EFFECT OF STAND DENSITY ON FLEXURAL PROPERTIES OF LUMBER FROM TWO 35-YEAR-OLD LOBLOLLY PINE PLANTATIONS[1]

Evangelos J. Biblis
Professor

Honorio Carino
Associate Professor

Richard Brinker
Assistant Professor
School of Forestry and Alabama Agricultural Experiment Station
Auburn University, AL 36849-5418

and

C. William McKee
Former Timber Resource Manager
J. River Timber Corporation
Pennington, AL 36916

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ABSTRACT

This study reports on the effect of stand density on the flexural properties and grade compliance of lumber from two 35-year-old loblolly pine plantations. Grade compliance determination involved performing bending strength tests on the lumber, which was visually graded according to Southern Pine Inspection Bureau (SPIB) rules, to ascertain if the actual strength values were consistent with the requirements of the assigned visual grades. The results indicate that stand density is an important factor influencing the flexural strength and grade compliance of the lumber produced from the plantations studied. Specifically, lumber from the denser 35-year-old stand, which had 70/25 site index, 8- × 8-ft original spacing (thinned only once at age 18) and 230 trees/acre with 141-sq ft basal area at harvest time, has about 92% and 64% compliance to required design flexural strength and stiffness values, respectively. It is now evident from the results of this study and a previous study by the authors that even dense stands must be older than 35 years of age before they can be harvested for lumber production to ensure attainment of at least 95% lumber grade compliance, i.e., strength values are consistent with assigned visual grades. More studies are definitely needed to determine the appropriate harvest age.

Keywords: Loblolly pine, lumber, grades, flexural properties, stand density, plantations.

INTRODUCTION

Harvesting pressure on southern forest resources, especially on southern yellow pines, has been increasing in the last few years. A major reason for this is the increased demand for residential construction, which contributed immensely to the increased demand and prices for stumpage, lumber, and other structural wood products. Federal regulation and litigation impose serious restrictions on harvesting softwoods on federal forest stands in the

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Northwest, and will add more harvesting pressure on southern forests.

The Northwest Forest Resource Council (1994) reports that between 1991 and the beginning of 1994, the volume of softwoods for harvesting under contract from federal stands in Oregon and Washington declined by 72%. In the same period, western product prices increased by 125% for Douglas-fir lumber and 84% for exterior Douglas-fir plywood. In the South, stumpage prices for southern pine sawtimber increased by 51% between December 1991 and December 1993 (Timber Mart-South 1993).

Within a few years, 50% of the available pine timber in the South will come from plantations consisting primarily of loblolly pine (*Pinus taeda L.*) and slash pine (*Pinus elliotti* Engelm.) trees. Presently there is no available information on the age distribution and stand densities of the existing southern pine plantations. Stand density (i.e., number of trees per acre or basal area) is considered a major factor affecting wood properties because it influences the development of juvenile wood and branches in the tree. The number and size of branches directly relate to the number and size of knots as well as to the localized slope of wood grain in lumber produced from such a tree. However, not much is known about the effect(s) of stand density on the flexural properties (MOE and MOR) and degree of compliance of plantation pine lumber to the required design values for a specified grade. Grade compliance determination involves performing bending strength tests on the lumber, which is visually graded according to SPIB rules, to ascertain if the actual strength values are consistent with the requirements of the assigned visual grades.

Final stand density has been observed to vary with initial planting density (spacing of seedlings), degree of stand thinning, and stand age. Many southern pine plantations were established with an initial spacing of 8 by 8 ft. Intensive management of such plantations resulted in very impressive growth rates, with diameter breast height (DBH) of 11.2 in. in 15 years (MacPeak et al. 1990) or 14.3 in. in 20 years (Pearson and Gilmore 1980). It has been documented (Zobel and Blair 1976) that fast-growing trees of pine plantations produce high amounts of juvenile wood at early ages; about 60% in 20-year-old and 30% in 30-year-old trees. Juvenile wood in loblolly and slash pines could occupy from 10 to 20 annual growth rings (Bendtsen and Senft 1986; Goggans 1964; Taras 1965; Zobel and Kirk 1972). Compared to mature wood, juvenile wood is known to be of lower density and with different anatomical characteristics that all contribute to lower strength and stiffness properties (Bendtsen 1978; Koch 1966; Pearson and Gilmore 1971; Taras 1965; Zobel and Blair 1976; Zobel and Kirk 1972).

Studies (MacPeak et al. 1990; Pearson and Gilmore 1980) have shown that lumber produced from 20- to 30-year-old loblolly and slash pine plantations planted at an 8- × 8-ft spacing has low strength and stiffness properties and shows considerably low compliance to visual lumber grade requirements. These results have been attributed to high percentages of juvenile wood. In another study (Biblis 1990), however, lumber from a 27-year-old slash pine plantation planted on a 6- × 6-ft original spacing, with a lower growth rate, exhibited exceptionally good lumber properties and compliance to visual lumber grades.

In a recent study (Biblis et al. 1993), the authors found that the flexural properties of loblolly pine plantation lumber with No. 1 and No. 2 grades increase with stand age (25 to 35 years). Furthermore, the percent of compliance of the tested lumber flexural properties to the required values for the grade increases as the stand age increases from 25 to 35 years. This could be attributed to the decreasing proportion of juvenile wood in the tree as it grew older.

This paper presents results of an investigation on the effect of stand density of two 35-year-old loblolly pine stands on the flexural properties and percent of compliance of the obtained lumber to required design values of the tested lumber grades.

TABLE 1. *Characteristics of the two 35-year old loblolly pine stands.*

Stand no.	Site index	Original spacing (feet)	Thinned at age (years)	Trees/acre	Basal area (sq. ft)
35A	70/25	8 × 8	18 + 27	130	105.8
35B	70/25	8 × 8	18	230	140.8

TABLE 2. *Measurements of the two samples (50 from each stand used in this study).*

Measurement	Mean	SD*	Minimum	Maximum
	Stand 35A			
DBH (inches)	12.1	2.2	7.1	18.5
Merchantable length (feet)	59.6	13.7	12.0	77.3
Merchantable top diameter (in.)	6.0	0.1	5.5	6.1
	Stand 35B			
DBH (inches)	10.8	2.6	6.0	17.0
Merchantable length (feet)	62.7	11.7	31.6	86.3
Merchantable top diameter (in.)	6.0	0.9	5.6	8.5

* SD = Standard deviation.

MATERIALS AND METHODS

Two loblolly pine stands, identified as 35A[2] and 35B, located in West Central Alabama were used in the study. The characteristics of the stands are listed in Table 1. Selection of the stands for the study was made on the basis of equal original planting spacing of 8 by 8 ft and equal site index of 70 (base age = 25). One stand (35B) was thinned once at age 18, the other (35A) thinned twice at 18 and 27 years, resulting in basal areas of 140.8 and 105.8 sq ft, respectively, for each stand at age 35.

Prior to tree selection from each stand, the DBH distribution for each stand was established by measuring DBH of all trees in four ¼-acre plots in each stand. Fifty trees from each stand were then selected to represent the predetermined DBH distribution in each stand. The sample trees from each stand were harvested, identified, and measured. These measurements are shown in Table 2. The average DBH of stands 35A and 35B was 12.1 and 10.8 inches, respectively.

The 50 harvested trees from each stand were transported to the sawmill cooperating in this study. The trees from each stand were segregated and processed in separate batches.

For this study, special arrangements were made with the cooperating sawmill to reduce the processing speed in order to allow for the identification of each piece of lumber according to origin (log location within the tree, tree, and stand). This was accomplished through a multistep process. Each tree was bucked into logs, following the bucking policy of the sawmill. Immediately after bucking, each log was identified and measured. Large- and small-end diameters inside bark and length were recorded. The large ends were spray-painted with different colors to identify each log type. In addition, a number on a 3 by 5 card indicating the stand and tree number was attached to the large end. Every log from each stand was processed through the chip-n-saw (chipper-canter), according to current sawing practices of the mill. Each piece of lumber from each log was identified by origin (stand and tree number), using a narrow aluminum identification tag attached with staples to the end of each piece. All green lumber was sorted by width and length and then stacked and kiln-dried to approximately 15% moisture content (MC). After kiln-drying, all the lumber pieces were dressed to the specifications of the mill and subsequently graded to SPIB visual grades by qualified lumber graders of the mill. While the tested lumber from stand 35A represented a sample of the obtained lumber, all the lumber obtained from stand 35B was tested.

In sampling the lumber from stand 35A for testing, an attempt was made to obtain a minimum of 28 pieces of lumber from each group by lumber grade, log type, lumber width, and stand. But because not every log type produced all grades and all widths, we were forced to accept an unequal number of test pieces in each group. Test pieces sized 2 by 8 in. or 2 by 6

[2] This stand was used also in a previous study (Biblis et al. 1993).

TABLE 3. *Flexural properties and compliance to visual grade requirements of southern pine lumber obtained from a 35-year-old Loblolly plantation A[a], tested edgewise according to ASTM D 198 with third point loading over the spans of 90 inches for 2 × 4's and 132 inches for 2 × 6's and 2 × 8's.*

Log type	SPIB visual grade	Pieces tested	M.C. (%)	S.G[b] (odb)	MOE[c] (Mpsi)	MOR[c] (psi)	5th[d] (%)	SPIB required BSV[e] (psi)	SPIB required MOE (Mpsi)	Meet standards "F_b" (%)	Meet standards "E" (%)
					Lumber size 2″ × 4″						
Butt	1	13	8.4	0.57	1.960	7,775		3,885	1.7	85	62
Second	1	22	9.6	0.53	1.970	7,122		3,885	1.7	86	73
Third	1	15	9.0	0.50	1.544	5,966		3,885	1.7	87	27
Fourth	1	9	8.9	0.51	1.492	6,096		3,885	1.7	78	78
Fifth	1	2	8.5	0.46	1.349	4,856		3,885	1.7	100	0
Butt	2	30	8.9	0.52	1.428	5,920		3,150	1.6	90	29
Second	2	41	9.7	0.52	1.673	5,169		3,150	1.6	88	49
Third	2	46	9.6	0.49	1.595	4,756		3,150	1.6	87	46
Fourth	2	26	9.9	0.46	1.368	4,255		3,150	1.6	65	23
Fifth	2	10	9.7	0.47	1.392	4,263		3,150	1.6	90	30
Butt	3	14	10.8	0.53	1.297	5,038		1,785	1.4	93	36
Second	3	9	9.2	0.53	1.951	5,933		1,785	1.4	100	89
Third	3	11	9.5	0.51	1.489	4,171		1,785	1.4	91	55
Fourth	3	11	9.7	0.47	1.256	4,008		1,785	1.4	91	45
Fifth	3	4	9.9	0.48	1.150	3,563		1,785	1.4	100	0
All logs	1	61	9.1	0.53	1.772	6,751	2,824	3,885	1.7	85	57
					(0.285)	(1,126)					
	2	153	9.5	0.50	1.531	4,978	2,385	3,150	1.6	85	39
					(0.135)	(698)					
	3	49	9.9	0.51	1.439	4,656	1,605	1,785	1.4	94	49
					(0.316)	(944)					
All logs + grades		263								87	45
					Lumber size 2″ × 6″						
Butt	1	27	9.2	0.60	2.128	7,759		3,465	1.7	100	89
Second	1	5	9.7	0.52	2.110	6,427		3,465	1.7	100	100
Third	1	4	9.5	0.45	1.513	4,523		3,465	1.7	50	0
Butt	2	43	9.6	0.53	1.675	5,677		2,625	1.6	95	47
Second	2	47	8.9	0.53	1.887	5,514		2,625	1.6	89	79
Third	2	27	9.3	0.48	1.483	4,020		2,625	1.6	78	30
Butt	3	14	9.2	0.60	1.938	6,114		1,575	1.4	100	79
Second	3	4	8.8	0.49	1.520	3,192		1,575	1.4	75	50
Third	3	10	9.3	0.50	1.475	3,734		1,575	1.4	100	50
All logs	1	36	9.3	0.57	2.057	7,214	4,058	3,465	1.7	94	81
					(0.350)	(1,626)					
	2	117	9.2	0.52	1.716	5,229	1,872	2,625	1.6	89	56
					(0.212)	(913)					
	3	28	9.2	0.55	1.713	4,847	986	1,575	1.4	96	64
					(0.255)	(1,554)					
All logs + grades		181								91	62
					Lumber size 2″ × 8″						
Butt	1	3	10.2	0.50	1.924	7,894		3,150	1.7	100	67
Butt	2	13	10.1	0.51	1.742	5,589		2,520	1.6	100	62
Second	2	9	10.4	0.49	1.450	4,457		2,520	1.6	78	56
Third	2	1	9.8	0.47	1.322	2,536		2,520	1.6	100	0
Second	3	1	9.8	0.45	1.275	2,163		1,470	1.4	100	0

TABLE 3. *Continued.*

Log type	SPIB visual grade	Pieces tested	M.C. (%)	S.G[b] (odb)	MOE[c] (Mpsi)	MOR[c] (psi)	5th[d] (%)	SPIB required BSV[e] (psi)	SPIB required MOE (Mpsi)	Meet standards "F_b" (%)	Meet standards "E" (%)
Third	3	2	10.3	0.44	1.041	1,643		1,470	1.4	50	0
All logs	1	3	10.2	0.50	1.924	7,894		3,150	1.7	100	67
	2	23	10.2	0.50	1.609 (0.215)	5,013 (1,543)		2,520	1.6	91	57
	3	3	10.1	0.44	1.119 (0.165)	1,816 (367)		1,470	1.4	67	0
All logs + grades		29								90	52

[a] See Table 1 for characteristics of 35-year-old loblolly plantation A.
[b] odb stands for oven-dry basis.
[c] Numbers in parenthesis are standard deviations.
[d] Non-parametric estimate of 5th percentile at 75% confidence limit.
[e] BSV is the required bending strength value obtained by multiplying the "F_b" by 2.1.

in. were trimmed to 12 ft long, and 2- by 4-in. pieces were trimmed to 8 ft long. Longer pieces of lumber that were shortened to the required length for testing were regraded by a qualified lumber grader.

All lumber for testing was transported and stored inside the Auburn University Forest Products Laboratory for a minimum of 3 weeks prior to testing. A total of 1,468 pieces of lumber were tested edgewise in flexure to failure with third-point loading according to ASTM D 198-84 (1985). The 2- by 6-in. and 2- by 8-in. pieces were tested over a span of 132 in., and the 2- by 4-in. pieces were tested over a 90-in. span. A Tinius-Olsen hydraulic testing machine with a capacity of 120,000 pounds was used to test the lumber. For flexure tests, the machine was equipped with an extended base made from a steel double I-beam 20.5 ft long and a steel loading head 7 ft long. Load and corresponding deflection-to-failure data were obtained with a Hewlett-Packard (H-P) data acquisition system connected to an H-P desk computer for processing. From the obtained data, the MOR, MOE, percent MC, and specific gravity (SG) for each tested piece of lumber were calculated.

RESULTS AND DISCUSSION

Results of the flexural tests of lumber from the two 35-year-old stands are reported in Tables 3, 4, and 5. Tables 3 and 4 show the flexural properties of lumber by width, visual grade, type of log, number of pieces tested, specific gravity (SG), and percent moisture (MC) for stands 35A and 35B, respectively. In addition, the bending strength value (BSV) required by SPIB grading rules for each visually graded piece and the stiffness design value, E, recommended by SPIB grading rules as the average value for each visual grade are also shown in Tables 3 and 4. Table 5 summarizes the overall flexural properties of all sizes of tested lumber from each sample stand by visual lumber grade irrespective of the lumber origin or log position in the tree.

The results obtained from the flexural tests were used as the basis for making comparisons with the required bending strength value for each visually graded piece. The process involved comparing the obtained MOR value of every piece to the required bending strength value (BSV) of a given visual lumber grade. The BSV was calculated by multiplying the SPIB required binding design value F_b for each grade by the combined adjustment factor 2.1 for safety and duration of load. This comparison is shown in Tables 3, 4, and 5 and is expressed as a percentage of the number of pieces exceeding the requirements to the total number of pieces tested. The tables also list the percentage of the tested pieces with E values above those recommended by SPIB grading rules (Southern Pine Inspection Bureau 1991) for the visual grade.

Results in Tables 3 and 4 indicate that the

TABLE 4. *Flexural properties and compliance to visual grades requirements of southern pine lumber obtained from a 35-year-old Loblolly plantation B*[a], *tested edgewise according to ASTM D 198 with third point loading over the spans of 90 inches for 2 × 4's and 132 inches for 2 × 6's and 2 × 8's.*

Log type	SPIB visual grade	Pieces tested	M.C. (%)	S.G[b] (odb)	MOE[c] (Mpsi)	MOR[c] (psi)	5th[d] (%)	SPIB required BSV[e] (psi)	SPIB required MOE (Mpsi)	Meet standards "F_b" (%)	Meet standards "E" (%)
Lumber size 2″ × 4″											
Butt	1	159	10.1	0.57	2.093	9,330		3,885	1.7	97	79
Second	1	82	10.3	0.53	2.052	8,531		3,885	1.7	99	83
Third	1	21	10.0	0.50	1.774	7,145		3,885	1.7	100	67
Butt	2	137	10.0	0.52	1.631	6,437		3,150	1.6	95	58
Second	2	165	9.8	0.52	1.676	5,994		3,150	1.6	91	59
Third	2	146	9.9	0.49	1.602	5,778		3,150	1.6	90	55
Fourth	2	53	9.2	0.46	1.403	4,929		3,150	1.6	79	33
Fifth	2	15	8.8	0.47	1.331	4,032		3,150	1.6	47	20
Butt	3	14	9.2	0.53	1.612	5,367		1,785	1.4	86	64
Second	3	20	9.1	0.53	1.740	4,351		1,785	1.4	90	90
Third	3	32	9.4	0.51	1.683	4,379		1,785	1.4	94	84
Fourth	3	43	8.9	0.47	1.381	3,783		1,785	1.4	86	58
Fifth	3	14	9.4	0.48	1.307	3,685		1,785	1.4	79	36
All logs	1	262	10.2	0.53	1.916	8,905	4,434	3,885	1.7	98	79
					(0.174)	(1,106)					
	2	516	9.8	0.50	1.605	5,884	2,822	3,150	1.6	89	53
					(0.152)	(956)					
	3	123	9.2	0.51	1.536	4,200	1,481	1,785	1.4	88	68
					(0.190)	(669)					
All logs + grades		901								92	62
Lumber size 2″ × 6″											
Butt	1	22	10.8	0.60	2.133	9,255		3,465	1.7	100	86
Second	1	4	10.4	0.52	1.687	7,103		3,465	1.7	100	75
Third	1	2	10.4	0.45	1.834	6,790		3,465	1.7	100	100
Butt	2	21	10.9	0.60	1.930	7,480		2,625	1.6	100	76
Second	2	19	9.5	0.49	1.878	6,398		2,625	1.6	100	74
Third	2	17	9.8	0.50	1.595	4,682		2,625	1.6	88	41
Fourth	2	5	10.3	0.55	1.841	4,820		2,625	1.6	100	80
All logs	1	28	10.7	0.57	2.048	8,771	4,147	3,465	1.7	100	86
					(0.227)	(1,342)					
	2	62	10.1	0.52	1.815	6,167	2,936	2,625	1.6	97	66
					(0.149)	(1,339)					
All logs + grades		90								98	72
Lumber size 2″ × 8″											
Second	1	2	9.5	0.55	2.249	8,324		3,150	1.7	100	100
Second	2	5	9.5	0.48	1.734	7,190		2,520	1.6	100	100
All logs + grades		7								100	100

[a] See Table 1 for characteristics of 35-year-old loblolly plantation A.
[b] odb stands for oven-dry basis.
[c] Numbers in parenthesis are standard deviations.
[d] Non-parametric estimate of 5th percentile at 75% confidence limit.
[e] BSV is the required bending strength value obtained by multiplying the "F_b" by 2.1.

TABLE 5. *Flexural properties and percent compliance to visual grade requirements of southern pine lumber from two 35-year-old loblolly pine plantation stands.*

Stand ID	SPIB visual grade	No. of pieces tested	Grade (%)	MC (%)	SG (odb)	MOE (Mpsi)	MOR (psi)	Meet standards "F_b" (%)	Meet standards "E" (%)
35A[a]	1	100	21	9.2	0.54	1.879	6,950	89	66
	2	293	62	9.5	0.51	1.611	5,080	87	47
	3	80	17	9.7	0.52	1.523	4,616	94	53
	All	473						89	52
35B[b]	1	292	30	10.2	0.55	1.931	8,888	98	80
	2	583	58	9.9	0.49	1.637	5,925	91	55
	3	123	12	9.2	0.47	1.536	4,200	88	68
	All	998						92	64

[a] Stand A's basal area = 106 sq. ft.
[b] Stand B's basal area = 141 sq. ft.

flexural properties MOR and MOE are influenced greatly by the log position in the tree. Lumber strength and stiffness decrease as the log position changes with tree height. The average strength and stiffness of 2- × 4-in. and 2- × 6-in. lumber from butt logs in 35A stand are 42 and 25% larger, respectively, than corresponding values from the third logs. In stand 35B, the average increases of lumber strength and stiffness from the butt logs to the third logs are 32 and 13%, respectively. Strength and stiffness values of lumber from higher positioned logs (fourth and fifth logs) are even lower in both stands.

Results in Table 5 indicate that the overall specific gravity appears not to be significantly different between stands 35A and 35B. Although stand 35B is denser in terms of number of trees and basal area per acre (Table 1), both stands most likely possess the same amount of juvenile wood since the first thinning on both stands took place at age 18 when formation of juvenile wood was more or less completed.

Table 5 also indicates that the visual grade distribution of lumber from stand 35B is better because it contains proportionately more higher grades than the lumber from stand 35A. Visual grades for southern pine lumber are assigned after considering several lumber characteristics, of which the most important for structural properties are the included knots (Southern Pine Inspection Bureau 1991). Knot size, number, and distribution influence the lumber grade and simultaneously influence to a greater degree the flexural strength (MOR) and to a lesser degree the flexural stiffness (MOE) (Doyle and Markwardt 1966; Markwardt and Wilson 1935; Southern Pine Inspection Bureau 1991).

To compare the mean values for both the MOE and MOR of lumber having the same grade from two stands t-tests were performed at 95% level of significance. Table 5 indicates that there is a significant difference in MOR values for No. 1 lumber grades between stands 35A and 35B. The mean MOR value of No. 1 lumber from stand 35B (8,888 psi) is 27% larger than corresponding value from stand 35A (6,950 psi). Possibly, sizes of knots in No. 1 lumber from stand 35B were smaller than those in No. 1 lumber from stand 35A because stand 35A was subjected to second thinning. The second thinning promoted the development of larger-sized knots, albeit within the limits of No. 1 grade. The same explanation is offered for the significantly larger mean MOR value of No. 2 lumber from stand 35B (5,960 psi) compared with the corresponding value of No. 2 lumber from stand 35A (5,080 psi).

On the other hand, Table 5 indicates that there is no significant difference in mean MOE values for the same lumber grade from the two stands. This can be attributable to the fact that the influence of knot sizes on lumber stiffness is small (Doyle and Markwardt 1966; Markwardt and Wilson 1935; Southern Pine Inspection Bureau 1991).

Finally, Table 5 indicates that the overall compliances to required design flexural strength and stiffness values for stand 35A are 89% and 52%, respectively, while for stand 35B the corresponding compliances are 92% and 64%, respectively. This means an improvement of 3% and 12% in compliance in strength and stiffness, respectively, to the required design values for the visual lumber grades tested from the denser stand 35B.

CONCLUSIONS

Based on the results of this study, it appears that higher density stands of loblolly pine plantations are expected to produce dimension lumber with greater degree of compliance to required design strength and stiffness values of corresponding lumber visual grades. The study shows that lumber from a 35-year-old loblolly pine plantation with a 70/25 site index, 8- × 8-ft original spacing, and thinned twice (at age 18 and 27), has about 89% and 52% compliance to required design flexural strength and stiffness values, respectively. A similar plantation, but representing a denser stand since thinning was done only once at age 18, was found to yield lumber that has about 92% and 64% compliance to required design flexural strength and stiffness values, respectively. From the results of this study and a previous study (Biblis et al. 1993) by the authors, it is now evident that even dense stands (e.g., stand 35B) must be older than 35 years of age before they can be harvested for lumber production to ensure attainment of at least 95% compliance to required design values. More studies are definitely needed to determine the appropriate harvest age.

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