM D2915-84.

2 "x" indicates no correlation data.

Table 6
Estimated Allowable Stress[1] for Sweetgum and Poplar Structural Lumber

Test	Species	Width	N	3-Parameter Weibull Allowable Stress	Normal Allowable Stress	Poplar Design Values
	Calculation Method -->					
Bending	all		522	1536	1293	
						Sel. Str.
Bending	Sweetgum	all	275	1804	1545	1700
Bending	Sweetgum	2x4	138	1717	1476	No. 1
Bending	Sweetgum	2x8	137	1966	1713	1450
						No. 2
Bending	Y-Poplar	all	247	1348	1030	1200
Bending	Y-Poplar	2x4	142	1970	1749	No. 3
Bending	Y-Poplar	2x8	105	967	314	675
Tension	all		452	748	289	
						Sel. Str.
Tension	Sweetgum	all	212	1019	441	875
Tension	Sweetgum	2x4	105	928	186	No. 1
Tension	Sweetgum	2x8	107	1118	803	750
						No. 2
Tension	Y-Poplar	all	240	679	158	625
Tension	Y-Poplar	2x4	139	866	469	No. 3
Tension	Y-Poplar	2x8	101	564	135	350
Comp	all		494	2934	2817	
						Sel. Str.
Comp	Sweetgum	all	253	3555	3365	1050
Comp	Sweetgum	2x4	133	3543	3372	No. 1
Comp	Sweetgum	2x8	119	3573	3354	825
						No. 2
Comp	Y-Poplar	all	241	2735	2639	650
Comp	Y-Poplar	2x4	136	2541	2447	No. 3
Comp	Y-Poplar	2x8	105	3223	3002	400

1 Allowable Stress = $(LOWER_{.05})*(1/(1.5/(Ft/1)))$
Rep member allow = 1;
factor of safety = 1.5;
duration of load = 1
Ft = time of test factor (Tens; 1.025: Bend; 1.092)

Estimated Allowable stress = $L_{.05}$ * $(1/(1.5/F_t/1))$

Where:

$L_{.05}$ = Lower 5th percentile

Repetitive member factor = 1.0 (single member)

Factor of safety = 1.5

Duration of load factor = 1.0 (long term)

F_t (time of test factor) = 1.025 for tension

= 1.092 for bending

All of the estimated allowable stress values determined from the $L_{.05}$ Weibull values exceed the published allowable stress values for yellow-poplar structural lumber (NFPA, 1982; SIB, 1982). The allowable stresses by defect grade are presented in Table 7. Again all allowable stresses for sweetgum and yellow-poplar, based on the 3 parameter Weibull, exceed accepted design values for yellow-poplar. For sweetgum, defect grade No. 1 and 2 (pine rules) exceed poplar design values for select structural. This indicates that pine grading rules do not accurately assess strength and stiffness of sweetgum dimension lumber. As stated previously, much downgrading of sweetgum was due to slope of grain. However, with interlocking grain, the surface slope of grain does not always reflect the average slope of grain through the thickness of the board. In many cases, downgrading for surface slope of grain may not be justified. A modified set of grading rules may have to be established for sweetgum structural lumber.

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 was included as a study control. Properties of tension, compression and bending (edgewise and plank) were measured in laboratory tests on sweetgum and yellow-poplar 2x4's and 2x8's 12 feet long. In all, about 1200 pieces of lumber were tested. In addition, about 1600 pieces of lumber were graded for defects and warp (before and after drying). All lumber was machine stress rated (through a CLT) to evaluate plank bending stiffness under production conditions.

The conclusions from the analysis of results may be 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.

Table 7
Estimated Allowable Stress[1] by Grade

Test	Calculation Method --> Species	N	3-Parameter Weibull Allowable Stress	Normal Allowable Stress	Poplar Design Values
			GRADE # 1		
Bending	All	174	1989	1761	
Bending	Sweetgum	57	3026	2602	
Bending	Yellow-poplar	117	1714	1414	1450
Tens ion	All	189	1074	627	
Tens ion	Sweetgum	51	1015	634	
Tens ion	Yellow-poplar	138	1113	617	750
			GRADE # 2		
Bending	All	234	1689	1405	
Bending	Sweetgum	138	2071	1754	
Bending	Yellow-poplar	96	1399	968	1200
Tens ion	All	166	875	568	
Tens ion	Sweetgum	103	1136	832	
Tens ion	Yellow-poplar	63	696	233	625
			GRADE # 3		
Bending	All	102	1136	855	
Bending	Sweetgum	68	1407	996	
Bending	Yellow-poplar	34	922	569	675
Tens ion	All	92	470	-476	
Tens ion	Sweetgum	53	847	-305	
Tens ion	Yellow-poplar	39	405	-55	350

1 Allowable Stress = $(LOWER_{.05})*(1/(1.5/(Ft/1))$
Rep member allow = 1;
factor of safety = 1.5;
duration of load = 1
Ft = time of test factor (Tens; 1.025: Bend; 1.092)

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.

LITERATURE CITED

1. American Society for Testing and Materials. 1980a. Standard methods of static tests of timbers in structural sizes. ASTM D-198-76. 1980 Annual Book of ASTM Standards. Part 22, Wood: Adhesives. American Society for Testing and Materials. Philadelphia. pp 120-145.

2. American Society for Testing and Materials. 1980b. Standard methods of testing small clear specimens of timber. ASTM D-143-52(1978). 1980 Annual Book of ASTM Standards. Part 22, Wood: Adhesives. American Society for Testing and Materials. Philadelphia. pp 58-110.

3. American Society for Testing and Materials. 1980d. Standard methods for establishing clear wood strength values. ASTM D-2555-78. 1980 Annual Book of ASTM Standards. Part 22, Wood: Adhesives. American Society for Testing and Materials. Philadelphia. pp 739-760.

4. American Society for Testing and Materials. 1987. Standard method for evaluating allowable properties for grades of structural lumber. ASTM D-2915-84. 1987 Annual Book of ASTM Standards. Section 4, Vol. 04.09 Wood. American Society for Testing and Materials. Philadelphia. pp 573-588.

5. Bailey, R.L. 1974. Announcement: Computer programs for quantifying diameter distributions with the Weibull function. Forest Science 29(3):229.

6. Buchanan, A.H.. The bending strength of lumber. Journal of Structural Engineering (in press).

7. Evans, J.W., R.A. Johnson, and D.W. Green. 1984. Estimating the correlation between variables under destructive testing, or how to break the same board twice. Technometrics. 26(3):278-297.

8. Galligan, W.L., D.W. Green, D.S. Gromala, and J.H. Haskell. 1980. Evaluation of lumber properties in the United States and their application to structural research. Forest Products Journal. 30(10):45-50.

9. Green, D.W. 1983. In-grade testing: impetus for change in the utilization of structural lumber. Proceedings. From Stump Thru Mill: Recent Advances in Spruce-Fir Utilization Technology. August 17-19, University of Maine, Orono. Society of American Foresters Publication No. 83-13.

10. Green, D.W., J.W. Evans, and R.A. Johnson. 1984. Investigations of the procedure for estimating the concomitance of lumber strength properties. Wood and Fiber Science. 16(3):427-440.

11. National Forest Products Association. 1982. A supplement to the 1982 edition: National Design Specification For Wood Construction. National Forest Products Association, Washington, D.C. 32p.

12. SAS Institute, Inc.. 1985. SAS User's Guide: Statistics, Version 5 Edition, Cary, NC. 956p.

13. Softwood Inspection Bureau. 1982. Standard Grading Rules for Northern and Eastern Lumber. Softwood Inspection Bureau, Northern Hardwood and Pine Manufacturers Association Inc. Green Bay. 125p.

14. Southern Pine Inspection Bureau. 1977. Grading rules: 1977 edition. Southern Pine Inspection Bureau, Pensacola. 213p.

15. U.S. Department of Agriculture, Forest Service. 1974. Wood Handbook: Wood as an Engineering Material. Agriculture Handbook No. 72. Forest Products Laboratory. Madison, WI.

16. Us. Department of Agriculture, Forest Service. 1977. The demand and price situation for forest products, 1976-77. U.S. Dep. Agric. For. Serv., Misc. Publ. 1357. 53p. U.S. Gov. Print. off. , Washington, D.C..

17. U.S. Department of Agriculture, Forest Service. 1988. The south's Fourth Forest; Alternatives for the Future. Forest Resource Report No. 24. U.S. Gov. Print. Off., Washington, D.C..

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