Wood and Bark Properties of Spruce Pine

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Weighted stem averages were determined for wood and bark of 72 trees representing the commercial range of Pinus glabra Walt. *The trees were stratified into three age classes (15, 30, and 45 years) and two growth rates (averaging 4.9 and 9.0 rings per inch). Within-stem variation was determined from 1,296 earlywood and latewood sampling points in the 72 stems. Tracheid length increased with tree age and averaged 0.2 mm. longer in fast-grown trees than in slow-grown. Tracheid diameter did not differ with age, but radial and tangential diameters averaged 2 to 4 μm. larger in fast-grown trees. Wall thickness did not differ with age; walls of fast-grown latewood tracheids averaged 0.27 μm. thicker than those from slow-grown stems. Tracheids near the pith were short, of small diameter, and had thin walls with large fibril angles; those near the bark were longest and had greatest diameters, thickest walls, and smallest fibril angles. Extracted specific gravity did not differ with age class or growth rate in earlywood or latewood. However, wood specific gravity averaged lower in fast-grown trees (0.408 unextracted) than in slow-grown (0.442) because fast-grown trees contained a greater proportion of large-diameter, thin-walled earlywood tracheids. Bark specific gravity averaged 0.391 in slow-grown trees and 0.371 in fast-grown. Bark thickness increased with tree age. Wood chemical components did not vary with age class or growth rate, and mechanical properties did not differ greatly. Microtensile strength and longitudinal shrinkage of earlywood and latewood did not vary with position in stem. Green volumes and ovendry weights are tabulated for bark and wood components.*

The research reported here attempted to delineate the effects of tree age and growth rate on the stem wood and bark properties of an entire pine species throughout its commercial range. The data are for spruce pine, *Pinus glabra* Walt., one of the 10 species known as the southern pines. This minor member of the hard pine group was chosen for two reasons. First, the literature contains little information on it, even though it comprises a sizable volume in some States. Second, the species' range is compact enough to permit ready sampling.

The wood properties studied were those deemed of importance in the manufacture of fiber or solid products. Sampling was intensive enough to determine within-stem variation as well as average values for merchantable stems.

Spruce pine (fig. 1) occasionally occurs in pure stands but is more often associated with shortleaf *(Pinus echinata* Mill.) and loblolly *(P. taeda* L.) pines and with various hardwoods. It is a medium-sized tree, 80 to 90 feet high, with distinctive bark resembling that of black oak *(Quercus velutina* Lam.) while it grows in moist, sandy loam soils throughout the coastal region from southern South Carolina to southeastern Louisiana, it occurs in greatest numbers, and attains commercial importance, in the Florida parishes of Louisiana and in southern Alabama and Mississippi (fig. 2). This three-State area contains approximately 80 percent of the standing volume (Sternitzke and Nelson 1970).

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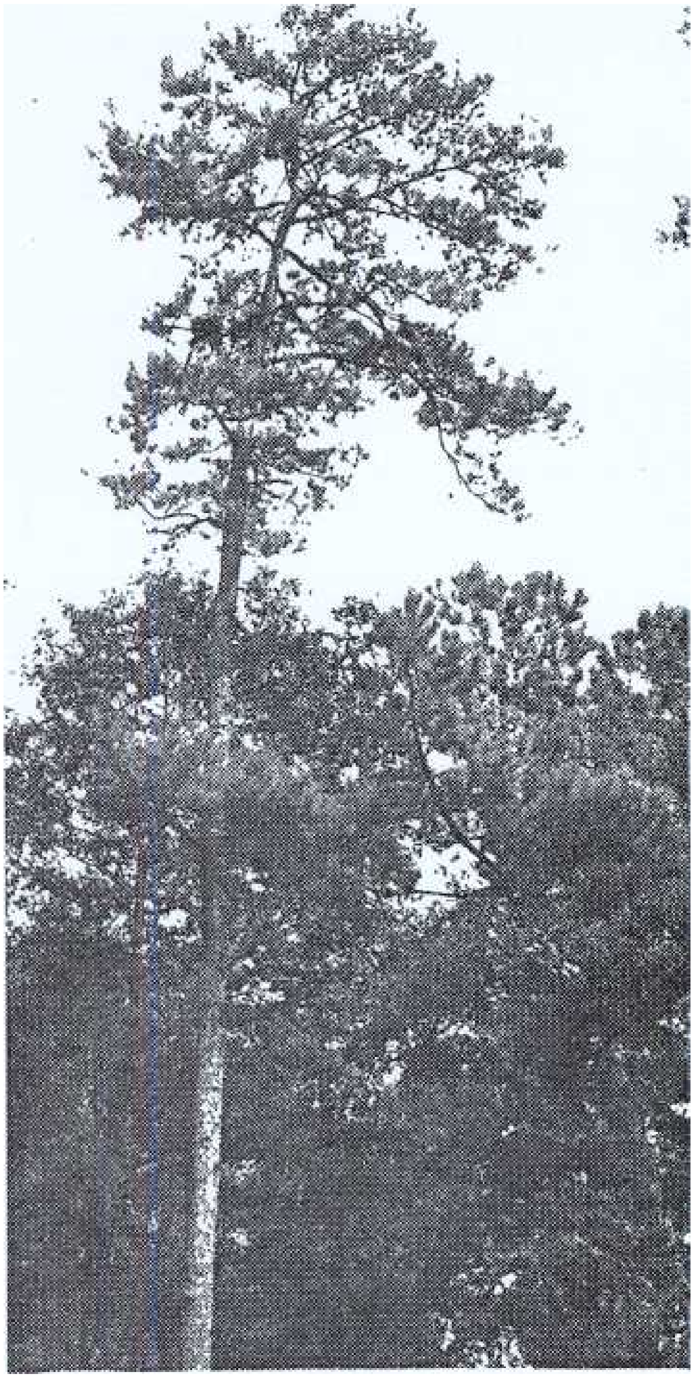
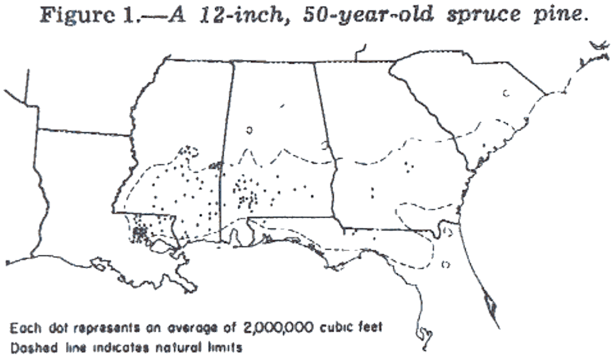


Figure 1.—*A 12-inch, 50-year-old spruce pine.*



PROCEDURE

Specimen Collection and Preparation

Twelve sample locations, each considered a replication, were selected within the three-State area (fig. 3). At each location, six trees were cut—one for each combination of two growth rates and three age classes. Fast-grown trees showed less than six annual rings per inch and slow-grown more than six. The three age classes were 15 years (range of 8-22 years), 30 years (23-37), and 45 years (38-52). Tree age and growth rate were determined from increment cores taken at stump height. Only trees with a relatively uniform rate of growth were selected. The location of each tree was recorded for later determination of its latitude and longitude. Each tree was felled and 3-inch-thick disks were removed at 8.25-foot intervals along the stem between stump height (0.75 foot) and a 4-inch top outside bark. Disks were sprayed with fungicide to prevent bluestain, placed in polyethylene bags to prevent loss of moisture, and removed to the laboratory, where they were stored under refrigeration until analyzed.

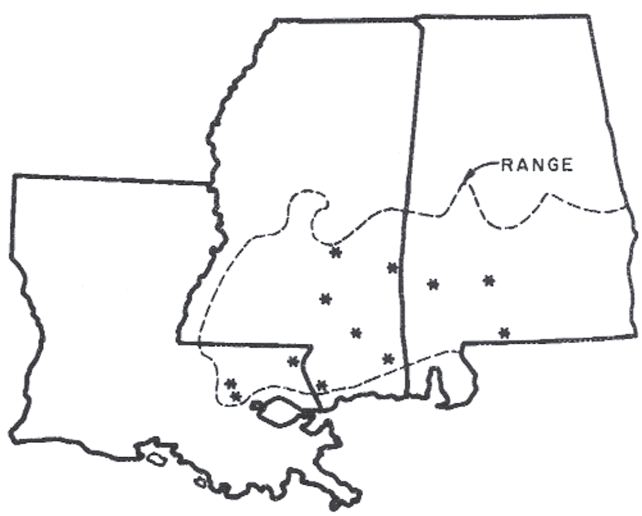


Figure 3.—*Spruce pine sample locations. One tree of each age and growth rate category (six trees total) was cut at each location.*

For determination of mechanical properties, a bolt was removed from each tree that was over 7 inches d.b.h. and fell into the 30- and 45-year age classes. This bolt was 4 feet long in large-diameter trees and 8 feet long in smaller trees. The bolts were stored under water until processed. By the traditional Standard D143-52 of the American Society for Testing and Materials (ASTM), a minimum of five "representative" trees are selected and a number of specimens taken at several heights for each test conducted. In the present study, however, the approach was that of Krahmer and Snodgrass (1967), in which more trees are sampled less intensively. These authors found that for western hemlock one bolt from each of 39 trees and two specimens from each bolt was most efficient in obtaining a precision of ±5 percent.

To identify heartwood, the appropriate area on the surface of each disk was stained with benzidine—25 percent hydrochloric acid in solution with 10 percent sodium nitrite (Kutscha and Sachs 1962). Annual rings were counted, and heartwood radius, disk diameter, and bark thickness were measured to the nearest 0.01 inch at 45° intervals. Two opposed 30° angles were marked off on the surface of each disk (fig. 4), avoiding concentrations of compression wood. For determination of stem averages, three pairs of samples were removed from each pair of wedges:

Two opposed bark samples, each measuring 2 inches along the grain, for determination of bark specific gravity.

Two opposed 30° wedges, measuring 1 inch along the grain, for determination of chemical content and fiber morphology.

Two opposed 30° wedges, measuring ¼-inch along the grain, one for unextracted and one for extractive-free specific gravity.

Within-stem variability in earlywood and latewood was measured on samples from three of the disks in each tree—at the butt, at a 4-inch top, and approximately halfway between. At each height three annual rings were selected at 1/6, 3/6, and 5/6 of the count from pith to bark (fig. 4). Distance from the pith in both rings and inches and width of earlywood and latewood tissue were recorded for each ring selected. There were a total of 1,296 such sampling points: (three age classes) (two growth rates) (12 replications of trees) (three heights) (three radial positions) (two cell types). At each point two blocks were removed:

a. A block measuring about ¼-inch along the grain, ¾-inch tangentially, and at least three rings radially, for determination of tracheid transverse dimensions and specific gravity.

b. A microtome block measuring ¾-inch tangentially, 1¼ inches along the grain, and at least three rings radially.

Blocks *b* were saturated and a minimum of six wafers cut from the radial face. Wafers were nominally 300 μm. thick in the tangential direction. They supplied specimens for determination of microtensile strength, fiber length, fibril angle, and longitudinal shrinkage.

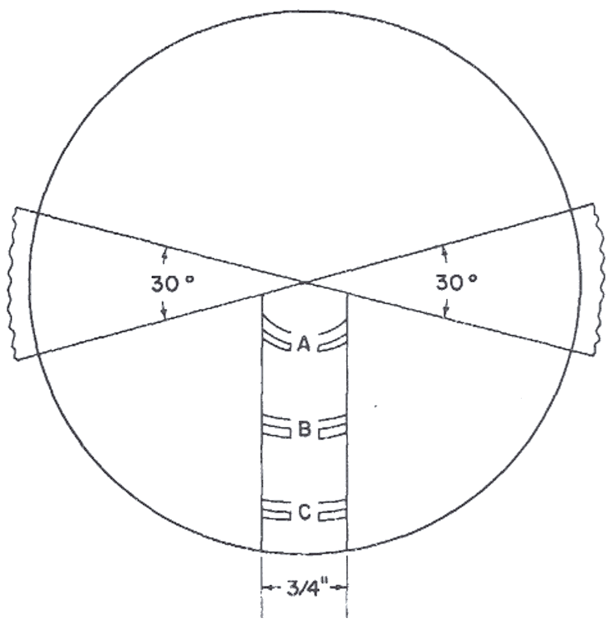


Figure 4.—*Two stem-sampling systems were employed. Two opposed 30° wedges were removed at stem intervals of 8.25 feet to obtain weighted stem averages. At the butt, at the 4-inch top, and at the approximate midpoint, earlywood and latewood samples were removed at 1/6 (A), 3/6 (B), and 5/6 (C) of the ring count for determination of within-stem variation.*

Analytical Techniques

Stem means.—The 1-inch-thick wedges taken in pairs at 8.25-foot intervals sampled the wood of the stem in proportion to its occurrence by volume. Wedges from each tree were reduced to chips of uniform size and combined. The resulting pile of chips furnished material for determination of stem-average values of fiber dimensions, fibril angle, and chemical content.

From each pile, 100 chips were randomly selected, and a sample was split from the radial surface of each. The samples were further reduced to matchstick size and then macerated with equal parts of glacial acetic acid and 6 percent hydrogen peroxide. An ampliscope was used to measure the length of 150 fibers from each tree. Cell and lumen diameters and wall thickness of 100 swollen fibers were measured with a microscope equipped with a micrometer eyepiece.

Mean fibril angle of the S_2 layer was measured by polarization (Preston 1952, p. 116). In this procedure, macerated fibers are glued to a slide and sliced longitudinally with a microtome knife. Only the back wall remains on the slide. The major extinction position, which is parallel with the long axis of the microfibrils, is located with the aid of a Red I retardation plate. The angle between the position of extinction and the long axis of the cell is the fibril angle. This angle was measured with a graduated rotating stage. Fibril angle was determined on 120 fibers per tree.

For analysis of chemical components, the chips representing a tree were ground in a Wiley mill and only that portion passing through a 40-mesh screen used. Stem averages for extractive and lignin contents were determined by ASTM Standard Procedures D1107-56 and D1106-56, respectively. Erickson's (1962) method was followed for holocellulose and alpha-cellulose except that the amount of sodium chlorite solution per cycle was doubled for holocellulose determinations. Hemicellulose content was taken to be the difference between holocellulose and alpha-cellulose contents. For ash determination, the wood flour was first partially decomposed with 5 ml. of concentrated nitric acid in five 1-ml. steps, dried, and then fired in a muffle furnace at 475° C. for 6 hours (McMillin 1969). Weights of analysis samples were 2 g. for extractive content, 1 g. for ash, and 0.5 g. for lignin and for cellulose fractions. Two such samples from each tree were averaged for ash analysis, and five were averaged for each of the other components. Extractive content was expressed as percent of ovendry weight of unextracted wood. Results for the remaining components were expressed as percent of ovendry weight of extractive-free wood.

Stem-average specific gravity was determined for bark and for wood of each tree; values were based on ovendry weight and green volume, with the latter obtained by water immersion. One of the opposed ¼-inch-thick, 30° wedges at each stem height was used for unextracted specific gravity. The other wedge was extracted for 24 hours with acetone. Bark samples taken at each height were used to determine unextracted specific gravity only. To obtain mean unextracted specific gravity of the wood, the combined weight of the ovendry wedges was divided by total weight of the water they displaced. The same procedure was followed to obtain stem-average values for specific gravity of extracted wood and of unextracted bark.

Mechanical properties.—Forty-two trees from the 30- and 45-year age classes yielded a log for determination of mechanical properties. Six of the 30-year-old slow-grown trees were too small. Each tree furnished one or two 4-foot bolts which were sawn into 2½-inch-square sticks, tangentially paired. One stick of each pair was machined to proper size for testing in the green condition. The other was conditioned to a moisture content of approximately 12 percent and then machined to test dimensions. Two pairs from each tree were randomly assigned to each mechanical test and moisture category (Krahmer and Snodgrass 1966). The tests, which were conducted according to ASTM Standard D143-52, included static bending, tension perpendicular to the grain in radial and tangential directions, radial and tangential shear parallel to the grain, radial and tangential toughness, compression parallel and perpendicular to the grain, and end and side hardness.

The air-dry specimens came to equilibrium at 10 to 14 percent moisture content. By Wilson's equation (Markwardt and Wilson 1935, p. 51), strength values were adjusted to what they would be at 12 percent. For a particular property, the equation requires knowledge of the ratio of strength at 12 percent moisture content to that in the green condition. Bendtsen's (1968) spruce pine averages were used for most of these ratios. For maximum tensile strength perpendicular to the grain and for fiber stress at the proportional limit in compression parallel to the grain (which Bendtsen did not evaluate), the ratio used was that given by Markwardt and Wilson (1935, p. 54) for softwoods in general. For spruce pine the literature contains no ratio for toughness, and therefore a ratio was computed from the study means. This procedure seemed reasonable because air-dry moisture content of toughness specimens averaged 11.8 percent.

Within-stem variation.—From data collected at the 1,296 sampling points in the 72 spruce pine stems, within-stem trends were evaluated for several properties of wood and fibers. Three annual rings at each of three heights were sampled in each tree. When data from all trees were combined for regression analysis, however, all heights (in 8.25-foot increments) to the 4-inch top and most annual rings were represented.

For measurement of fiber length and fibril angle, earlywood and latewood tissues of the selected ring were excised from one of the 300-μm.-thick wafers taken from each sampling point. The two tissues were macerated separately. Fiber length was measured with an ampliscope and fibril angle by polarization as described earlier. From each sample point, 20 fibers of each tissue type were measured for each parameter.

Fiber cross-sectional dimensions were measured at each sample point on the transverse surface of blocks *a*, previously described, with a dual-linear micrometer (Smith 1965). The blocks were saturated and the surfaces prepared with a scalpel and stained with fast-green. Four traverses across each tissue type were made in the radial direction. Average tracheid diameter, wall thickness, and lumen diameter were obtained. Four passes of 50 cells each were made in the tangential direction within each tissue type; only average diameter was measured.

Extractive-free specific gravity at each sample point was computed from tracheid dimensions obtained with the dual-linear micrometer. The method was that of Smith (1965), in which percentage of cross-sectional area occupied by the water-swollen cell walls is multiplied by wall specific gravity. The multiplier is considered constant for extractive-free walls of a species. The value used for spruce pine was 0.988 (Kellogg and Wangaard 1969).

Microtensile strength was measured on specimens derived from wafers removed at each of the nine points sampled within each stem. Tensile strength of small specimens has been found to be considerably lower than values obtained from ASTM Standard specimens (Salamon 1966; Biblis 1969). At least part of this difference is caused by cell wall deformation induced during microtomy; the deformations can be minimized by proper positioning of the knife (Dinwoodie 1966; Keith and Côté 1968; Biblis 1970; Kennedy and Chan 1970). Ifju et al. (1965) have shown that rectangular specimens give higher tensile strength values and more reproducible results than necked-down specimens, and Biblis (1970) has demonstrated that tensile strength is positively correlated with thickness of microtome sections.

Radial wafers were therefore cut from saturated blocks with a power microtome at a nominal thickness of 300 μm. Earlywood and latewood rectangular specimens were punched from the selected annual ring with a pair of microtome knives separated by a metal strip. Width of the specimens varied with tissue types and ranged from 100 to 500 μm. A pair of note-card tabs was glued with epoxy to each end of all specimens. The distance between tabs, the gage length, was ½-inch. Specimens were conditioned at 50-percent relative humidity and 73° F. They were pulled to failure in tension with a universal testing machine at a load rate of 0.006 in./min. Cross-sectional dimensions of each specimen were measured (in the vicinity of the failure) with a microscope fitted with a micrometer eyepiece.

Longitudinal shrinkage, from water-swollen to ovendry, was measured in specimens excised from each of the 1,296 sampling points. Shrinkage of three specimens was measured at each point. Radially cut wafers with a nominal thickness of 300 μm. were used. Sadoh and Christensen (1967) have shown that longitudinal shrinkage in sections more than 80 μm. thick differs little from that in thicker sawn specimens. Earlywood and latewood specimens were excised from the air-dry wafers with a razor blade. The radial dimension varied with tissue width, but the smallest measured approximately 1,200 μm. in earlywood and 650 μm. in latewood. Gage length was 1 inch along the grain and was established by two minute notches made in one side of each specimen, one near each end.

The specimens were resaturated and lengths measured in the swollen and ovendry conditions. Total shrinkage is reported as a percentage of the swollen length. Measurements were made with a dual-linear micrometer to the nearest 0.1 μm. To maintain their ovendry condition, the specimens were measured between two hot slides. They could be held for 3 minutes without elongating. To keep the dry specimens straight, they were pressed against a straightedge glued to the bottom slide and held flat by the clips of the microscope stage.

Stem weights and volumes.—Weights and volumes of wood and bark were derived from the measurements made at 8.25-foot intervals along the stem to the 4-inch top. Stumpwood was excluded. For determination of volumes, each 8-foot log was considered to be a truncated cone. The radius at each end was the mean of eight radii. Mean bark thickness was derived from a measurement at each of the eight radii. For wood, heartwood, and bark, log volumes were added to obtain stem volume.

Earlywood and latewood volumes were computed by first determining the percent of latewood at one radius on each end of the log. Latewood percentage was computed by an equation (Miller and Malac 1956) which recognizes that a latewood band near the bark contributes more to area than does one of equal width near the pith:

$$\text{Percent of latewood} = \frac{2\,\Sigma(r_0 x) - \Sigma x^2}{R^2}\,(100) \qquad \textbf{(1)}$$

where:

r_0 = distance from pith to end of the annual ring

x = width of ring's latewood

R = wedge radius

The percentages for the two log ends were averaged and multiplied by log wood volume to arrive at log latewood volume. Earlywood volume was computed as the difference between wood and latewood volumes.

For both wood and bark, total weight (ovendry) was computed from stem volume and specific gravity. Because heartwood specific gravity was not determined, heartwood weight was not calculated.

Tree average specific gravities were not available for conversion of earlywood and latewood volumes to weights. However, earlywood specific gravities calculated from the dual-linear micrometer measurements were found to be relatively uniform. They were highest at the butt and highest near the pith at all levels, but there were no differences among age classes or between growth rates. Therefore, the average of all 648 earlywood samples (0.376, based on green volume and ovendry weight) was used to convert earlywood volume to weight. Latewood weight was taken to be the difference between weights of stem wood and of earlywood.

Data on all aspects of the study were analyzed statistically, and all comparisons mentioned are significant at the 0.05 level of probability.

RESULTS

The 72 spruce pines (table 1) ranged in age from 13 to 56 years. Slow-grown trees averaged 9.0 rings per inch at stump height, while fast-grown trees averaged 4.9 rings. While age classes were nominally 15, 30, and 45 years, they averaged 18.5, 30, and 46.5 years.

Latitude and longitude were not correlated with any of the properties measured.

Tracheid Morphology

As has been described, tracheid dimensions and fibril angle were measured by two approaches. Tree-average values were derived from macerated tissue sampled in proportion to occurrence by volume in the merchantable stem. Within-stem trends were observed by sampling earlywood and latewood tissue at nine locations in each stem. Fiber length and fibril angle were measured on macerated tissue; transverse dimensions were measured on the transverse surface of water-swollen blocks. For all 72 stems there were therefore 648 unweighted sample points within each tissue type; the effect was to sample virtually all annual rings at all heights (in 8-foot incre-

Table 1.—*Average age and size of the 72-tree spruce pine sample*

Tree age class and growth rate (rings/inch)	Age	Growth rate	D.b.h.	Total height	Length of stem to 4-inch top, o.b.
	Years	*Rings/inch*	*Inches*	– – *Feet*	– –
15 years					
>6	**19.4**	**8.3**	**4.9**	**38.0**	**13.5**
<6	**17.7**	**4.6**	**8.0**	**49.0**	**31.5**
30 years					
>6	**30.6**	**9.2**	**6.7**	**50.5**	**32.0**
<6	**29.2**	**4.8**	**12.1**	**70.5**	**56.5**
45 years					
>6	**49.0**	**9.6**	**10.6**	**67.5**	**53.0**
<6	**44.3**	**5.3**	**16.7**	**83.5**	**72.0**

ments). Regression analysis was employed to describe within-stem patterns. It will be recognized that this scheme prohibits removal of between-tree variation.

Tracheid length.—Tree-average tracheid lengths for each age class and growth rate are presented in table 2. Tracheids were longer in fast-grown trees, and length increased with increasing age of trees.

Tree growth rate	Tracheid length
Rings per inch	*Mm.*
>6	3.5
<6	3.7

Tree age class	Tracheid length
Years	*Mm.*
15	3.3
30	3.6
45	4.0

The grand mean for all trees was 3.6 mm., with standard deviation of 0.4 mm.

When earlywood and latewood values were averaged separately and unweighted, growth rate was not significant, but fiber length again increased significantly with each age class for both tissue types.

Table 2.—*Stem-average values for dimensions and fibril angle of macerated tracheids from 72 spruce pines*

Tree age class and growth rate (rings/inch)	Tracheid length [1]	Fibril angle [2]	Tracheid radial diameter [3]	Lumen radial diameter [3]	Tracheid wall thickness [3]
	Mm.	*Degrees*	– – – – – –	*μm.*	– – – – –
15 years					
>6	3.2	36.7	42.1	31.4	5.3
<6	3.4	39.4	44.3	33.5	5.4
30 years					
>6	3.4	35.4	39.5	27.5	6.0
<6	3.7	36.4	45.4	32.5	6.4
45 years					
>6	3.9	33.2	44.2	32.5	5.8
<6	4.0	34.0	48.2	36.4	5.9

[1] Means from 12 trees with 150 tracheids measured per tree.
[2] Means from 12 trees with 120 tracheids measured per tree.
[3] Means from 12 trees with 100 tracheids measured per tree.

Tree age class	Tracheid length	
	Earlywood	Latewood
Years	- - *Mm.* - -	
15	3.0	3.4
30	3.2	3.6
45	3.3	3.7

The grand mean for all earlywood tissue was 3.2 mm., with standard deviation of 0.7 mm.; latewood tracheids averaged 3.5 mm. in length, with standard deviation of 0.7 mm.

Tracheid length varied more with position in stem than did other properties measured. Tracheid length contour lines were hand-fitted to the data, as were curves showing the relationship between length and radial position at various heights in the stem (fig. 5). Length increased radially with age until about the 8th to 12th year and then remained relatively constant. Tracheids were shortest near the pith and at the base of the tree; they tended to be longest near the bark at a height 15 to 25 feet above ground level.

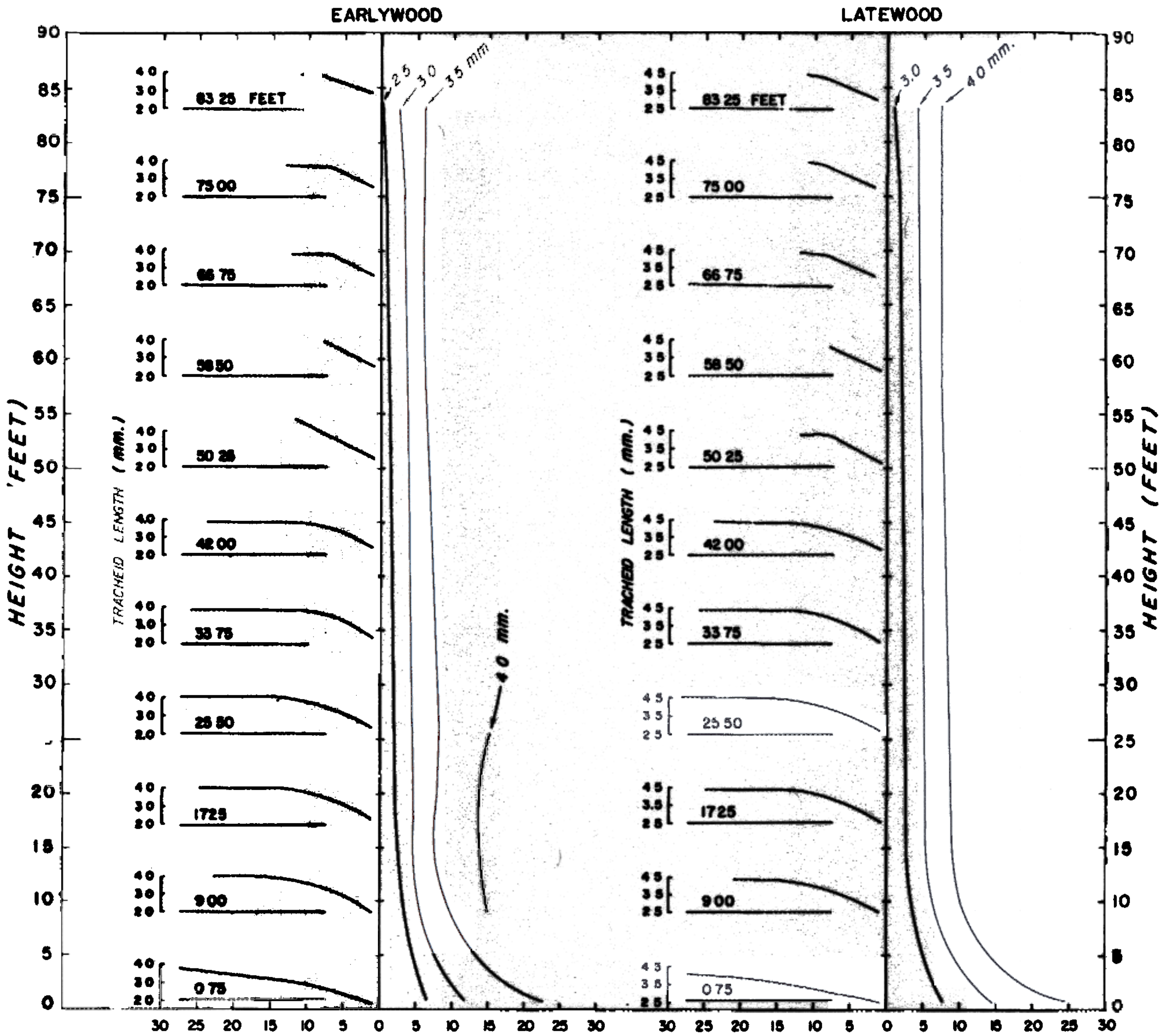


Figure 5.—*Length variation of macerated earlywood and latewood tracheids with position in the stem. To the right of pith are vertical tracheid-length contour lines. To the left are curves showing relationship between tracheid length and years from pith at the heights sampled. No data were extrapolated to make the curves.*

Regression equations were derived in terms of number of rings from pith to specimen and specimen height above ground, in feet:

Earlywood tracheid length,

$$\text{mm.} = 2.142 + 0.08992\,(\text{number of rings}) - 0.001268\,(\text{number of rings})^2 + 0.003129\,(\text{height}) + 0.004484\,(\text{number of rings})(\text{height}) - 0.00003444\,(\text{number of rings})(\text{height})^2 - 0.0001183\,(\text{number of rings})^2(\text{height}) \quad (2)$$

The equation accounted for 48.6 percent of the variation ($R^2 = 0.486$). Standard error of the estimate (SE), computed as $\sqrt{\text{residual mean square}}$, was 0.49 mm.

Latewood tracheid length,

$$\text{mm.} = 2.56 + 0.08651\,(\text{number of rings}) - 0.001375\,(\text{number of rings})^2 + 0.003154\,(\text{number of rings})(\text{height}) - 0.000003\,(\text{number of rings})^2(\text{height})^2 \quad (3)$$

$R^2 = 0.415$. SE = 0.56 mm.

Tracheid diameter.—For tree-average weighted samples, only radial diameter was measured on the macerated tracheids (table 2). Tracheids from fast-grown trees averaged significantly larger (45.9 μm.) than those from slow-grown (41.9 μm.). There were no significant differences among age classes. The grand mean was 43.9 μm., with standard deviation of 7.4 μm. The chemical treatment required for maceration causes swelling, and diameters therefore are larger than when tracheids are measured in place.

As measured on the surface of water-swollen blocks, earlywood tracheid radial diameter averaged 37.4 μm., with standard deviation of 5.1 μm.; latewood radial diameter averaged 24.3 μm., with standard deviation of 3.6 μm.

In both earlywood and latewood tissue, radial diameter averaged larger in fast-grown trees. The unweighted means (based on nine samples per tree) were:

Tree growth rate	Radial diameter	
	Earlywood	Latewood
Rings per inch	– – – *μm.* – – –	
<6	38.4	25.3
>6	36.4	23.3

Radial diameter (fig. 6) was smallest near the pith and increased radially with distance, tending to reach a maximum. It varied little with height near the pith. In earlywood, radial diameter appeared to reach a maximum near the bark about 20 feet above the ground; in latewood there did not appear to be a clear-cut trend with height in stem.

A greater percentage of the within-stem variation in transverse dimensions was accounted for by expressing distance from the pith in inches rather than in number of annual rings. The regressions were:

Earlywood tracheid radial diameter,

$$\mu\text{m.} = 33.69 + 1.382\,(\text{distance from pith}) - 0.0009352\,(\text{height})^2 + 0.1268\,(\text{distance})(\text{height}) - 0.0005091\,(\text{distance})^2(\text{height})^2 \quad (4)$$

$R^2 = 0.399$. SE = 4.0 μm.

Latewood tracheid radial diameter,

$$\mu\text{m.} = 21.29 + 2.258\,(\text{distance from pith}) - 0.1542\,(\text{distance})^2 - 0.007654\,(\text{distance})^2(\text{height}) + 0.0001381\,(\text{distance})^2(\text{height})^2 \quad (5)$$

$R^2 = 0.226$. SE = 3.2 μm.

Tracheid tangential diameter (unweighted) in both earlywood and latewood varied with growth rate and with tree age. Diameter was larger in fast-grown trees. Latewood tracheids were somewhat narrower than earlywood tracheids.

Tree growth rate	Tangential diameter	
	Earlywood	Latewood
Rings per inch	– – – *μm.* – – –	
<6	30.7	29.4
>6	29.2	27.5

For earlywood, diameter of the 15-year age class was significantly smaller than that of the 45-year class; in latewood there was no difference between averages for the 15- and 30-year classes, but both were smaller than that of the 45-year class.

Tree age class	Tangential diameter	
	Earlywood	Latewood
Years	– – – *μm.* – – –	
15	29.2	27.7
30	30.0	28.4
45	30.7	29.4

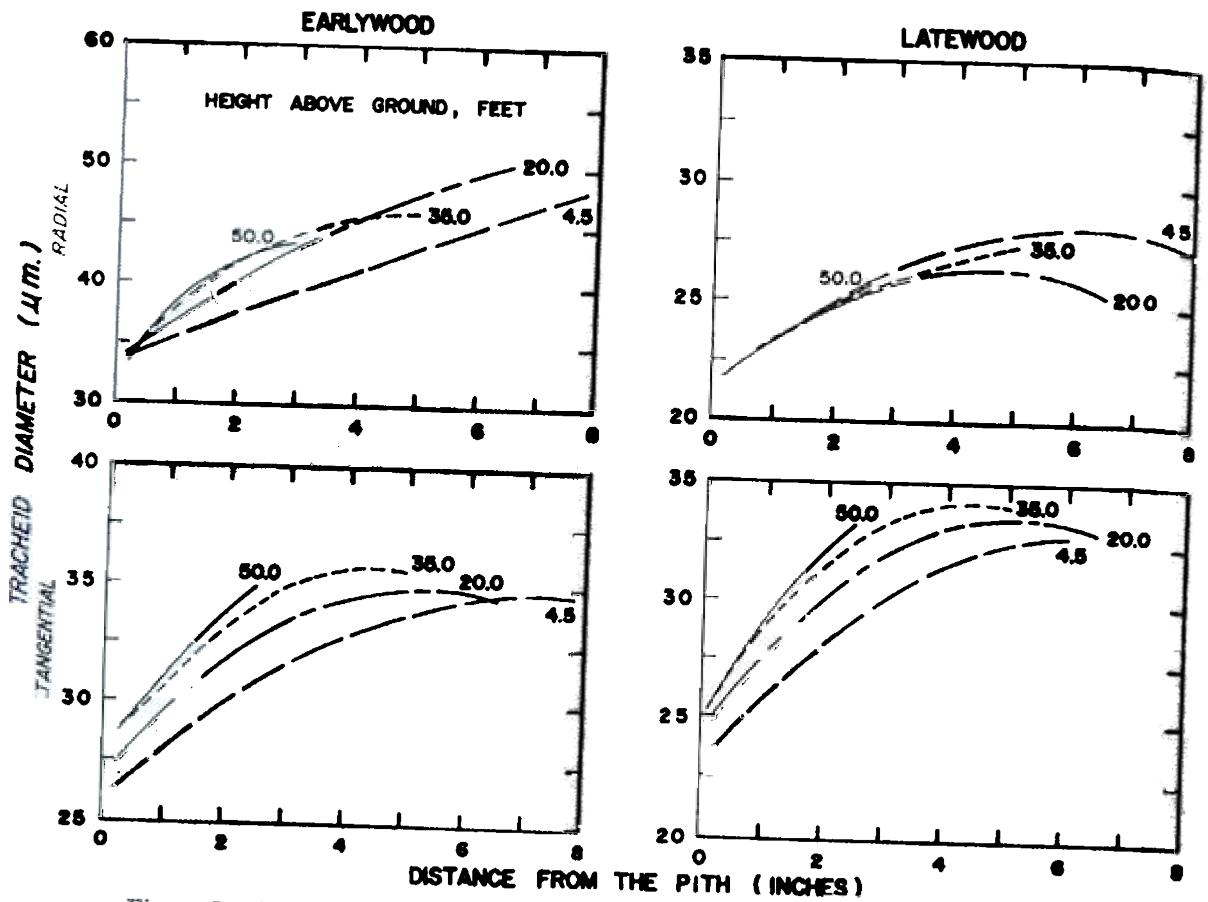


Figure 6.—*Tracheid radial and tangential diameters as related to height above ground and distance from pith. Diameters were measured on surfaces of water-swollen blocks.*

For all samples combined, tangential diameter of earlywood averaged 30.0 µm., with standard deviation of 3.4 µm.; latewood diameter averaged 28.5 µm., with standard deviation of 3.6 µm.

Tangential diameter increased radially from the pith until it reached a maximum (fig. 6). At all radial positions, it increased with increasing height in the stem.

Where distance from pith was expressed in inches, the equation for earlywood accounted for 51.2 percent of the variation.

Earlywood tracheid tangential diameter,
µm. = 25.55 (6)
+ 2.121 (distance from pith)
— 0.1158 (distance)^2
+ 0.08707 (height)
— 0.001279 (height)^2
+ 0.05331 (distance)(height)
— 0.009517 (distance)^2(height)
$R^2 = 0.512$. SE = 2.4 µm.

The equation for latewood was:

Latewood tracheid tangential diameter,
µm. = 22.79 (7)
+ 2.715 (distance from pith)
— 0.1684 (distance)^2
+ 0.1059 (height)
— 0.001362 (height)^2
+ 0.04618 (distance)(height)
— 0.00946 (distance)^2(height)
$R^2 = 0.532$. SE = 2.5 µm.

Tracheid lumen diameter.—For weighted tree-average measurements, only lumen radial diameter was measured in macerated tissue (table 2). For all trees the grand mean was 32.3 µm., with standard deviation of 10.0 µm. Statistically there was no difference between growth rates or among age classes.

As measured on the surface of water-swollen blocks, both earlywood and latewood lumen radial diameter averaged larger in fast-grown trees.

Growth rate	Lumen radial diameter	
	Earlywood	Latewood
Rings per inch	- - - *µm.* - - -	
<6	31.2	13.2
>6	29.5	11.7

The mean for earlywood was 30.4 µm., with standard deviation of 4.9 µm. Latewood lumen radial diameter averaged 12.5 µm., with standard deviation of 2.5 µm.

Diameter increased radially from the pith, tending to reach a maximum and then remain constant (fig. 7). In latewood the radial increase became less pronounced with increasing height in the stem. In both earlywood and latewood, radial diameter was largest near the bark in the lower portion of the stem.

From the 648 within-stem sampling points, the earlywood regression equation accounted for 37.2 percent of the observed variation, with standard error of 3.9 µm.

Earlywood lumen radial diameter,

$$\begin{aligned} \mu m. = {} & 26.26 \\ & + 1.4475 \text{ (distance from pith)} \\ & - 0.0003774 \text{ (height)}^2 \\ & + 0.2442 \text{ (distance)(height)} \\ & - 0.002777 \text{ (distance)(height)}^2 \\ & - 0.04884 \text{ (distance)}^2\text{(height)} \\ & + 0.0006476 \text{ (distance)}^2\text{(height)}^2 \end{aligned} \tag{8}$$

The latewood regression equation accounted for only 9.1 percent of the observed variation, with standard error of 2.4 µm.

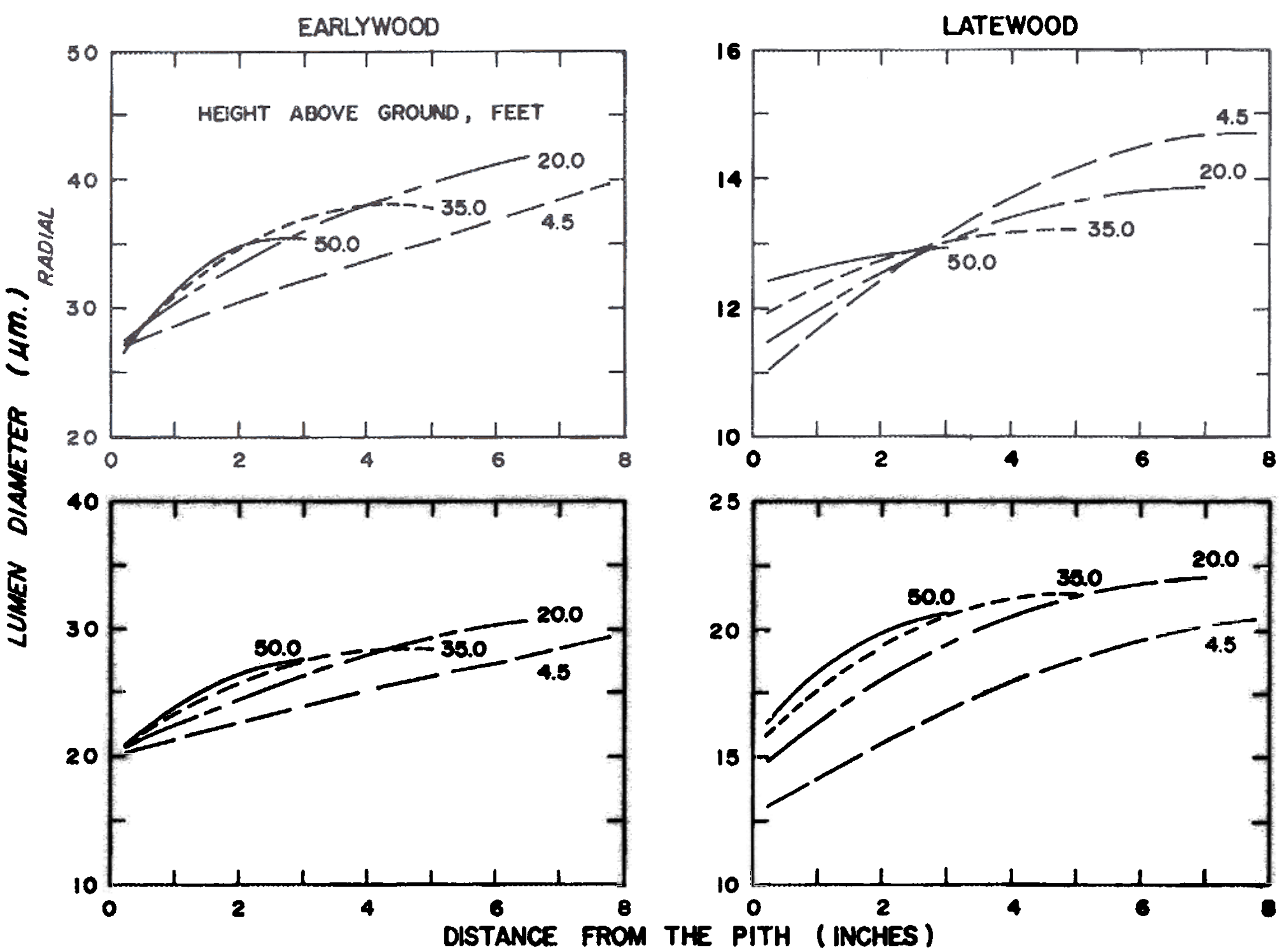


Figure 7.—*Lumen radial and tangential diameters as related to height above ground and distance from pith. Diameters were measured on surfaces of water-swollen blocks.*

Latewood lumen radial diameter,

$$\mu m. = 10.65 \qquad (9)$$
$$+ 1.024 \text{ (distance from pith)}$$
$$+ 0.03388 \text{ (height)}$$
$$- 0.05929 \text{ (distance)}^2$$
$$- 0.01315 \text{ (distance)(height)}$$

Lumen tangential diameter was calculated for earlywood and latewood by subtracting radial wall thickness from tracheid tangential diameter. The latter value was measured; radial wall thickness, not measured, was assumed to equal tangential wall thickness. Subsequent observations (Koch 1972, p. 164) indicate that this assumption may be in error; i. e., radial walls of latewood (but not earlywood) appear to be slightly thicker than tangential walls.

For both earlywood and latewood, lumen tangential diameter increased radially with distance from the pith (fig. 7); it then tended to remain constant in outer portions of the stem. Changes with height were not pronounced in earlywood. In latewood, diameter increased with height near the pith, but in the outer portion of the stem it tended toward 21-22 μm. at all heights.

The regressions were:

Earlywood lumen tangential diameter,

$$\mu m. = 20.28 \qquad (10)$$
$$+ 0.8502 \text{ (distance from pith)}$$
$$- 0.0002276 \text{ (distance)}^2$$
$$+ 0.08332 \text{ (distance)(height)}$$
$$- 0.0003482 \text{ (distance)}^2\text{(height)}^2$$
$$R^2 = 0.390. \quad SE = 2.5\ \mu m.$$

Latewood lumen tangential diameter,

$$\mu m. = 12.26 \qquad (11)$$
$$+ 1.46 \text{ (distance from pith)}$$
$$- 0.07604 \text{ (distance)}^2$$
$$+ 0.1223 \text{ (height)}$$
$$- 0.001032 \text{ (height)}^2$$
$$+ 0.03133 \text{ (distance)(height)}$$
$$- 0.0001626 \text{ (distance)}^2\text{(height)}^2$$
$$R^2 = 0.370. \quad SE = 2.8\ \mu m.$$

Wall thickness.—As measured on macerated tissue, the weighted tree average for tracheid tangential wall thickness was 5.8 μm., with standard deviation of 1.7 μm. There was no significant difference between growth rates or among tree age classes (table 2).

Measured on the transverse surface of water-swollen blocks, thickness of earlywood tangential walls did not differ with tree growth rate or age class when the 648 unweighted within-stem averages were compared. The average was 3.5 μm., with standard deviation of 0.6 μm.

Latewood tangential walls averaged 5.9 μm., with standard deviation of 1.1 μm. Tracheids of fast-grown trees had significantly thicker walls than those of slow-grown trees:

Tree growth rate	Thickness of tangential wall
Rings per inch	*μm.*
<6	6.1
>6	5.8

In both earlywood and latewood, wall thickness increased radially outward from the pith for 5 to 6 inches; it then remained relatively constant (fig. 8). The increase was more rapid in latewood than in earlywood. In earlywood, wall thickness did not vary with height, but in latewood it decreased with increasing height in the stem at all radial positions.

The equations were:

Earlywood wall thickness,

$$\mu m. = 3.16 \qquad (12)$$
$$+ 0.2877 \text{ (distance from pith)}$$
$$- 0.02247 \text{ (distance)}^2$$
$$R^2 = 0.168. \quad SE = 0.51\ \mu m.$$

Latewood wall thickness varied with both radial distance and with height in tree.

Latewood wall thickness,

$$\mu m. = 5.24 \qquad (13)$$
$$+ 0.6828 \text{ (distance from pith)}$$
$$- 0.01022 \text{ (height)}$$
$$- 0.0595 \text{ (distance)}^2$$
$$R^2 = 0.273. \quad SE = 0.93\ \mu m.$$

Fibril angle.—Though tree age was not related to orientation of the S_2 microfibrils in either earlywood or latewood considered separately, stem-average values (table 2) decreased with increasing age:

Tree age class	Fibril angle
Years	*Degrees*
15	38.1
30	35.9
45	33.6

Mean fibril angle for all 72 trees was 35.9° with standard deviation of 4.1°.

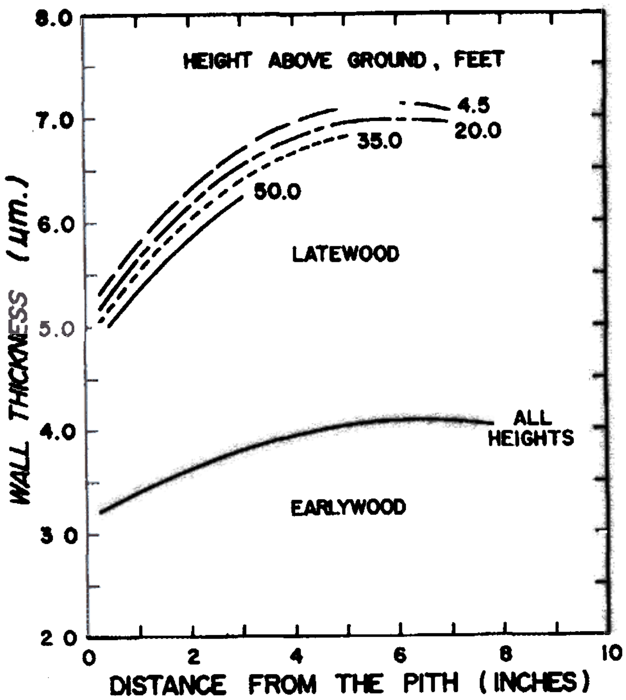


Figure 8.—*Thickness of tracheid tangential walls as related to height above ground and distance from pith. Thicknesses were measured on surfaces of water-swollen blocks.*

Neither tree means nor latewood fibril angle varied with growth rate. In earlywood, however, the angle averaged 37.5° in slow-grown trees and 39.0 in fast-grown, a significant difference. It averaged 38.3° for all trees, with standard deviation of 7.2°. Latewood angle averaged 34.7°, with standard deviation of 6.8°.

It was highest close to the pith near the base of the tree. In the lower portion of the stem it decreased with increasing height, but above approximately 30 feet it remained relatively constant. At all heights it decreased with distance radially from the pith.

Fibril angle did vary significantly with position in the stem (fig. 9).

The equations were:

Earlywood fibril angle,

$$\begin{aligned}\text{degrees} = {} & 44.03 \\ & - 0.08788\ (\text{number of rings}) \\ & - 0.3058\ (\text{height}) \\ & + 0.002805\ (\text{height})^2 \\ & - 0.02326\ (\text{number of rings})(\text{height}) \\ & + 0.0003174\ (\text{number of rings})(\text{height})^2 \\ & + 0.0004478\ (\text{number of rings})^2(\text{height})\end{aligned} \quad (14)$$

$R^2 = 0.246$. SE = 6.3°.

Latewood fibril angle,

$$\begin{aligned}\text{degrees} = {} & 40.02 \\ & - 0.141\ (\text{number of rings}) \\ & - 0.3593\ (\text{height}) \\ & + 0.004136\ (\text{height})^2\end{aligned} \quad (15)$$

$R^2 = 0.177$. SE = 6.2°.

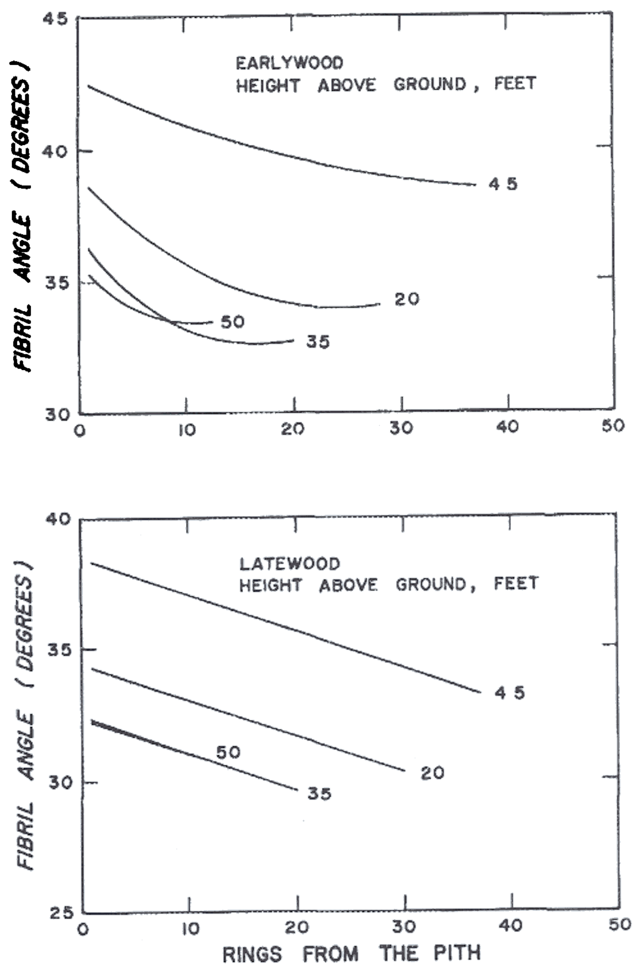


Figure 9.—*Fibril angle as related to height above ground and rings from pith. Angle of macerated tracheids was determined by polarization.*

Correlation coefficients.—Simple correlations were determined between mean values of properties measured at the 1,296 within-stem sampling points. Table 3 lists all correlations whose "r" values were 0.20 or higher.

In addition to the obvious relationships (as that lumen radial diameter is highly correlated with tracheid radial diameter), a few trends were evident. In earlywood, radial and tangential diameters tended to be correlated both in tracheids ($r = 0.61$) and in lumens ($r = 0.69$). To a lesser extent, tracheid and lumen

Table 3.—*Simple correlations for within-stem variables* [1]

Variable	Tracheid		Lumen		Tangential wall thickness	Fibril angle	Ring width	Tissue width	Latewood percent	Specimen location		
	Radial diameter	Tangential diameter	Radial diameter	Tangential diameter						From pith, ring	From pith, inch	Above ground
Specific gravity	−0.32	−0.35	−0 51	−0.62	0.75	.	.	.	0.24			
	.	.	*−.41*	*−.60*	*.76*							
Tracheid												
Length	.53	.57	.50	.52	.22	0.31				0.49	0.50	
	.26	*.56*		*.38*	*.33*	*−.31*				*46*	*.48*	
Radial diameter		.69	.98	.61	.32	.		0 26	−.21	.36	.51	
		.42	*.80*		*.73*	.	*0.26*			*31*	*.44*	
Tangential diameter			.65	.94	.30	.	.26	.27		.41	.57	
			.27	*.81*	*.37*	*− 21*	*.30*			*.38*	*57*	
Lumen												
Radial diameter				.65	.	.	.	25	− 24	32	.45	.
				.	.	.	*.31*	.	.	.	*.25*	.
Tangential diameter					.	.	21	25	.	.34	.46	
					−.24	.	*.27*	.	.	.	*.32*	*0.38*
Tangential wall thickness						.	.	.	.	.27	39	.
						.	.	.	.	*.41*	*.44*	*−.29*
Fibril angle							.26	.	.23	.	.	− 36
							.	*.30*	*.24*	.	*.25*	*− 26*

[1] Leaders (.) indicate correlations of less than 0.20. Upper value of each pair is for earlywood, and lower value (in italics) is for latewood.

diameters were correlated with tracheid length (r = 0.50 and 0.57). These relationships were less evident in latewood, where the coefficient for radial and tangential tracheid diameters was 0.42 and tracheid length was related only to tangential diameters of tracheids (r = 0.56) and of lumens (r = 0.38).

As expected, specific gravity was positively correlated with wall thickness (r = 0.75). In earlywood, specific gravity was related more to lumen radial (r = —0.52) and tangential (r = —0.62) diameters than to tracheid diameters (r = —0.32 and —0.35). The same relations occurred in latewood but were less pronounced.

Wall thickness in latewood was positively correlated with radial diameter (r = 0.73). The relationship was less evident for tangential diameter (r = 0.37) and for earlywood diameters (r = 0.32 and 0.30).

Fibril angle was not highly correlated with any of the other variables.

Longitudinal Shrinkage

Percent of shrinkage from water-swollen to ovendry condition was measured for three specimens at each of the 1,296 within-stem sampling points. Shrinkage did not vary significantly with tree growth rate, age class, or position in the stem. Longitudinal shrinkage averaged 0.49 percent for earlywood and 0.26 for latewood, with standard deviations of 0.09 and 0.08 percent.

The sampling points were separated into those falling into heartwood and those falling into sapwood.

Type of wood	Longitudinal shrinkage	Observations
	[illegible]	*Number*
Earlywood		
Heartwood	0.54	29
Sapwood	.49	619
Latewood		
Heartwood	.29	29
Sapwood	.26	619

For reasons unclear, heartwood specimens shrank more than sapwood.

Specific Gravity

Specific gravity of bark, based on weighted samples at 8-foot stem intervals, averaged 0.381

(basis of ovendry weight and green volume) for all trees; standard deviation was 0.03.

Tree age class and growth rate (rings per inch)	Bark specific gravity
15 years	
<6	0.355
>6	.380
30 years	
<6	.376
>6	.396
45 years	
<6	.382
>6	.398

Slow-grown trees, with an average gravity of 0.391, had denser bark than fast-grown (0.371). The 30- and 45-year age classes did not differ significantly, but bark of trees in the 15-year age class (0.368) was less dense than that in either of the older classes (0.386 and 0.390).

Figure 10 charts bark specific gravity in terms of butt growth rate (rings per inch) and tree age. The equation was:

$$\text{Tree bark specific gravity} = 0.3308 + 0.004364\ (\text{butt growth rate}) + 0.000635\ (\text{tree age}) \quad (16)$$

$$R^2 = 0.22. \quad SE = 0.029.$$

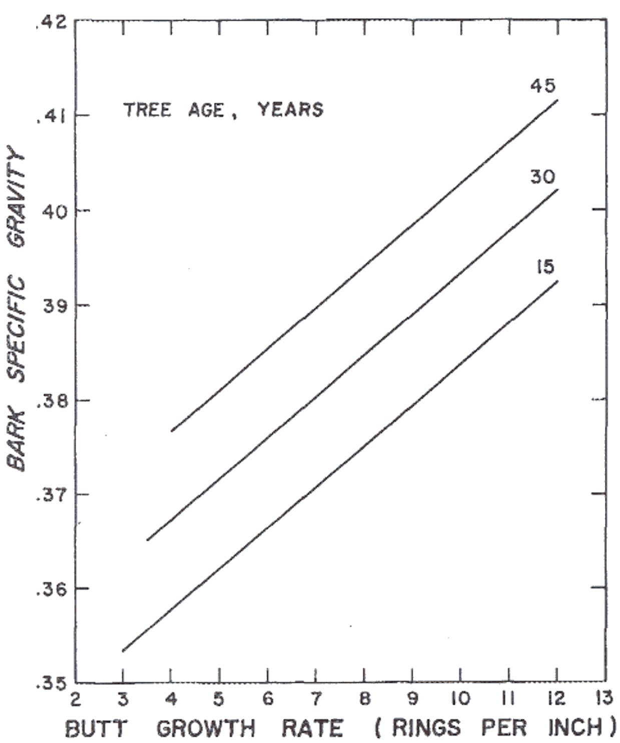


Figure 10.—*Tree-average bark specific gravity as related to tree age and growth rate at butt.*

In the merchantable stem, specific gravity of unextracted wood averaged 0.425 (basis of ovendry weight and green volume) for all 72 trees. Extracted specific gravity averaged 0.413, about 2.8 percent less.

A regression equation accounted for 75.7 percent of the variation between tree averages for extracted and unextracted wood; standard error of the estimate was 0.017:

$$\text{Extracted specific gravity} = 0.0713 + 0.8056\ (\text{unextracted specific gravity}) \quad (17)$$

Slow-grown trees were denser than fast-grown, but there were no differences among age classes.

Condition and tree age class (years)	Less than 6 rings per inch (avg. 4.9)	More than 6 rings per inch (avg. 9.0)
	Tree average specific gravity	
Unextracted		
15	0.414	0.448
30	.406	.450
45	.403	.426
Extracted		
15	.398	.433
30	.397	.442
45	.389	.422

Unextracted specific gravity averaged 0.442 for slow-grown and 0.408 for fast-grown trees. For extractive-free wood, comparable stem means were 0.432 and 0.395.

Taras and Saucier (1968) computed a spruce pine species average from a sample of 1,155 unstratified trees. Their value was 0.426, very close to the present 0.425. They found that increment core gravity at breast height averaged 0.443.

Earlywood and latewood extractive-free specific gravities were determined by dual-linear micrometer from the 648 unweighted sample locations within each tissue type (72 trees × 3 heights × 3 radial positions). Earlywood averaged 0.376, and latewood 0.691. There were no significant differences among age classes or between growth rates for either earlywood or latewood. Within both tissue types, however, some differences occurred with location in the stem.

Regressions illustrated these differences but accounted only for a limited amount of the variation (fig. 11). Earlywood specific gravity was negatively correlated with number of rings from the pith and decreased with increasing height in the stem. Latewood, in contrast, tended to increase with age in the upper stem but to remain constant near the base.

The equations were:

Earlywood specific gravity (extractive-free) = 0.4069 (18)
— 0.0008555 (number of rings)
— 0.002078 (height)
+ 0.0000242 $(\text{height})^2$
$R^2 = 0.092$. SE = 0.051.

Latewood specific gravity (extractive-free) = 0.7193 (19)
— 0.001685 (height)
+ 0.000001243 (number of rings)$(\text{height})^2$
$R^2 = 0.174$. SE = 0.06.

Neither earlywood nor latewood gravities differed with growth rate, but stem-average values were lower for fast- than for slow-grown trees.

On the average, an annual ring in fast-grown trees contained greater numbers of both types of tracheids, with no differences among age classes. A radial file averaged 75.5 earlywood cells in slow-grown trees and 116.5 in fast-grown. Latewood averaged 35.2 cells per file in slow-grown trees and 47.2 in fast-grown. The number of latewood tracheids in a radial file thus decreased from 31.8 percent in slow-grown trees to 28.8 percent in fast-grown. In consequence, radial width of latewood tissue decreased from 24.9 percent to 21.1 percent. Finally, by equation (1), the weighted percentage of latewood in the merchantable stem decreased from 30.8 percent in slow-grown trees to 25.4 percent in fast-grown trees; there was no difference among age classes. For these reasons, fast-grown trees contained smaller proportions of latewood and hence had lower density.

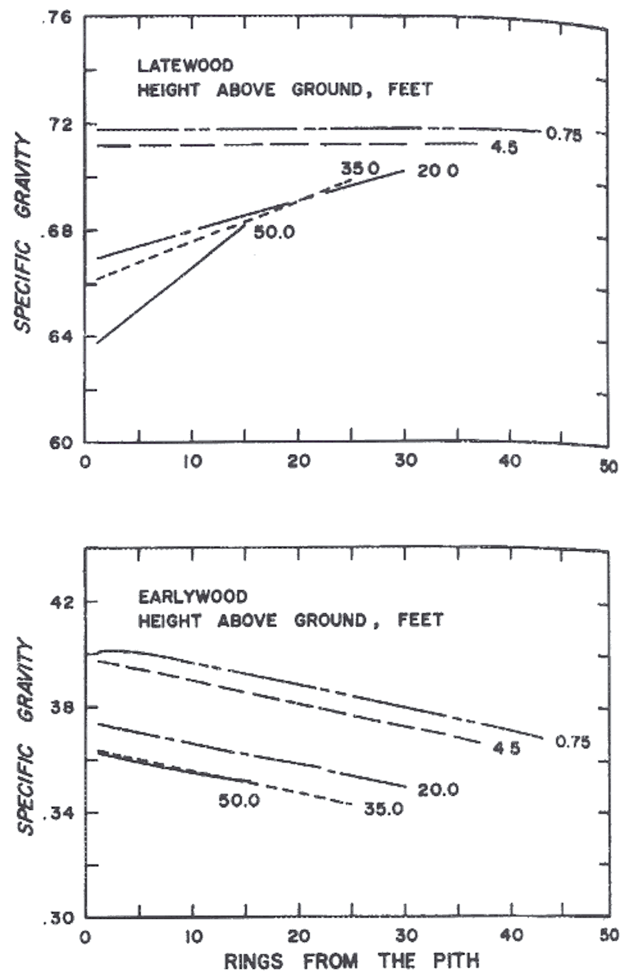


Figure 11.—*Extracted specific gravity (basis of ovendry weight and green volume) as related to height above ground and and rings from the pith.*

Regression analysis, although statistically significant in terms of number of rings from pith and height in tree, explained little of the observed variation of latewood percentage within the stem.

Stem Weights and Volumes

Green volumes and ovendry weights of bark and wood components are presented in table 4. With the exception of heartwood volume, all means for weight and volume follow the same pattern. For stems of the 15-year age class there were no significant differences between growth rates. These trees averaged 0.5 cubic foot of bark to a 4-inch top and 4.2 cubic feet

Table 4.—*Tree-average green volumes and ovendry weights of merchantable stem portions from 72 spruce pines*[1]

Tree age class and growth rate (rings/inch)	Green volume					Ovendry weight			
	Whole wood	Bark	Heart-wood	Early-wood	Late-wood	Whole wood	Bark	Early-wood	Late-wood
	Cu. ft.					*Pounds*			
15 years									
>6	1.4	0.2	0.0	1.0	0.4	38.7	5.4	23.0	15.7
<6	7.0	.8	.0	5.3	1.7	172.3	18.6	124.2	48.1
30 years									
>6	5.5	.7	.0	3.6	1.9	155.3	17.5	86.2	69.1
<6	23.1	2.6	.3	16.9	6.2	581.3	61.1	397.8	183.5
45 years									
>6	18.6	2.1	.6	13.1	5.5	481.5	50.5	308.1	173.4
<6	53.9	4.8	1.9	39.7	14.2	1,338.5	114.4	931.0	407.5

[1] Merchantable stem to a 4-inch (outside bark) top with butt height of 0.75 ft.

of wood—of which 3.2 cubic feet were earlywood and 1.0 cubic foot latewood.

For both the 30- and 45-year age classes, in every column of table 4 (except heartwood) fast-grown trees yielded significantly more wood and bark than did slow-grown. For all ages there were no differences in weights or volumes between fast-grown trees of one age class and slow-grown trees of the next older class; 30-year-old fast-grown trees and 45-year-old slow-grown trees, for example, contained the same weight and volume of wood components and of bark, although there was an average difference of 20 years (table 1).

Spruce pine has little or no heartwood until about age 45. In this age class, fast-grown trees had an average of 1.9 cubic feet of heartwood; slow-grown trees had 0.6 cubic foot. Heartwood volume was measurable in none of the 15-year-old class, in 42 percent of the 30-year class, and in all of the 45-year class. The bark-free portion of the merchantable stems averaged 1.3 percent heartwood by volume in the 30-year class and 3.5 percent in the 45-year class.

Occurrence of heartwood was compared with disk age for each of the 430 disks removed from the 72 trees. Of the 22 disks containing 20 annual rings, approximately 18 percent contained heartwood. Of the 177 disks with 19 or fewer rings only 6 contained any. Heartwood was present in 78 percent of the disks with 27 rings and in 100 percent of the disks with 37 rings.

For those trees containing heartwood, a regression equation was derived for heartwood volume expressed as percent of the merchantable stem. Variables considered were tree age, age^2, crown length, crown width, total height of tree, and butt growth rate. The best equation was:

$$\text{Heartwood volume, percent} = 9.515 - 0.174\ (\text{crown length in feet}) \quad (20)$$
$$R^2 = 0.204. \quad SE = 3.6 \text{ percent.}$$

Equations were derived for ovendry weight and green volume of bark (to a 4-inch top) in terms of diameter (in inches) outside bark at breast height and tree total height in feet (fig. 12).

$$\text{Bark volume, cu. ft.} = 0.003\ (\text{d.b.h.})(\text{tree height}) - 0.616 \quad (21)$$
$$R^2 = 0.938. \quad SE = 0.4 \text{ cu. ft.}$$

$$\text{Bark weight, pounds} = 0.091\ (\text{d.b.h.})(\text{tree height}) - 15.0 \quad (22)$$
$$R^2 = 0.940. \quad SE = 10.6 \text{ lbs.}$$

For trees of all ages, bark comprised about 10.7 percent of stem total volume (to a 4-inch top) and about 9.8 percent of stem ovendry weight.

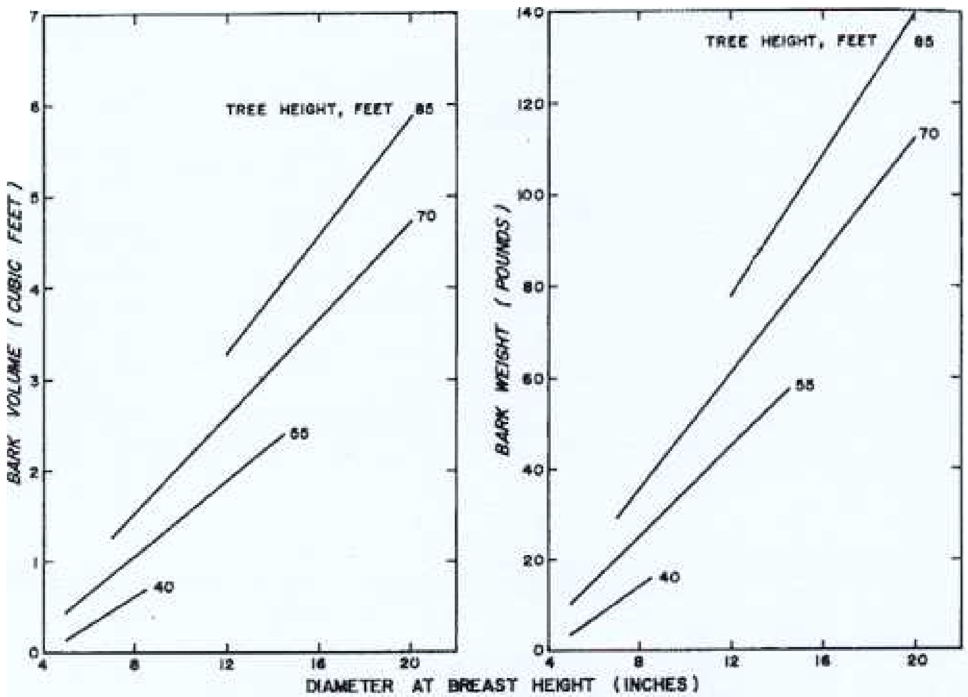


Figure 12.—*Ovendry weight and green volume of stem bark (to a 4-inch top outside bark) as related to diameter outside bark at breast height and total tree height.*

Tree age class and growth rate (rings per inch)	Bark volume	Bark weight	Bark thickness, stump height
	Percent –		*Inch*
15 years			
>6	**14.1**	**12.2**	**0.22**
<6	**10.8**	**9.7**	**.27**
30 years			
>6	**11.2**	**10.1**	**.25**
<6	**10.0**	**9.5**	**.32**
45 years			
>6	**10.0**	**9.5**	**.28**
<6	**8.2**	**7.9**	**.36**

Bark thicknesses from all heights were averaged to obtain a mean thickness for the merchantable stem. Fast-grown trees had thicker bark (0.22 inch) than slow-grown (0.19 inch). Bark thickness increased significantly with age; it averaged 0.18 inch in the 15-year age class, 0.20 in the 30-year class, and 0.23 in the 45-year class.

The best equation for bark thickness at any point was in terms of diameter inside bark, in inches, at that point and height above ground in feet (fig. 13).

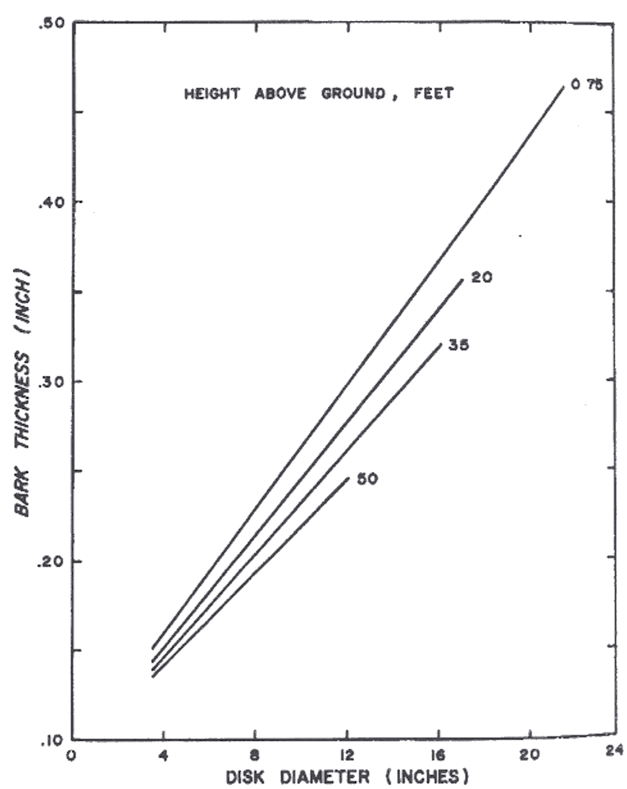


Figure 13.—*Bark thickness as related to disk diameter inside bark at various heights above ground.*

$$\text{Bark thickness, inch} = 0.0891 + 0.0175\,(\text{diameter inside bark}) - 0.0000871\,(\text{height}) \qquad (23)$$

$$R^2 = 0.670. \quad SE = 0.045 \text{ inch.}$$

Wood Chemical Constituents

Amounts of chemical constituents in the merchantable stem generally did not differ significantly with tree age or growth rate (table 5). For all trees, extractive content averaged 2.7 percent of the ovendry weight of the unextracted wood.

With extractives removed, ash content averaged 0.46 percent of ovendry weight. Variation among trees was substantial, but may have resulted from the sampling procedure. Two ash samples were run per stem, whereas there were five samples for each of the other components.

Lignin and cellulose means were not adjusted for ash content. Lignin content averaged 28.0 percent of the extractive-free wood for all trees. Only the means for 45-year-old fast- and slow-grown trees, 27.5 and 28.4 percent, were significantly different. Holocellulose content averaged 77.8 percent, of which 49.1 percent was alpha-cellulose and 28.7 percent was hemicellulose.

Mechanical Properties

Standard strength properties were determined for 42 trees of the 30- and 45-year age classes (table 6); the 15-year-old trees and six of the 30-year, slow-grown trees were too small to yield specimens.

Wood from fast-grown trees differed in only a few properties from that of slow-grown trees.

Moisture condition and strength property	Slow grown	Fast grown
Green:		
Modulus of rupture, p.s.i.	7,250	6,470
Modulus of elasticity, p.s.i.	1,430,000	1,130,000
Maximum tensile stress perpendicular to grain (tangential), p.s.i.	270	340
12-percent moisture content:		
Modulus of elasticity, p.s.i.	1,800,000	1,410,000
Hardness (side), pounds	840	700

In general, slow-grown wood was stronger, but only for hardness (12 percent) did specific gravity differ significantly with growth-rate class.

Specimens from the 30-year age class differed significantly from those of the 45-year age class in two properties:

Strength property	Tree age class: 30 years	45 years
Work to maximum load, green specimens, in.-lb. per cu. in.	12.3	
Hardness, side grain, 12-percent specimens, pounds	837	

Table 5.—*Stem-average values for extractives, ash, lignin, and cellulose fractions of 72 spruce pine trees*

Tree age class and growth rate (rings/inch)	Extractives [1]	Ash [2]	Lignin [3]	Holocellulose [3]	Alpha-cellulose [3]	Hemicellulose [3]
	Percent					
15 years						
>6	2.7	0.46	27.8	78.6	49.2	29.4
<6	2.7	.52	28.2	77.8	48.4	29.4
30 years						
>6	2.8	.51	28.2	80.0	49.6	30.4
<6	2.5	.39	27.9	76.3	48.9	27.5
45 years						
>6	2.6	.43	28.4	76.7	49.0	27.7
<6	2.8	.43	27.5	77.5	49.5	28.0
Mean	2.7	.46	28.0	77.8	49.1	28.7

[1] Based on weight of ovendry, unextracted wood.
[2] Based on weight of ovendry, extractive-free wood.
[3] Based on weight of ovendry, extractive-free wood, not corrected for ash.

Table 6.—*Among-tree variation in clear wood properties of spruce pine*

Strength property	Green			12-percent moisture content		
	42-tree average[1]	Range	Standard deviation	42-tree average[1]	Range	Standard deviation
Static bending						
Fiber stress at proportional limit, p.s.i.	2,830	1,640-4,360	691	4,880	2,710-7,780	1,223
Modulus of rupture, p.s.i.	6,820	3,890-9,480	1,211	10,200	5,530-14,120	2,132
Modulus of elasticity, p.s.i.	1,260,000	480,000-2,240,000	384,000	1,580,000	900,000-3,560,000	500,000
Work to proportional limit, in.-lb per cu. in	0 40	0.12-1.01	0 18	0.93	0.28-1.66	0 34
Work to maximum load, in.-lb per cu in	10 54	5.55-19.60	3.54	9.22	0.84-23 30	4.18
Compression parallel to the grain						
Fiber stress at proportional limit, p.s.i.	1,960	1,160-2,730	337	3,660	2,340-5,430	702
Maximum crushing strength, p.s.i.	2,840	1,580-3,940	497	5,670	4,430-7,320	742
Compression perpendicular to the grain						
Fiber stress at proportional limit, p.s.i.	375	245-529	64	796	470-4,705	160
Maximum shear stress parallel to the grain						
Radial, p.s.i.	846	659-1,065	110	1,244	622-1,741	263
Tangential, p.s.i.	841	537-1,048	108	1,214	793-1,631	201
Maximum tensile stress perpendicular to grain						
Radial, p.s.i.	288	128-418	63	371	199-583	92
Tangential, p.s.i.	312	123-462	69	397	270-558	79
Hardness (load required to embed a 0.444-inch ball to one-half its diameter)						
Side grain, lb.	535	373-789	107	741	436-1,385	202
End grain, lb.	562	375-889	124	1,064	738-1,620	201
Toughness (specimen 0.79 by 0.79 inch tested over a 9.47-inch span with load applied to radial and tangential faces)						
Radial, in.-lb.	394	109-652	177	148	53-299	56
Tangential, in.-lb.	373	74-648	170	181	49-314	70

[1] Eighteen trees in 30-year class (six slow- and 12 fast-grown) and 24 trees in 45-year class (12 slow- and 12 fast-grown).

In both cases sample specific gravity averaged significantly higher from the 30-year-old trees. For work-to-maximum-load specimens, it was 0.461 and 0.431 (basis of green volume and ovendry weight); for hardness, it was 0.492 and 0.460 (basis of volume at 12 percent moisture content and ovendry weight).

Specific gravity is related to strength, since it is a measure of the cell wall material present per unit volume of wood. Regression equations were derived for most strength properties to determine the degree of linear association with specific gravity (tables 7 and 8). Specific gravity was not measured on air-dry specimens used to determine compression and tension perpendicular to the grain.

Only two strength properties were unrelated to specific gravity. They were work to the proportional limit in static bending and tensile stress perpendicular to the grain when failure is in the tangential plane.

The properties most closely associated with changes in specific gravity (r above 0.75) were modulus of rupture, hardness, and compressive strength parallel to the grain—the latter in green wood only. Properties with correlation coefficients between 0.58 and 0.70 were modulus of elasticity (in both green and dry specimens), maximum crushing strength (dry), and —in green specimens only—work to maximum load, shear stress parallel to the grain, and tensile stress perpendicular to the grain. The specific gravity-strength relationships for four of the properties are shown in figure 14

Bendtsen (1968) sampled 35 randomly selected spruce pines to obtain a species average for several mechanical properties. His results are summarized in table 9; they are not directly comparable with the values in table 6, since Bendtsen's trees were unstratified while those in the present study were stratified by age and growth rate. Further, specific gravity of test specimens averaged higher in the current study: 0.435 (basis of green volume and ovendry weight) and 0.479 (volume at 12 percent moisture content and ovendry weight), as compared to Bendtsen's 0.413 and 0.441, respectively.

Table 7.—*Linear relationships between strength properties of green spruce pine wood and specific gravity*[1]

	Constants a	Constants b	Correlation coefficient	Standard error of the estimate
Static bending				
Fiber stress at proportional limit, p.s.i.	518	5,237	0 29	885
Modulus of rupture, p.s.i.	−2,666	21,355	.87	620
Modulus of elasticity, p.s.i.	−709,240	4,454,145	58	312,941
Work to maximum load, in.-lb. per cu in.	−11 8	50 3	.63	3.2
Compression parallel to the grain				
Fiber stress at proportional limit, p.s.i.	585	3,090	.36	426
Maximum crushing strength, p.s.i.	−515	7,571	.77	340
Compression perpendicular to the grain				
Fiber stress at proportional limit, p.s i.	141	533	48	70
Maximum shear stress parallel to the grain[2], **p.s.i.**	124	1,675	.70	90
Maximum tensile stress perpendicular to grain				
Radial, p s i.	535	62	.63	56
Hardness				
Side grain, lb.	−396	2,116	.94	40
End grain, lb	−459	2,321	.88	62
Toughness				
Radial, in.-lb.	−121	1,159	.33	171
Tangential, in.-lb.	−78	1,014	.34	162

[1] The constants are from the expression $y = a + bx$ In the equation, y is the strength property of interest and x is unextracted specific gravity (basis of green volume and ovendry weight).
[2] Combined data from wood stressed in both radial and tangential directions.

Table 8.—*Linear relationships between strength properties of airdry spruce pine wood and specific gravity*[1]

Property	Constants a	Constants b	Correlation coefficient	Standard error of the estimate
Static bending				
Fiber stress at proportional limit, p.s.i.	−900	12,443	0.46	1,364
Modulus of rupture, p.s.i.	−4,856	32,401	.76	1,612
Modulus of elasticity, p.s.i.	−1,373,376	6,259,895	.59	364,652
Work to maximum load, in.-lb. per cu. in.	−10.1	41.4	.45	4.7
Compression parallel to the grain				
Fiber stress at proportional limit, p.s.i.	1,108	5,322	.36	831
Maximum crushing strength, p.s.i.	1,454	8,735	.59	705
Maximum shear stress parallel to the grain,[2] **p.s.i.**	201	2,134	.41	258
Hardness				
Side grain, lb.	−982	3,659	.91	89
End grain, lb.	−550	3,420	.81	130
Toughness				
Radial, in.-lb.	−98	503	46	56
Tangential, in.-lb.	−133	645	.42	80

[1] The constants are from the expression $y = a + bx$. In the equation, y is the strength property of interest and x is unextracted specific gravity (basis of volume at 12 percent moisture content and ovendry weight).
[2] Combined data from wood stressed in both radial and tangential directions.

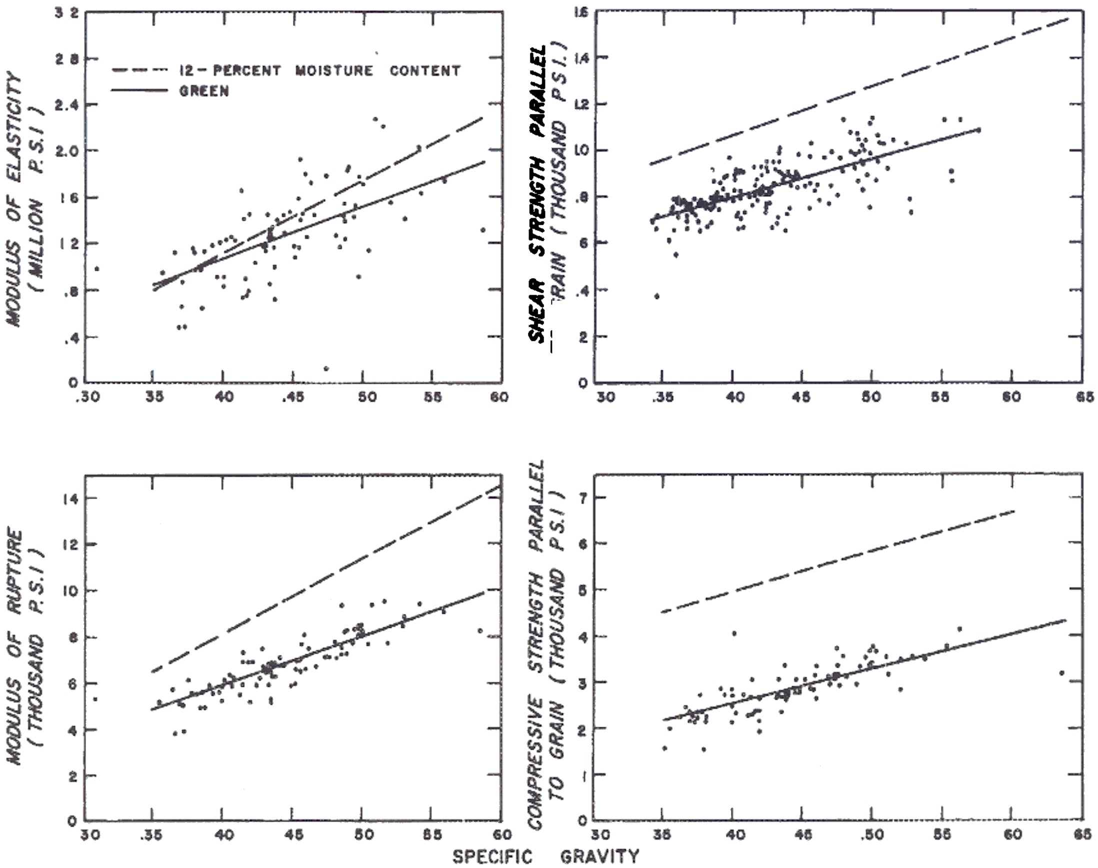


Figure 14.—*Relationship of four strength properties to unextracted specific gravity (basis of ovendry weight and volume at test) of green and air-dry spruce pine wood. Data points are plotted for green specimens only.*

Table 9.—*Species average values for spruce pine mechanical properties based on a 35-tree randomly selected sample (after Bendtsen 1968)*

Property	Green	12% moisture content
Static bending		
Modulus of rupture, p.s.i.	6,004	10,368
Modulus of elasticity, p.s.i.	1,002,000	1,229,000
Stress at proportional limit, p.s.i.	2,939	5,079
Work to proportional limit, in.-lb. per cu. in.	0.510	1.22
Compression parallel to grain		
Maximum crushing strength, p.s.i.	2,835	5,646
Modulus of elasticity, p.s.i.	1,163	1,374
Maximum shearing strength parallel to grain		
Radial, p.s.i.	905	1,485
Tangential, p.s.i.	885	1,491
Compression perpendicular to grain		
Crushing strength at proportional limit, p.s.i.	279	733
Hardness		
End, lb.	477	817
Side, lb.	447	661

Microtensile strength parallel to the grain was measured at each of the 1,296 within-stem sampling points (18 unweighted samples per tree). Values for earlywood and latewood did not differ significantly with tree age class or growth rate.

Property	Earlywood	Latewood
	---- P.s.i. ----	
Modulus of elasticity	505,944	1,103,931
Maximum tensile stress	8,233	19,430

DISCUSSION

Probably most properties of southern pines vary more within individual trees and among trees of a single species than they do between species. Nevertheless interspecies differences undoubtedly do exist.

Density of the merchantable stem averaged 0.43 in the present study, and Taras and Saucier (1968) also obtained this value. Species averages compiled by Koch (1972, p. 244) varied from 0.42 for Ocala sand pine *(P. clausa* (Chapm.) Vasey) and 0.45 for Virginia pine *(P. virginiana* Mill.) up to 0.58 for South Florida slash pine *(P. elliottii* var. *densa* Little and Dorman). Thus, spruce pine is in the low end of the range. Values for spruce pine did not differ with tree age class, but data for other species have shown a positive correlation between stand age and tree-average density (e.g., Zobel et al. 1965).

In Koch's compilation (1972, table 10-2, p. 408), wood of spruce pine ranks below that of Virginia pine in mechanical properties, and both of these species are considerably less strong than the four major southern pines. The data in this paper, though not comprising species averages, are in general agreement with those summarized by Koch. The values for modulus of elasticity and compression perpendicular to the grain are higher than those given by Koch but still lower than for most species. Only in work to maximum load (green) and in side hardness do present values compare with those of other species.

Spruce pine wood may contain a smaller proportion of extractives than the other southern pines. Extractive content averaged 2.7 percent of the stem ovendry weight, about one-half of that found in other species (Koch 1972, p. 205).

It is of interest to compare wood properties of trees in the three age classes, since rotation age is generally reduced to the minimum permitted by the market for which wood is grown. Fiber length of spruce pine trees would be reduced by about 0.2 mm. by cutting 15-year-old trees rather than those in the 30-year age class. Tracheid radial diameter and wall thickness apparently would not be reduced, and tangential diameter would be only about 1 μm. less in younger trees. Fibril angle of the S_2 layer would be greater in young trees.

Wood specific gravity would evidently not be affected by rotation age alone, and strength properties would not differ greatly between the two older age classes. Finally, relative proportions of chemical components would not differ with tree age.

Growth rate obviously has a great effect on weights and volumes produced at any age. At the rates study trees were growing (4.9 and 9.0 rings per inch), 30-year-old, fast-grown trees had 320 percent more wood volume than did slow-grown trees. They contained as much wood as 45-year-old, slow-grown trees although averaging 20 years younger. Volume gains were smaller in the 45-year age class, but fast-grown trees contained almost three times as much wood as slow-grown trees and almost double the wood found in 30-year-old, fast-grown trees.

Wood specific gravity, however, averaged lower in fast-grown trees—by about 0.04—than in slow-grown. Specific gravity of earlywood and latewood tissues was not related to tree growth rate, but fast-grown trees contained greater proportions of the low-density earlywood. Most mechanical properties did not differ with growth rate.

Tracheids of fast-grown trees averaged 0.2 mm. longer than those of slow-grown trees, and they were 2 to 4 μm. larger in both radial and tangential diameters. Fibril angle and wall thickness did not differ greatly with growth rate. Regression equations relating tensile stress and modulus of elasticity to position in the stem by height and distance from the pith were significant, but they accounted for less than 10 percent of the variation.

The reader interested in additional study of the utilization of spruce pine should find the following references useful:

Subject	Reference
Anatomy	Côté and Day (1969); Howard and Manwiller (1969); Koch (1972, p. 83-186)
Bark anatomy	Howard (1971); Koch (1972, p. 467-533)
Needle anatomy	Howard (1972b); Koch (1972, p. 575-601)
Distinguishing features	Ward (1963); Koch (1972, p. 30, 47)
Volume in each State	Sternitzke and Nelson (1970); Koch (1972, p. 5-10)
External characteristics of bark	Koch (1972, p. 484)
Moisture content in trees	Choong (1969b); Koch (1972, p. 268)
Hygroscopicity	Choong (1969a)
Specific heat	Koch (1969; 1972, p 367)
Heat of combustion	Howard (1972a); Koch (1972, p. 378-382)
Friction	Lemoine et al. (1970); McMillin et al. (1970-a,b); Koch (1972, p. 357-366)
Strength	Bendtsen (1968)
Specific gravity	Taras and Saucier (1968); Kellogg and Wangaard (1969); Koch (1972, p. 236-264)

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