EFFECTS OF SILVICULTURAL PRACTICE AND MOISTURE CONTENT LEVEL ON LOBLOLLY PINE VENEER MECHANICAL PROPERTIES

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ABSTRACT

Loblolly pine veneer specimens were obtained from five silviculturally different stands. Clear specimens were cut parallel to the grain from full size veneer sheets and tests were done at either air-dry or ovendry conditions to determine differences in bending modulus of rupture (MOR_b), bending modulus of elasticity (MOE_b), tensile modulus of elasticity (MOE_t), and tensile strength (TS). A statistical analysis revealed no significant difference between the stands for MOR_b, MOE_b, and MOE_t. There were no significant differences between air-dry and ovendry properties of MOE_b, TS, and MOE_t. Bending properties were significantly correlated, as were tensile properties.

Structural panels using veneer faces and composite cores have great potential to extend the wood resource by reducing the demand on solid wood. Chow (9) has shown that a bending stress value very close to that for walnut lumber could be obtained from a walnut-veneered, particleboard composite panel. Another study by Chow and Hanson (10) found that the application of 1/28-inch red oak veneer to 3/4-inch hardboard considerably increased stiffness values. Hse (16) showed that 1/2-inch-thick structural, exterior composite panels of various constructions can be manufactured in a one-step process, with a core of mixed southern hardwood flakes and southern yellow pine (SYP) veneer overlay on the faces. Biblis and Chiu (4) produced sandwich wood floor panels 7/8-inch thick (5/8-in. particleboard core reinforced with 1/8-in. SYP faces) that were 236 percent stronger and 285 percent stiffer in flexure than the widely used two-layered floor system (1/2-in. plywood subfloor + 5/8-in. particleboard underlayment).

The Com-Ply project (7) showed high strength and stiffness can be obtained by bonding two veneers on each edge and thus fabricating a structural, composite stud at less cost than regular plywood for the same end use. Biblis and Mangalousis (5) showed that the physical and mechanical properties of 1/2-inch composite plywood, fabricated from 1/8-inch-thick southern pine veneer faces and 1/4-inch unidirectionally oriented strand cores made from a mixture of southern oaks, as well as a mixture of oak and southern pine, can yield properties that are equal to, and in some cases, superior to the properties of 1/2-inch southern pine CDX plywood. Biblis et al. (6) also showed similar improvement with oriented strandboard cores (85% SYP and 15% soft hardwoods) and southern pine veneer on the faces.

In order to more efficiently utilize present and future composites that include a veneer component, it is necessary to investigate the mechanical properties of the veneer itself. Furthermore, the increase in plantation-grown timber has increased the need to determine the effect of different silvicultural strategies on veneer quality.

The literature is sparse concerning the mechanical properties of veneer. McAlister (21) investigated the tensile and stresswave timer modulus of elasticity (MOE) distribution of loblolly pine veneer as related to location within the stem

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TABLE 1. — Basic stand information mean values of the five harvested loblolly pine trees from the five stands growing near Crossett, Ark.

Stand	Age	Height	DBH[a]	Basal area	Site index	Live crown ratio[b]
	(yr.)	(ft.)	(in.)	(ft. ²/acre)		(%)
1 - Sudden sawlog	48	94.2	21.1	90	95	56
2 - Conventional	48	93.8	15.3	118	95	39
3 - Natural	48	98.6	16.4	76	100	39
4 - Single tree	49	88.6	16.4	72	89	55
5 - Crop tree	79	110.2	24.7	42	97	56

and specific gravity. He found that veneer peeled from the second bolt (8.5 ft. to 17 ft. above the stump cut) had the highest mean MOE and the butt bolt gave the lowest mean tensile MOE. The stiffest veneer was peeled from the outside of the blocks, and veneer from the trees 16 inches DBH and smaller had higher mean MOE than that of the larger trees. Moreover, preliminary investigations on loblolly pine veneer by Groom and Mullins (14) suggested that the inner core of each log produces veneer with lower MOE and specific gravity (SG).

Hunt et al. (17) developed a database for tensile properties of yellow-poplar veneer strands. Pugel (23) investigated the angle-to-grain tensile strength for thin wood specimens of loblolly pine and Douglas-fir. However, these specimens were planed down from dimension lumber.

The objectives of this research were to determine the effect of silvicultural management strategy and moisture content (MC) level on the modulus of rupture in bending (MOR_b), tensile strength (TS), MOE in bending (MOE_b), and tensile MOE (MOE_t) of loblolly pine veneer strips. This research is intended to serve as a database to guide further research concerning the effects of silvicultural practice on mechanical properties of veneer strips individually and possibly collectively in a novel composite panel.

MATERIALS

A detailed description of the veneer processing methods is described in a previous paper (26) and the stands are described by Baker and Bishop (2). A brief summary is presented here. Five representative trees each from five silviculturally different loblolly pine (*Pinus taeda* L.) stands growing near Crossett, Ark. were harvested and bucked into peeler bolts (**Table 1**). Three of the silvicultural regimes were even-aged and consisted of stand 1 (sudden sawlog), stand 2 (conventional), and stand 3 (natural regeneration). The term sudden sawlog originated at the USDA Forest Service, Crossett Experimental and Demonstration Forest at Crossett, Ark. This term was developed because the goal of a sudden sawlog silvicultural strategy is to produce trees of sawlog dimension as rapidly as possible. The uneven-aged stand investigated was subdivided into two tree age classes: stand 4 (single tree selection) and stand 5 (crop trees).

Four hundred clear, 1/8-inch-thick by 1-inch-wide by 12-inch-long specimens were cut parallel to the grain from randomly selected full-size (54 in. by 98 in.) veneer sheets from each stand regardless of veneer grade. No more than two samples were cut from an individual veneer sheet in order to better represent each stand. From each stand, 100 specimens were tested for bending in the ovendry condition and 100 specimens were tested for bending in the air-dry condition. In addition, 100 specimens were tested in tension at ovendry conditions, and 100 tensile specimens were tested air-dry for each stand. The air-dry specimens were stacked for 6 months in a constantly air-conditioned laboratory with approximately 1/4-inch-wide veneer stickers between them to allow for proper air flow. Repeated weightings yielded constant results and indicated that the equilibrium MC of most specimens was near 9 to 10 percent.

TEST METHOD

For both bending and tensile testing, specimen dimensions were obtained by measuring the width and thickness of each specimen in three locations. The mean of these measurements was used for subsequent mechanical properties and specific gravity determination. The widths were determined with a digital caliper to the nearest 0.0001 inch and the lengths with a digital micrometer to the nearest 0.0001 inch. The thickness of each specimen was determined to the nearest 0.0001 inch with a digital micrometer. The air-dry specimens were weighed at the time of test and then ovendried at 105°C for 24 hours for MC determination. The ovendry specimens were weighed before ovendrying and again at the time of the test (ovendry condition) for MC determination.

SPECIMEN TESTING AND ANALYSIS

Bending specimens were 12- by 1- by 1/8-inches and were tested over a 6-inch span (48:1 span-to-depth ratio) (S:D) on an Instron Universal Testing Machine with an MTS upgrade using a PC-driven software package from MTS. For bending tests, the specimens were centrally loaded at a constant rate of 0.40 inch/minute until failure. Deflection was measured to the nearest 0.0001 inch. Tensile specimens were tested to failure at a gauge length of 10 inches using a constant rate of 0.20 inch/minute. The manually operated grips for the tensile tests were faced with rigid urethane. Specimen failures inside the grips were rejected and replaced with another specimen. Specimen deformation was determined from crosshead movement by the PC software package.

Data were downloaded from the MTS testing program, and the 2 × 5 factorial treatment structure was analyzed by analysis of variance (ANOVA) and regression techniques (27) in accordance with SAS programming procedures (25). There were two levels of MC (air-dry and ovendry) and five levels of the stand factor. The bending and tensile tests were treated as separate experiments in the ANOVA.

RESULTS AND DISCUSSION

BENDING PROPERTIES

Table 2 presents the mean mechanical properties, SG, and MC at each MC level for each of the five stands. **Table 3** shows that loblolly pine MOR_b and MOE_b are not significantly affected by silvicultural practice since the stand effect was an insignificant source of variance for both dependent variables. The ANOVA also indicated that the moisture level factor was significant for MOR_b but not for MOE_b. It has previously been established that the MOE of wood below the fiber saturation point is not greatly influenced

TABLE 2. — Mean mechanical and physical properties of loblolly pine veneer strips (mean of 200 specimens) from five silviculturally different stands tested either air-dry or ovendry in either tension or bending.

	Stand[a]									
			2		3		4		5	
Property	AD[b]	OD[b]	AD	OD	AD	OD	AD	OD	AD	OD
SG[c]	0.50	0.54	0.50	0.54	0.41	0.55	0.42	0.52	0.42	0.52
	(11.87)[d]	(11.25)	(10.72)	(9.25)	(5.09)	(13.53)	(4.39)	(13.17)	(3.65)	(12.15)
MC[e] (%)	8.81	0	9.25	0	8.62	0	9.87	0	9.59	0
	(10.76)		(10.00)		(10.31)		(9.99)		(10.02)	
TS[f] (psi)	11,606	14,025	11,499	13,611	10,607	12,845	13,102	13,359	11,614	14,088
	(28.26)	(26.15)	(29.05)	(31.33)	(29.68)	(35.10)	(33.76)	(31.99)	(21.41)	(26.83)
MOE_t	1.47	1.49	1.62	1.59	1.27	1.48	1.69	1.63	1.54	1.57
($\times 10^6$ psi)	(25.93)	(24.76)	(28.18)	(25.70)	(26.90)	(32.18)	(30.35)	(26.32)	(24.19)	(28.75)
MOR_b (psi)	5,101	5,461	3,210	5,075	4,278	6,057	5,493	5,743	4,651	5,691
	(24.55)	(19.43)	(18.35)	(20.09)	(20.09)	(18.29)	(21.09)	(21.98)	(21.09)	(20.09)
MOE_b	0.98	1.09	0.79	1.09	1.01	1.11	1.00	1.08	1.00	1.08
($\times 10^6$ psi)	(20.01)	(22.98)	(18.06)	(21.09)	(16.06)	(19.96)	(21.97)	(21.07)	(21.08)	(21.96)

[a] Stand 1 = sudden sawlog; Stand 2 = conventional; Stand 3 = natual regeneration; Stand 4 = single tree selection; Stand 5 = crop trees.
[b] AD = air-dry; OD = ovendry.
[c] Specific gravity was determined based on conditions at time of test (ovendry or air-dry).
[d] Values in parentheses are coefficients of variation (%).
[e] Moisture content on ovendry basis. OD samples were tested ovendry, and AD samples were tested air-dry.
[f] Tensile strength.

by changes in MC (19). Moreover, the small difference in the MC at the time of the tests of our two groups (ovendry and air-dry) also contributes to the similar MOE between the two MC groups for each of the stands.

The interaction of stand and MC was highly significant for both MOR_b and MOE_b (**Table 3**). The interaction of stand × MC for MOR_b is largely due to stands 1 (sudden sawlog) and 4 (single tree selection) in which the ovendry specimens yielded only slightly greater values than the corresponding air-dry specimens. The stand × MC interaction for MOE_b appears to be attributable to stand 2 (conventional), which yielded a much lower air-dry value than any of the other stands.

TENSILE PROPERTIES

Table 2 shows the mean TS and MOE_t values for each stand at each moisture level. The ANOVA for TS and MOE_t is summarized in **Table 3**. TS differed significantly among stands, but did not differ statistically between moisture levels (**Table 3**). Air-dry TS showed little difference between stands except for stand 4 (single tree selection) (13,102 psi), which was greater by 11, 12, 19, and 11 percent compared to stands 1 (sudden sawlog), 2 (conventional), 3 (natural regeneration), and 5 (crop trees), respectively. Ovendry TS specimens also displayed little difference between stands. Stand 5 (crop trees) (14,088 psi) and stand 1 (sudden sawlog) (14,025 psi) yielded slightly higher TS values than the other stands (**Table 2**). The stand effect was a significant source of variation for TS (**Table 3**).

There was no statistical difference among the stands with regard to MOE_t (**Table 3**). Within the stands, the air-dry and ovendry samples were also not statistically different for MOE_t. As was the case for MOE_b, the effect of moisture on MOE_t is minimal below the fiber saturation point (19).

McAlister (21) determined the dynamic modulus of elasticity (E_d) of loblolly pine veneer from three blocks within trees and three zones within blocks to range from 1.61 to 2.10×10^6 psi. Our mean values for MOE_t range from 1.27 to 1.69×10^6 psi, and MOE_b ranged from 0.79 to 1.11×10^6 psi. As expected, a correlation analysis indicated that MOE_b and MOR_b were significantly correlated ($r = 0.66$) as were MOE_t and TS ($r = 0.75$) (**Table 4**). Woodson has shown that MOR_b of 3-ply SYP plywood was unrelated to E_d of single veneers (28). Numerous previous researchers have found strong correlations, especially flatwise, between MOR_b and MOE_b of lumber (12,13,15,18,20). It appears based on our bending and tension data that MOR and MOE are also correlated for veneer strips.

It should be noted that our MOE_t values are much less than those reported by McAlister (21) using stresswave techniques over a 92-inch gauge length. Furthermore, previous studies by Hunt et al. (17) and McAlister (22) yielded similar results for TS of yellow-poplar veneer strips, although these researchers used different gauge lengths. It therefore appeared that MOE was not sensitive to the length of the specimen under stress. Our MOE_t values are much less than the E_d reported by McAlister (21) for loblolly pine. If the stresswave method is to be accepted as an accurate predictor of MOE, then it would appear that gauge length is likely critical in MOE determination when comparing our data with that of McAlister (21). It is recognized that the stresswave timer will give more reproducible results with a longer gauge length, but accurate results have been obtained with flake-sized specimens. Moreover, since E_d is a dynamic test and is not subjected to rheological effects, its values are typically 5 to 10 percent higher than similar static MOE values (8). Also, our tensile specimen deformation was measured using crosshead movement, which could yield lower results due to possible specimen slippage in the grips.

The nondestructive method of E_d is widely considered to be an acceptable alternative to destructive bending tests. The numerous investigations that have been conducted to confirm the strong correlation between E_d and destructive MOE are summarized by Ross and Pellerin (24).

Bending and Tensile Differences

Results for flexural strength (MOR_b) were dramatically less than tensile strength (TS). This decrease for MOR_b when compared with TS is largely attributable to the S:D (48:1) used for this project. It is recommended by ASTM D 143 (1) to use a 28-inch span (14:1 S:D) for 2- by 2- by 30-inch specimens. It was shown by Baumann (3) that the MOR decreases with a decreasing ratio of span to depth, and only for values with an S:D ≥ 20:1 does the bending strength of wood become approximately constant. Since our S:D ratio was greater than 20:1, this partially explains the lower bending values. Also, we realize that any specimen slippage in the grips will lead to lower tensile values when deformation is measured by crosshead movement.

Furthermore, the bending specimens were loaded with the tight side of the veneer in the compression zone, and consequently the loose side was in the tension zone. MOR is largely a defect-controlled property, and it is believed that failure in flexure is largely governed by defects in the tension zone (11). Therefore, it is important to consider that the lathe checks were on the tension side of our bending specimens. The lathe checks, which are oriented parallel to the length of the specimen and also parallel to the grain, were on the tension side of the veneer. These lathe checks may be deep enough for exceptionally rough veneer to have an effect on specimen failure similar to biological defects, such as knots.

Tensile properties have traditionally been greater than bending properties because of the helical nature of the cellulose molecular chains that comprise the fibrils in the cell wall. These strands are nearly parallel to the strain applied in tension. The cellulose strands, and thus a wood specimen itself, will typically require more force to cause failure under tensile loading than in flexure. Another principal reason for this difference is due to the fact that compression parallel-to-the-grain strength is less than tension parallel-to-the-grain strength for clear specimens. Therefore, in bending tests, the specimens usually fail first in compression parallel to the grain (this is often not a catastrophic failure but does result in damage to the specimen), and as the test progresses, eventually the specimen may fail in tension parallel to the grain in the tension zone. Therefore, the ultimate strength from a bending test of clear specimens is usually lower than the strength from a tension parallel-to-the-grain test.

TABLE 3. — Statistical analysis of loblolly pine static bending data.

Source	DF	F-value	p-value
Bending MOR			
Stand[a]	4	1.2368	0.4209
Moisture level (ML)		17.8797	0.0134*
Stand × ML	4	3.5867	0.0065**
Bending MOE			
Stand	4	3.8088	0.1117
ML		0.3357	0.5934
Stand × ML	4	3.6994	0.0054**
Tensile strength			
Stand	4	14.3763	0.0121*
ML		7.1991	0.0550
Stand × ML	4	0.4106	0.8011
Tensile MOE			
Stand	4	1.8033	0.2910
ML	1	5.1317	0.0862
Stand × ML	4	1.2833	0.2747

[a] Stand 1 = sudden sawlog; Stand 2 = conventional; Stand 3 = natual regeneration; Stand 4 = single tree selection; Stand 5 = crop trees.
[b] * indicates significance at α = 0.05; ** indicates significance at α = 0.01.

TABLE 4. — Correlation coefficients (r) between modulus of elasticity in tension (MOE_t) and bending (MOE_b), tensile strength (TS), and modulus of rupture in bending (MOR_b) of loblolly pine veneer strips.

	MOR_b	MOE_b	TS	MOE_t
Air-dry and ovendry samples				
MOR_b	1.00	0.63** (0.0001)[a]	0.02 (0.5143)	-0.03 (0.3812)
MOE_b		1.00	0.01 (0.9494)	-0.01 (0.7689)
TS			1.00	0.69** (0.0001)
MOE_t				1.00
Air-dry samples				
MOR_b	1.00	0.66** (0.0001)	0.02 (0.5999)	-0.05 (0.2896)
MOE_b		1.00	0.01 (0.7819)	-0.01 (0.9376)
TS			1.00	0.75** (0.001)
MOE_t				1.00
Ovendry samples				
MOR_b	1.00	0.51** (0.0001)	-0.02 (0.6449)	0.01 (0.9666)
MOE_b		1.0	-0.06 (0.1604)	-0.03 (0.4635)
TS			1.00	0.66** (0.0001)
MOE_t				1.00

[a] Values in parenetheses are p-values.
[b] ** indicates signficance at alpha = 0.01

Conclusions

This study has examined the effect of silvicultural practice on the static bending properties of small, rotary-peeled loblolly pine veneer specimens parallel to the grain at two levels of MC. It is hoped that other researchers can add to the database in order to model the mechanical properties of loblolly pine veneer.

The following conclusions can be drawn based upon this research.

1. Veneer tensile strength was significantly affected by silvicultural practice but bending MOR, bending MOE, and tensile MOE were not statistically affected by the silvicultural treatments.

2. Bending MOR was the only mechanical property found to be significantly less in the air-dry condition than the ovendry condition.

3. Bending properties (MOE_b and MOR_b) are significantly correlated to each other as are tensile properties (TS and MOE_t).

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