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The Effect of Silvicultural Treatments on Certain Mechanical and Physical Properties of Loblolly Pine Wood Composites.

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THE EFFECT OF SILVICULTURAL TREATMENTS ON CERTAIN MECHANICAL AND PHYSICAL PROPERTIES OF LOBLOLLY PINE WOOD COMPOSITES

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ABSTRACT

The effects of silvicultural treatments on mechanical and physical properties of loblolly pine (*Pinus taeda* L.) wood composites, veneer tensile and bending properties, and basic chemical properties were investigated.

Stands managed in a plantation setting showed higher extractive contents. Holocellulose and alpha-cellulose were minimally affected by the silvicultural strategies. Klason lignin showed an inverse relationship with holocellulose. The effect of wood type was significant for the extractives because the innerwood region yielded much greater values than the outerwood. Holocellulose and alpha-cellulose increased in concentration from innerwood to outerwood.

Veneer tensile strength was significantly affected by silvicultural practice, but other mechanical properties were unaffected. The differences between the stands were minimal for the mechanical properties investigated. Specimens tested in the ovendry condition yielded higher mean mechanical property values than specimens tested airdry.

The stands had laminated veneer lumber panels produced using either all A-grade or all C-grade veneer. Also, five different veneer grade based layups were investigated for one stand only. Stand one (sudden sawlog) produced the highest flexural strength and stiffness mean values for the all A-grade panels in both testing orientations. The optimal location of A-grade veneer placement in a panel influenced modulus of elasticity but not ultimate bending strength.

Plywood panels were produced according to four different veneer grade arrangements for each stand. Bending and shear properties were significantly affected by silvicultural practice. Plywood fabricated with all A-grade veneer gave the most favorable mechanical properties. The effect of panel layup was significant for most mechanical properties.

Particleboard and Fiberboard panels were produced according to stand and wood type. On average, stand 2 (conventional), stand 3 (natural regeneration) and stand 4 (single tree selection) yielded the most favorable mechanical properties. However, differences within the stands were typically minimal and nonsignificant for most properties. Innerwood composites did show a higher compaction ratio than outerwood composites, but the differences in panel density, thickness swell, water adsorption, modulus of rupture, modulus of elasticity, and internal bond were minimal between the wood types for all stands.

CHAPTER 1

INTRODUCTION

Loblolly pine (*Pinus taeda* L.) is the principal timber species in the South for a variety of wood-based products. Consequently, numerous investigations have been conducted to assess its properties. Southern yellow pine plantations presently make up one-third of the acreage in pine forests but are projected to account for 56 percent of all pine stands by the year 2000. By 2030, plantations are expected to make up two-thirds of the South's pine forests (Brown and McWilliams 1990). The literature is currently lacking in studies that have extensively examined the effect of different silvicultural strategies on the wood composite properties of loblolly pine.

The main objective of this study was to determine the effect of five different silvicultural strategies on the chemical properties, veneer mechanical properties, laminated veneer lumber mechanical properties, plywood mechanical and physical properties, and particleboard and fiberboard mechanical and physical properties of loblolly pine. In addition, the effect of wood type was addressed for the chapters on (1) chemical properties and (2) particleboard and fiberboard. Another objective for the veneer mechanical property chapter was to determine the effect of veneer moisture level on mechanical properties. An additional objective of the plywood and laminated veneer lumber studies were to determine the effect of different veneer layups with respect to veneer visual grades.

Stand Descriptions

For this study, five representative trees each from five silviculturally different loblolly pine stands growing near Crossett, AR were harvested and bucked into peeler bolts (Table 1). All stands are described in detail by Baker and Bishop (1986). Three of the silvicultural regimes were even-aged and consisted of stand 1 (sudden sawlog), stand 2 (conventional), and stand 3 (natural regeneration). The sudden sawlog and conventional stands were the only true plantations included in the study. The uneven-aged stand investigated was subdivided into two tree age classes: stand 4 (single tree selection) and stand 5 (crop trees).

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

Stand	Age (Years)	Height (ft.)	DBH[1] (in.)	Basal area (ft. ^{2}/acre)	Site index	Live crown ratio (%)[2]
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

[1]Diameter at breast height.
[2]Live crown ratio = {length of live crown / total length of tree} x 100

The even-aged stands can be described as follows. Stand 1 (sudden sawlog) was harvested at age 48 and was subjected to green pruning and biennial mowing. The goal of a sudden sawlog silvicultural strategy is to produce trees of sawlog dimension as rapidly as possible. Stand 2 (conventional) was 48-years-old at harvest and was moderately thinned. It was never pruned or treated for understory control. This stand is typical of many pine stands throughout the South. Stand 3 (natural

regeneration) was 47-49 years old. These trees were naturally regenerated and were never subjected to thinning, pruning, or understory control.

The mature, uneven-aged site had been under selection management for 50-years. During this time, two age-classes of trees developed. Stand 4 (single-tree selection) included 47- to 51-year-old dominant and codominant trees. Stand 5 (crop trees) was 77 to 85 years old and was harvested from the same stand as the single-tree selection. These two groups are hereafter referred to as separate stands for simplicity even though both were actually growing together. These crop trees had been left uncut by all previous thinning operations and were easily separated from the single tree selection group (stand 4) based on size and crown morphology.

Veneer Processing

The bolts were rotary-peeled by Hunt Plywood at Pollock, LA to a target thickness of 1/8-in. and clipped to approximately 54 in. x 98 in. The veneer was coded according to stand, tree number, bolt number, and location within each bolt as it was peeled. The veneer was dried commercially to a moisture content (MC) of 6 - 8%, transported to the USDA - Forest Service, Southern Research Station in Pineville, LA, stored in a controlled environment of 72 F and 36 percent relative humidity (RH), and graded by an APA - The Engineered Wood Association veneer grader.

CHAPTER 2

DIFFERENCES IN SOME CHEMICAL PROPERTIES OF INNERWOOD AND OUTERWOOD FROM FIVE SILVICULTURALLY DIFFERENT LOBLOLLY PINE STANDS

Loblolly pine is extensively used for pulp and paper production in the South. Loblolly pine pulpwood is typically plantation grown using intensive silviculture to shorten the rotation age. Consequently, researchers have addressed the effect of various silvicultural practices on selected chemical properties of wood. Zobel et al. (1961) addressed the effect of fertilizer on the alpha-cellulose and holocellulose contents of loblolly pine wood. More recent research by Shupe et al. (1996) investigated the individual and interactive effects of fertilization, thinning, and pruning on the extractive content, Klason lignin, holocellulose, and alpha-cellulose contents of 12-year-old loblolly pine innerwood and outerwood.

The objectives of this study were to expand the study by Shupe et al. (1996), which was on 12-year-old loblolly pine trees, and to address the effect of various silvicultural treatments on the chemical properties of older loblolly pine trees. Specifically, the objectives of this study were to (1) determine the effect of five different silvicultural strategies on the chemical composition of loblolly pine wood and (2) evaluate the differences in the chemical composition of loblolly pine innerwood and outerwood.

Materials and Methods

Veneer sampling was limited to the bottom two peeler bolts for all stands. Innerwood was considered the last ten veneer sheets removed from a peeler bolt, and

outerwood was treated as the first ten sheets peeled from a bolt. All bolts were peeled to a final diameter of 7.62 cm. Therefore, the innerwood was considered to be entirely juvenile wood and heartwood, and the outerwood was clearly in the sapwood zone.

Laboratory Experimentation and Data Analysis

Chemical constituent values were obtained using the following test procedures: (1) alcohol-benzene extractive content (ASTM D 1105-84), (2) hot-water extractive content (ASTM 1110-84), (3) ether extractive content (ASTM 1108-84), (4) Klason lignin content (D 1106-84), (5) holocellulose content (ASTM D 1104-56), and (6) alpha-cellulose content (ASTM D 1103-60) (ASTM 1982, 1993).

The statistical analysis was conducted using SAS programming methods (SAS 1989) in conjunction with analysis of variance (AOV) techniques (Steel and Torrie 1980, Box et al. 1978). The significance of each factor and factor interactions were determined at the $\alpha = 0.05$ level using Type III Sum of Squares. It was determined that samples were normally distributed with different means and with a common variance.

Results and Discussion

Extractives (Extraneous Material)

Extractive content values obtained by three methods using innerwood and outerwood from the five silviculturally different stands are presented in Table 2. Tukey's mean separation letters are listed next to each mean value.

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Table 2. Summarized means of alcohol-benzene, ether, and hot-water extractive contents in loblolly pine outerwood and innerwood five different silvicultural treatments.

Stand[1]-wood type	Extractive content (%)			
	Alcohol-benzene	Ether	Hot-water	Total
1-Outerwood	4.53[2] A[3]	0.50 A	3.97 A	9.00 A
2-Outerwood	4.03 A	0.42 A	3.93 A	8.38 A
3-Outerwood	3.39 B	0.39 A	3.35 B	7.13 B
4-Outerwood	2.58 C	0.41 A	3.22 B	6.21 B
5-Outerwood	2.50 C	0.40 A	3.15 B	6.05 B
1-Innerwood	6.98 A	0.53 A	5.01 A	12.52 A
2-Innerwood	6.92 A	0.55 A	4.75 A	12.22 A
3-Innerwood	5.49 B	0.42 A	3.82 A	9.73 B
4-Innerwood	5.32 B	0.41 A	3.53 B	9.26 B
5-Innerwood	5.23 B	0.39 A	3.23 B	8.85 C

[1]Stand 1 = Sudden sawlog.
Stand 2 = Conventional.
Stand 3 = Natural regeneration.
Stand 4 = Single tree selection.
Stand 5 = Crop trees.
[2]Represents the mean of 12 samples.
[3]Within either wood type grouping, means followed by the same letters indicate no significant difference exists between means for a particular property according to the Tukey mean separation procedure. Significant differences were declared at α =0.05. The grouping "A" pertains to the group with the highest mean value, B to the group with the second highest mean values, and C to the third highest mean values.

differences (Table 2). These findings are comparable with those of Shupe et al. (1996) who found mean outerwood extractive values of 2.90 %, 0.41 %, and 3.18 % for alcohol-benzene, ether, and hot-water, respectively.

A similar pattern was detected for innerwood extractive contents. Again, stands 1 (sudden sawlog) and stand 2 (conventional) gave significantly greater alcohol-benzene and hot-water extractives. Stand 3 (natural) gave a statistically similar mean value to stand 1 (sudden sawlog) and stand 2 (conventional) for hot-water extractives. No differences were detected for ether extractives due to the small range (0.39 % - 0.55 %).

These values are greater than those reported by Max (1945) for alcohol-benzene (2.76%) and hot-water (1.24%) on green loblolly pine wood. However, Max (1945) found a much greater value for ether extractives of 1.83%. It is interesting to note that all of the values for innerwood are much greater than that reported by Max (1945) even though the wood was well seasoned (air-dried) prior to extraction, which typically reduces the amount of extractives removed by the alcohol-benzene or ether extraction methods. Pettersen (1984) reported the following mean extractive contents for loblolly pine: 1% NaOH (11%), hot-water (2%), and alcohol-benzene (3%).

The findings regarding higher extractive contents for stand 1 (sudden sawlog) and stand 2 (conventional) are logical because Kramer and Kozlowski (1979) have shown that extractives are products of metabolic tree growth. Therefore, silvicultural treatments that serve to increase tree growth and vigor should increase

the extractive content. This hypothesis was not directly tested in this study but it appears to be valid in this study because stand 1 (sudden sawlog) and stand 2 (conventional) were the only plantations sampled and were actively managed for rapid growth. In general, Shupe et al. (1996) found this hypothesis not to be true because they found minimal and inconsistent differences due to fertilization, pruning, and stand density using the same three extractive content methods of determination.

As expected, the hot-water and alcohol-benzene extractive contents were significantly greater in innerwood than outerwood. Naturally, the innerwood wood type contained a higher percentage of extractives than the outerwood wood type. The difference in extractive content between southern pine heartwood (high extractive concentration) and sapwood (low extractive concentration) extractive content has been well documented (Ritter and Fleck 1926, Wahlenberg 1960, Posey and Robinson 1969, McMillin 1968). The mean values for ether extractives showed little variation between innerwood and outerwood in this study and also in the Shupe et al. (1996) study.

Non-extraneous Material

The mean Klason lignin, holocellulose, and alpha-cellulose contents obtained from the innerwood and outerwood portions of five silviculturally different stands is presented in Table 3. In contrast to the extractive content findings, the slower-grown stands gave higher mean values for both innerwood and outerwood. Specifically, stand 4 (single tree) and stand 5 (crop tree) yielded significantly higher mean values for holocellulose and alpha-cellulose for both innerwood and outerwood

wood types. Holocellulose values ranged from 70.37 % - 74.53 % for outerwood and showed no significant differences between the stands. In the innerwood region, stand 4 (single tree) and stand 5 (crop tree) yielded significantly less holocellulose than the other stands. The lower holocellulose content was expected since these stands (4 and 5) gave comparatively higher values for Klason lignin. The procedures used allow for a summative analysis of total polysaccharide and non-polysaccharide structural material. On an oven-dried wood basis, the holocellulose and Klason lignin contents should sum to 100 % but can vary due to the alcohol-benzene extractive content and the destructive nature of the testing (Shupe 1993).

Most growth-accelerating silvicultural treatments reported in the literature have failed to significantly influence Klason lignin, holocellulose, or alpha-cellulose. However, Shupe et al. (1996) did find a significantly higher Klason lignin content with wood from a fertilized plot than from a unfertilized plot. Zobel et al. (1961) failed to detect a significant difference between heavily and moderately fertilized 25-year-old loblolly pine plantations and a control plantation for water-resistant carbohydrates, "holocellulose," and alpha-cellulose. Moreover, Shupe et al. (1996) found fertilization and pruning to have an insignificant effect and stand density to have a minimal effect on holocellulose and alpha-cellulose. Therefore, most forms of silvicultural manipulation have a minimal effect on the nonextraneous content of loblolly pine wood. The concentration of holocellulose and alpha-cellulose tends to closely parallel the natural increase in wood density from pith to bark as described by Megraw (1985). As wood specific gravity increases during the juvenile period, so

Table 3. Summarized means of Klason lignin, holocellulose, alpha-cellulose in loblolly pine outerwood and innerwood from five different silvicultural treatments. Values are percentages of extractive-free oven-dried wood.

Stand[1]-wood type	Non-extraneous material (%)		
	Holocellulose	Klason lignin	Alpha-cellulose
1-Outerwood	74.53[2] A[3]	25.43 B	46.98 B
2-Outerwood	73.39 A	26.41 B	43.68 B
3-Outerwood	73.33 A	26.68 B	42.37 B
4-Outerwood	71.32 A	29.70 A	49.68 A
5-Outerwood	70.37 A	30.31 A	50.98 A
1-Innerwood	79.79 A	20.25 B	40.32 B
2-Innerwood	78.63 A	21.22 B	38.38 C
3-Innerwood	78.50 A	21.43 B	37.32 C
4-Innerwood	75.61 B	24.30 A	44.33 A
5-Innerwood	74.43 B	25.52 A	45.32 A

[1]Stand 1 = Sudden sawlog.
Stand 2 = Conventional.
Stand 3 = Natural regeneration.
Stand 4 = Single tree selection.
Stand 5 = Crop trees.
[2]Represents the mean of 12 samples.
[3]Within either wood type grouping, means followed by the same letters indicate no significant difference exists between means for a particular property according to the Tukey mean separation procedure. Significant differences were declared at $\alpha = 0.05$. The grouping "A" pertains to the group with the highest mean value, B to the group with the second highest mean values, and C to the third highest mean values.

will the holocellulose and alpha-cellulose concentration because these compounds are the primary constituents of the cell wall.

Lower values were found in innerwood for Klason lignin and alpha-cellulose. Many previous investigations have found that loblolly pine outerwood possesses more holocellulose and alpha-cellulose than innerwood (Byrd et al. 1965; McMillin 1968; Stamm and Sanders 1966; Zobel and McElwee 1958; Zobel et al. 1966). These differences between innerwood and outerwood can largely be attributed to the

relationship between wood density and the structural cell-wall material (i.e., holocellulose and alpha-cellulose) (Panshin and deZeeuw 1980). Koch (1972) associated the changes in polysaccharide content across a tree diameter to the presence of juvenile wood. In short, juvenile wood, located primarily in the innerwood region, is less dense than mature wood, located largely in the outerwood region. The density of wood is determined by the amount of structural cell-wall material present. Therefore, since juvenile wood is less dense than mature wood, it follows that it also contains less holocellulose and alpha-cellulose than mature wood.

CHAPTER 3

EFFECTS OF SILVICULTURAL PRACTICE AND MOISTURE CONTENT LEVEL ON LOBLOLLY PINE VENEER MECHANICAL 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 (1972) has shown that a bending stress value very close to that for walnut lumber could be obtained from a walnut-veneered, particleboard composite panel with a shelling ratio of 0.50. Another study by Chow and Hanson (1980) found that the application of 1/28-in. red oak veneer to 3/4-inch hardboard considerably increased stiffness values. Hse (1976) showed that 1/2-in. 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 (1972) produced sandwich wood floor panels 7/8-in. 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 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 (1975). Biblis and Mangalousis (1983) showed that the physical and mechanical properties of 1/2-in. composite plywood, fabricated from 1/8-in.-thick southern pine veneer faces and 1/4-in. 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-in. southern pine CDX plywood. Biblis et al. (1996) also showed similar improvement with oriented strand board cores (85% SYP and 15% low density 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 (1976) investigated the tensile and stresswave timer modulus of elasticity (MOE) distribution of loblolly pine veneer as related to location within the stem 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 (1992) suggest that the inner core of each log produces veneer with lower MOE and specific gravity (SG).

Hunt et al. (1989) developed a data base for tensile properties of yellow-poplar veneer strands. Pugel (1990) 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 (1) silvicultural management strategy and (2) 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 and Methods

Four hundred clear, 1/8-in. thick by 1 in- wide by 12-in. long specimens were cut parallel to the grain from randomly selected full-size (54 in. x 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 airdry condition. In addition, 100 specimens were tested in tension at ovendry conditions, and 100 tensile specimens were tested airdry for each stand. The airdry specimens were stacked for six months in a constantly air-conditioned laboratory at room temperature with approximately 1/4-in. wide veneer stickers between them to allow for proper airflow. Ovendry specimens were dried for 48 hours at 105° C. Repeated weightings yielded constant

results and indicated that the equilibrium moisture content of most specimens was near 9 - 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-in. and the lengths with a digital micrometer to the nearest 0.0001-in. The thickness of each specimen was determined to the nearest 0.0001-in. with a digital micrometer. The airdry specimens were weighed at the time of test and then ovendried at 212 F 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 Data Analysis

Bending specimens were 1/8 in. thick and were tested over a 6-in. span (48:1 span to depth ratio) (S:D) on an Instron Universal Testing Machine with a MTS upgrade using a PC driven software package from MTS. For bending tests, the specimens were loaded at a constant rate of 0.40 in./min. until failure. Deflection was measured to the nearest 0.0001 in. Tensile specimens were tested to failure at a gauge length of 10 in. using a constant rate of 0.20 in./min. Specimen failures inside the grips were rejected and replaced with another specimen. A 5,000 lb. load cell

was calibrated for both bending and tensile testing to an accuracy of 0.01% of the measured load.

Data were downloaded from the MTS testing program, and the 2 x 5 factorial treatment structure was analyzed by AOV and regression techniques (1980) in accordance with SAS programming procedures (1989). There were two levels of MC (airdry and ovendry) and five levels of the stand factor. The bending and tensile tests were treated as separate experiments in the AOV.

Results and Discussion

Bending Properties

The mean mechanical and physical properties of the veneer specimens at airdry and ovendry moisture conditions for all five stands is summarized in Table 4. The AOV is summarized in Table 5. Loblolly pine MOR_b and MOE_b are not affected by silvicultural practice since the stand effect was an insignificant source of variance for both dependent variables (Table 5). The AOV 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 by changes in moisture content (19). Moreover, the small difference in the MC at the time of the tests of the two groups (ovendry and airdry) 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 5). The means values for MOR_b and MOE_b at airdry and ovendry moisture conditions are illustrated in Figure 1 and Figure 2, respectively. The

interaction of stand x MC for MOR_b is largely due to stands 1 (sudden sawlog) and 4 (single tree selection) in which the ovendry specimens yielded barely greater values than the corresponding airdry specimens (Figure 1). The stand x MC interaction for MOE_b appears to be attributable to stand 2 (conventional), which yielded a much lower airdry value than any of the other stands (Figure 2).

Tensile Properties

Table 4 shows the mean TS and MOE_t values for each stand at each moisture level. The AOV for TS and MOE_t is summarized in Table 5. TS differed significantly among stands (Table 5), but did not differ statistically between moisture levels. Airdry 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 than that of 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 4). The stand effect was a significant source of variation for TS (Table 5).

There was no statistical difference among the stands with regards to MOE_t. (Table 5). Within the stands, the airdry and ovendry samples were also not statistically different for MOE_t. (Table 5). As was the case for MOE_b, the effect of moisture on MOE_t is minimal below the fiber saturation point (Kollman and Côté 1984).

McAlister (1976) determined the dynamic modulus of elasticity (MOE_d) of loblolly pine veneer from three blocks within trees and three zones within blocks to range from 1.61 - 2.10 x 10^6 psi. The mean values for MOE_t range from 1.27 - 1.69 x 10^6 psi, and MOE_b ranged from 0.79 - 1.11 x 10^6 psi. The lower values of MOE_b than MOE_t was expected because TS mean values were greater than MOR_b. A correlation analysisindicated that MOE_b and MOR_b were significantly correlated (R = 0.66) as were MOE_t and TS (R = 0.75) (Table 6). Woodson (1973) has shown that MOR_b of 3-ply SYP plywood was unrelated to MOE_d of single veneers, but numerous previous researchers have found strong correlations, especially flatwise, between MOR_b and MOE_b of lumber (Doyle and Markwardt 1966; Galligan et al. 1977; Hoyle 1968 ; Johnson 1965). It appears based on the bending and tension data that MOR and MOE are also correlated for veneer strips.

It should be noted that these MOE_t values are much less than those reported by McAlister (1976) using stresswave techniques over a 92-in. gauge length. Furthermore, previous studies by Hunt et al. (1989) and McAlister (1982) 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. The MOE_t values are much less than the MOE_d reported by McAlister (1976) 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 this data with that of McAlister (1976). It is recognized that the stresswave timer will give more reproducible results with a longer gauge length, but accurate results have been

Table 4. Mean mechanical and physical properties of loblolly pine veneer strips from five silviculturally different stands tested either airdry or ovendry in either tension or bending.

	Stand[1]									
	1		2		3		4		5	
Property	AD[2]	OD[2]	AD	OD	AD	OD	AD	OD	AD	OD
Specific gravity[3]	0.50[4]	0.54	0.50	0.54	0.41	0.55	0.42	0.52	0.42	0.52
	(11.87)[5]	(11.25)	(10.72)	(9.25)	(5.09)	(13.53)	(4.39)	(13.17)	(3.65)	(12.15)
Moisture content[6]	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)	
Tensile strength	11,606	14,025	11,499	13,611	10,607	12,845	13,102	13,359	11,614	14,088
(psi)	(28.26)	(26.15)	(29.05)	(31.33)	(29.68)	(35.10)	(33.76)	(31.99)	(21.41)	(26.83)
Tensile modulus of elasticity	1.47	1.49	1.62	1.59	1.27	1.48	1.69	1.63	1.54	1.57
(x 10^6 psi)	(25.93)	(24.76)	(28.18)	(25.70)	(26.90)	(32.18)	(30.35)	(26.32)	(24.19)	(28.75)
Bending modulus of rupture	5,101	5,461	3,210	5,075	4,278	6,057	5,493	5,743	4,651	5,691
(psi)	(24.55)	(19.43)	(18.35)	(20.09)	(20.09)	(18.29)	(21.09)	(21.98)	(21.09)	(20.09)
Bending modulus of elasticity	0.98	1.09	0.79	1.09	1.01	1.11	1.00	1.08	1.00	1.08
(x 10^6 psi)	(20.01)	(22.98)	(18.06)	(21.09)	(16.06)	(19.96)	(21.97)	(21.07)	(21.08)	(21.96)

[1]Stand 1 = Sudden sawlog.
Stand 2 = Conventional.
Stand 3 = Natural regeneration.
Stand 4 = Single tree selection.
Stand 5 = Crop trees.
[2]AD = Airdry , OD = ovendry.
[3]Specific gravity was determined based on conditions at time of test (ovendry or airdry).
[4]Represents the mean of 200 specimens.
[5]Coefficient of variation (%).
[6]Moisture content on ovendry basis. OD samples were tested ovendry, and AD samples were tested airdry.

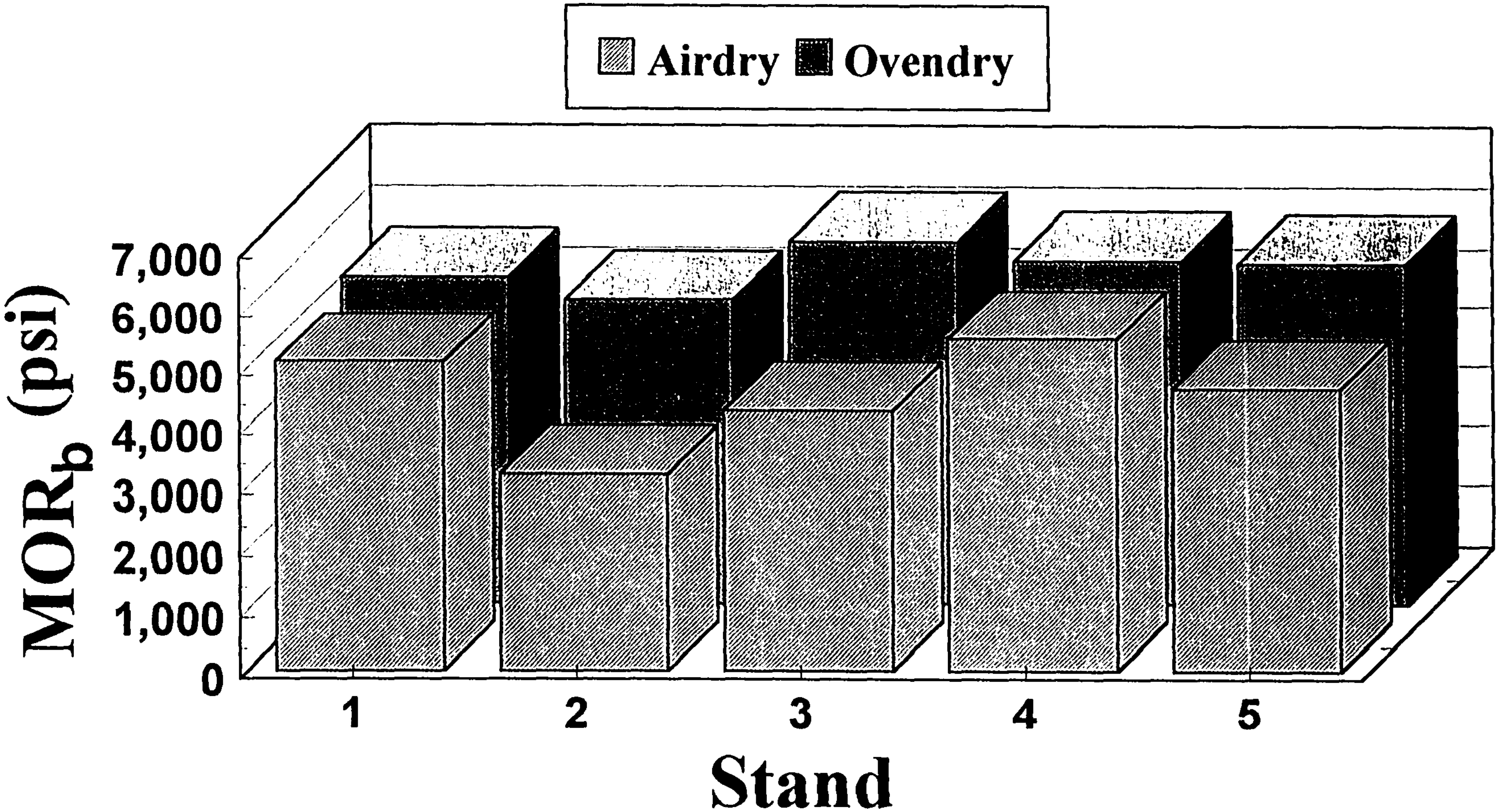

Figure 1. Bending MOR(MOR_b) of loblolly pine veneer from five silviculturally different stands at airdry and ovendry moisture conditions

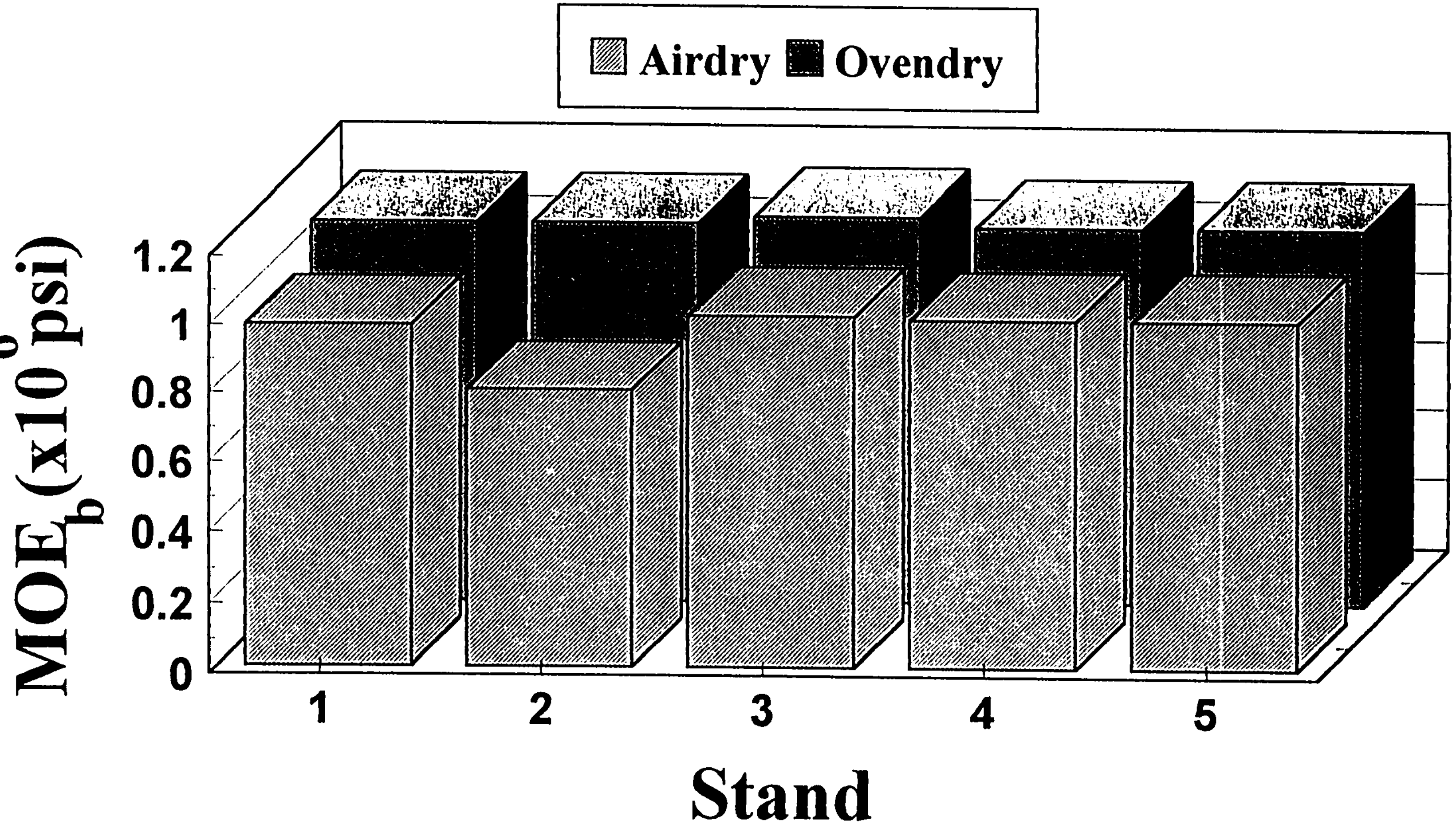

Figure 2. Bending MOE (MOE_b) of loblolly pine veneer from five silviculturally different stands at airdry and ovendry moisture conditions

Table 5. Statistical analysis of loblolly pine static bending data.

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

[1]Stand 1 = Sudden sawlog.
Stand 2 = Conventional.
Stand 3 = Natural regeneration.
Stand 4 = Single tree selection.
Stand 5 = Crop trees.
Note: **Denotes significance at $\alpha = 0.01$.

Table 6. 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
		Airdry and ovendry samples		
MOR_b	1.00	0.63** (0.0001)[1]	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
		Airdry samples		
	MOR_b	MOE_b	TS	MOE_t
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	MOE_b	TS	MOE_t
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

[1]P value.

Note: **Denotes significance at alpha = 0.01.

obtained with flake-sized specimens. Moreoever, since MOE_d is a dynamic test and is not subjected to rheological effects, its values are typically 5 - 10 % higher than similar static MOE values (Bodig and Jayne1982).

The nondestructive method of MOE_d is widely considered to be an acceptable alternative to destructive determination of MOE of wood. The numerous investigations that have been conducted to confirm the strong correlation between MOE_d and destructive MOE are summarized by Ross and Pellerin (1994).

Bending and Tensile Differences

Results for flexural strength (MOR_b) were dramatically less than tensile strength (TS). The mean MOR_b for stands 1, 2, 3, 4, and 5 were 56, 72, 43, 58, and 60 percent lower in the airdry condition, respectively. The mean MOR_b for the ovendry specimens from stands 1 - 5 was 61, 63, 67, 57, and 60 percent lower, respectively. This decrease for MOR_b 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 in. span (14:1 S:D) for 2 in. x 2 in. x 30 in. specimens. It was shown by Baumann (1922) that the modulus of rupture decreases with decreasing ratio of span to depth , and only for values with a S:D $\geq$ 20:1 does the bending strength of wood becomes approximately constant. Since the S:D ratio was greater than 20:1, this partially explains the lower bending values.

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. Since MOR is largely a defect-controlled property, and it is believed that failure in flexure is largely governed by defects in the tension zone (Crisswell and Vanderbilt 1982); therefore,

it is important to consider that the lathe checks were on the tension side of the 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. Also, 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 stain 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.

CHAPTER 4

EFFECT OF SILVICULTURAL PRACTICE AND VENEER GRADE LAYUP ON SOME MECHANICAL PROPERTIES OF LOBLOLLY PINE LVL

A constantly increasing global population has lead to a greater demand for wood. Many different wood-based composites have been developed to help reduce the demand on solid wood. Products such as plywood, particleboard and medium density fiberboard provide building materials in a much larger and more convenient sizes than solid wood. These panel type products are accepted for sheathing purposes. However, many of these wood-based composites lack the necessary strength and stiffness properties required for structural applications. Laminated veneer lumber (LVL) is an alternative wood-based composite to solid wood for structural applications. LVL provides not only larger and more convenient product sizes but also higher and more reliable engineering properties. LVL is one of the latest of the ever evolving new types of wood composites, which possesses more reliable strength for design purposes and allows for superior utilization efficiency of the timber resource. LVL possesses many of the critical mechanical properties of lumber and has been researched and commercially produced for several years in the United States.

Early research by Koch showed that a greater MOE and allowable fiber stress can be obtained with 2 in. x 4 in. southern yellow pine (SYP) LVL compared to sawn lumber of equal dimensions (Koch 1967a; Koch 1967b). Beam strength was found to be optimum with the stiffest veneers on each face (Biblis and Carino 1993;

Koch 1967a; Koch 1967b; Koch 1973; Koch and Bohannan 1965). Additional information regarding the effect of butt joints (Koch and Woodson 1968) and finger joints (Biblis and Carino 1993) is also available.

With regards to silvicultural effects on SYP LVL, Biblis and Carino (1993) manufactured 13-ply panels and found a greater MOE and MOR with B-grade veneer from a 50-year-old stand than from C-grade veneer from a 20-year-old stand. A detailed study by Kretschmann et al. (1993) found that SYP and Douglas-fir LVL manufactured with increasing percentages of juvenile wood exhibited an expected decrease in MOR and MOE. Their study showed that LVL of structural integrity can be fabricated with significant percentages of juvenile wood but will consequently lead to products of lower design values than mature wood.

The objectives of this study were not to compare juvenile and mature wood properties but rather to study LVL properties from five silviculturally different SYP stands. Also, this project attempted to determine the optimal placement of different veneer visual grades in a LVL panel. Specifically, the objectives were to (1) determine the effect of silvicultural practice on the MOR and MOE of SYP LVL from five silviculturally different stands and (2) determine the effect of five different veneer grade layups on MOR and MOE.

Panel Fabrication and Data Analysis

For determination of the effect of silvicultural practices, LVL was manufactured from stands 1-4, with either (1) all A-grade veneer or (2) all C-grade veneer. For stand 2, some knot-free, B-grade veneer was used in addition to A-

grade. Each panel type was replicated four times. Veneer from stand 5 (crop trees) was excluded from the effect of silvicultural practices study in order to have sufficient veneer to determine the effect of five different veneer layups on MOR and MOE. All layups were fabricated four times.

Panel fabrication was accomplished at a Riverwood International plywood mill at Joyce, LA. A commercial extended phenolic resin (52 % solids) was applied to veneers with a curtain coater at a rate of 92 pounds per 1,000 $ft.^2$ of double glue-line. The tight side was outermost on both faces of all panels and inner veneers were assembled randomly with respect to tight side and loose side. Finished billets were stored at the mill for 10 hours before shipping. The four replicate billets of each specific assembly type were cut into beams of approximately 1.5 in. x 3.75 in. x 8 ft. Beams that showed obvious glue-line defects, such as blowout, were discarded.

Edge-wise bending specimens were cut to 86-in. lengths and tested over an 80-in. span. Flat-wise bending tests were conducted with 38-in.-long specimens over a 30-in. span. Sample beams were air-dried to an approximate equilibrium MC of 11 %. The airdry specimens were stacked for six months in a constantly air-conditioned laboratory with lumber stickers every 18 inches to allow for proper airflow. Repeated weight measurements yielded constant results and indicated that the equilibrium moisture content of most specimens was near 10 - 11 percent. Testing was done in accordance with ASTM D-198 (1994). Mechanical properties tests were accomplished with an Instron testing machine using a MTS software package. The software package allowed for data to be downloaded and analyzed using a

factorial analysis on SAS (1989). Tukey's Honestly Significant Difference test was employed to determine significance between means. Deflection was measured to the nearest 0.001 in. After each test, a six-inch long sample was cut from outside the failure zone for SG and moisture content (MC) determination.

Results and Discussion

Effect of Silvicultural Practice

The effects of silvicultural practice and veneer grade on edgewise MOR and MOE and flatwise MOR and MOE are shown in Figure 3 and Figure 4, respectively. Table 7 shows the mean MC and SG of these specimens. For any specimen group , the number to the left of the dash is the stand number (1, 2, 3, 4, or 5) and the letter to the right of the dash is the veneer visual grades within the panel (A or C).

Results from unpaired t-tests indicate that the MOR in the edgewise orientation of the A-grade panels from stand 1 (1-A) (12,045 psi) is significantly higher than 2-A (10,268 psi), 3-A (9,584 psi), and 4-A (10,631 psi) by 17, 26, and 13 percent , respectively (Table 5). In the flatwise testing orientation, 1-A (13,751 psi) was significantly higher (Table 5), respectively, than the mean values obtained from 2-A (9,120 psi), 3-A (10,606 psi), and 4-A (8,638 psi) by 51, 30, and 59 percent, respectively. The high strength of LVL made from stand 1 (sudden sawlog) can be partially attributed to the higher specific gravity of these panels (Table 7).

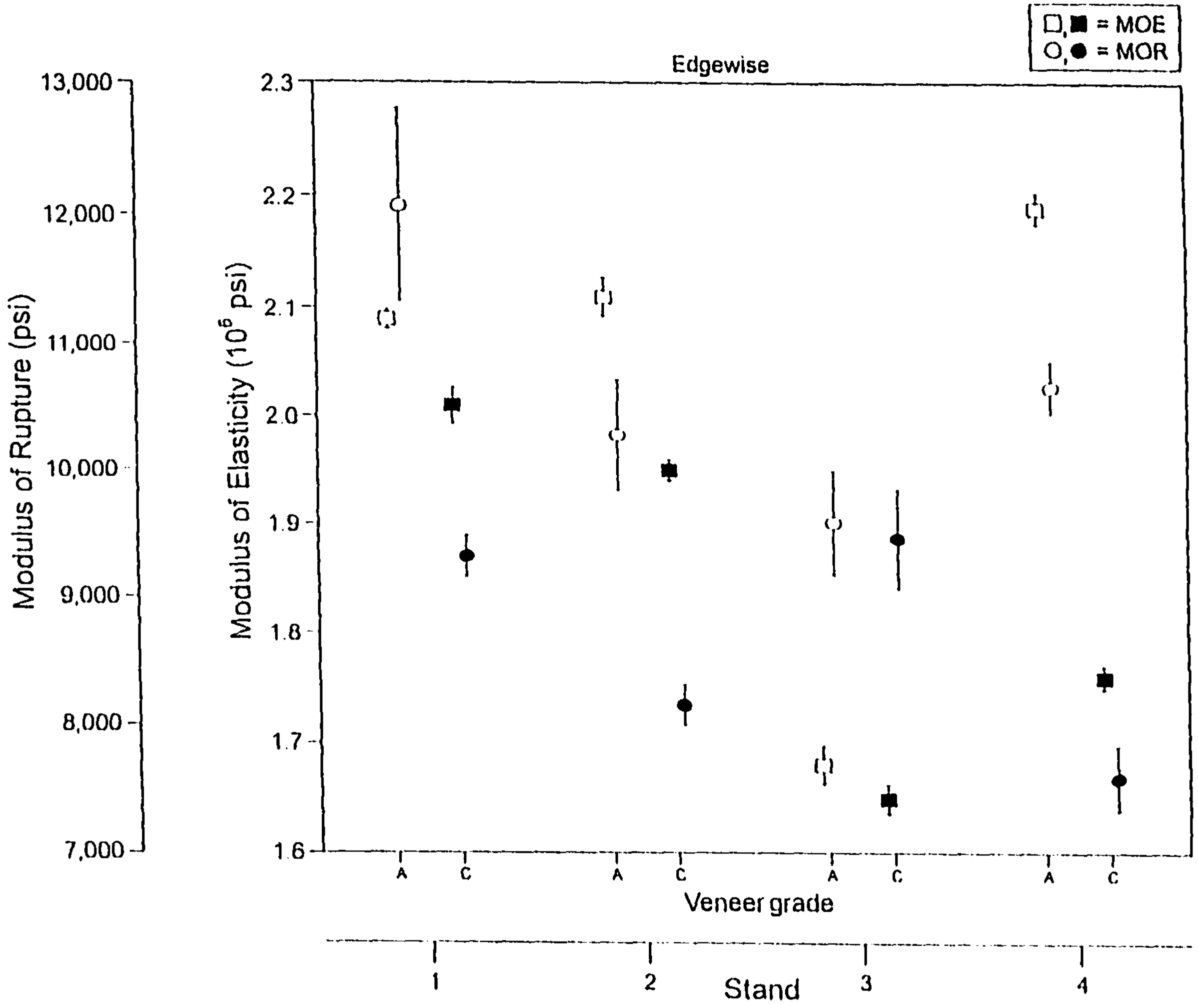

Figure 3. The effect of four different silvicultural treatments and two different veneer visual grades on edgewise modulus of rupture and modulus of elasticity of 13-ply loblolly pine laminated veneer lumber. The white circle and white square denote solid A-grade specimens, and the black circle and black square represent solid C-grade specimens.

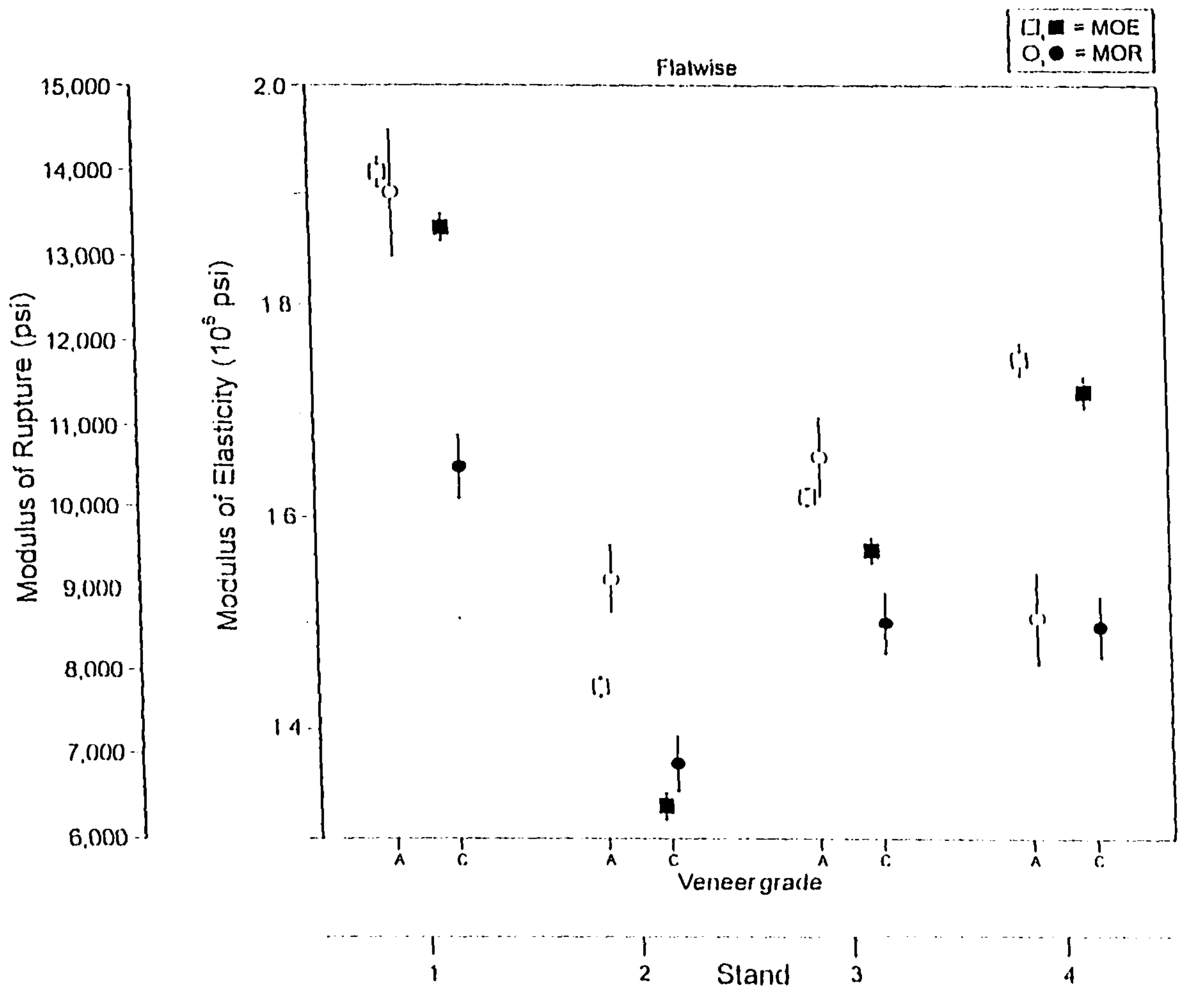

Figure 4. The effect of four different silvicultural treatments and two different veneer visual grades on flatwisese modulus of rupture and modulus of elasticity of 13-ply loblolly pine laminated veneer lumber. The white circle and white square denote solid A-grade specimens, and the black circle and black square represent solid C-grade specimens.

Table 7. Effect of silvicultural practice and veneer grade on basic physical properties of loblolly pine laminated veneer lumber.

Stand-Veneer grade[1]	Moisture content (%)	Specific gravity[2]
1-A	11.45[3] (5.04)[4]	0.73 (3.31)
1-C	11.49 (4.12)	0.68 (2.98)
2-A	10.43 (3.19)	0.70 (3.33)
2-C	10.23 (4.00)	0.65 (3.98)
3-A	11.48 (2.95)	0.66 (4.09)
3-C	11.23 (1.09)	0.64 (4.10)
4-A	10.86 (3.06)	0.68 (4.65)
4-C	10.79 (4.95)	0.64 (3.93)

[1]The number to the left of the dash represents the stand and the letter to the right corresponds to panel fabrication with either all A-grade veneer (A) or all C-grade veneers.
Stand 1 = Sudden sawlog.
Stand 2 = Conventional.
Stand 3 = Natural regeneration.
Stand 4 = Single tree selection.
[2]Specific gravity based on volume at 11% equilibrium moisture content and ovendry weight.
[3]Represents the mean of 11 samples.
[4]Values in parenthesis are coefficients of variation (%).

Table 8. Ratio of mean values of laminated veneer lumber groups of differing stands and veneer visual grades.

	Edgewise		Flatwise	
Comparison[1]	MOR	MOE	MOR	MOE
1-A/2-A	1.17*	0.99	1.51*	1.33
1-A/3-A	1.26*	1.24	1.30*	1.19
1-A/4-A	1.13*	0.95	1.59*	1.10
2-A/3-A	1.07	1.26	0.86	0.89
2-A/4-A	0.97	0.96	1.06	0.82
3-A/4-A	0.90	0.77	1.23*	0.93
1-C/2-C	1.14*	1.03	1.52*	1.41
1-C/3-C	0.98	1.22	1.22*	1.19
1-C/4-C	1.23*	1.14	1.23*	1.09
2-C/3-C	0.86*	1.18	0.80	0.85
2-C/4-C	1.07	1.11	0.81	0.77
3-C/4-C	1.24*	0.94	1.01	0.91

*Denotes significance at alpha = 0.05.
[1]Stand 1 = Sudden sawlog.
Stand 2 = Conventional.
Stand 3 = Natural regeneration.
Stand 4 = Single tree selection.

A similar trend was observed for the MOR of the C-grade specimens. The edgewise MOR of group 1-C (9,307 psi) was significantly greater than 2-C (8,156 psi) and 4-C (7,595 psi) by 14 and 23 percent, respectively (Table 8). However, 3-C (9,454 psi) yielded a slighter higher edgewise MOR than 1-C, although not significantly greater. In terms of flatwise MOR, 1-C (10,491 psi) was 52, 22, and 23 percent greater statistically (Table 8) than 2-C (6,887 psi), 3-C (8,587 psi), and 4-C (8,533 psi), respectively. The MOR pattern with regards to the different stands and veneer grade layups is more clearly illustrated in Figure 3. This figure shows that in general, stand 1, particularly 1-A, is the most favorable in terms of both flatwise and edgewise MOR; there were few significant differences between the other stands for MOR (Table 8).

When comparing the edgwise and flatwise MOR mean values of the eight silvicultural-grade combinations, on four occasions the mean flatwise MOR was greater than the corresponding mean edgewise MOR (Figure 3, Figure 4). This can largely be attributed to the ability to cut samples from the 1.5 in. x 3.75 in. x 8 ft. beams for flatwise testing that contained visually sound gluelines. Edgewise specimens were tested over a much longer span and therefore had a greater probability of containing areas of lesser glueline integrity.

It is interesting to note from data in an earlier study on these same stands by Groom and Mullins (1992) that all of the A-grade veneer from stand 1 (sudden sawlog) came from the bottom 20 ft. of the trees. All of the C-grade veneers were obtained from the area 20-30 ft. above the stumps. None of the stand 1 (sudden

sawlog) veneer came from the live crown area, which is the upper area of the crown that is still alive. The live crown ratio (percentage of total tree height comprised of living branches) for harvested trees from this stand was fifty-six percent (Table 7).

Stands 2-4 had 39, 39 55, and 56 percent, respectively, live crown ratios. This live crown region is critical for both lumber and veneer because MOR is largely a defect controlled property, and failure in flexure is largely governed by defects in the tension zone (Criswell and Vanderbilt 1982). The live crown has many branches and the veneer obtained from this region will be knotty. Therefore, the C-grade LVL from stand 1 was less knotty and consequently stronger than that from the other stands.

MOE, which is slightly more controlled by fibril angle than MOR (4), was less definitive. Figure 3 and Figure 4 show that A- and C-grade LVL from stands 1-4 yielded fairly similar MOE mean values for either edgewise or flatwise testing orientations. Furthermore, there were no significant differences detected between any of the groups for either testing orientation (Table 8). The homogeneity of the MOE data suggests that the 12 stiff glue lines were similar between panels and dominated the flexibility of these 25 layered composites, i.e., 13 veneer sheets and 12 glue lines.

It is known that knots will decrease numerous mechanical properties of wood, including MOE. However, the similar MOE values for A- and C-grade LVL for each stand reinforces the theory that MOE is mainly an anatomical property, not a defect driven property, since C-grade veneer will contain more knots than A-grade.

The strong relationship between longitudinal Young's modulus and fibril angle has been shown by Meylan and Probine (1969) and Cave (1968). However, for some inexplicable reason A-grade from stand 4 gave a much greater MOE than C-grade when tested edgewise. Since the phenomenon did not occur in the flatwise orientation, it is possible that this can be attributed to the aforementioned specimen size differences and probability of greater glueline integrity with shorter specimens, i.e. flatwise specimens. Further research is needed to exactly determine the nature of the discrepancy between A- and C-grade LVL in the edgewise testing orientation.

The differences in the edgewise MOE mean comparisons ranged from 1-26 percent and from 7-41 percent for flatwise (Figure 4). It is emphasized that the veneer for this study came from peeler bolts located all along the bole. The veneer was not separated by outer, middle, and core regions or by location within the bolts but was grouped according to stand, tree number, and visual grade. Consequently, any of the veneer obtained for either A- or C-grade from any stand will likely have had a wide variation in anatomical properties, such as fibril angle, and therefore, the differences in MOE values between stands are minimal. The pattern of decreasing fibril angle from pith to bark of SYP trees has been well documented by Megraw (1985). Biblis and Carino (1993) believed that the small differences in MOE values from SYP LVL with different finger-jointing orientation and/or different direction of load application is probably due to the fact that MOE values correspond to relatively smaller stress levels compared to ultimate stress level at which the MOR values are determined.

Table 9. Edgewise design values for 2 in. - 4 in. thick x 2 in. - 4 in. wide visually graded Southern pine lumber and the stand-veneer grade and groups that meet the design value based on edgewise MOE (E) mean value.

Commercial grade	Modulus of elasticity (E) ($x10^6$ psi) [1]	Stand-veneer grade[2] and groups[3] meeting requirement
Dense select structural	1.9	1-A, 1-C, 2-A, 2-C, 4-A, group II, group III, group IV
Select structural	1.8	group V
Non-dense select structural	1.7	--
No. 1 Dense	1.8	--
No. 1	1.7	4-C
No. 1 Non-dense	1.6	3-A, 3-C, group I
No. 2 Dense	1.7	--
No. 2	1.6	--
No. 2 Non-dense	1.4	--
No. 3	1.4	--
Stud	1.4	--

[1]Source: American National Standards Institute/National Forest Products Association (1991).

[2]Stand 1 = Sudden sawlog.
Stand 2 = Conventional.
Stand 3 = Natural regeneration.
Stand 4 = Single tree selection.

[3]Group I = AACCCCCCCCCCAA
Group II = ACCCACCCACCCA
Group III = AACCCCCCCCCCCA
Group IV = ACCCCCACCCCCA
Group V = AACCCCACCCCAA

The mean values obtained from this study were compared with those required for 2 in. x 4 in. SYP visually graded lumber. Although 1-A (2.09 x 10^6 psi) and 4-A (2.19 x 10^6 psi) gave the most favorable results, several other groups yielded mean values sufficient for dense select structural grade. The poorest LVL groups still made the requirement for No. 1 Non-dense (Table 9).

Effect of Veneer Grade Layup

The effect of veneer layup on edgewise and flatwise MOR and MOE of SYP LVL is summarized in Figure 5 and was done exclusively with veneer from stand 5 (crop trees). Table 10 summarizes the basic physical properties of these five groups, i.e., I, II, III, IV, and V.

No significant differences were detected for edgewise MOR values. This was expected due to the importance of the 12 rigid glue lines in edgewise loading. Group III and group IV gave the highest mean values of 9,850 psi and 9,299 psi, respectively. The mean comparison range was fairly small (0-27 percent) (Table 11).

A similar pattern was detected for flatwise MOR with group III (11,806 psi) and group IV (10,483 psi) possessing the largest means (Figure 5). Statistical significance was detected in that group II (10,128 psi), group III (11,860 psi), and group IV (10,483 psi) were all significantly greater than group V (8,253 psi), which was not statistically different from group I (8,777 psi).

Edgewise MOE was the only test in which group III did not yield the highest mean value. Group III (2.00 x 10^6 psi) and group IV (2.02 x 10^6 psi) were both

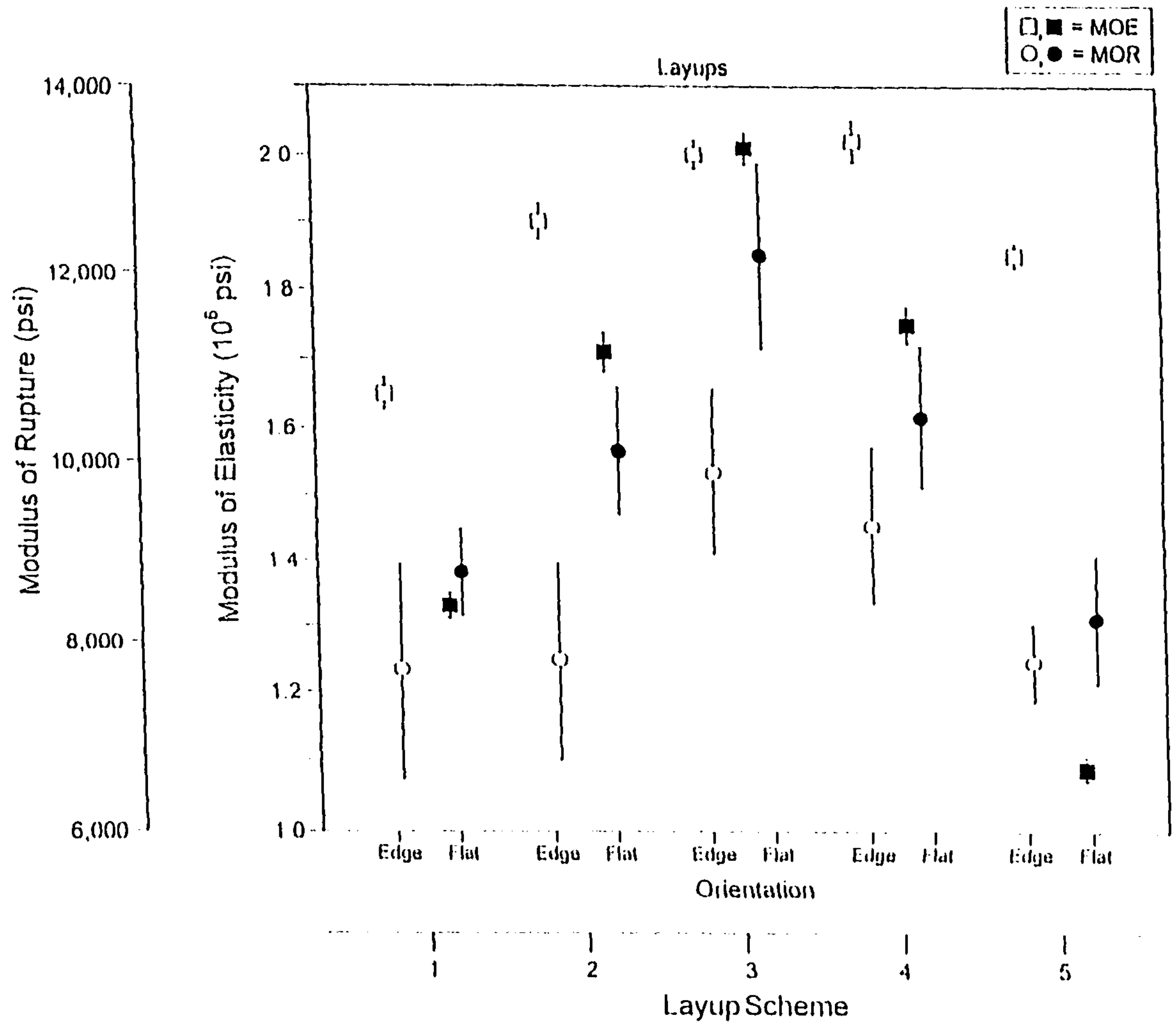

Figure 5. The effect of five different veneer visual grade layups on edgewise and flatwise modulus of rupture of 13-ply loblolly pine laminated veneer lumber. The white circle and white square denote edgewise properties, and the black circle and black square represent flatwise properties.

Table 10. Effect of various veneer grade layups on basic physical properties of 13-ply loblolly pine laminated veneer lumber using veneers from stand 5 (crop trees) exclusively.

Group	Layup	Moisture content (%)	Specific gravity[1]
I	AACCCCCCCCCAA	11.7[2] (7.68)[3]	0.65 (5.59)
II	ACCCACCCACCCA	11.8 (7.35)	0.64 (3.53)
III[4]	AACCCCCCCCCCA	11.3 (5.99)	0.66 (7.14)
IV	ACCCCCACCCCCA	11.1 (3.72)	0.65 (4.70)
V	AACCCCACCCCAA	11.6 (6.04)	0.64 (4.25)

[1]Specific gravity based on volume at 11% equilibrium moisture content and ovendry weight.
[2]Represents the mean of 11 samples.
[3]Values in parentheses are coefficients of variation (%).
[4]Group III was tested with AA side in compression and A side in tension; all other layups were symmetric with regards to veneer grades within the panel.

Table 11. Ratio of mean values of loblolly pine laminated veneer lumber groups of differing veneer visual grade layups using veneers from stand 5 (crop trees) exclusively.

	Edgewise		Flatwise	
Group comparison[1]	MOR	MOE	MOR	MOE
I / II	0.99	0.87	0.87	0.78
I / III	0.78	0.83*	0.74	0.66*
I / IV	0.83	0.82*	0.84	0.76
I / V	0.99	0.89	1.06	1.22
II / III	0.79	0.95	0.85	0.85
II / IV	0.84	0.94	0.97	0.98
II / V	1.00	1.03	1.23*	1.57*
III / IV	1.06	0.99	1.13	1.15
III / V	1.27	1.08	1.44*	1.84*
IV / V	1.20	1.09	1.27*	1.61*

*Denotes significance at alpha = 0.05.

[1]Group I = AACCCCCCCCCAA
Group II = ACCCACCCACCCA
Group III = AACCCCCCCCCCA
Group IV = ACCCCCACCCCCA
Group V = AACCCCACCCCAA

statistically similar to each other and group II (1.90 x 10^6 psi) and group V (1.85 x 10^6 psi) as well. All groups were significantly higher than group V (1.65 x 10^6 psi). Group II, group III, and group IV all met the requirements for Dense select structural 2 in. x 4 in. SYP visually graded lumber (Table 9).

For flatwise MOE, group III (2.01 x 106 psi), group IV (1.75 x 106 psi), and group II (1.71 x 106 psi) were all statistically similar. Group III was 34 and 16 percent greater than group I and group V, respectively. A similar pattern for edgewise and flatwise MOE is shown in Figure 5.

These results have many implications. One is that group III, which contained two A-grade veneers on one face and one A-grade veneer on the opposite face, showed the highest mean for all categories except edgewise MOE. Group IV, which had a single A-grade veneer on each face and one in the middle of the panel, gave the highest edgewise MOE and was second for all other categories. These two groups gave much higher values than those of group I and group V, which contained 4 and 5 A-grade veneers, respectively.

A possible financial gain may be realized by using only 3 A-grade veneers but placing them in a manner similar to group III or group IV. This theory was first proposed by Koch and Bohannan (1965), and Koch (Koch 1967a; Koch 1967b). They proposed placing the stiffest laminae in the outer portions and the most limber

in the center of the billet. There is little to gain by placing a single A-grade veneer in the middle of the panel as was the case with group IV.

Mechanical properties can be significantly improved by optimal arrangement of A-grade veneer within a panel. It is emphasized that all of the LVL groups for the effect of veneer grade layup study were manufactured with veneer from stand 5 (crop trees).

CHAPTER 5

EFFECTS OF SILVICULTURAL PRACTICE AND VENEER LAYUP ON SOME MECHANICAL PROPERTIES OF LOBLOLLY PINE PLYWOOD

SYP plywood is an accepted building material and is used in numerous structural and nonstructural applications. With the inevitable increase in world population, SYP plywood production will need to continue to become more efficient. Numerous investigations have been conducted to improve the quality of this wood composite panel. Many have focused on improving plywood adhesives and hot-pressing technology.

Research addressing the effect of silvicultural practice on SYP plywood is sparse. MacPeak et al. (1987) have found that plywood manufactured from veneer cut from fast-grown trees (20 - 25-years-old) had mechanical properties that were marginal in terms of stiffness and modulus of elasticity and reduced for bending strength. Research addressing the effect of different veneer grades within the panel is also sparse for SYP bending properties. Biblis and Lee (1987) reported on the effect of veneer quality and moisture content (MC) on the compressive, but not on bending, properties of SYP plywood and found a significant increase in compressive strength of 3-ply SYP plywood by improving the grades of the face veneers from C and D to B.

The objectives of this research were to (1) determine the effect of silvicultural practices on SYP plywood strength properties, (2) evaluate the effect of different

veneer grades within a panel, and (3) to examine the effect of moisture level on bending properties.

Materials and Methods

Full size (54 in. x 98 in.) A- and C-grade veneer sheets from each stand were randomly selected and a 21 in.^{2} piece was cut with the grain parallel in one direction. Three-ply plywood panels were produced from veneer from each stand with four different layups. The layups were (1) all A-grade veneer (AAA), (2) all C-grade veneer (CCC), (3) A-grade veneer on one face only and C-grade veneer on the other face and core (ACC), and (4) A-grade veneer on each face and C-grade veneer in the core (ACA). Four panels (21 in. x 21 in.) were manufactured for each specific veneer layup from each of the five stands. Phenol formaldehyde resin (43% solids) was spread at 75 lbs. per 1,000 ft.^{2} of double glueline and the veneers were immediately assembled into 3-ply panels with the tight side facing out on each face veneer. The open assembly time was minimal in order to resemble full size plant manufacturing conditions. After sandwich assembly, panels were prepressed for 25 minutes at 10 psi. Panels were then hot-pressed for two minutes at a platen temperature of 285 F and 175 psi. As the panels were removed, they were placed in a hot-stack box where they remained overnight.

Panels were edged to 19 in.^{2} dimensions. Six bending specimens (1 in. x 19 in.) were cut from each panel. The remaining portion of each panel was cut into shear samples (1 in. x 3.25 in.). All bending samples were conditioned to the nominal MC of 7.2 % at 40% RH and 100 F in an Aminco chamber. From each

panel, three bending specimens were tested at approximately 7 % MC, and three were tested in a wet condition (after a 24-hr. water soak) (American Society of Testing and Materials 1994). The width and thickness of all samples were measured at 3 approximately evenly spaced locations with a digital caliper to the nearest 0.0001 in. The average of these three measurements was used for subsequent mechanical and physical property determination. The 24-hour soak bending samples were measured before and after soaking to determine width and thickness swell. Swelling was determined as a percentage of dimension increase from the original dry dimensions (7 % MC). One third of the shear samples from each panel were allocated to one of three shear tests and all were tested wet. The vacuum-soak samples were placed in a pressure vessel and submerged in water at 120 F during which a vacuum of 15 in. of Hg was drawn. After the vacuum was released, the samples continued to soak for 15 hours at atmospheric pressure. The boil-dry-boil samples were boiled in water for 4 hours and then dried for 20 hours at 145 $\pm$ 5 F and then boiled again for 4 hrs and cooled in water. The vacuum-pressure samples were subjected to 25 in. Hg for 30 min., then 65-70 psi pressure for 30 min. (American Plywood Association - The Engineered Wood Association 1983).

At the conclusion of shear testing, all samples were ovendried and the percentage of wood failure was visually estimated. From each stand, three shear samples were randomly selected and cut to 0.25 in. lengths. The widths and thicknesses remained approximately 1 in. and 0.375 in., respectively. These samples were sanded on the ends (1 in. x 0.375 in. faces) and placed on a Hewlett-Packard

ScanJet IIc/ADF image scanner, which produced a digitized black and white image that was transferred to a computer algorithm to determine the percentage of black (latewood) and white (earlywood) in the image.

Specimen Testing and Data Analysis

Static bending tests were conducted over a 18 in. span with a crosshead speed of 0.19 in./min. using a computer-driven software package on an Instron testing machine with a MTS upgrade. All samples were symmetric with respect to veneer grade arrangement except ACC. The ACC samples were consistently tested with the A-grade veneer on the compression side and the C-grade veneer on the tension side during the bending tests. The software package allowed for data to be downloaded and analyzed using a factorial analysis on SAS (1989). Tukey's Honestly Significant Difference test was employed to determine significance between means.

Results and Discussion

Bending Properties

Silvicultural Effect. The results of the factorial analyses of the bending strength data are summarized in Table 12. The stand effect is a significant source of variation for modulus of rupture (MOR) and modulus of elasticity (MOE) of the wet samples and for the MOE of dry samples. The moduli in both wet and dry conditions were significantly affected by the layup of veneer grades in the panels.

Significant differences in mechanical properties attributable to the stand effect were anticipated due to the heterogeneity of the five silvicultural strategies employed

Table 12. Factorial analysis of modulus of rupture (MOR) and modulus of elasticity (MOE) of 3-ply loblolly pine plywood.

		MOR - P values		MOE - P values	
SOV	df	Dry condition	Wet condition	Dry condition	Wet condition
Stand (site)	4	0.1639	0.0002**	0.0152*	0.0027**
Layup	3	0.0031**	0.0005**	0.0063**	0.0036**
Stand*Layup	12	0.0096**	0.7218	0.0002**	0.0110*

*Denotes significance at alpha = 0.05.
**Denotes significance at alpha = 0.01.

on each of the five stands and the differing stand ages. The mean latewood percentage from the five stands ranged from 53 - 61 percent and seems not to be influential for mechanical properties (Table 13).

Stand 2 (conventional) gave the highest dry MOR (14,008 psi) and was significantly superior for MOE in the dry condition. This finding is important in that a conventional SYP stand, which was managed for lumber production, yielded plywood MOR that was 6 and 10 percent higher, respectively, than stand 1 (sudden sawlog) and stand 3 (natural regeneration). The sudden sawlog silvicultural method is considered advantageous for rapidly producing sawlogs, but appears less favorable for plywood. Therefore, these finding suggests that foresters will not need to segregate stands for either end-product (lumber or plywood), but simply continue to manage in a traditional manner and produce whatever product that is most economically advantageous at harvest. In short, no special silvicultural method appears necessary to produce Southern pine plywood with favorable mechanical properties.

Table 13. Basic physical properties in the dry condition and MOR and MOE reduction in the wet condition of 3-ply loblolly pine plywood.

	Dry condition (40 % RH, 110 F)			Wet condition (24-hr. water soak)				
Stand	Latewood (%)	MC[4] (%)	SG[5]	MC[3] (%)	MOR reduction (%)	MOE reduction (%)	Thickness swell (%)	Width swell (%)
1[1]	57.15[2]	7.2[6]	0.67	28.83	64.46	42.72	13.99 (A)[7]	1.60 (A)
	(2.15)[3]						(0.49)[8]	(0.98)
2	53.14	7.3	0.68	28.91	65.48	43.10	15.46 (A)	1.58 (A)
	(2.54)						(0.75)	(0.38)
3	60.72	7.3	0.65	30.01	61.28	36.19	12.04 (B)	1.54 (A)
	(0.70)						(0.35)	(0.61)
4	60.81	7.4	0.69	27.71	52.92	24.76	9.79 (C)	1.52 (A)
	(1.76)						(0.51)	(0.43)
5	56.86	7.7	0.63	26.11	58.34	25.81	9.62 (C)	1.58 (A)
	(1.19)						(0.43)	(0.60)

[1]Stand 1 = Sudden sawlog.
Stand 2 = Conventional.
Stand 3 = Natural regeneration.
Stand 4 = Single tree selection.
Stand 5 = Crop trees.
[2]Each mean value represents the mean of 12 samples.
[3]Coefficient of variation (%).
[4]Moisture content (%) ovendry basis.
[5]Specific gravity based on volume and weight at 40% RH and 110 F.
[6] Each mean value represents the average of 96 samples.
[7]Tukey grouping.
[8]Coefficient of variation (%).

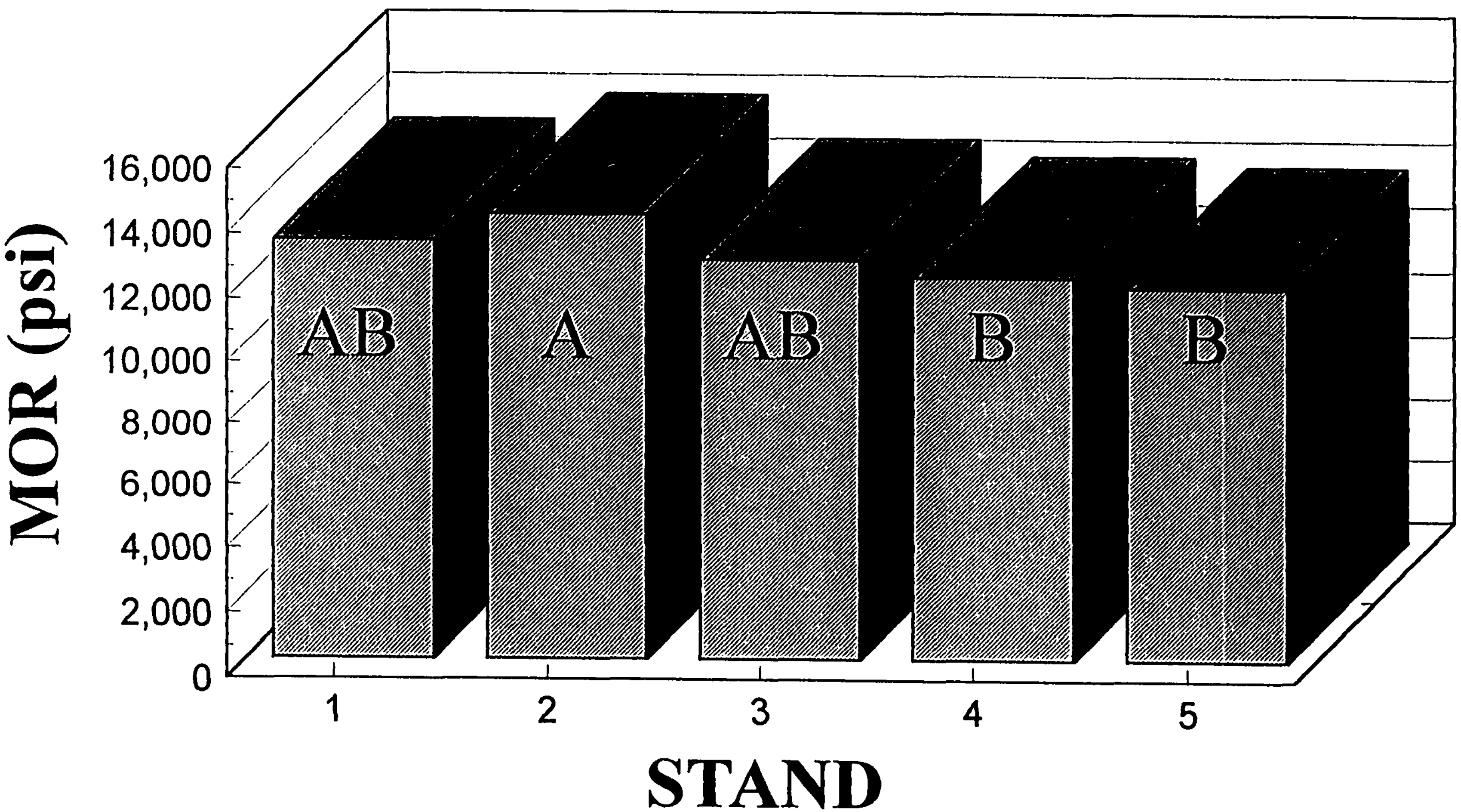

Figure 6. Effect of five different silvicultural strategies on on the mean MOR of 3-ply loblolly pine plywood. The letters proximate the means are Tukey values.

It is emphasized that stand 1 (sudden sawlog) (13,202 psi) and stand 3 (natural regeneration) (12,632 psi) were not found to be significantly different from stand 2 (conventional) for MOR in terms of Tukey groupings (Figure 6). The sudden sawlog silvicultural method was designed to produce sawlog size logs as rapidly as possible.

However, it appears that while the quantity of timber is relatively high for stand 1 (sudden sawlog) (basal area = 90 $ft.^2$/acre) the quality of plywood from this stand and quantity of timber is less than that of stand 2 (conventional) (basal area = 118 $ft.^2$/acre). It is known that factors such as knottiness, stem taper, growth rate, and percentage of juvenile wood should have similar detrimental effects on both lumber and plywood properties. Therefore, the lumber quality of stand 1 (sudden sawlog) is questionable given the plywood results. Further study towards this end is necessary.

The live crown region is the percentage of the total length of the stem that is covered by live branches. This region is critical for both lumber and veneer because wood obtained from this region is knotty and not as strong as defect-free wood. Also, since wood from this region is near the photsynthetically active live crown its properties are detrimentally influenced more than wood from lower on the bole. The increase in specific gravity from pith to bark is slower and levels out later in the upper bole than in the lower 2 m of the bole (Megraw 1985). Data by Groom and Mullins (1992) indicates that all of the veneer from stand 1 (sudden sawlog) came from outside the live crown area. Fifty six percent of the total tree height of the

harvested trees from this stand is in the live crown area (Table 14). Given our knowledge of the live crown effect of wood properties, the fact that stand 2 (conventional) outperformed stand 1 (sudden sawlog) is surprising.

The stands displayed a similar pattern for MOE as was shown for MOR (Table 13). Stand 2 (conventional) (2.39×10^6 psi) was significantly superior to stands 1 (sudden sawlog), 3 (natural regeneration), 4 (single tree selection), and 5 (crop trees) by 11, 12, 12, and 22 percent, respectively (Figure 7). MOE is largely governed by anatomical properties, such as fibril angle, rather than defects, such as knots. Veneer was randomly selected from various trees, peeler bolts and locations within the bolts for each stand for panel fabrication. This would allow the panels from each stand to be more representative of a particular stand and differences between stands to be attributable to the stands rather than bias sampling from specific peeler bolts or zones within a bolt.

The finding concerning MOE is significant in that random veneer sampling from specific stands has been previously reported to prevent the detection of significant differences in 13-ply, SYP laminated veneer lumber from the same stands used for this study (Shupe et al. 199-). It was speculated by the authors that a random veneer selection for a particular stand would consequently contain veneer of various fibril angles, and detection of significant MOE differences between stands for LVL would be hindered by the inherent variation of anatomical properties within the stands, which largely govern MOE.

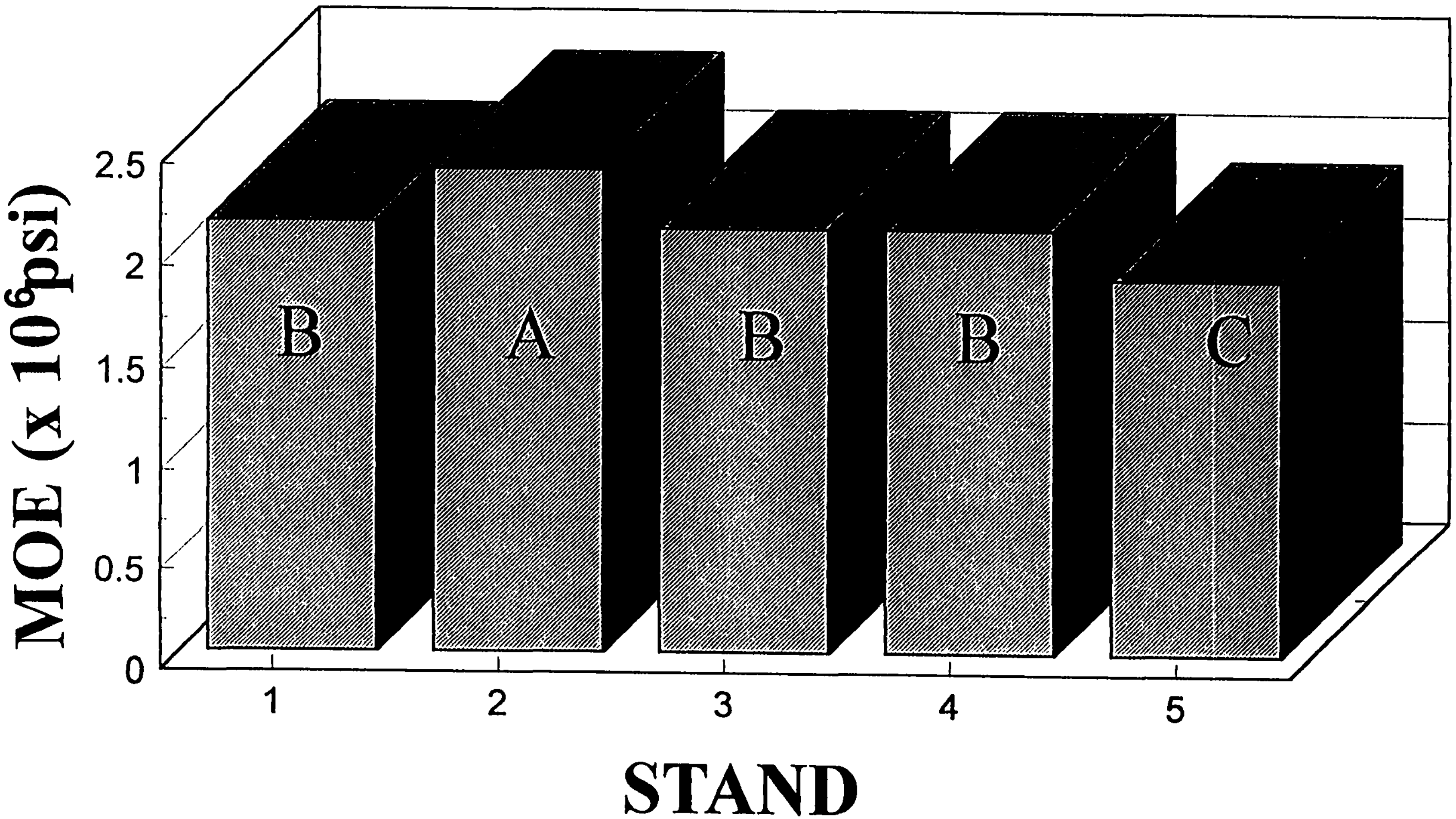

Figure 7. Effect of five different silvicultural strategies on the mean MOE of 3-ply loblolly pine plywood. The leters proximate the means are Tukey values.

Table 14. MOR and MOE at two moisture levels and four veneer grade arrangements of 3-ply loblolly pine plywood.

	Dry condition (40 % RH, 110 F)		Wet condition (24-hr. water soak)				
Layup	MC[1] (%)	SG[2]	MC (%)	MOR reduction (%)	MOE reduction (%)	Thickness swell (%)	Width swell (%)
AAA	7.8[3]	0.69	28.8	62.87	35.47	11.88 (AB)[4] (1.23)[5]	1.65 (A) (1.98)
CCC	7.2	0.66	27.7	57.40	33.16	12.40 (AB) (0.98)	1.68 (A) (1.69)
ACA	7.2	0.69	26.8	62.26	34.55	13.09 (A) (1.23)	1.62 (A) (1.12)
ACC	7.7	0.61	29.6	59.49	36.71	11.61 (B) (1.11)	1.54 (A) (1.43)

[1]Moisture content (%) ovendry basis.
[2]Specific gravity based on volume and weight at 40% RH and 110 F.
[3] Each mean value represents the average of 96 samples.
[4]Tukey grouping.
[5]Coefficient of variation (%).

Table 15. Mean mechanical and physical property values for southern pine plywood produced from five stands according to four layup patterns.

	Dry condition (40 % RH, 110 F)				Wet condition (24-hr. water soak)				
Stand-Layup	Latewood (%)	SG (MC%)	MOR (psi)	MOE (x10⁶ psi)	MOR (psi)	MOE (x10⁶ psi	SG (MC%)	Thickness swell (%)	Width swell (%)
1-AAA	60.19[1]	0.70	15,650[3]	2.46	5,373	1.49	0.70	13.54	1.42
	(9.67)[2]	(7.36)	(1.97)	(1.20)	(0.86)	(1.15)	(36.21)	(1.29)	(1.33)
1-CCC	77.08	0.66	10,847	1.87	4,087	1.15	0.65	12.74	1.79
	(1.55)	(7.28)	(2.57)	(1.72)	(1.25)	(1.88)	(36.29)	(1.32)	(5.67)
1-ACA	49.76	0.69	13,104	2.12	4,913	1.21	0.67	14.78	1.30
	(1.91)	(7.26)	(1.76)	(1.14)	(1.00)	(1.13)	(38.27)	(1.25)	(1.82)
1-ACC	52.58	0.64	13,104	2.07	4,274	1.00	0.67	14.94	1.40
	(2.23)	(7.97)	(1.76)	(1.60)	(2.51)	(1.30)	(37.19)	(3.53)	(4.28)
2-AAA	65.34	0.69	15,900	2.57	5,163	1.46	0.69	13.85	1.75
	(4.30)	(8.38)	(0.75)	(0.77)	(0.69)	(1.07)	(35.33)	(0.53)	(1.33)
2-CCC	46.83	0.68	13,563	2.22	4,806	1.23	0.67	15.65	1.80
	(13.45)	(8.16)	(1.38)	(1.32)	(1.43)	(1.22)	(36.53)	(1.25)	(1.27)
2-ACA	41.31	0.68	14,312	2.41	4,678	1.39	0.68	17.98	1.97
	(10.59)	(8.69)	(1.34)	(0.87)	(2.64)	(1.21)	(37.48)	(4.80)	(1.25)
2-ACC	59.08	0.69	12,256	2.35	4.698	1.34	0.67	14.36	1.63
	(9.64)	(8.33)	(2.34)	(0.85)	(0.81)	(1.84)	(34.45)	(1.48)	(1.98)

(table con'd.)

		Dry condition (40 % RH, 110 F)			Wet condition (24-hr. water soak)				
	Latewood (%)	SG (MC%)	MOR (psi)	MOE (x10⁶ psi)	MOR (psi)	MOE (x10⁶ psi	SG (MC%)	Thickness swell (%)	Width swell (%)
3-AAA	56.02	0.69	14,126	2.35	5,158	1.41	0.70	12.28	1.31
	(1.19)	(8.34)	(1.27)	(0.50)	(0.86)	(1.30)	(35.27)	(1.71)	(1.44)
3-CCC	60.84	0.61	9,879	1.74	4,610	1.18	0.62	12.50	1.26
	(2.98)	(8.19)	(2.99)	(1.50)	(1.96)	(1.37)	(38.26)	(1.52)	(2.18)
3-ACA	62.20	0.66	14,902	2.31	5,161	1.52	0.63	11.24	1.44
	(2.98)	(8.00)	(0.93)	(0.53)	(1.14)	(1.85)	(40.27)	(1.38)	(2.94)
3-ACC	63.83	0.62	11,620	1.99	4,679	1.24	0.63	11.24	1.44
	(2.70)	(8.79)	(2.49)	(1.42)	(2.29)	(1.07)	(38.27)	(1.38)	(2.94)
4-AAA	69.71	0.70	13,139	2.00	6,269	1.65	0.71	8.94	1.91
	(5.19)	(7.49)	(2.10)	(1.78)	(1.57)	(1.98)	(38.41)	(1.89)	(1.61)
4-CCC	43.30	0.66	9,691	1.85	5,148	1.43	0.67	11.40	1.99
	(3.92)	(7.45)	(2.08)	(1.30)	(1.66)	(1.59)	(36.26)	(2.21)	(1.70)
4-ACA	67.48	0.71	14,375	2.34	5,661	1.58	0.69	9.53	1.96
	(2.07)	(7.13)	(1.49)	(1.35)	(1.22)	(1.43)	(37.40)	(1.85)	(1.38)
4-ACC	62.75	0.71	11,275	2.21	5,748	1.66	0.70	9.27	1.84
	(5.08)	(7.58)	(3.04)	(0.93)	(1.97)	(1.65)	(39.44)	(1.36)	(2.41)
5-AAA	59.70	0.69	14,853	2.34	5,342	1.51	0.68	10.84	1.80
	(2.21)	(7.78)	(1.31)	(0.91)	(0.94)	(1.03)	(35.34)	(1.37)	(1.80)
5-CCC	62.59	0.60	10,952	1.66	4,703	1.24	0.61	9.76	1.60
	(4.05)	(7.54)	(1.16)	(1.05)	(1.38)	(1.19)	(37.18)	(1.03)	(1.74)
5-ACA	56.53	0.46	7,290	1.26	5,788	1.78	0.73	10.62	1.79
	(2.29)	(7.96)	(6.98)	(4.90)	(0.65)	(1.49)	(38.35)	(1.96)	(4.05)
5-ACC	48.64	0.61	11,254	1.72	4,697	1.29	0.62	8.60	1.39
	(7.20)	(7.74)	(1.35)	(0.73)	(1.03)	(1.93)	(39.40)	(1.58)	(2.10)

[1]Represents the mean of 3 observations. [2]Coefficient of variation (%). [3]Represents the mean of 12 observations.

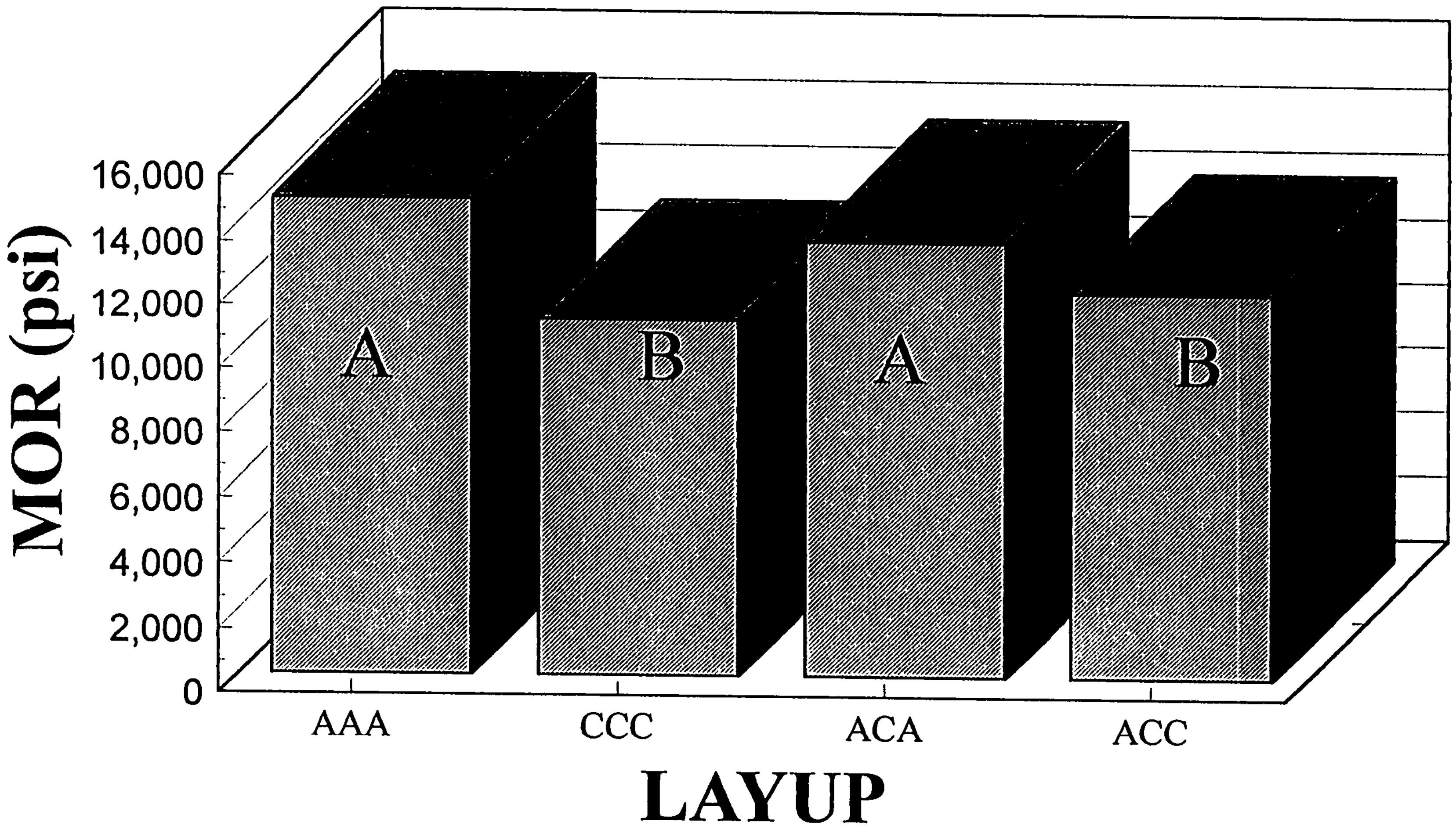

Figure 8. Effect of four different veneer grade layups on the mean MOR of 3-ply loblolly pine plywood. The letters proximate the means are Tukey values.

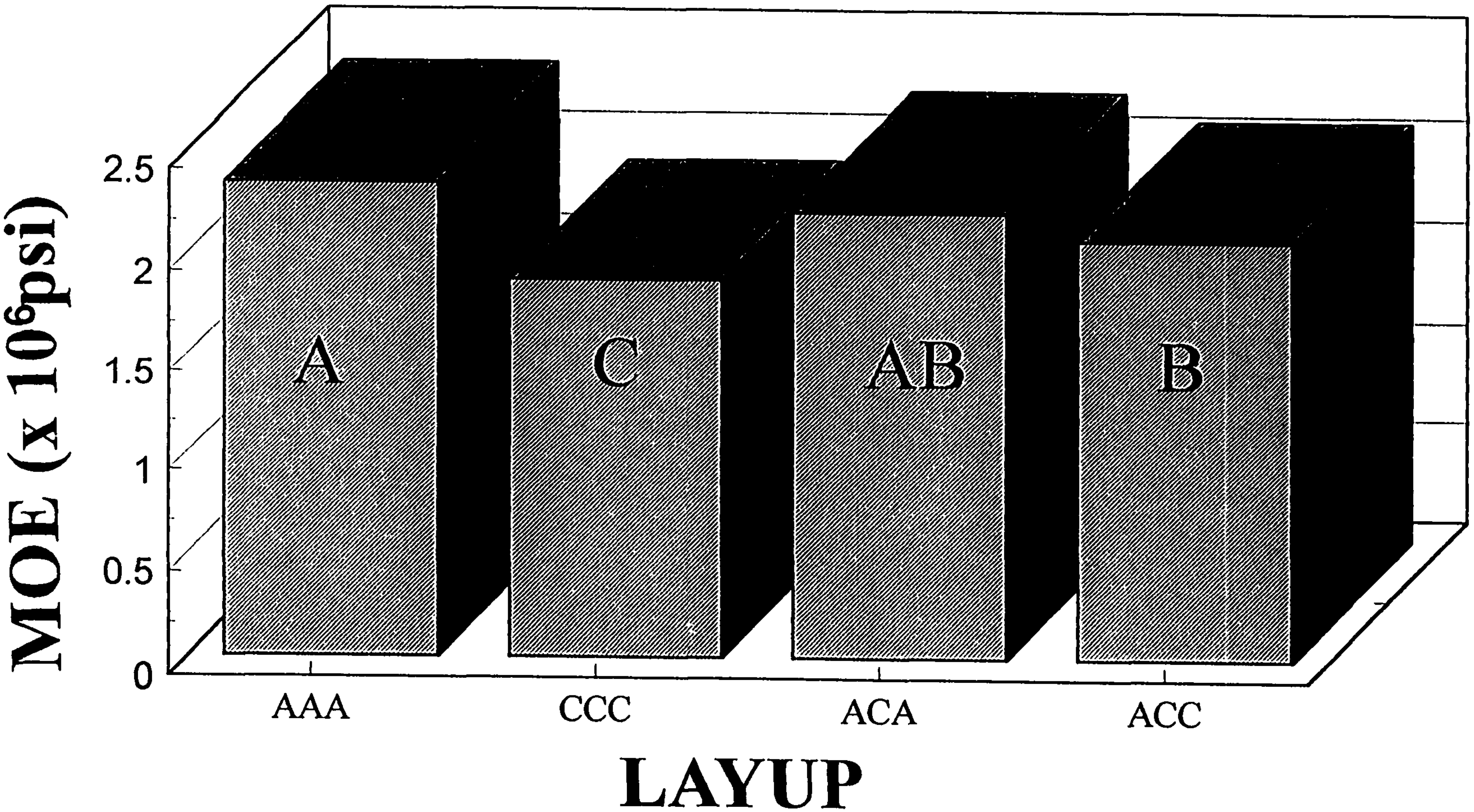

Figure 9. Effect of four different veneer layups on the mean MOE of 3-ply loblolly pine plywood. The letters proximate the means are Tukey values.

Veneer Grade Layup Effect. With regards to veneer grade placement in a panel, the results indicate that MOR is highest for the dry samples when A-grade veneers are on both faces of the panel. There was no significant difference for MOR between AAA (14,734 psi) and ACA (11,902 psi) (Figure 8). As with MOR, there was no significant difference in MOE between AAA (2.34 x 10^6 psi) and ACA 2.20 (x 10^6 psi). However, contrary to the MOR findings, the difference in MOE between ACA and ACC was not significant. The ACA layup did not significantly differ from ACC (2.07 x 10^6 psi) (Figure 9).

The effect of MC on mechanical properties of plywood is given in Table 15. The general pattern displayed by the stands for bending MOR and MOE determination at both moisture levels was the following: AAA > ACA > ACC > CCC. This pattern held consistent for most, but not all, of the stands. In short, as the number of A grade veneer in the panel decreases, bending properties will diminish. The AAA group was 8, 19, and 25 greater in MOR than CCC, ACA, and ACC, respectively. Similarly, AAA was 6, 12, and 20 percent greater in MOE than CCC, ACA, and ACC, respectively. The detrimental effect of knots on mechanical properties has been thoroughly studied (Kollmann and Côté 1984).

It is interesting to note that the MOR reduction in the wet condition for the four different veneer grade arrangements ranged from 60 - 63 percent, and the MOE reduction was much less (33-37 percent). It has previously been shown that of the elastic constants, Young's modulus along the grain is the least sensitive to moisture content (Kollmann and Côté 1984).

Shear Strength

Table 16 indicates little difference in mean shear strength between the stands for a particular shear test treatment. In general, the vacuum soak specimens yielded highest mean shear strength retention and the boiled specimens yielded lowest. The percentage of wood failure appeared to be indifferent to the type of shear test performed or the stand effect.

Table 16. Effect of silvicultural practice (stand) on loblolly pine plywood shear strength (psi) and percentage of wood failure as determined by three treatments.

Stand[1]	Vacuum- soak	Vacuum-pressure	Boil-dry-boil
1	272.7[2]	243.7	232.2
	(66.3)[3]	(66.8)	(70.6)
2	266.9	250.4	236.2
	(72.4)	(77.8)	(72.5)
3	262.5	269.4	246.3
	(67.9)	(62.9)	(65.7)
4	274.5	278.7	243.0
	(77.9)	(77.1)	(74.9)
5	273.4	286.8	248.8
	(76.6)	(75.6)	(76.0)

[1]Stand 1 = Sudden sawlog.
Stand 2 = Conventional.
Stand 3 = Natural regeneration.
Stand 4 = Single tree selection.
Stand 5 = Crop trees.
[2]Each value is the mean of 131 samples.
[3]Numbers in parenthesis are wood failure (%).

The effect of different veneer layup patterns on shear strength retention appears to be minimal. The highest shear strength was obtained with AAA. The other three layups

showed very little difference in mean shear strength retention. The AAA panels yielded the most favorable results because of the different processing of A- and C-grade veneer. These tests were done on clear specimens, but clear wood from C-grade veneer has a high frequency of knots in the full size 54 in. 98 in. sheets. These knots and density differences between earlywood and latewood will lead to lathe vibrations (Koch 1972), and thus the clear wood will become rough if not full of micro-compression failure and excessive lathe checks (Grozdits 1996).

It is interesting to note that very comparable shear properties can be obtained with a single A-grade veneer on one face (ACC) as compared to A- grade veneer on both faces (ACA) (Table 17). In fact the ACC panels gave slightly higher mean shear strengths for 2 (vacuum-pressure-soak and boil) of the 3 treatments.

Table 17. Effect of different veneer layup patterns and accelerated aging treatments on loblolly pine plywood shear strength (psi) and wood failure.

Layup	Vacuum-soak	Vacuum-pressure	Boil-dry-boil
AAA	291.83[1]	286.04	246.98
	(65.81)[2]	(70.72)	(68.93)
CCC	266.26	263.47	234.03
	(73.13)	(75.49)	(75.61)
ACA	263.22	251.14	241.84
	(81.03)	(76.86)	(76.86)
ACC	260.59	264.40	245.26
	(69.00)	(68.10)	(68.55)

[1]Each mean value represents the average of 164 samples.
[2]Numbers in parenthesis are wood failure (%).

CHAPTER 6

EFFECT OF SILVICULTURAL PRACTICE AND WOOD TYPE ON LOBLOLLY PINE PARTICLEBOARD AND MEDIUM DENSITY FIBERBOARD PROPERTIES

The literature is voluminous in describing the effects of silvicultural practice on anatomical, mechanical, chemical, and physical properties of southern pine wood. Numerous studies have shown the detrimental effect of juvenile wood on lumber, paper, and plywood. However, little research has been conducted to evaluate the effect of silvicultural practice on particleboard and fiberboard.

As the demand for wood continues to increase, the production of wood-based composites will likely increase. Particleboard and fiberboard are two wood-based composites that can be produced from trees much too small for lumber. Pugel et al. (1989a, 1989b) conducted studies on composites from southern pine juvenile wood and believed the effect of juvenile wood on composites should be evaluated not only in terms of problems but in terms of the potential for using this type of furnish to produce economical, effective, and possibly, new products. Also, regardless of whether juvenile wood helps or hinders the performance of composites, more of it is being used in composites through the harvesting of fast-grown trees and whole-tree utilization. The studies by Pugel et al. (1989a, 1989b) are some of the few studies that have investigated the effect of juvenile wood on composite products such as particleboard or fiberboard.

This study does not attempt to directly determine the effect of juvenile wood on southern pine particleboard or fiberboard. Instead this research was designed to

address the increase in plantation-grown SYP wood by sampling five silviculturally different stands. Furthermore, innerwood (juvenile wood) and outerwood (mature wood) was selected from each of the five stands to determine the extent of wood type differences between and among the stands. The objectives of this study were to determine the effect of (1) silvicultural strategy and (2) wood type (innerwood or outerwood wood) on the mechanical and physical properties of loblolly pine particleboard and fiberboard.

Materials and Methods

Veneer, peeled to 1/8 in. thickness, was randomly selected from the bottom two bolts of the trees from each of the five stands. The first 12 veneers peeled from a bolt were considered outerwood and the last 12 veneers were labeled as innerwood. The selected veneers were passed through a standard lawn and garden chipper and then ground to particle size in a laboratory disk refiner. The refiner was adjusted to a narrower clearance and water was injected to reduce particles to fibers. Excess water from the fiber slurry was removed via a laboratory vacuum. Fiber was then dried at 80 F for 24 hours. Before spraying, fiber bundles were separated in the spray drum by the beating action of a propeller in the bottom of a 50 gallon drum. Air was injected into the top of the drum, and air currents were recorded to range between 45 - 55 miles per hr. in the drum.

<u>Particleboard Manufacture</u>

Particles were sprayed with a urea formaldehyde (UF) resin (65 percent solids) which increased the particle moisture content (MC) from near 0 % to 2.84%.

Resin was applied at the rate of 6 percent solids based on the ovendry weight of the wood particles. No wax was applied. The same drum blender and resin sprayer was used to prepare each mat. The drum blender was carefully cleaned between groups to avoid cross contamination. Panels were manufactured at a target density of 45 pounds per cubic foot (pcf). Two panels were pressed simultaneously with each press cycle. All particleboard panel types were replicated four times. Mats were hand-felted and randomly oriented in a 17 in. x 19 in. forming box for a target thickness of 1/2-in. The hot press schedule consisted of reduction of initial pressure after 2 minutes and gradual relief of pressure during the last minute of the 4.5-minute press cycle. The platen temperature was 340 F. Panels were stacked on edge for 24-hours prior to cutting test specimens.

Fiberboard Manufacture

Fibers were also sprayed with a urea formaldehyde (UF) resin (65 percent solids) which increased the fiber MC from near 0 % to 9.2%. Resin was applied in similar manner for the fibers. No wax was applied. Resin was applied in a 50 gallon drum equipped with air-injection to keep the fibers in suspension and optimize resin distribution. The same drum and resin sprayer was used to prepare each mat. The drum was carefully cleaned between groups to avoid cross contamination. Panels were manufactured at a target density of 44 pcf. One panel was pressed for each press cycle. All fiberboard panel types were replicated three times. Mats were hand-felted and randomly oriented in a 14 in. x 14 in. forming box for a target thickness of 1/2-in. The hot press schedule consisted of reduction of initial pressure after 2

minutes and gradual relief of pressure during the last minute of the 5.0-minute press cycle. The platen temperature was 430 F. Panels were stacked on edge for 24 hours prior to cutting test specimens.

Testing

Particle and fiber size distributions were determined on a Bauer-McNett screen system. Five samples of each group, weighing 100 g each, were processed and their results averaged. All the size classifications were conducted on ovendry material. Particles and fibers were dried overnight at 101 F to an average moisture content (MC) of 0.72 %.

For particleboard, three bending specimens (3 in. x 17 in.) were selected from each of the four panel replications (12 bending specimens for each combination of stand and wood type). For fiberboard, three bending specimens (2 in. x 12.5 in. were cut from each of the three panel replications (9 bending specimens for each combination of stand and wood type). All specimens were stored on stickers for 3 weeks at 72 F and 66 % RH. Tests to determine MOE, MOR, and internal bond (IB) were conducted in accordance with ASTM D 1037-94 (ASTM 1994d). Four IB specimens and one MC-density specimen were cut from undamaged portions of all the failed bending specimens. Swelling was determined on a 2- and 24-hr. basis as a percentage of dimension increase from the original dry dimensions, and water adsorption was determined as the percentage of weight gain from the original dry dimensions after 2- and 24-hr. water submersion. The software package used in conjunction with the Instron testing machine allowed for data to be downloaded and

analyzed using a factorial analysis on SAS (1989). Tukey's Honestly Significant Difference test was employed to determine significance between means. Two 6 in. x 6 in. samples were cut from each panel for thickness swell and water adsorption determinations in accordance with ASTM D 1037-94 (ASTM 1994d).

Results and Discussion

Particle and Fiber Size Analysis

The analysis of particle and fiber sizes is presented in Table 18. The refining process produced similar size distributions between the stands for the particles and fibers. Moreover, the size analysis showed minimal differences between innerwood and outerwood. Since the size differences within the particle and fiber category were small, we assumed that this factor did not influence the panel properties of particleboard or fiberboard, respectively, appreciably for any stand or wood type.

The particle and fiber sizes were analyzed using the same set of screens to illustrate the differences between these two particle types. Therefore, the fibers had low retention on the No. 8 screen and a high proportion passing the No. 60 screen. We emphasize that these results were obtained using laboratory produced furnishes that were intended mainly to determine the effect of silvicultural strategy and wood type on basic mechanical and physical properties. These furnishes are not necessarily representative of current commercial furnishes.

Panel Densities and Compaction Ratio

The density of the veneer used to produce the furnishes, density and MC of the panels, and compaction ratios are presented in Table 19. The panel densities did

Table 18. Particle and fiber size analysis of loblolly pine wood composites furnishes.

	Stand[1]									
	1		2		3		4		5	
Particles (%)[2]	Inner[3]	Outer[3]	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer
No. 8	0.72	0.47	0.82	0.68	3.14	0.49	0.79	0.48	0.30	0.35
No. 10	1.67	1.35	2.53	3.19	7.79	1.68	2.58	2.22	2.15	2.26
No. 20	65.71	67.26	70.47	73.63	68.46	70.83	72.23	72.38	77.55	69.72
No. 40	22.21	21.66	20.36	17.48	15.00	19.79	17.19	17.71	15.82	20.16
No. 60	4.64	4.76	3.13	2.84	2.60	3.91	3.65	3.35	1.89	4.02
P-60	5.04	4.50	2.68	2.19	3.02	3.31	3.57	3.86	2.29	3.49
Fibers (%)[2]										
No. 8	3.02	2.01	1.02	2.65	3.68	3.00	3.02	2.00	2.32	2.03
No. 10	5.03	4.32	6.32	4.63	4.12	4.11	5.00	4.32	4.85	5.02
No. 20	10.51	9.62	11.36	8.63	9.63	11.12	10.65	8.96	9.68	10.52
No. 40	26.68	29.21	28.65	27.56	25.63	25.64	26.98	27.25	27.00	27.56
No. 60	26.51	27.53	25.32	26.67	27.89	26.98	27.82	29.63	26.32	27.63
P-60	28.25	27.59	27.33	29.98	29.00	29.00	27.89	28.11	29.99	28.25

[1]Stand 1 = Sudden sawlog.
Stand 2 = Conventional.
Stand 3 = Natural regeneration.
Stand 4 = Single tree selection.
Stand 5 = Crop trees.
[2]Percentage of material retained on Bauer-McNett screen sizes. P-60 denotes material passing through the No. 60 size screen.
[3]Inner = Innerwood, Outer = Outerwood.

Table 19. Loblolly pine wood panel densities and compaction ratios.

	Stand[1]									
	1		2		3		4		5	
	Inner[2]	Outer[2]	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer
Veneer										
Density[3] (pcf)[4]	28.75	34.38	29.54	34.57	27.56	33.88	28.69	34.51	29.02	34.07
Particleboard										
Moisture content (%)	6.0	6.0	5.9	6.1	6.6	6.4	7.5	7.6	7.6	7.5
Panel density[5] (pcf)	41.7	42.2	42.1	41.2	40.9	43.3	42.0	41.9	42.4	41.2
Compaction ratio	1.44	1.23	1.43	1.19	1.48	1.28	1.46	1.21	1.46	1.21
Fiberboard										
Moisture content (%)	6.3	6.5	6.5	6.3	6.1	6.1	6.5	6.6	6.6	6.5
Panel density[5] (pcf)	41.22	39.95	39.16	39.98	40.72	43.37	38.16	40.19	41.39	39.79
Compaction ratio	1.43	1.16	1.22	1.16	1.48	1.28	1.33	1.16	1.43	1.16

[1]Stand 1 = Sudden sawlog.
Stand 2 = Conventional.
Stand 3 = Natural regeneration.
Stand 4 = Single tree selection.
Stand 5 = Crop trees.
[2]Inner = Innerwood, Outer = Outerwood.
[3]Based on airdry weight and volume.
[4]Pounds per cubic foot.
[5]Based on volume at 6% MC and ovendry weight.

not greatly differ between the stands or wood types for either panel type. It was therefore assumed that panel density was not significant in interpreting mechanical or physical property differences between the stands or wood types for either panel type.

The target densities of 45 and 44 pcf were not met for the particleboard or fiberboard panels, respectively. The densities were lower by 2 to 4 pcf for the particleboard panels and 1 to 5 pcf for the fiberboard panels. These lower densities were expected due to the tendency of mats to spread during press closure (Pugel et al. 1989a). It is therefore not uncommon for mats to fail to meet the target density. The density values are acceptable because they do not greatly differ between the stands or wood types, and thus should not contribute to mechanical or physical property differences.

The compaction ratio was consistently greater for innerwood than outerwood for all stands and both panel types. It is generally recognized that a compaction ratio of 1.3 and greater is sufficient to promote proper bonding (Maloney 1977). All panels made from outerwood had a compaction ratio less than 1.3, and all but one of the innerwood panels showed a compaction ratio greater than 1.3. These results are in agreement with those of Pugel et al. (1989a) who found fast-grown wood to have a higher compaction ratio than mature wood for both particleboard and fiberboard. The innerwood used for this study likely displayed faster growth than wood obtained from the outerwood region.

Modulus of Rupture (MOR)

The mean MOR values for a given wood type and product are presented in Figure 10 and significant differences are shown in Table 20. The mean MOR ranged from 596 to 1870 psi for particleboard and from 668 to 1122 psi for fiberboard. The higher values were expected for particleboard due to the larger particle sizes and slightly higher panel densities. Particleboard and fiberboard manufactured either from outerwood furnish or from innerwood furnish showed no significant differences in MOR mean values among the five stands.

It is interesting to note that stand 2 (conventional) gave the highest mean value for outerwood particleboard, stand 3 (natural regeneration) the highest mean value for fiberboard outerwood, stand 4 (single tree selection) the highest mean value for particleboard innerwood, and stand 5 (crop trees) yielded the highest mean value for fiberboard innerwood. It is therefore difficult to extend recommendations that endorse a particular silvicultural strategy for a particular panel product. Moreover, industry practice does not currently separate innerwood (juvenile) and outerwood (mature) furnishes. However, if a stand is harvested at an age when the trees are still in the juvenile period of wood production, then inferences from the innerwood portion of this study would be valid. For a young stand, a silvicultural strategy similar to stand 5 (crop trees) could be beneficial for strong fiberboard panels and a scheme analogous to stand 3 (natural regeneration) should be beneficial for strong particleboard because the innerwood furnishes were produced when these stands were young. If a stand is old enough to be producing mature wood, then

recommendations cannot be directly drawn from this study because only panels from either innerwood or outerwood were produced, rather than mixed furnish panels. Moreover, most particleboard and fiberboard mills currently chip trees harvested from early thinning operations comprised almost entirely of juvenile wood

Table 20. Comparison of loblolly pine particleboard and fiberboard mean mechanical properties by Tukey's test for significantly different means.

Stand[1]-wood type	Particleboard			Fiberboard		
	MOR	MOE	IB	MOR	MOE	IB
1-Outerwood	1251	1.74	125	668	1.89	37.09
	(A)[2]	(B)	(A)	(A)	(A)	(A)
2-Outerwood	1473	2.20	130	949	2.00	35.27
	(A)	(AB)	(A)	(A)	(A)	(A)
3-Outerwood	1324	2.52	119	1005	2.35	39.06
	(A)	(A)	(A)	(A)	(A)	(A)
4-Outerwood	807	2.04	116	779	1.46	32.11
	(A)	(AB)	(A)	(B)	(AB)	(A)
5-Outerwood	596	1.80	118	728	1.23	35.61
	(A)	(B)	(A)	(B)	(AB)	(A)
1-Innerwood	1119	2.05	120	843	2.05	31.38
	(A)	(A)	(A)	(A)	(A)	(A)
2-Innerwood	851	2.48	132	1042	1.17	36.30
	(A)	(A)	(A)	(AB)	(B)	(A)
3-Innerwood	1068	2.04	111	838	1.67	35.81
	(A)	(A)	(A)	(B)	(A)	(A)
4-Innerwood	1870	2.16	133	802	2.4	40.65
	(A)	(A)	(A)	(B)	(A)	(A)
5-Innerwood	1406	2.48	128	1122	2.41	39.98
	(A)	(A)	(A)	(B)	(A)	(A)

[1]Stand 1 = Sudden sawlog.
Stand 2 = Conventional.
Stand 3 = Natural regeneration.
Stand 4 = Single tree selection.
Stand 5 = Crop trees.
[2]Within either wood type grouping, similar letters indicate no significant difference exists between means for a particular property. Significant differences were declared at α =0.05.

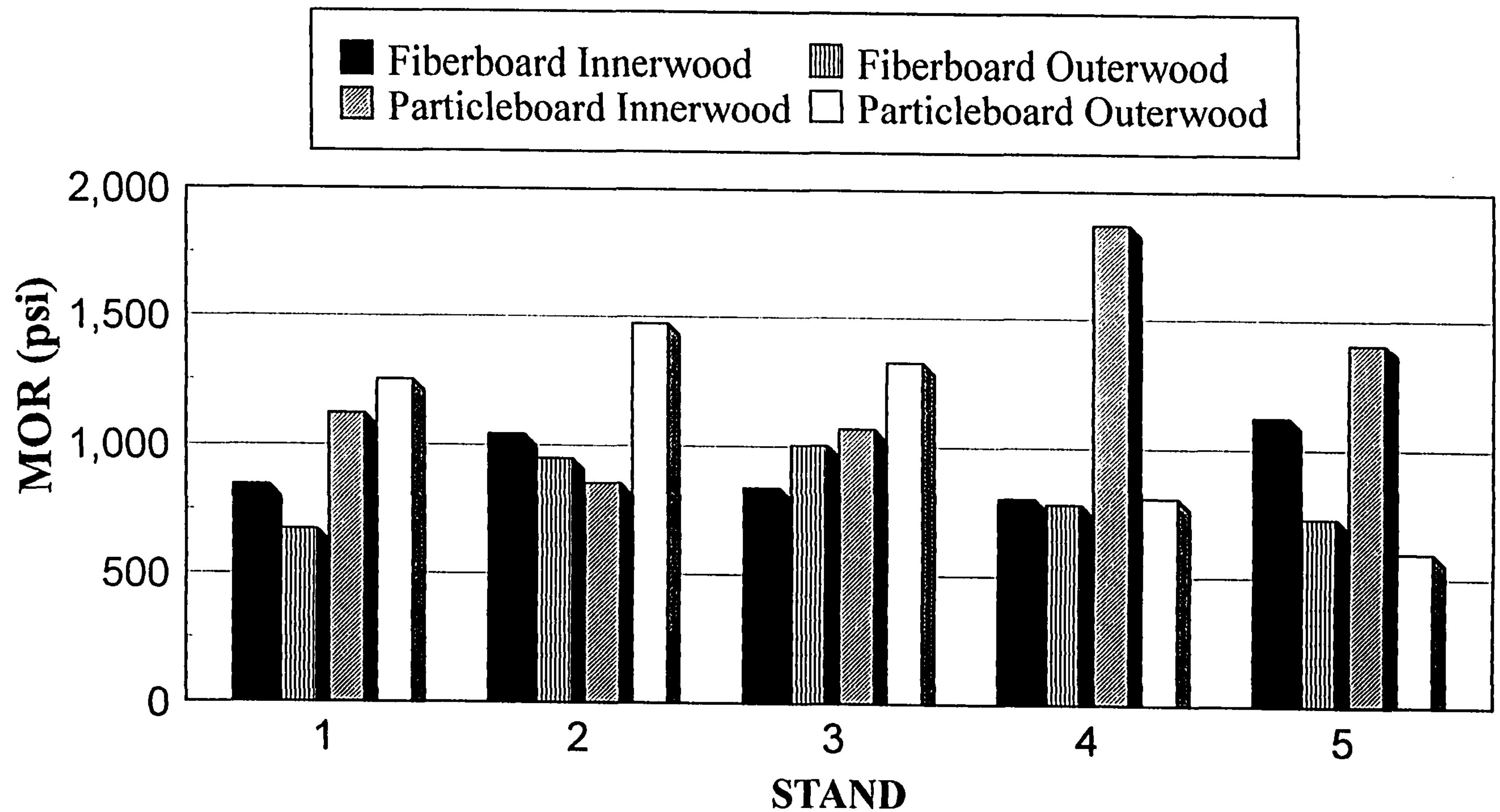

Figure 10. MOR of loblolly pine particleboard and fiberboard

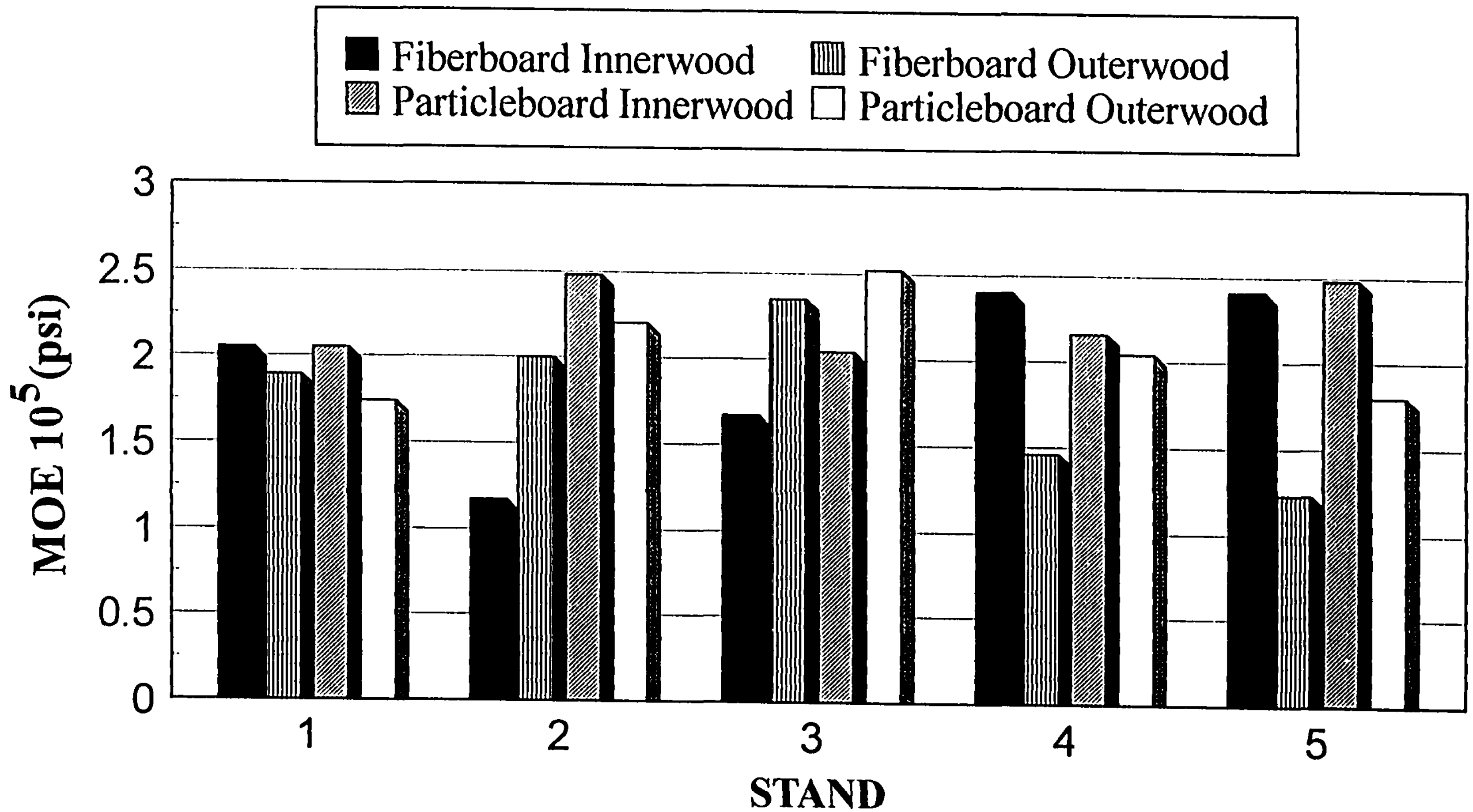

Figure 11. MOE of loblolly pine particleboard and fiberboard

or use chips and planer shavings (juvenile and mature wood) from a nearby sawmill/planer mill. Nevertheless, if a particular stand is old enough so that a vast majority of its wood is mature, then inferences can be drawn with the outerwood portion of this study.

Modulus of Elasticity (MOE)

The mean MOE values are presented in Figure 11 and significant differences are shown in Table 20. The mean MOE ranged from 1.7 x 10^5 to 2.5 x10^5 psi for particleboard and 1.2 x 10^5 to 2.4 x 10^5 psi for fiberboard. The decreased particle size for fiberboard did not serve to greatly decrease the MOE of fiberboard for most of the stands at a given wood type.

Stand 3 (natural regeneration) yielded the highest mean values for both outerwood fiberboard and outerwood particleboard. This stand was significantly greater than stand 1 (sudden sawlog) and stand 5 (crop trees) for outerwood particleboard, but there were no significant differences for outerwood fiberboard. The stands varied slightly with regards to innerwood MOE. Particleboard manufactured from the innerwood furnishes did not significantly differ in MOE, but for innerwood fiberboard, stand 2 (conventional) was significantly lower in MOE than the other stands. Pugel et al. (1989a) found particleboard and fiberboard mature wood panels to be slightly weaker than core wood panels.

Internal Bond (IB)

The mean IB values are illustrated in Figure 12 and significant differences are shown in Table 20. The mean IB ranged from 116 to 132 psi for particleboard and

32 to 41 psi for fiberboard. The low IB values for fiberboard are indicative of unsatisfactory resin performance. Although the fiberboard IB values are unacceptable for most applications, they are still useful in determining differences between the stands and the wood types. The resin performed poorly but should have performed equally poorly for all groups.

There were no significant differences among stands for the particleboard or fiberboard IB mean values. Stand 2 gave the highest mean for outerwood particleboard, stand 3 the highest for outerwood fiberboard, stand 4 the highest mean value for innerwood fiberboard and innerwood particleboard. Innerwood outperformed outerwood for three of the stands for both panel types. However, the difference between innerwood and outerwood were small for each stand.

Physical Properties

The mean values for 2- and 24-hr. thickness swell are presented together with the mean values for 2- and 24-hr. water absorption in Figure 13. Significant differences are shown in Table 21. Stand 1 (sudden sawlog) and stand 5 (crop trees) showed significantly greater 2-hr. thickness swell for outerwood particleboard. For innerwood particleboard, stand 1 (sudden sawlog) displayed significantly greater 2-hr. thickness swell than the other four stands. With regards to outerwood fiberboard, stand 5 (crop trees) was significantly higher than the other stands for 2-hr. thickness swell. It is also interesting to note that stand 4 (single tree selection) gave a significantly lower 2-hr. thickness swell mean than the other stands for innerwood fiberboard (Table 21).

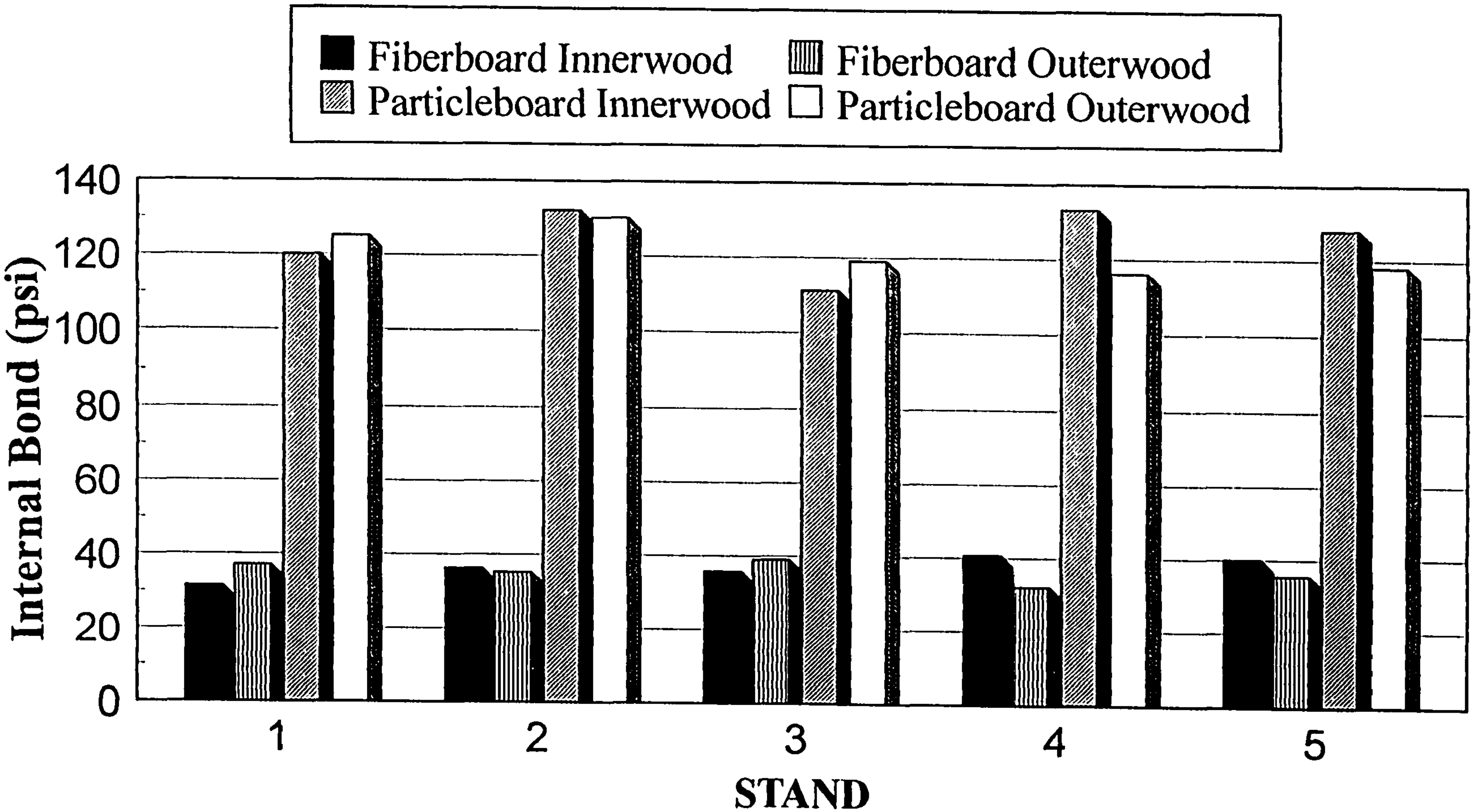

Figure 12. IB of loblolly pine particleboard and fiberboard

Table 21. Comparison of loblolly pine particleboard and fiberboard mean physical properties by Tukey's test for significantly different means.

Stand[1]-wood type	Particleboard				Fiberboard			
	2-hr. TS[2]	24-hr. TS	2-hr. WA[2]	24-hr. WA	2-hr. TS	24-hr. TS	2-hr. WA	24-hr. WA
1-Outerwood	25.55 (A)[3]	27.16 (A)	50.40 (A)	52.38 (A)	21.60 (B)	23.53 (B)	50.85 (A)	53.15 (A)
2-Outerwood	22.96 (B)	25.19 (AB)	46.09 (A)	48.19 (A)	20.39 (B)	23.02 (B)	50.09 (A)	52.96 (A)
3-Outerwood	21.24 (B)	23.43 (B)	45.49 (A)	47.85 (A)	22.42 (B)	24.44 (B)	52.32 (A)	54.84 (A)
4-Outerwood	20.82 (B)	22.40 (B)	48.42 (A)	49.96 (A)	22.52 (B)	24.21 (B)	52.91 (A)	54.61 (A)
5-Outerwood	25.31 (A)	27.43 (A)	48.52 (A)	51.09 (A)	29.90 (A)	31.38 (A)	52.73 (A)	53.78 (A)
1-Innerwood	27.02 (A)	29.39 (A)	49.41 (A)	50.80 (A)	23.64 (A)	25.45 (A)	51.02 (A)	53.17 (A)
2-Innerwood	22.18 (B)	24.52 (AB)	47.12 (A)	49.85 (A)	17.96 (A)	20.74 (A)	52.25 (A)	53.68 (A)
3-Innerwood	21.97 (B)	24.05 (AB)	47.32 (A)	49.65 (A)	19.74 (A)	21.95 (A)	51.32 (A)	51.77 (A)
4-Innerwood	22.41 (B)	24.29 (AB)	47.61 (A)	49.72 (A)	13.79 (B)	15.19 (B)	53.72 (A)	55.02 (A)
5-Innerwood	20.73 (B)	22.31 (B)	46.08 (A)	47.56 (A)	23.27 (A)	25.01 (A)	53.50 (A)	55.31 (A)

[1]Stand 1 = Sudden sawlog.
Stand 2 = Conventional.
Stand 3 = Natural regeneration.
Stand 4 = Single tree selection.
Stand 5 = Crop trees.
[2]TS = thickness swell, WA = water absorption.
[3]Within either wood type grouping, similar letters indicate no significant difference exists between means for a particular property. Significant differences were declared at $\alpha = 0.05$.

A statistical significance pattern similar to that of 2-hr. thickness swell was detected for 24-hr. thickness swell for fiberboard made from both innerwood and outerwood furnishes. For outerwood particleboard, stand 1 (sudden sawlog) and stand 5 (crop trees) were significantly greater than stands 3 (natural regeneration) and stand 4 (single tree selection). The only conclusion for 24-hr. thickness swell of innerwood particleboard is that stand 1 (sudden sawlog) showed greater swelling than stand 5 (crop trees).

The favorable thickness swell performance of stand 4 (single tree selection) can largely be attributed to the comparatively lower panel densities for both panel types and wood types from this stand, particularly fiberboard innerwood and particleboard outerwood (Table 19). It has been previously shown that a strong relationship exists between panel density and thickness swell (Maloney 1977). Also, panels with high compaction ratios have been shown to produce durable juvenile wood composites but with the detrimental effect of higher thickness swell (Suchland and Xu 1989). Wasniewski (1989) showed that Douglas-fir flakeboard made from juvenile wood had low 24-hr. thickness swell due to the higher compaction ratio of this furnish. Kelly (1977) has shown that greater densification may restrict moisture from entering a panel and thus allow minimal swelling.

With regards to both 2- and 24-hr. water adsorption, there were no significant differences detected for 2- or 24-hr. water absorption. Pugel et al. (1989b) found that juvenile wood sources can produce composites that have adequate initial properties and durability, but inadequate dimensional stability when

compared to mature wood composites. This study found fiberboard outerwood to give higher 2- and 24-hr. thickness swell mean values than fiberboard innerwood for four of the five stands. Particleboard outerwood gave higher 2- and 24-hr. thickness swell mean values for 2 of the 5 stands. A reverse situation was observed for water absorption. Fiberboard outerwood gave higher mean values for only 1 stand for both 2- and 24-hr. water absorption. Particleboard outerwood was higher for 3 stands for both 2- and 24-hr. water absorption. It is emphasized that there were very small differences between the stands or wood types for water absorption.

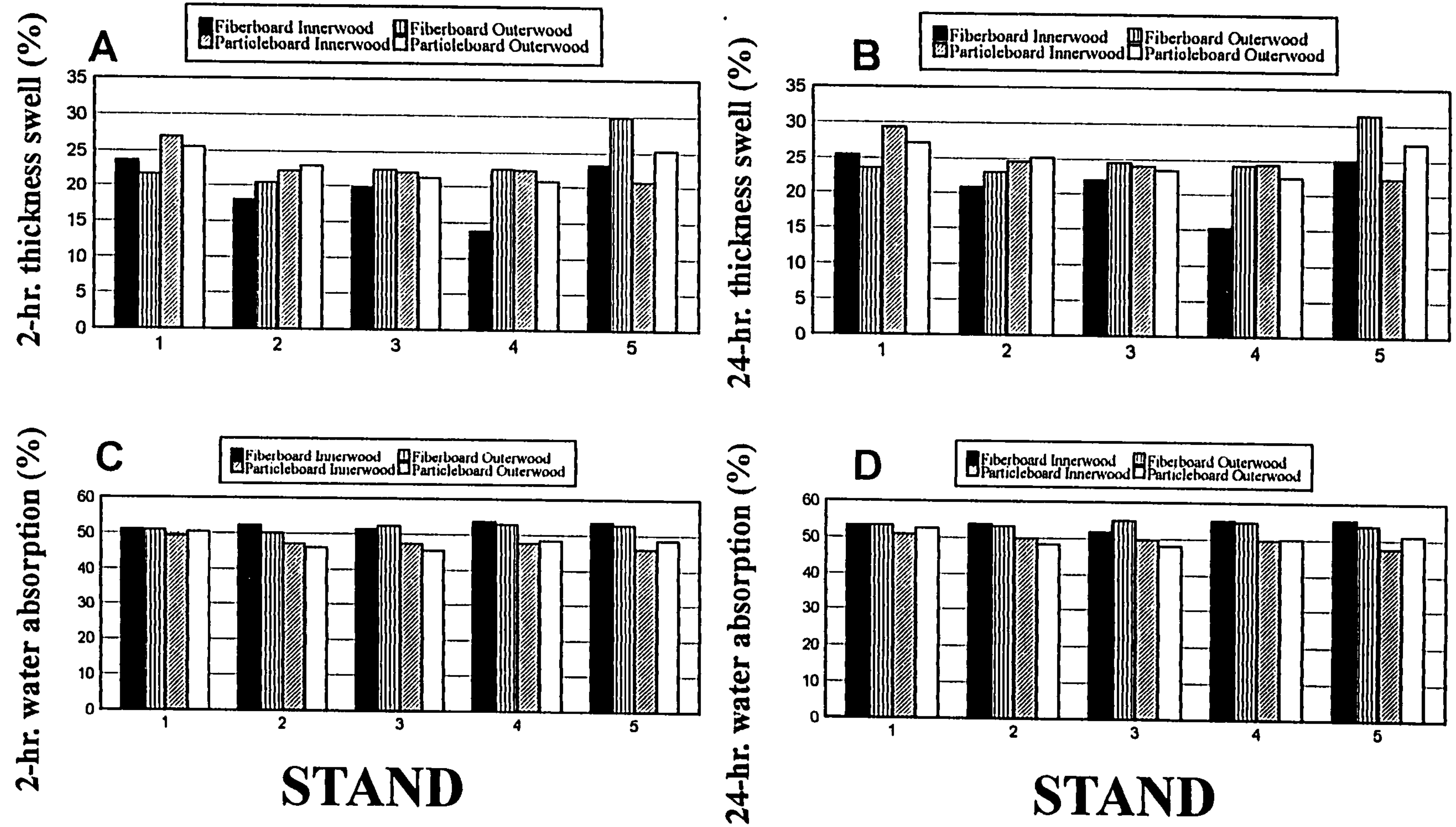

Figure 13. (a) 2-hr. thickness swell, (b) 24-hr. thickness swell, (c) 2-hr. water absorption, and (d) 24-hr. water absorption of loblolly pine particleboard and fiberboard

CHAPTER 7

CONCLUSIONS

Loblolly pine is the principal timber species in the South for lumber, wood composites, and paper. The growing stock of this important species is likely to increase in the future as the global population and the demand for wood fiber increases. In addition, loblolly pine is almost exclusively grown for commercial uses in a plantation setting using numerous silvicultural treatments. This research was initiated to determine the effect of different silvicultural treatments on the mechanical and physical properties of loblolly pine wood composites. In addition, basic wood chemical properties and veneer mechanical properties were investigated. Based upon this research, the following conclusions are offered.

With regards to loblolly pine chemical properties, stands that have been managed using growth-accelerating treatments in a plantation setting showed higher extractive contents than the other stands. Wood produced during the juvenile period (innerwood) when a tree is exhibiting its most vigorous growth displayed a greater extractive content than mature wood (outerwood), which is produced after tree growth and vigor have declined. Holocellulose and alpha-cellulose are minimally affected by silvicultural strategies. The concentration of these chemicals mimics the natural pattern of wood density from pith to bark. Therefore, any cultural treatment that affects this natural pattern will be manifested in the polysaccharide content. Klason lignin showed an inverse relationship with holocellulose. This is logical since

the total polysaccharide and non-polysaccharide structural material should sum to 100%. Therefore, an increase in holocellulose will cause a decrease in Klason lignin.

The study on the static bending and tensile properties of small, rotary-peeled loblolly pine veneer specimens parallel to the grain at two levels of MC provided the following conclusions. Veneer tensile strength was significantly affected by silvicultural practice, but bending MOR, bending MOE, and tensile MOE were unaffected by the silvicultural treatments. Bending MOR was the only mechanical property found to be significantly less in the airdry condition than the ovendry condition. Bending properties (MOE_b and MOR_b) are significantly correlated to each other as are tensile properties (TS and MOE_t). It is hoped that other researchers can add to the data base in order to model the mechanical properties of loblolly pine veneer.

The LVL study found maximum flexural strength and stiffness values were obtained from stand 1 (sudden sawlog), which was managed to produce sawlogs as rapidly as possible. All A-grade veneer panels from stand 1 (1-A) gave significantly higher values for edgewise and flatwise MOR, but no significant differences were observed for either edgewise or flatwise MOE. Stands 1-4 can be considered statistically similar for MOE. This research has shown that by classifying veneer peeler logs based on silvicultural growing conditions, superior LVL can be produced that meets the design values for several high grades of 2 in. x 4 in. SYP lumber.

The highest LVL mechanical properties were generally obtained with a veneer grade layup that placed 2 A-grade veneers on one face and a single A-grade

veneer on the other face (i.e., group III). It was shown that strategic A-grade veneer placement in a panel will influence MOE values but not ultimate bending strength.

Future LVL research is recommended to address the significance of veneer grade layups group III and group IV manufactured from stand 1 (sudden sawlog) instead of stand 5 (crop trees) because of the favorable performance of stand 1 (sudden sawlog) for the effect of silvicultural practice study.

The plywood portion of this study has shown that 3-ply, loblolly pine plywood bending and shear properties are significantly affected by silvicultural practices. Also, the arrangement of the veneer grades within the panel greatly affects bending properties. Plywood manufactured with all A-grade veneer gave the most favorable results for mechanical properties. Plywood with one A-grade veneer on one face (ACC) showed similar mechanical properties as plywood with A-grade veneer on both faces (ACA). Differences in mean shear strength retention can not definitively be attributed to differences in percentage of wood failure or contact angle because of the homogeneity of strength and wood failure readings between the stands and layups. Since bending and shear properties are similar between ACA and ACC, a possible financial gain may be achieved by placing an A-grade veneer on only one face of the panel, instead of both faces.

The two particle-based composites that were addressed were particleboard and fiberboard. Of the five stands investigated, stand 2 (conventional), stand 3 (natural regeneration), and stand 4 (single tree selection) on average were favorable for most mechanical and physical properties. No single stand is consistently superior

for all mechanical and physical properties for any of the wood composites evaluated. This study has shown that innerwood composites do not have greater thickness swell or water adsorption than outerwood composites. Also, the MOR, MOE, and IB for innerwood and outerwood are very comparable for a particular stand and product. Innerwood composites always have a higher compaction ratio than outerwood composites. However, the differences in panel densities were slight. Therefore, differences in most mechanical and physical properties were minimal.

An overall conclusion for this study is that silvicultural practice does affect most mechanical and physical properties of laminated veneer lumber and plywood but has a minimal effect on particleboard or fiberboard. Future research is recommended to address other silvicultural treatments and wood composites. Moreover, economically advantageous processing techniques should be developed to produce products from stands that yield comparatively poor wood composite properties using conventional gluing techniques.

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VITA

Todd Finley Shupe was born October 21, 1970 in Alton, Illinois to Harold and Margaret Jean Shupe. He attended elementary school and high school in Carrollton, Illinois. He graduated high school in 1988 and enrolled as a Jonathon Baldwin Turner Scholar in forestry at the University of Illinois at Urbana-Champaign later that same year. He graduated with honors in 1992 with a bachelor of science degree in forest science and wood science. Shupe continued at the University of Illinois and earned a master of science degree in wood science and technology in 1994 under the direction of Dr. Poo Chow. His thesis was titled "An Assessment of Some of the Chemical Properties of Ten-Year-Old Short-Rotation Hardwood Biomass Grown in Illinois. Shupe began a doctoral studies program at Louisiana State University in 1994 that addressed the effects of silvicultural treatments on some mechanical and physical properties of loblolly pine wood composites. He is scheduled to complete his doctoral program in 1996. Shupe is currently a forest products utilization specialist with the Louisiana Cooperative Extension Service. He has authored refereed publications on wood anatomy, wood chemistry, wood physics, and wood composites. He belongs to the following professional societies and organizations: Forest Products Society, Society of American Foresters, International Association of Wood Anatomists, Technical Association of Paper and Pulp Industry, Xi Sigma Pi, Alpha Zeta, Sigma Xi, and American Association for the Advancement of Science.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Todd Finley Shupe

Major Field: Forestry

Title of Dissertation: The Effect of Silvicultural Treatments on Certain Mechanical and Physical Properties of Loblolly Pine Wood Composites

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

10/15/96