Fiberboards from Loblolly Pine Refiner Groundwood:

Effects of Gross Wood Characteristics and Board Density

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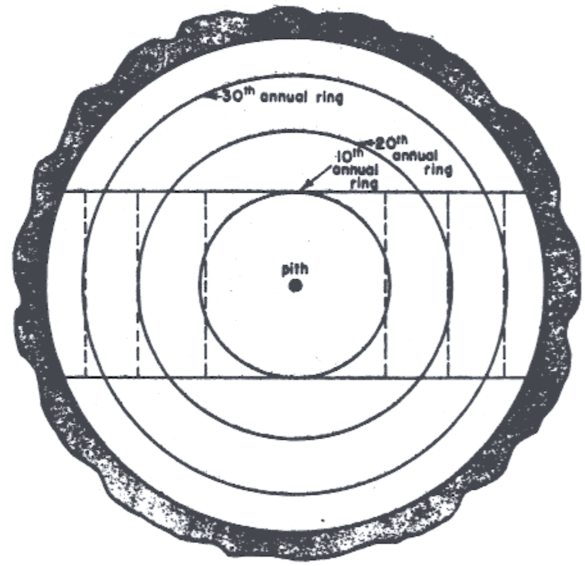

Figure 1. — Method of log breakdown.

Abstract

The gross wood properties of specific gravity, proportion of latewood, and growth rate affected the strengths of fiberboards in tension and bending, as well as their dimensional stability. For the refining conditions and formation procedures studied, and after allowance for the effect of board specific gravity, most properties were improved by using fiber refined from dense wood having low latewood content.

BOARDS FOR INSULATION AND STRUCTURAL USES are being manufactured in increasing quantities. The coarse fiber required for these products can be disk-refined from untreated wood chips. Since such fiber is produced in essentially one mechanical operation, continuous control is required of the raw material as well as the refining process.

Considerable research has been published concerning the effects of refiner operation and board-formation variables on the physical properties of fiberboards. Less well established are the independent effects of wood quality. If these effects can be adequately defined, industrial operations may be able to apply the information by isolating or selecting wood having the desired characteristics or by modifying the refining process in accordance with the characteristics of the raw material.

A broad program of research to establish interrelations between pulp quality, wood chemical composition, morphology of wood, board density, and the physical properties of fiberboards has been undertaken at the Southern Forest Experiment Station's utilization laboratory in Alexandria, La. The ultimate objective is to develop criteria useful in predicting and controlling the board-making potential of disk-refined fiber from loblolly pine (*Pinus taeda* L.). This paper discusses interrelationships between certain gross wood characteristics, board density, and the physical properties of the boards.

Procedure

A factorial experiment with four within-sample replications was designed with wood variables as follows: Specific gravity of unextracted wood (ovendry weight and green volume)—Less than 0.49; more than 0.49. Growth rate—Less than 6 rings per inch; more than 6 rings per inch. Rings from the pith (Position in tree)—0 to 10 rings (corewood); 11 to 20 rings (middle wood); 21 to 30 rings (outer wood).

Held constant were: Specific refining energy—single refiner pass at 40 hp days/air-dry ton; refining consistency—20 percent; actual feedrate—21 tons of ovendry wood/day; refiner—Bauer Bros. #410, 40-inch, double-disk, 250 hp motors; chip sample size—25 pounds, ovendry; refiner plate

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pattern—Bauer Bros. #40106; chip moisture content—100 percent; rotational speed of plates—1200 rpm; dilution water temperature—130° F.

The study variables were selected to provide broad variation in gross wood characteristics. Sampling at three distances from the pith was chosen as a simple means of securing a range of morphological and chemical characteristics. Loblolly pine was used because of its moderate pitch level and its commercial importance in southern forests.

A refining energy of 40 hp days/air-dry ton was selected (after trial runs) to achieve fiberization in the widely divergent wood types. Since the purpose of the study was to establish basic relationships, no attempt was made to optimize board properties by applying different refining energies or plate patterns. To maintain the energy at the selected level, nominal plate clearance was varied in response to the characteristics of the raw material. This approach was followed because specific refining energy appears largely to determine the quality of the refiner groundwood fiber and is universally used to maintain process control.

Four gross wood properties were measured—specific gravity of extracted and unextracted wood, growth rate in rings per inch, and proportion of latewood—and correlated with seven board properties in each of three board specific gravity classes (0.4 to 0.5, 0.5 to 0.7, and 0.7 to 0.9).

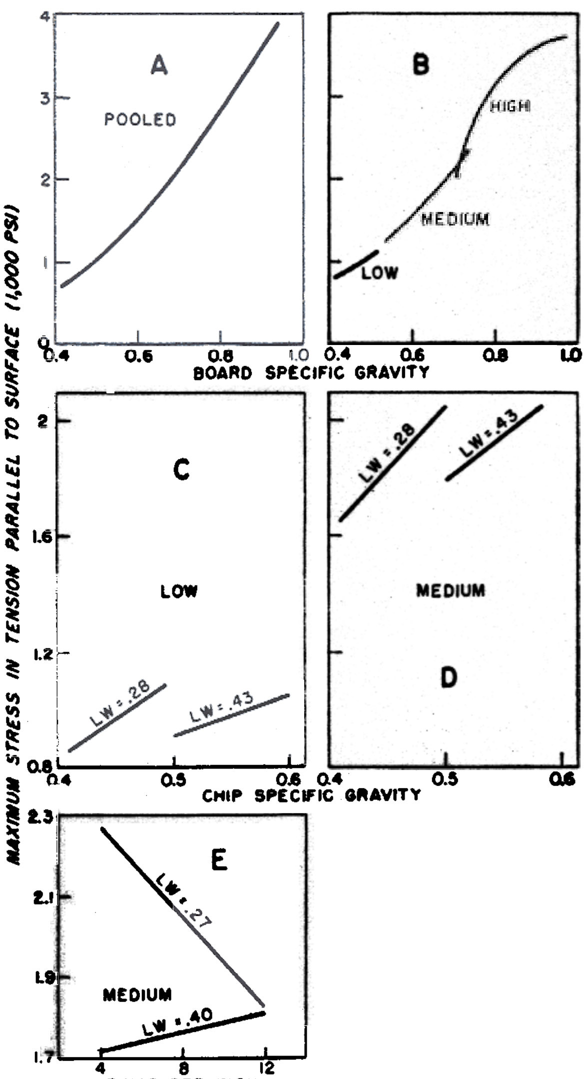

Figure 2. — Maximum stress in tension parallel to the surface as related to study variables. The graphed lines in this and subsequent figures were obtained by substituting a range of values for the variables on the X-axis and fixing the remaining variables in the regression equation at the indicated levels or at their mean values.

Test Material and Refining

Fifty standing trees, 40 years or older, were selected from a natural stand in central Louisiana. After they were felled, those portions of each tree that had at least 40 annual rings were bucked into 8-foot lengths. The top end of each log was marked as shown in Figure 1 to facilitate sawing into boards of the prescribed age classes. Logs were culled if they had defects such as excessive sweep and decay or exhibited visible evidence of compression wood.

Two slabs were removed and discarded. The resulting pith-center cant was ripped along the 10th, 20th, and 30th growth increments to form 5 boards of the required age classes. Thickness and width of the boards thus varied with growth rate of the tree. The boards were immediately stored under water to prevent sapstain and moisture loss.

A 1-inch-wide wafer was cut at midlength of each board for determination of specific gravity (ovendry weight, green volume) and growth rate. The boards were then segregated according to specific gravity, growth rate, and rings from the pith. Boards with specific gravity near 0.49 or growth rate near 6 rings per inch were excluded. Twelve bundles of 200 pounds each (the green weight of material required for four refiner replications) were dipped in water-soluble penta preservative to prevent sapstain, and sealed in polyethylene sheets. All wood was fiberized within 5 days, and no evidence of deterioration or moisture loss was visible.

The wood in each category was separately chipped and screened to eliminate chips larger than 1-inch. Acceptable chips were randomly divided into four equal replications. A random subsample of approximately 1,000 chips was taken from each replicate for measurement of wood properties.

The feed mechanism of the refiner was equipped with controls for obtaining consistent results with the quantities of chips used here. As chips entered the refining chamber, plate separation was manually adjusted to maintain energy input at the predetermined level. Simultaneously, the total power demand was recorded and the run time noted. Specific refining energy in terms of horsepower days per air-dry ton was calculated from these data. Shaft horsepower values were used after deducting losses for motor efficiency (8.5%).

Pulps can be held for extended periods if placed in cold storage with a fungicide incorporated in the slurry[2]. Accordingly a commercial pulp fungicide was added to the refiner dilution water, thus assuring a thorough mixture throughout the slurry. Pulps were stored at 30° F., and no deterioration was observed.

Determination of Wood Properties

Unextracted chip specific gravity, based on green volume and ovendry weight, was determined on 500 chips from each 1,000-chip replicate. Green volume was determined by water immersion[3]. Extracted specific gravity was calculated by reducing the observed ovendry weight by the weight of the alcohol-benzene extractive content of a matched sample. Extractive content was determined by TAPPI Standard Method T 6 os-59.

Since growth rate and proportion of latewood could not be readily determined from chips, they were measured on the cross-sectional surfaces of the wafers used to segregate the material prior to chipping. A lowpower microscope with a calibrated eyepiece was employed to distinguish the characteristically abrupt transition between earlywood and latewood. Because boards varied in cross-sectional area, measurements were weighted by area in calculating the mean. The means thus calculated were assumed representative of each replicate.

Preparation of Boards and Determination of Properties

Three test boards having specific gravities of approximately 0.45, 0.60, and 0.80 (low, medium, and high density) were manufactured from each of the 48 sample pulps. Since each pulp varied in drainage, formation, and pressing characteristics, it was not possible to establish a procedure for accurate control of board specific gravity. Board density is known to affect strength properties, and the variation within board density classes was considered in evaluating the independent effects of gross wood factors.

The ovendry weight of pulp required to form one board measuring 12 inches square and 0.250 inch thick was calculated from a consistency sample for each pulp and for each board-density class. The pulp was diluted with water and disintegrated for 5 minutes. After further dilution, the slurry was transferred to the deckle box of the board former and mixed.

After movement of the stock had quieted, a constant vacuum of 20 inches of mercury was applied through a receiving tank until all water had disappeared from the board surface and the mat began to part from the deckle. The suction was then shut off and the deckle removed. A stainless

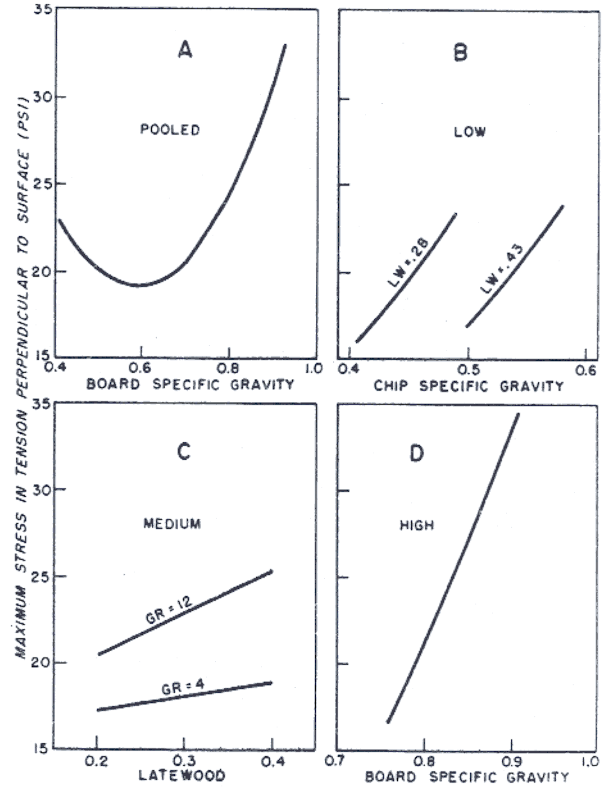

Figure 3. — Maximum stress in tension perpendicular to the surface, as related to study variables.

steel plate was placed over the mat and the suction reapplied until further obvious reduction in mat thickness ceased.

The mat was then faced on one side with a screen and placed between stainless steel cauls. Each mat was dewatered in a cold press to approximately 50 percent consistency. All mats were hot-pressed to 0.250 inch stops at 380° F. for 15 minutes. Trial runs had shown this schedule to be satisfactory for the range of pulps and board densities used here. After pressing, all boards were conditioned to equilibrium moisture content in a room maintained at 50 percent relative humidity and 72° F.

Each board was sanded on the screen side to 0.200 ± 0.005 inch and trimmed to panels measuring 10 inches square. Two specimens for each of the seven property determinations were cut from each board.

Strength in bending was determined in accordance with ASTM D 1037. One specimen was tested with the screen side up, the second with the screen side down. The results were averaged to obtain a single value of stress at the proportional limit (*PL*), modulus of elasticity (*MOE*), and modulus of rupture (*MOR*). After test, a 1-inch wafer was cut from the end of each bending specimen for determination of specific gravity, and the results were averaged. Specific gravity was based on volume at test (determined by mercury immersion) and ovendry weight.

[2]Chilson, W. U.S. Forest Products Laboratory, Madison, Wisconsin. Personal Communication.

[3]Smith, D. M. 1961. Method of determining specific gravity of small wood chips. U.S. Forest Products Laboratory Report 2209. Madison, Wis.

Strengths in tension parallel and in tension perpendicular to the surface were also determined in accordance with ASTM D 1037. Specific gravities (ovendry weight and volume at test) were determined on samples cut from the end of each tension-parallel specimen after test and from matched samples adjacent to the tension-perpendicular specimens.

Dimensional stability was evaluated by measuring the shrinkage in length and thickness of a 2-inch-wide by 10-inch-long specimen between two moisture contents: Equilibrium moisture content at 90 percent relative humidity and ovendry. Results were expressed as a percentage of the ovendry dimension. The specific gravity of each test specimen was determined on the basis of ovendry weight and ovendry volume.

Processing the Data

The effects of gross wood properties and board specific gravity were studied by multiple regression analysis. Each density class was considered separately. Equations were developed by stepwise introduction of the independent variables in de-

Table 1. — WOOD CHARACTERISTICS AND BOARD PROPERTIES FOR THREE BOARD SPECIFIC GRAVITY CLASSES[a].

				Tension parallel to surface		Tension perpendicular to surface		Bending				Dimensional change		
Position in tree	Unextracted chip specific gravity	Proportion of latewood	Rings per inch	Max. stress	Board specific gravity	Max. stress	Board specific gravity	Stress at PL	MOE	MOR	Board specific gravity	Lineal	Thickness	Board specific gravity
				P.s.i.		P.s.i.		P.s.i.				%	%	
						Low board density								
Core	0.431	0.237	4.75	1083	0.460	21.9	0.478	957	250,322	1696	0.460	0.501	6.99	0.488
Core	.456	.239	10.13	1067	.490	21.9	.482	943	255,825	1699	.490	.596	7.56	.506
Core	.496	.310	4.47	1132	.486	23.9	.493	1006	251,245	1818	.486	.632	7.02	.503
Core	.535	.345	12.39	978	.456	25.7	.462	967	236,005	1549	.456	.579	6.98	.473
Middle	.442	.265	5.52	975	.464	19.5	.466	762	188,379	1406	.464	.581	7.36	.484
Middle	.466	.303	6.84	919	.494	17.2	.482	764	205,098	1417	.494	.584	7.97	.499
Middle	.510	.345	4.78	1011	.490	19.4	.494	832	204,562	1509	.490	.606	8.07	.508
Middle	.531	.386	8.34	963	.479	21.4	.476	781	220,489	1470	.479	.566	7.41	.492
Outer	.470	.351	5.21	835	.475	18.4	.477	695	170,552	1239	.475	.602	7.03	.489
Outer	.449	.329	8.15	934	.492	18.9	.502	780	192,885	1402	.493	.581	8.03	.517
Outer	.517	.411	6.30	1012	.485	18.2	.491	745	203,658	1478	.485	.576	7.46	.493
Outer	.534	.424	9.86	984	.480	18.3	.480	725	199,610	1415	.480	.531	7.75	.491
						Medium board density								
Core	.431	.237	4.75	2187	.672	17.9	.663	1610	487,795	3340	.672	.535	8.96	.677
Core	.456	.239	10.13	1713	.635	20.6	.610	1377	441,713	3029	.635	.542	8.51	.637
Core	.494	.310	4.47	2436	.709	19.8	.690	1953	585,329	4117	.709	.557	8.57	.764
Core	.535	.345	12.39	2013	.671	23.4	.655	1673	517,502	3541	.670	.504	7.42	.670
Middle	.442	.265	5.52	1800	.658	17.8	.654	1295	403,027	2838	.658	.532	9.15	.667
Middle	.466	.303	6.84	1754	.673	20.3	.655	1269	407,398	2815	.673	.500	9.50	.683
Middle	.510	.345	4.78	1745	.637	20.0	.647	1105	332,293	2482	.637	.542	8.89	.649
Middle	.531	.386	8.34	2074	.693	24.5	.665	1474	434,573	3195	.693	.522	8.45	.685
Outer	.470	.351	5.21	1870	.680	20.2	.646	1373	412,814	2953	.680	.550	9.08	.673
Outer	.449	.329	8.15	1720	.660	18.6	.649	1228	388,605	2733	.660	.542	9.18	.653
Outer	.517	.411	6.30	1808	.677	20.8	.656	1234	377,752	2784	.677	.537	8.55	.679
Outer	.534	.424	9.86	1952	.676	24.8	.665	1413	426,728	2928	.676	.512	9.31	.679
						High board density								
Core	.431	.237	4.75	3515	.838	24.8	.825	2240	665,135	4879	.838	.529	8.27	.855
Core	.456	.239	10.13	3817	.908	29.6	.869	3144	831,378	5701	.908	.539	7.90	.904
Core	.494	.310	4.47	3534	.834	24.5	.809	2401	730,156	5268	.834	.546	7.82	.845
Core	.535	.345	12.39	3123	.809	25.9	.792	2637	755,293	5152	.809	.496	7.67	.827
Middle	.442	.265	5.52	3226	.831	22.7	.837	2278	632,609	4554	.832	.549	8.10	.864
Middle	.466	.303	6.84	3208	.871	32.2	.861	2365	692,600	5139	.871	.552	9.13	.885
Middle	.510	.345	4.78	3572	.881	25.6	.867	2378	688,429	5065	.881	.576	8.63	.892
Middle	.531	.386	8.34	3318	.851	24.7	.844	2284	674,539	4998	.851	.536	8.09	.865
Outer	.470	.351	5.21	3513	.868	25.9	.831	2388	711,502	5008	.868	.549	8.80	.877
Outer	.449	.329	8.15	3685	.893	27.0	.889	2440	770,610	4968	.893	.545	9.57	.900
Outer	.517	.411	6.30	3674	.927	32.4	.875	2166	638,940	5052	.884	.589	8.63	.884
Outer	.534	.424	9.86	3349	.880	27.0	.871	2075	655,693	4933	.880	.536	8.19	.889

[a]Each numerical value is the average of four replications except that the values for proportion of latewood and rings per inch are based on one observation.

creasing order of their individual contribution to the cumulative R^2. All were the type $y = b_0 + b_1x_1 + b_2x_2 + \ldots\ldots$, where y is a dependent variable, for example, *MOR*, *MOE*; b_i, a regression coefficient; and x_i, an independent variable, for example, growth rate or proportion of latewood. The equations were tested at the 95 percent level, and all included variables were significant at that level.

The single variables were: UG—unextracted chip specific gravity; EG—extracted chip specific gravity; LW—proportion of latewood, expressed as a decimal fraction; GR—growth rate, rings per inch; BG—board specific gravity.

The factor combinations were: (UG) (GR); (EG) (GR); (GR) (LW); (UG)/(LW).

Various transformations of the single factors were also considered, for example, board specific gravity squared. The board specific gravity values were those obtained for the particular board property under consideration.

Results

Table 1 summarizes wood and board properties for each density class. The values are carried to an extreme number of significant figures to permit the present statistical analysis and to allow future statistical manipulations of the same data. As expected, all measured wood properties exhibited a wide range and reflected the method of specimen preparation.

Table 2. — MULTIPLE REGRESSION EQUATIONS DEVELOPED TO ESTIMATE BOARD STRENGTH.

Eq. no.	Board gravity class	Equation	R^2	S_e
		Maximum stress in tension parallel to surface (P.s.i.)		
1	All (0.42 - 0.97)	$y = -88.6029 + 4640.2772(BG)^2$	0.954	226
2	Low (0.42 - 0.52)	$y = -1{,}531.1871 + 3{,}232.1394(BG)^2 + 767.5793(UG)/(LW) + 1{,}877.7974(LW)$	.398	112
3	Medium (0.54 - 0.74)	$y = -1{,}945.9067 + 4{,}277.1341(BG)^2 + 1{,}387.9765(UG)/(LW) - 192.9302(GR) + 513.1896(LW)(GR)$	.771	145
4	High (0.71 - 0.97)	$y = -22{,}132.1845 + 54{,}408.0154(BG) - 28{,}619.6454(BG)^2$	.474	247
		Maximum stress in tension perpendicular to surface (P.s.i.)		
5	All (0.43 - 0.93)	$y = 62.3574 + 124.1791(BG)^2 - 146.5305(BG)$	.360	5.0
6	Low (0.43 - 0.52)	$y = -10.8806 + 11.9735(UG)/(LW) + 55.0608(UG)^2$	.328	3.2
7	Medium (0.52 - 0.75)	$y = 15.9037 + 1.9925(LW)(GR)$	.367	2.7
8	High (0.75 - 0.93)	$y = -22.8493 + 69.2104(BG)^2$	.329	6.9
		Stress at proportional limit in bending (P.s.i.)		
9	All (0.42 - 0.93)	$y = 97.8157 + 3{,}057.9214(BG)^2$	.882	246
10	Low (0.42 - 0.52)	$y = -894.0134 - 2{,}784.0220(LW) + 3{,}426.6133(UG) + 2{,}026.8426(BG)$	.521	104
11	Medium (0.54 - 0.78)	$y = -2{,}299.1274 + 4{,}764.5729(BG)^2 + 728.0359(UG)/(LW) + 1{,}970.3457(UG)^2$	.624	205
12	High (0.75 - 0.93)	$y = 1{,}499.6329 + 2{,}635.2851(BG)^2 - 850.9264(UG)/(LW) + 857.6457(UG)(GR) - 1{,}173.3574(LW)(GR)$	.778	182
		Modulus of rupture in bending (P.s.i.)		
13	All (0.42 - 0.93)	$y = -35.4088 + 6{,}842.1267(BG)^2$	.944	367
14	Low (0.42 - 0.52)	$y = -1{,}471.8103 + 812.6071(UG)/(LW) + 5{,}144.1110(BG)^2 + 2{,}381.1290(UG)^2$	.516	164
15	Medium (0.54 - 0.78)	$y = -7{,}963.4693 + 13{,}286.2315(BG) - 7{,}842.5590(LW) + 9{,}668.1205(UG)$	.750	323
16	High (0.75 - 0.93)	$y = -3{,}668.8732 + 5{,}162.3073(BG)^2 + 1{,}320.8521(UG)/(LW) + 5{,}592.5766(UG)$	.680	323
		Modulus of elasticity in bending (P.s.i.)		
17	All (0.42 - 0.93)	$y = 5{,}422.1070 + 938{,}552.2460(BG)^2$	.910	64,840
18	Low (0.42 - 0.52)	$y = -543{,}068.9040 + 268{,}737.1880(UG)/(LW) + 628{,}365.2800(LW) + 628{,}689.3280(BG)^2$	.611	21,960
19	Medium (0.54 - 0.78)	$y = -1{,}284{,}707.9350 + 2{,}129{,}568.4080(BG) - 1{,}298{,}096.6000(LW) + 1{,}478{,}520.9590(UG)$	.739	52,010
20	High (0.75 - 0.93)	$y = 156{,}824.9740 + 648{,}802.5200(BG)^2 + 98{,}912.9980(UG)(GR) - 120{,}151.1810(LW)(GR)$	.573	60,328
		Dimensional stability parallel to the surface (%)		
21	All (0.45 - 0.98)	$y = 0.9567 - 1.1437(BG) + 0.7674(BG)^2$	.288	0.03
22	Medium (0.54 - 0.78)	$y = 0.5569 - 0.0108(LW)(GR)$	.137	.03
23	High (0.79 - 0.98)	$y = 0.3336 + 0.0213(GR) + 0.8010(LW) - 0.0860(LW)(GR)$	.392	.03
		Dimensional stability perpendicular to the surface (%)		
24	All (0.45 - 0.98)	$y = -2.9675 + 31.6591(BG) - 21.2405(BG)^2$	.420	.66
25	Low (0.45 - 0.52)	$y = 0.3807 + 14.3044(BG)$	.303	.46
26	Medium (0.54 - 0.78)	$y = 9.5558 - 0.2161(UG)(GR)$	.188	.63
27	High (0.79 - 0.98)	$Y = 21.4808 - 5.2770(UG)/(LW) - 15.5412(LW)$	.321	.61

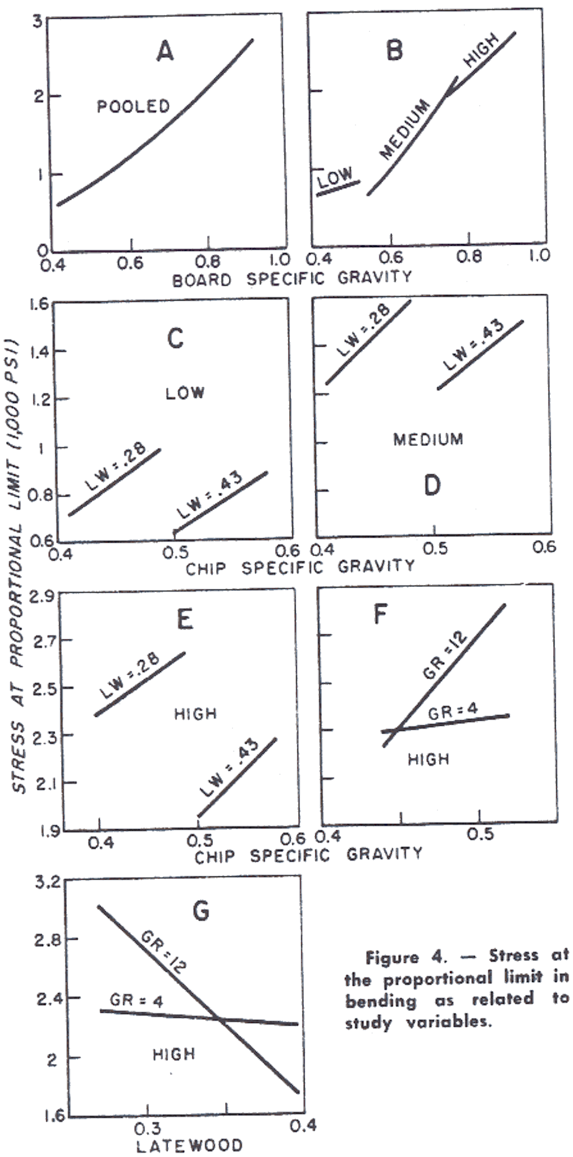

Figure 4. — Stress at the proportional limit in bending as related to study variables.

Several of the independent variables used in multiple regression estimates of board properties were correlated. Unextracted chip specific gravity was positively correlated with extracted chip specific gravity (r = 0.910) and proportion of latewood (r = 0.809); extracted chip specific gravity was also positively correlated with proportion of latewood (r = 0.889). Correlations between growth rate and other independent variables were low.

For the pooled data, several board properties proved highly interrelated. Notably, stress in tension parallel to the surface was positively correlated with stress at *PL* (r = 0.944), *MOR* (r = 0.970), and *MOE* (r = 0.954). Stress at *PL* was also positively correlated with *MOR* (r = 0.970) and *MOE* (r = 0.969), while *MOR* was positively correlated with *MOE* (r = 0.986).

Variance analysis showed no significant difference in specific refining energy between runs.

Table 2 lists multiple regression equations which most accurately describe board properties for each density class in terms of board specific gravity and gross wood characteristics; all positions in the tree are considered. Also listed are equations relating board properties to board specific gravity for all density classes (pooled data). The variables are shown in the order included, along with the cumulative R^2 values and the standard error of the estimate (S_e).

Tension Parallel to the Surface

For the pooled data, maximum stress in tension parallel to the surface increased with increasing board specific gravity (Equation 1 and Figure 2,A). The rate of increase became slightly greater with increasing board specific gravity.

Board specific gravity proved the most significant single variable when board classes were considered separately. Its positive effect on tensile strength for each board class is shown in Figure 2,B.

For boards of low density, the proportion of latewood and also the ratio of unextracted chip specific gravity to proportion of latewood proved significant after board specific gravity was considered (Equation 2). Tensile strength increased with increasing chip specific gravity, the rate of increase being greater for wood with a low proportion of latewood (Figure 2,C). For a given chip specific gravity, tensile strength increased with decreasing proportion of latewood. Although latewood content and unextracted chip specific gravity are related (r = 0.81), chip specific gravity exhibited a range of values for all latewood contents. Unextracted chip specific gravity in this and subsequent equations proved more highly correlated with board properties than did extracted chip specific gravity. All wood factors considered, tensile strength parallel to the surface was increased by using fiber refined from wood of high specific gravity and containing a relatively low proportion of latewood.

For boards of medium density, the growth rate, the ratio of unextracted chip specific gravity to proportion of latewood, and the product of growth rate and proportion of latewood proved significant after board specific gravity (Equation 3). The effect of chip specific gravity at two latewood contents was similar to that obtained for boards of low density (Figure 2,D). The relation between tensile strength and rings per inch at two latewood contents is shown in Figure 2,E. Tensile strength increased slightly with increasing rings per inch for wood of high latewood content, while it decreased with increasing rings per inch for wood of low latewood content. All wood factors considered, the tensile strength of medium-density boards was improved by using fiber refined from fast-grown, dense wood of low latewood content.

Only board specific gravity proved significant for boards of high density (Equation 4 and Figure 2,B).

Tension Perpendicular to the Surface

For the pooled data (Equation 5) maximum stress perpendicular to the surface first decreased slightly with increasing board specific gravity, reaching a minimum at about 0.6, and then increased rapidly (Figure 3,A).

For boards of low density the significant factors were unextracted chip specific gravity and the ratio of unextracted chip specific gravity to proportion of latewood. Board specific gravity did not prove significant. Tensile strength perpendicular to the surface increased with increasing chip specific gravity (Equation 6, Figure 3,B) and, for a given chip specific gravity, increased with decreasing latewood content. All factors considered, tensile strength perpendicular to the surface of low-density boards was increased by using fibers refined from dense wood having a low proportion of latewood.

For boards of medium density, the product of latewood content and rings per inch proved significant. Board specific gravity was not significant (Equation 7). Maximum stress increased with increasing latewood, the rate being greater for slow-grown than for fast-grown wood. For a given latewood content, tensile strength increased with increasing rings per inch (Figure 3,C). All wood factors considered, strength perpendicular to the surface was increased by using fiber refined from slow-grown wood containing a high proportion of latewood.

Board specific gravity proved the only significant factor affecting the tensile stress in high-density boards (Equation 8). Its positive effect is shown in Figure 3,D.

Stress at PL in Bending

The relation between board specific gravity and stress at *PL* for boards of all densities is given by Equation 9. As shown in Figure 4,A, stress increased rapidly with increasing board specific gravity.

For boards of both low and medium density, proportion of latewood, unextracted chip specific gravity, and board specific gravity proved significant (Equations 10 and 11). The positive effect of board specific gravity is shown in Figure 4,B.

The effect of chip specific gravity is shown in Figures 4,C and 4,D at two latewood contents. Stress increased with increasing chip specific gravity for wood of both high and low latewood content. At a given level of chip specific gravity, stress increased with decreasing latewood content. For all wood factors affecting low- and medium-density boards, stress at the *PL* was improved by using fiber refined from dense wood containing a low proportion of latewood.

After the positive effect of board specific gravity (Figure 4,B), the ratio of chip specific gravity to latewood content, the product of chip specific gravity and rings per inch, and the product of latewood content and rings per inch proved significant wood factors for boards of high density (Equation 12).

Stress increased with increasing chip specific gravity (Figure 4,E); the level of the relationship increased with decreasing latewood content. The effect of chip specific gravity at two growth rates is shown in Figure 4,F. Stress increased with increasing chip specific gravity, the rate of increase being substantially greater for wood of slow growth. The effect of latewood content at two growth rates is shown in Figure 4,G. Stress decreased with increasing latewood, the decrease being greater for wood of slow growth. All wood factors considered, stress at the *PL* for high-density boards was increased by using fiber refined from slow-grown wood of high density and low proportion of latewood.

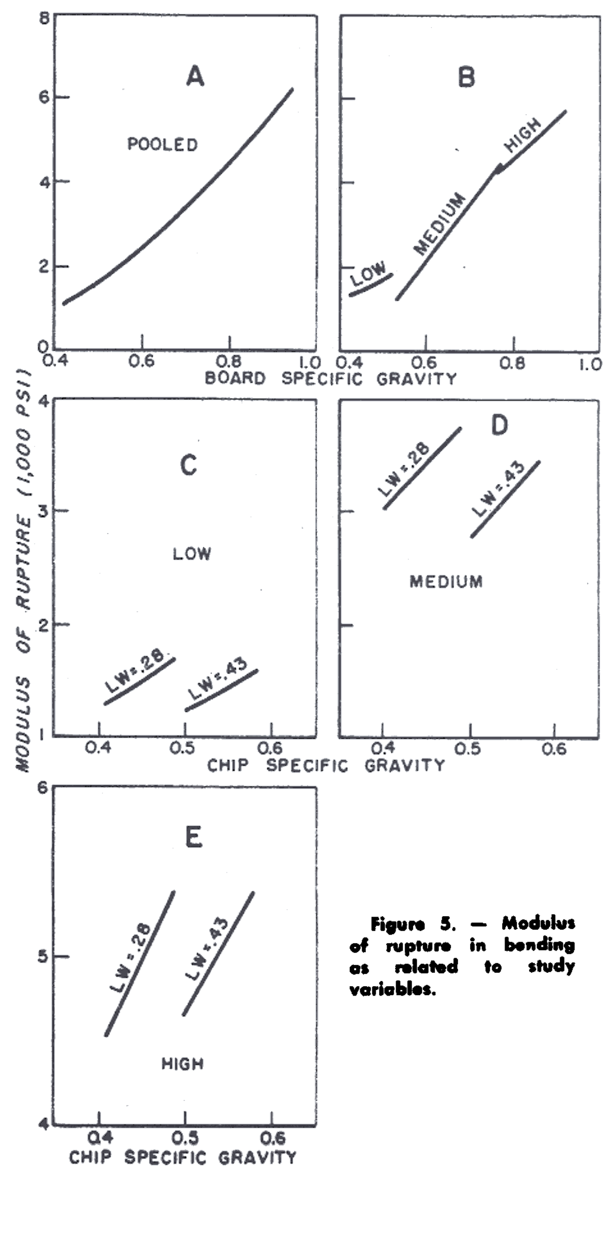

Figure 5. — Modulus of rupture in bending as related to study variables.

Modulus of Rupture

The relation between board specific gravity and *MOR* for the pooled data is given by Equation 13. As shown in Figure 5,A, *MOR* increased rapidly with board specific gravity, the rate becoming greater with increasing board specific gravity.

For boards of low density, the ratio of unextracted chip specific gravity to latewood content, the square of unextracted chip specific gravity, and the square of board specific gravity proved significant (Equation 14). The positive effect of board specific gravity on *MOR* is shown in Figure 5,B. *MOR* also increased with increasing chip specific gravity; for a given chip specific gravity *MOR* increased with decreasing proportion of latewood (Figure 5,C).

Both medium- and high-density boards behaved similarly. Rates were linear with medium boards but varied between latewood contents in high-density boards (Equations 15 and 16 and Figures 5,D and 5,E).

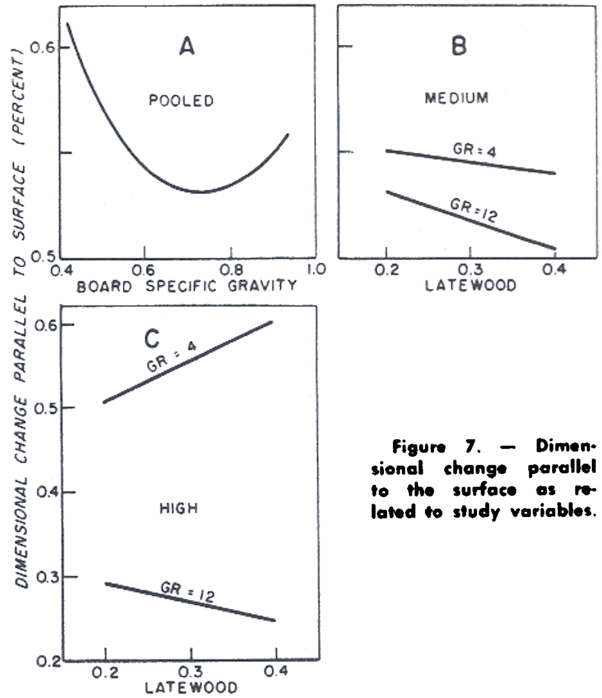

Figure 7. — Dimensional change parallel to the surface as related to study variables.

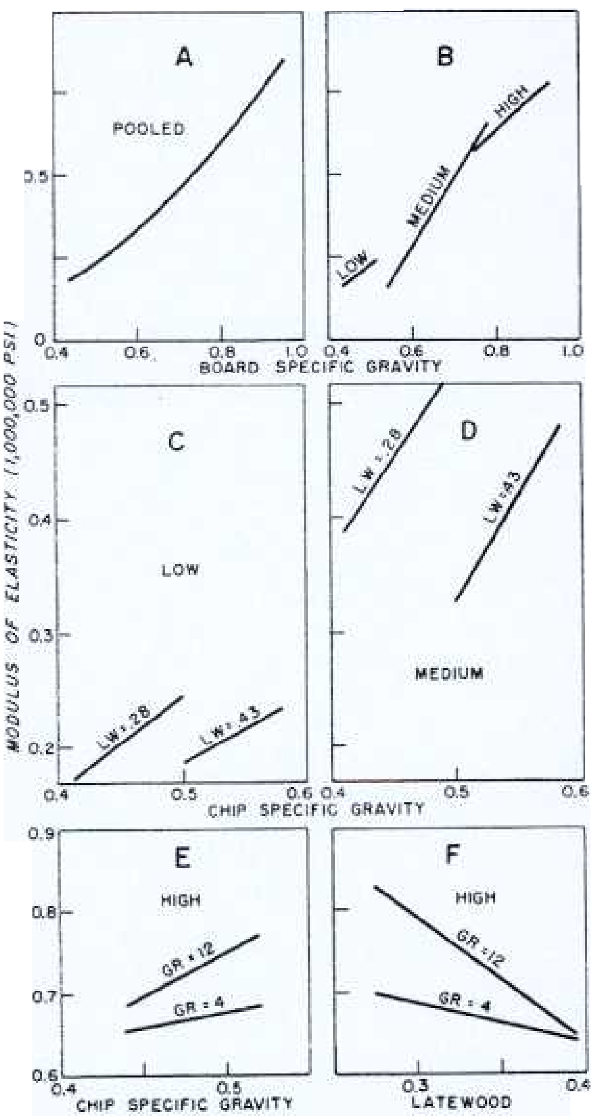

Figure 6. — Modulus of elasticity in bending as related to study variables.

All wood factors considered, *MOR* of low-, medium-, and high-density boards was improved by using fibers refined from wood of high density containing a relatively low proportion of latewood.

Modulus of Elasticity

The relation between *MOE* and board specific gravity for the pooled data is given by Equation 17. *MOE* increased with board specific gravity, the relationship being curvilinear (Figure 6,A).

For boards of low density, the significant factors were proportion of latewood, the ratio of unextracted chip specific gravity to proportion of latewood, and the square of board specific gravity (Equation 18). *MOE* increased with increasing board specific gravity (Figure 6,B) and with increasing chip specific gravity (Figure 6,C). For a given chip specific gravity *MOE* increased with decreasing latewood content. Medium-density boards displayed a similar relationship except that there was no interaction between chip specific gravity and latewood content (Equation 19 and Figures 6,B and 6,D). All wood factors considered, *MOE* of both low-and medium-density boards was increased by using fibers refined from wood of high density containing a low proportion of latewood.

The significant factors for high-density boards were board specific gravity, the product of wood chip specific gravity and growth rate, and the product of latewood content and growth rate. *MOE* increased with chip specific gravity, the rate being greater for wood of slow growth (Figure 6,E). *MOE* also decreased with increasing proportion of latewood, the rate of decrease being greater for wood of slow growth (Figure 6,F). All wood factors considered, *MOE* for high-density boards was increased by using fibers refined from slow-grown, dense wood with low proportions of latewood.

Stability Parallel to Surface

For the pooled data, dimensional change parallel to the surface decreased with increasing board specific gravity to a minimum at about 0.7 specific gravity, and then increased slightly (Figure 7,A, Equation 21).

For boards of low density, no study factors proved significantly related to dimensional change parallel to the surface, and no equation was provided.

For boards of medium density, the product of latewood content and growth rate proved significant (Equation 22). Board specific gravity was not significant. Dimensional change decreased with increasing latewood (Figure 7,B); the rate of decrease was greater for wood of slow growth, but the amount of dimensional change was less for this slow-grown wood.

For boards of high density, growth rate, proportion of latewood, and their interaction proved significant (Equation 23). Board specific gravity was not significant. For wood of slow growth, dimensional change parallel to the surface decreased with increasing latewood content; with wood of fast growth, dimensional change increased with increasing latewood content (Figure 7,C).

For boards of both medium and high density, dimensional change parallel to the surface was minimized by using fiber refined from wood of slow growth containing a high proportion of latewood.

Stability Perpendicular to Surface

For the pooled data, dimensional change perpendicular to the surface increased until board specific gravity reached about 0.7, then decreased slightly (Figure 8,A, Equation 24).

For boards of low density, only board specific gravity significantly affected dimensional change perpendicular to the surface (Equation 25). Its positive effect is shown in Figure 8,B.

For boards of medium density, the interaction of unextracted chip specific gravity and rings per inch of growth rate proved the only significant factor (Equation 26). Dimensional change decreased with increasing chip specific gravity, the rate and amount of decrease being greater for wood of slow growth (Figure 8,C). For medium-density boards, dimensional change perpendicular to the surface was minimized by using fiber refined from slow-grown wood of high density.

For boards of high density, the significant factors were proportion of latewood and the ratio of unextracted chip specific gravity and proportion of latewood (Equation 27). Dimensional change decreased with increasing chip specific gravity and, for a given specific gravity, increased with increasing latewood content (Figure 8,D). All factors considered, dimensional change perpendicular to the surface of high-density boards was minimized by using fiber refined from dense wood having a low proportion of latewood.

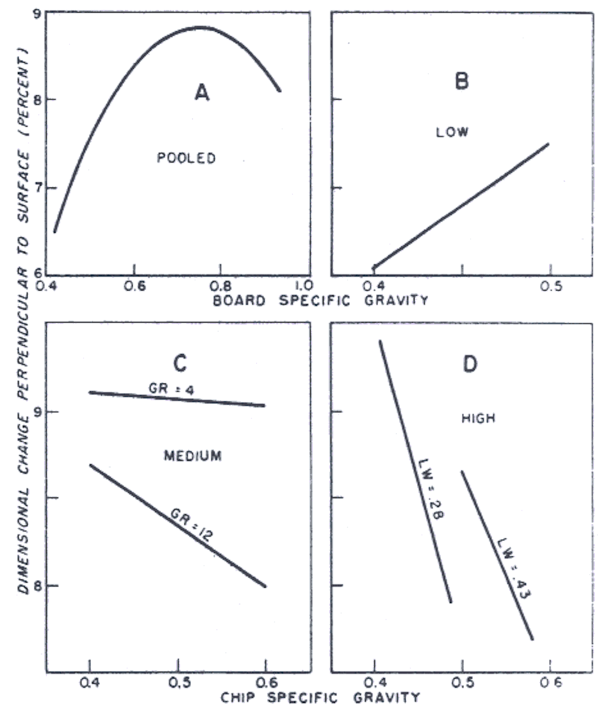

Figure 8. — Dimensional change perpendicular to the surface as related to study variables.

Discussion

Most fiberboard properties considered here were increased by use of fiber refined from dense wood containing a relatively low proportion of latewood. Wood from three positions in the stem was considered: core, middle, and outer.

The latewood content of loblolly pine characteristically increases with distance from the pith. In the present study it increased significantly (0.05 level) from 0.262 for inner wood to 0.339 for middle wood, and 0.380 for outer wood. Wood of high and low specific gravity and of slow and fast growth was considered at each position. Because of the forced stratification of wood specific gravity at each radial position, the correlation between latewood content and unextracted specific gravity was relatively low ($R^2 = 0.66$) as compared to that in stems. Thus, proportion of latewood exhibited a range of values at all levels of chip specific gravity.

From this it may be surmised that fiber prepared from corewood of high unextracted specific gravity will yield boards of superior strength. The data in Table 1 confirm this observation. Thus, dense veneer cores would appear to be a desirable raw material for fiberboards from a strength standpoint. In contrast, fiber refined from slabs and edgings of low density would be expected to yield boards of inferior strength.