Wood Science and Technology Vol. 2 (1968) p. 166—176

Morphological Characteristics of Loblolly Pine Wood as Related to Specific Gravity, Growth Rate and Distance from Pith

By CHARLES W. MCMILLIN, Alexandria, La.

Summary

Earlywood and latewood tracheid length and transverse cellular dimensions of wood removed from stems of loblolly pine (*Pinus taeda* L.) and factorially segregated by specific gravity, rings from the pith, and growth rate were determined from sample chips. The independent relationships of each factor with fiber morphology are described.

Zusammenfassung

An Probespänen wurden Tracheidenlänge und Zell-Querabmessungen im Früh- und Spätholz von Loblolly pine (*Pinus taeda* L.) bestimmt und faktoriell gegen die Dichte, den Abstand von der Markröhre bzw. die Wuchsgeschwindigkeit abgegrenzt. Die „gereinigte" Beziehung jedes Faktors zur Fasermorphologie wird erörtert.

The wood in a large second-growth southern pine stem characteristically increases in specific gravity with increasing rings from the pith, while the growth rate slows. For a given number of rings from the pith, however, the range of variation in specific gravity and growth rate between stems is remarkably large. For example, it is possible to isolate corewood of low density and slow growth from one stem while corewood from a second stem may also be of low density but of fast growth. As another example, the outer wood of one stem and the corewood of a second stem may both contain fast-grown wood of low density.

In the research reported here, an analysis was made of cellular morphology of loblolly pine wood (as distinct from the cellular morphology of stems) in relation to three gross wood characteristics that can readily be measured. The characteristics, or factors, were rings from the pith, growth rate, and specific gravity. By removing wood from many stems and stratifying it by two densities and two growth rates at each of three radial positions in the stem, it was possible to isolate the independent relationships of each wood characteristic with fiber morphology.

This approach is quite different from studies where it is desired to determine the radial variation of fiber morphology in stems. In these cases, the variation is usually measured along sections, wedges, or increment cores removed from the stem. Since the typical change in specific gravity and growth rate along such sections precludes stratification by specific gravity and growth rate at all radial positions, the independent relationship of each factor with fiber morphology is confounded.

Since the sample was limited to wood from trees in central Louisiana, the present results must be regarded as exploratory and not as representative of the species *Pinus taeda* L. Nevertheless, if the morphology of wood can be predicted

The Roy O. Martin Lumber Company, Alexandria, Louisiana, and J. Adams, Brauer Bros. Company, Springfield, Ohio, assisted in collecting and preparing the experimental material. D. Bower, Mathematical Statistician, Southern Forest Experiment Station, New Orleans, Louisiana, aided in the statistical interpretation.

from gross factors, industry may be able to apply the information by isolating or selecting material having the desired characteristics. In effect, some selection of wood types within a tree is already taking place in the pulp industry. Thus, a batch of chips from southern pine veneer cores will differ considerably from a batch made from slabs and edgings taken from the periphery of a large saw log. As another example, plantation wood grown on a short rotation may display morphology different from that in wood from natural stands.

A subsequent paper will examine wood chemical constituents in relation to gross wood characteristics.

Procedure

Fifty trees in a stand near Alexandria, Louisiana, were field-identified as loblolly pine and felled. Portions of the stems that exhibited 40 annual rings or more were bucked into 8-foot lengths and the top end of each length was marked (Fig. 1). Logs with visible defects, such as compression wood and decay, were discarded.

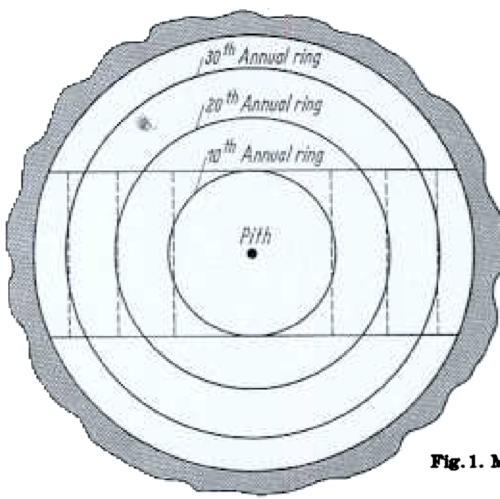

Fig. 1. Method of log breakdown.

The logs were then slabbed to a pith-center cant which was ripped along the 10th, 20th, and 30th growth increments to form five boards. Boards were stored under water to prevent sap stain and moisture loss. The specific gravity (oven-dry weight and green volume) and growth rate were determined on a 1-inch sample cut from midpoint of each board; removal of this sample reduced the boards to 4-foot lengths. On the basis of these preliminary measurements, 200 pounds of wood were selected for each category in each of two blocks in the factorial design outlined below. Boards having specific gravities and growth rates near the category division points were rejected.

Variables in the design were:

Unextracted specific gravity (oven-dry 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 ... 10 (corewood)	11 ... 20 (middle wood)	21 ... 30 (outer wood)

Table 1 *Results of Wood Property Determinations*[1]

Rings from pith				Tracheid wall thickness µm	Lumen diameter µm	Tracheid diameter µm	Tracheid length mm	Earlywood Tracheid wall thickness µm	Lumen diameter µm	Tracheid diameter µm	Tracheid length mm
						Block 1					
0–10	0.431		4.75	9.75	15.05	34.54	4.03	4.60	47.05	56.14	3.77
0–10	.456		10.13	9.59	13.00	32.02	4.05	4.57	42.96	52.07	3.68
0–10	.494		4.47	9.67	14.29	33.32	3.85	4.55	42.23	51.16	3.46
0–10	.535		12.39	9.41	13.12	31.91	3.61	4.31	41.33	49.93	3.29
11–20	.442		5.52	9.69	14.80	34.21	4.39	4.85	49.68	58.85	4.20
11–20	.466		6.84	9.58	14.79	33.83	4.23	4.32	49.95	58.58	4.21
11–20	.510		4.78	10.63	13.10	34.24	4.30	5.34	41.11	51.62	3.98
11–20	.531		8.34	10.17	12.94	33.06	4.07	4.51	45.00	53.99	3.98
21–30	.470		5.21	10.16	14.46	34.63	4.45	4.95	51.76	60.75	4.29
21–30	.449		8.15	9.89	13.68	33.30	4.28	4.52	46.25	55.28	4.12
21–30	.517		6.30	9.78	13.88	33.42	4.05	4.50	49.05	57.82	3.81
21–30	.534		9.86	10.82	12.35	33.75	3.98	4.60	44.83	54.04	3.93
Average	.486		7.23	9.93	13.79	33.52	4.11	4.63	45.94	55.02	3.89
						Block 2					
0–10	.427	.400	4.11	8.88	15.51	33.16	3.60	4.27	45.64	54.17	3.51
0–10	.457	.421	7.59	9.60	14.97	34.17	4.02	4.82	47.82	56.76	3.59
0–10	.492	.441	4.80	9.15	14.43	32.73	3.42	4.49	42.67	51.47	3.31
0–10	.515	.449	11.83	9.23	12.30	30.75	3.74	4.22	42.26	50.68	3.57
11–20	.445	.419	5.53	9.92	14.06	33.82	4.07	4.65	47.27	56.41	3.72
11–20	.459	.441	7.08	9.94	14.46	33.91	4.25	4.49	48.60	57.54	4.03
11–20	.512	.491	5.30	9.77	14.30	33.74	3.89	4.51	44.21	53.23	3.56
11–20	.524	.493	12.38	9.86	12.81	32.36	3.84	4.53	43.14	52.15	3.65
21–30	.458	.443	4.91	9.50	14.31	33.30	4.21	4.36	48.28	56.99	3.98
21–30	.438	.424	8.27	9.70	14.05	33.43	4.34	4.58	49.29	57.96	4.05
21–30	.534	.519	5.53	9.67	15.54	34.51	4.02	4.36	45.69	54.40	3.83
21–30	.511	.495	8.27	10.48	13.14	34.10	4.33	4.61	47.05	56.22	3.99
Average	.481	.453	7.13	9.64	14.16	33.33	3.98	4.49	45.99	54.83	3.73

[1] Each nu[illegible]l value is the average of four determinations except that growth rate is based on one [illegible]tion.

Sample boards in each block and each category were separately reduced to chips that averaged somewhat less than 1 inch in length. After being mixed, each of the 24 groups of chips was randomly divided into four replications each. A random subsample of 1000 chips was then taken from each of the 96 samples for measurement of physical and anatomical properties. Chips were stored in capped jars at 34° F.

Specific gravity (for use in subsequent analyses) was measured on 500 of the subsample chips; the method was that described by SMITH [1965]. Specific gravity of extractive-free wood was calculated by reducing the oven-dry weight of chips by the weight of the alcohol-benzene extractive content of a matched sample: TAPPI Standard Method T 6 os-59 was used.

Growth rate in rings per inch could not be determined from chips. It was therefore measured prior to chipping on the samples used for segregating the boards. Because boards had variable cross-sectional areas, measurements were weighted by area in calculating the mean growth rates, which were then considered representative of the chips in each replication.

Tracheid length was determined on 40 chips randomly selected from each 1000-chip replicate. Chips were dissected into earlywood and latewood slivers and macerated for 2 days in a 50/50 solution of 30-percent hydrogen peroxide and glacial acetic acid at 50° C. Samples of the macerated material were mounted in water on 10 glass slides. With a calibrated projection microscope (×40), five tracheids were measured on each slide—the five unbroken tracheids lying adjacent to a dot in the center of the projection screen. Thus, 50 observations were made on each 40-chip sample.

On different tracheids—macerated as described above—single-wall thickness of cells, lumen diameter, and tracheid diameter for both earlywood and latewood were separately determined by viewing the radial fiber surface. Fifty observations of each dimension were made at the midpoint of the tracheids (5 observations on each of 10 slides) with a compound microscope equipped with a Filar eyepiece (×400). Radial surfaces were identified by the presence of pits. Thickness of both cell walls was measured and the results averaged for each observation.

Variation in fiber morphology with height in the stem was not measured. Since only logs displaying 40 annual rings or more were selected, the study material came mostly from the lower 32 feet of the stems.

Results

Fiber morphology proved significantly related to wood specific gravity, growth rate, and position in tree. Table 1 summarizes the wood-property determinations for the replications in each wood category of each block. The values are from a total of more than 39,000 observations.

Tracheid Length

By analysis of variance, both earlywood and latewood tracheid lengths differed significantly with changes in the level of each primary variable except growth rate (Table 2). Analysis was based on the averages of four replications, i.e. on 24 groups of chips with the block × treatment interaction constituting the error term.

For all positions and growth rates, wood of low specific gravity had longer tracheids than wood of high specific gravity. Latewood tracheids in wood of low specific gravity averaged 4.16 mm, as compared to 3.92 mm in wood of high specific gravity. For earlywood tracheids the corresponding values were 3.93 and 3.69 mm.

Table 2. *Effect of Study Variables on Loblolly Pine Wood Morphology*[1]

Factor	Latewood				Earlywood			
	Tracheid wall thickness	Lumen diameter	Tracheid diameter	Tracheid length	Tracheid wall thickness	Lumen diameter	Tracheid diameter	Tracheid length
	μm	μm	μm	mm	μm	μm	μm	mm
(UG) Unextracted specific gravity		*		*		*	*	*
Less than 0.49 (avg. 0.45)	9.7	14.4	33.7	4.16	4.6	47.9	56.8	3.93
More than 0.49 (avg. 0.52)	9.9	13.5	33.2	3.92	4.5	44.0	53.1	3.69
(NR) Number of rings from the pith	*		*	*		*	*	*
0–10 (core)	9.4	14.1	32.8	3.79	4.5	44.0	52.8	3.52
11–20 (middle)	9.9	13.9	33.6	4.13	4.6	46.1	55.3	3.91
21–30 (outer)	10.0	13.9	33.8	4.21	4.6	47.8	56.7	4.00
(RI) Rings per inch		*	*					
Less than 6 (avg. 5.1)	9.7	14.5	33.8	4.02	4.6	46.2	55.3	3.78
More than 6 (avg. 9.3)	9.9	13.5	33.0	4.06	4.5	45.7	54.6	3.84
Grand mean	9.8	14.0	33.4	4.04	4.6	46.0	54.9	3.81

[1] All factors were tested at the 0.05 level; significant differences are indicated by*.

Tracheid length increased with increasing rings from the pith. Latewood tracheid length averaged 3.79 mm for corewood, 4.13 mm for middle wood, and 4.21 mm for outer wood. A similar significant trend was established in earlywood.

Latewood tracheids were consistently longer (avg. 4.04 mm) than earlywood tracheids (avg. 3.81 mm) regardless of position in tree, specific gravity, or growth rate.

The study variables were also related to morphological characteristics by stepwise multiple regression. Equations were developed by introducing the independent variables in decreasing order of their individual contribution to the cumulative R^2. All equations were of the type $y = b_0 + b_1 x_1 + b_2 x_2 + \cdots$, where y is a dependent variable, e.g. tracheid length or tracheid wall thickness; b_i, a regression coefficient; and x_i, an independent variable, e.g. rings from the pith or specific gravity. The values used for number of rings from the pith were averages: 5, 15, and 25. The individual variables and their interactions were considered. All equations were tested at the 0.05 level, and all variables are significant at that level.

Correlations between independent variables were low (less than 0.39). The factorial design avoided certain correlations that exist in a tree stem. For example, the correlation between specific gravity and number of rings from the pith was low ($r = 0.13$) because wood of both high and low gravity was considered at all positions. Hence the use of all independent variables in a single regression equation is statistically valid.

The equations do not mean that a cause-and-effect relationship necessarily exists between independent variables and a given characteristic. Rather, they indicate that the values of the dependent variable are associated with those of the independent variable in such a way that they can be described by an equation [FREESE 1964].

The best equations for tracheid length were:

$$LT = 4.8016 + 0.0643\,(NR) - 2.7281\,(UG) - 0.0014\,(NR)^2 \quad (1)$$

$$ET = 4.2468 + 0.0737\,(NR) - 2.2138\,(UG) - 0.0016\,(NR)^2 \quad (2)$$

where

LT = latewood tracheid length in millimeters
ET = earlywood tracheid length in millimeters
NR = average number of rings from the pith
UG = unextracted chip specific gravity, based on oven-dry weight and green volume.

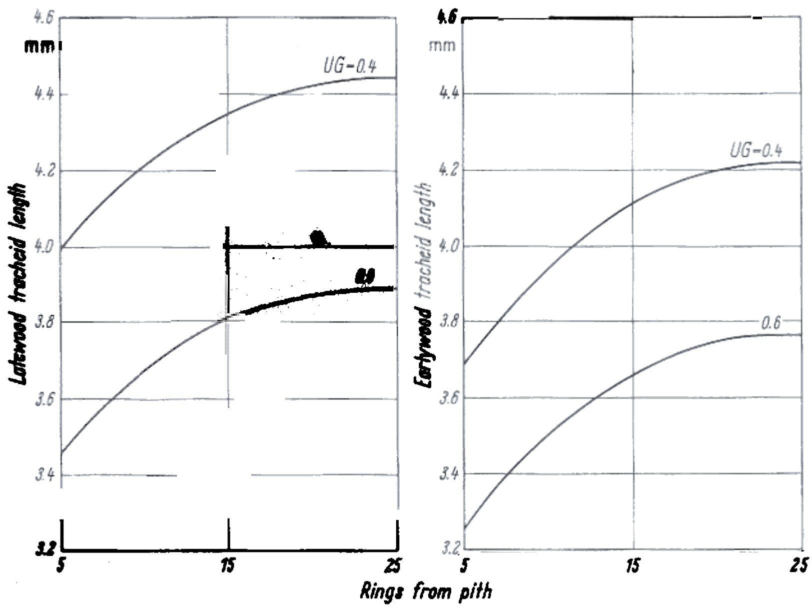

Fig. 2. Tracheid length as related to distance from pith and unextracted chip specific gravity. UG Unextracted specific gravity.

From Eq. (1), latewood tracheid length proved independently related to unextracted chip specific gravity and number of rings from the pith. The equation accounted for 47 percent of the total variation in this property; the standard error of the estimate was 0.23. Fig. 2 shows that, for a given specific gravity, latewood tracheids increased in length rapidly for the first 15 rings, then slowed. For a given number of rings from the pith, latewood tracheid length increased with decreasing specific gravity. The graphed lines in this figure, and Figs. 3 and 4, were obtained by substituting a range of values for the variable on the X-axis and fixing the remaining variables in the regression equation at their mean values.

Eq. (2), relating earlywood tracheid length to rings from the pith and unextracted chip specific gravity, accounted for 51 percent of the total variation. The standard error of the estimate was 0.23. As with latewood tracheids, length increased rapidly for the first 15 rings (Fig. 2). The independent effect of chip specific gravity on earlywood tracheid length was similar to that on latewood tracheids.

Thus long tracheids were associated with mature, low-density wood. In contrast, the shortest tracheids were characteristic of high-density corewood.

Latewood tracheid length was positively correlated with earlywood tracheid length ($R^2 = 0.53$, standard error $= 0.21$). Regression analysis provided the equation: LT = 1.3425 + 0.7081 (ET).

Transverse Dimensions

As expected, cell walls were thicker in latewood (avg. 9.8 μm) than in earlywood (4.6 μm). By variance analysis, latewood cell-wall thickness differed significantly with only one of the primary variables: rings from the pith. Thus, when averaged over all growth rates and gravities, wall thickness increased from 9.4 μm for corewood to 9.9 μm for middle wood and averaged 10.0 μm for outer wood. In contrast, thickness of earlywood cell walls did not differ significantly with any of the primary variables.

Stepwise regression analysis of the continuous variables provided the following equation:

$$\text{LWT} = 9.3607 + 0.0081\ (\text{NR})\ (\text{UG})\ (\text{RI}) \qquad (3)$$

where

LWT = latewood tracheid wall thickness in μm (micrometers)[1]

RI = growth rate in rings per inch

The analysis showed a weak positive linear relationship between latewood wall thickness and the product of rings from the pith, unextracted chip specific gravity, and rings per inch growth rate. This equation accounted for 21 percent of the variation in latewood wall thickness, with a standard error of 0.53. However, inspection of the data in Table 1 indicates that most of this relationship was due to rings from the pith. A linear regression of rings from the pith on latewood wall thickness accounted for 16 percent of the total variation, with a standard error of 0.55. No equation was provided for earlywood wall thickness.

By variance analysis, latewood lumen diameter differed with specific gravity and growth rate. No differences were detected between positions in the tree. Wood of low specific gravity had larger lumens (avg. 14.4 μm) than wood of high specific gravity (avg. 13.5 μm). Fast-grown wood had larger lumens than slow-grown. Latewood lumen diameter averaged 14.5 μm for fast-grown wood and 13.5 μm for slow-grown. The interaction of growth rate and specific gravity proved significant.

Specific gravity	Latewood lumen diameter at two growth rates	
	Less than 6 rings/in. μm	More than 6 ring/in. μm
Less than 0.49	14.69	14.16
More than 0.49	14.26	12.78

An inference from this result is that latewood lumen diameter decreased with increasing specific gravity at a faster rate in slow-grown than in fast-grown wood.

The best stepwise equation for latewood lumen diameter was:

$$\text{LLD} = 15.9154 - 0.2708\ (\text{RI}) \qquad (4)$$

where

LLD = latewood lumen diameter in μm (micrometers)

[1] 1 μm (1 micrometer) $= 10^{-6}$ m $= 10^{-3}$ mm.

Eq. (4) accounted for 27 percent of the variation, with a standard error of 1.12. After growth rate, no additional factor proved significant.

Latewood lumen diameter also was inversely related to unextracted chip specific gravity by the linear regression equation:

$$\mathrm{LLD} = 19.1758 - 10.7627\,(\mathrm{UG}) \tag{5}$$

Eq. (5) accounted for 11 percent of the variation with a standard error of 1.25.

These results indicate that latewood tracheids with lumens of small diameter were characteristic of dense, slow-grown wood. In contrast, large lumens were associated with low-density wood of fast growth.

By variance analysis, earlywood lumen diameter differed with specific gravity and rings from the pith; no differences were found between growth rates. As with latewood lumens, wood of low specific gravity had larger earlywood lumens (avg. 47.9 μm) than wood of high specific gravity (avg. 44.0 μm). Earlywood lumens increased in diameter from 44.0 μm for corewood to 46.1 μm for middle wood, while in outer wood they averaged 47.8 μm.

The best stepwise regression equation for earlywood lumen diameter was:

$$\mathrm{ELD} = 63.3636 + 0.2174\,(\mathrm{NR}) - 42.7163\,(\mathrm{UG}) \tag{6}$$

where

ELD = earlywood lumen diameter in μm

Eq. (6), including number of rings and specific gravity, accounted for 42 percent of the variation with a standard error of 2.69. From this equation and Fig. 3, earlywood lumen diameter decreased with increasing unextracted specific gravity. For a given specific gravity, diameters increased with increasing rings from the pith.

Thus, earlywood tracheids with small-diameter lumens were associated with dense corewood while lumens were characteristic of low-density mature wood.

By variance analysis, latewood tracheid diameter increased significantly from 32.8 μm in corewood to 33.6 μm in middle wood, while in outer wood it averaged 33.8 μm. Latewood tracheids from fast-grown wood were slightly larger (avg. 33.8 μm) than those from slow-grown wood (avg. 33.0 μm). Tracheid diameter did not differ significantly with specific gravity.

Stepwise regression analysis of the continuous variables provided the equation:

$$\mathrm{LTD} = 34.9734 - 0.3083\,(\mathrm{RI}) + 0.0128\,(\mathrm{NR})\,(\mathrm{UG})\,(\mathrm{RI}) \tag{7}$$

where

LTD = latewood tracheid diameter in μm (micrometers)

This equation accounted for 29 percent of the total variation with a standard error of 1.15. From the equation, latewood tracheid diameter decreased with increasing growth rate and increased with increasing specific gravity and rings from the pith. However, the relationship was weak; distance from the pith and rings per inch growth rate accounted for most of the variation (24 percent).

The results indicate that large-diameter latewood tracheids were characteristic of mature wood of slow growth. In contrast, narrow tracheids were found in corewood of fast growth.

By variance analysis, earlywood tracheid diameter increased significantly from 52.8 μm in corewood to 56.7 μm for outer wood. Diameters did not significantly differ with growth rate but varied with specific gravity, averages being 56.8 μm for low-density wood and 53.1 μm for high-density wood.

The best equation was:

$$ETD = 75.1196 - 48.8068\,(UG) + 0.4673\,(NR)\,(UG) \qquad (8)$$

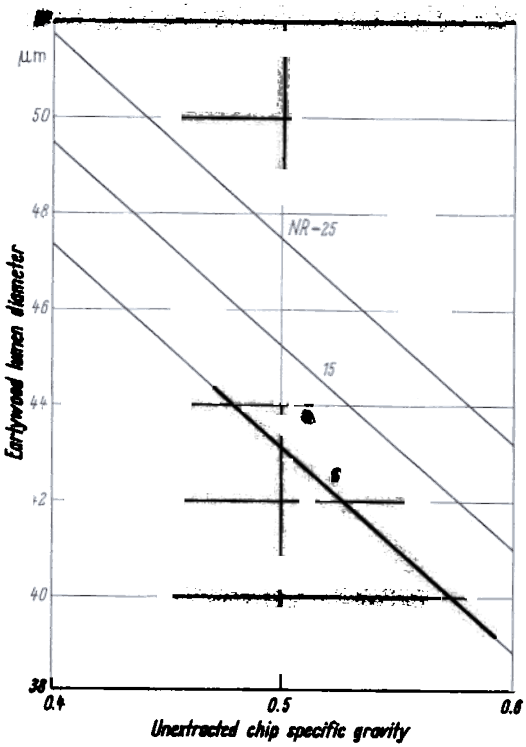

Fig. 3. Earlywood lumen diameter as related to distance from pith and unextracted chip specific gravity. NR Number of rings from the pith.

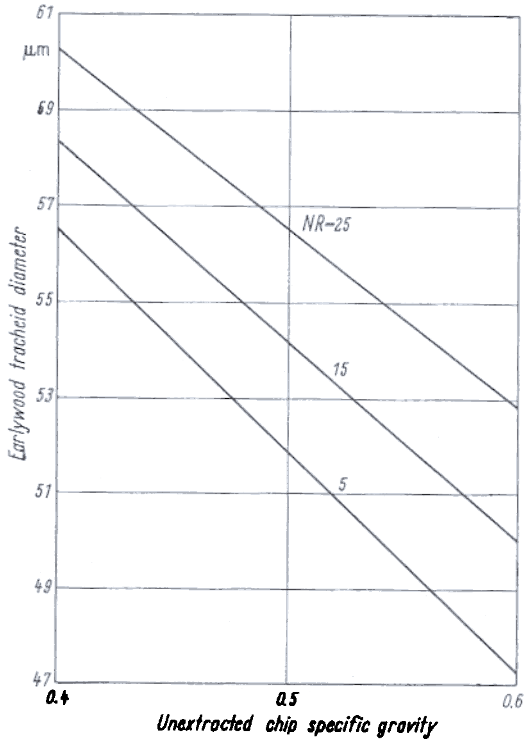

Fig. 4. Earlywood tracheid diameter as related to distance from pith and unextracted chip specific gravity. NR Number of rings from the pith.

where

ETD = earlywood tracheid diameter in μm (micrometers)

Eq. (8), including specific gravity and the interaction of specific gravity and rings from the pith, accounted for 47 percent of the variation with a standard error of 2.47. From this equation and Fig. 4, earlywood tracheid diameter decreased with increasing chip specific gravity, the rate of decrease becoming slightly greater with decreasing rings from the pith. For a given specific gravity, diameters increased with increasing distance from the pith; the rate increased with increasing chip specific gravity.

The results indicate that large-diameter earlywood tracheids were associated with mature wood of low density, while narrow tracheids were characteristic of dense corewood.

For reasons unclear, specific gravity of unextracted wood consistently proved more useful in regression analysis than did specific gravity of extracted wood.

Discussion

Characteristically, the specific gravity and latewood content of wood from loblolly pine stems increase with distance from the pith; i.e. corewood is usually less dense and contains less latewood than does mature wood. The patterns of variation in transverse cellular dimensions reported here are useful in interpreting the radial increase in specific gravity as independently related to distance from the pith. This is possible because dimensions associated with rings from the pith in Table 2 are averaged over all growth rates and specific gravities.

Since earlywood wall thickness remains constant with distance from pith, while lumen and tracheid diameters are increasing, the amount of wood substance per unit area is decreasing. Therefore, the specific gravity of a unit volume of earlywood must decrease with distance from the pith.

In contrast, the lumen diameters of latewood cells remain relatively constant with age, while the tracheid wall thicknesses and diameters increase. Thus, there is increased wood substance per unit cross-sectional area, and the specific gravity of latewood must increase with distance from the pith.

If wood structure is assumed to consist of uniform square tubes of unit length (with pits, resin canals, and all other structures ignored), it is possible to approximate the volume of wood substance in 1 cm^3 of either latewood or earlywood from the transverse cellular dimensions in Table 1. The averaged results from this rather simple model are as follows:

Table 3. *Volume of Wood Substance in 1 cm^3 of Latewood or Earlywood from the Transverse Cellular Dimensions*

Rings from pith	Approx. volume of cell-wall substance/cm^3 of wood	
	Latewood cm^3	Earlywood cm^3
0–10 (avg. 5)	0.8159	0.3056
10–20 (avg. 15)	.8286	.3042
20–30 (avg. 25)	.8304	.2894

Since the cell-wall volume per cm^3 of latewood increases with increasing rings from the pith, the specific gravity must increase proportionally. Conversely, the cell-wall volume of earlywood decreases with rings from the pith, and the specific gravity must decrease.

The calculated volumes of early- and latewood substances may be combined by the relative amounts of each tissue type for a given distance from the pith. Characteristic values for percent of latewood might be 20, 40, and 50 for wood averaging 5, 15, and 25 rings from the pith. The results are:

Rings from pith	Approx. volume of wood substance/cm^3 cm^3
0–10 (avg. 5)	0.4076
10–20 (avg. 15)	.5097
20–30 (avg. 25)	.5607

Since the volume of wood substance for the composite is increasing with increasing rings from the pith, the specific gravity must increase proportionally. If a specific gravity of 0.97 is assumed for water-saturated wood substance [SMITH 1965], the values calculated above result in realistic wood specific gravities of

0.40, 0.48, and 0.54. The analysis thus suggests that the characteristic increase of loblolly pine specific gravity with distance from pith is determined not only by the relative amount of earlywood and latewood present but also by the changing transverse dimensions of each tissue type as independently affected by distance from the pith.

Though the supposition was not tested by this study, it seems possible that all loblolly pine wood may have similar properties when stratified by distance from the pith, growth rate, and specific gravity. Could this surmise be proven, the implications for wood utilization and characterization would be great.

Conclusions

The present study of a sample of loblolly pine wood from central Louisiana characterized the morphology of wood removed from stems, as distinguished from the morphology of the stems themselves. The experiment is unique in that the factorial design permitted separation of the independent relationships with fiber morphology of wood specific gravity, growth rate, and number of rings from the pith.

Earlywood and latewood tracheid lengths were independently related to number of rings from the pith and wood specific gravity. Lengths increased with increasing distance from the pith and decreased with increasing specific gravity.

Latewood tracheid wall thickness was related to number of rings from the pith. It increased with distance from the pith.

Earlywood tracheid wall thickness was unrelated to number of rings from the pith, wood specific gravity, and growth rate.

Latewood lumen diameter was independently related to specific gravity and growth rate. It decreased with increasing specific gravity and increasing rings per inch.

Earlywood lumen diameter was independently related to number of rings from the pith and wood specific gravity. It increased with increasing distance from the pith and decreased with increasing specific gravity.

Latewood tracheid diameter was independently related to number of rings from the pith and growth rate. It increased with distance from the pith and decreased with increasing rings per inch.

Earlywood tracheid diameter was independently related to wood specific gravity and number of rings from the pith. It decreased with increasing specific gravity and increased with increasing distance from the pith.

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(Received February 22, 1968)

CHARLES W. McMILLIN, Wood Scientist, Southern Forest Experiment Station, Forest Service, U.S. Department of Agriculture, Alexandria, Louisiana.