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# THE RELATIONSHIP OF FIBRIL ANGLE TO CERTAIN FACTORS IN PLANTATION-GROWN RED PINE

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In the woody plant cell the orientation of the cellulose microfibrils in the central layer ($S_2$) of the secondary cell wall is the dominant orientation in the wall. Research has confirmed that this microfibril orientation (fibril angle) appreciably affects certain strength properties, particularly stiffness, in wood of plantation-grown red pine (*Pinus resinosa* Ait.) (Kramer, 1951; Shumway, 1969) and in other species (Mark, 1967; Fujisaki, 1964). Meylan (1968) found that longitudinal and tangential shrinkage is also influenced by fibril angle. Since fibril angle exerts such a marked influence on both the elastic properties and dimensional stability of wood, and because observation and measurement of actual microfibril orientation is both difficult and time consuming, it is desirable to estimate fibril angle by measuring other features of the cell wall which are less difficult to observe.

Normal softwood tracheids possess a very thin primary wall and a three-layered secondary wall. Within a given layer most of the microfibrils are arranged in a helical pattern about the cell. While the microfibrils in the primary wall form a somewhat random pattern, the microfibril orientation within the thin outer layer ($S_1$) and the thin inner layer ($S_3$) of the secondary wall exhibits a near horizontal helix. Within the thicker $S_2$ layer the microfibrils are usually more nearly parallel to the cell axis, and commonly directed in a right-handed Z helix (Berlyn, 1964).

Microfibril orientation has been determined by a variety of techniques such as: alignment of checks, pit apertures, and crystal depositions in the cell wall; enzymatic hydrolysis by soft rot fungi; polarized light; x-ray diffraction; and electron microscopy (Mark, 1967). For the sake of simplicity or due to equipment limitations, however, fibrillar orientation is most commonly determined by measuring either checks in the cell walls of longitudinal tracheids or the inclination of elongated half-bordered pit apertures in the crossfield (the elongated pit apertures between longitudinal tracheids and ray parenchyma). In both cases, earlywood measurements are often omitted since checks in the cell wall prove difficult to locate, elongated half-bordered pit apertures are absent, and

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previous studies have found that earlywood fibril angles correspond in their ring-to-ring variation to latewood fibril angles (Pillow, *et al.*, 1959).

Fibril angle in pine tracheids varies from approximately 0° to 45° or more within a tree (Hiller, 1964b). The fibril angle of the $S_2$ layer in latewood tracheids of slash pine (*Pinus elliottii* Engelm.), loblolly pine (*Pinus taeda* L.), and *Pinus attenuradiata* is less than those of earlywood tracheids (Hiller, 1964a,b). Average latewood fibril angle in loblolly pine decreases as distance from the pith increases at any given height level, and increases in the same year's radial growth as height above ground increases (Pillow, *et al.*, 1959). In contrast, earlywood fibril angle in western hemlock remains high during the first twenty years of growth and then gradually increases, while fibril angle in the latewood decreases steadily as the tree grows older (Wellwood, 1961).

The purpose of this study was to make an estimate of the average ring fibril angle within the stem of 48-year old plantation-grown red pine (*Pinus resinosa*, Ait.). It was also conducted to determine the degree of relationship between this estimated average ring fibril angle and various factors such as position in the tree, latewood percent, specific gravity, and growth rate. This study was one phase of an investigation designed to evaluate the effect of position in the tree stem and selected physical characteristics on the mechanical properties of wood from plantation-grown red pine (Shumway, 1969).

## Materials and Methods

Test material was harvested in 1968 from a plantation of red pine located on the University of Maine Forest in Old Town, Maine. The plantation was established in 1920 at a 6x6 foot spacing with 2-1 transplants of unknown parentage. The plantation received a first thinning at age 28 and was again thinned at age 34.

Sixteen well-formed dominant and codominant potential crop trees were selected from a 1/10 acre plot in the study area. Mensurational data for the sample trees is presented in table 1. Each tree was sectioned into bolts, four feet in length, which were numbered consecutively from the base to the top of the tree. The second, fifth, and eighth bolt from each tree were selected for study so that a representative sample from the butt, middle, and upper portion of each tree was obtained. A series of test specimens one inch square in cross section and one and one-third inches in length were prepared at each height level from a radial strip along the north-south radius of each bolt as seen on the cross-sectional face. The radial positions were numbered from one to three centripetally, giving up to three specimens on the north side from bark to pith and up to three on the south side from bark to pith, dependent upon tree D.B.H. and taper. Position 1 contained annual rings 18-31, position 2 contained annual rings 9-17 and position 3 contained annual rings 3-8.

Table 1

Mensurational Data for Sixteen Plantation-Grown Red Pine Trees

| | | Tree Height | | Crown | | |
|---|---|---|---|---|---|---|
| Tree Number | D.B.H.[1] (inches) | Total (feet) | To base of live crown (feet) | Length (feet) | Width (feet) | Live crown ratio (percent) |
| 1 | 7.2 | 61 | 33 | 28 | 13.0 | 46 |
| 2 | 9.2 | 62 | 34 | 28 | 16.0 | 45 |
| 3 | 8.9 | 60 | 33 | 27 | 13.0 | 45 |
| 4 | 10.2 | 64 | 32 | 32 | 13.0 | 44 |
| 5 | 9.8 | 61 | 34 | 27 | 16.0 | 44 |
| 6 | 10.0 | 61 | 31 | 30 | 12.0 | 49 |
| 7 | 8.9 | 60 | 30 | 30 | 12.0 | 50 |
| 8 | 10.0 | 62 | 31 | 31 | 15.0 | 50 |
| 9 | 10.2 | 65 | 33 | 32 | 16.0 | 49 |
| 10 | 9.0 | 60 | 30 | 30 | 14.0 | 50 |
| 11 | 10.0 | 62 | 33 | 29 | 13.0 | 47 |
| 12 | 9.8 | 60 | 35 | 25 | 15.0 | 42 |
| 13 | 9.5 | 63 | 36 | 27 | 11.0 | 43 |
| 14 | 9.4 | 61 | 34 | 27 | 12.0 | 44 |
| 15 | 9.2 | 59 | 33 | 26 | 11.0 | 44 |
| 16 | 11.0 | 62 | 27 | 35 | 13.0 | 56 |

[1] Diameter at breast height.

Fibril angle determinations were made from 150 samples, 1/3 inch in length which were sawn from original test samples, soaked in water, aspirated, and dehydrated through 30 and 50% ethanol. One radial section 13 microns thick was cut from each sample with a sliding microtome, placed on a microscope slide, secured with a fine wire mesh screen, and stained with a 1% aqueous solution of safranin. Sections were dehydrated and permanently mounted in Permount mounting media.

A Zeiss Photomicroscope with polarized light was used to measure the alignment of the pit apertures in relation to the longitudinal axis of the tracheids. Pit aperture alignments were measured at 400x with an eyepiece goniometer, and recorded to the nearest degree.

Within the latewood zone, fibril orientation was determined by measuring the alignment of half-bordered pits between ray perenchyma cells and longitudinal tracheids (figure 1). Within the earlywood zone, fibril orientation was obtained by measuring the alignment of flattened bordered pit apertures between ray tracheids and longitudinal tracheids (figure 2). A review of the literature has indicated that ray tracheid-longitudinal tracheid pitting apparently has not been utilized for determining fibril angle measurements. Extensive examination of both of the types of pitting referred to, when adjacent to one another has indicated

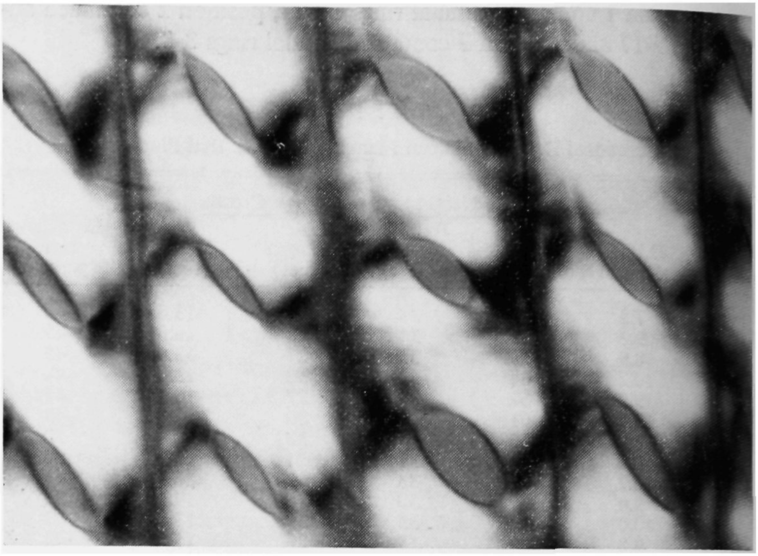

FIGURE 1. Alignment of half-bordered pits located between ray parenchyma cells and longitudinal tracheids. Alignment illustrates maximum fibrillar orientation observed, which was found in specimens taken adjacent to the pith at the butt level.

Radial section; butt level; north side; radial position 3; latewood; 1880x.

that their angles of inclination appear nearly identical (figures 2, 3). This has also been observed by other workers (Hiller, 1969). Thus, the use of the ray tracheid-longitudinal tracheid pitting for obtaining fibril angle measurements in the earlywood seemed justified.

Six fibril angle measurements were made from every annual ring in each of the specimens selected for measurement. Average earlywood fibril angle was obtained by making a measurement in the first-formed tracheid, in a tracheid representing the middle of the earlywood zone, and in a tracheid within the earlywood portion of the transition zone between earlywood and latewood. Similar measurements were made in the latewood area except that the next to last tracheid was selected rather than the last tracheid, as the latter is often markedly compressed, thereby obscuring the pit aperture's alignment.

Latewood percent was obtained from specimens which had provided the radial sections for fibril angle determinations since it was necessary to weight the average latewood fibril angle and the average earlywood fibril angle with the average latewood and earlywood percent respectively to obtain the average ring fibril angle. Latewood percent was determined by macroscopic measurement using a stain for differentiating late-

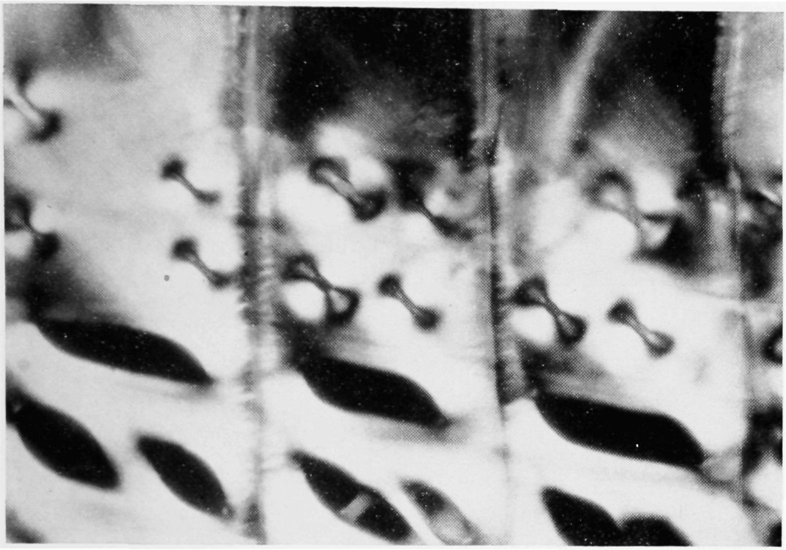

FIGURE 2. Alignment of bordered pits located between ray tracheid cells and longitudinal tracheids can be seen in upper half of micrograph. Half-bordered pits located between ray parenchyma cells and longitudinal tracheids can be seen in lower half of micrograph. Alignment of both types of pitting is nearly identical.

Radial section; butt level; north side; radial position 3; earlywood; 1290x.

wood from earlywood. The stain consisted of 0.015 grams of malachite green and 0.015 grams of methylene blue in 25 milliliters of 20% alcohol (Wiksten, 1946). Cumulative measurements of the latewood and earlywood widths were recorded to the nearest 0.01 millimeter (0.001 inches) across the central radial line of the sample using a De Rowen Dendrochronograph equipped with a 10x eyepiece.

Specific gravity and growth rate were determined from the balance of the original test specimen. Specific gravity, based on oven-dry weight and oven-dry volume, was obtained from unextracted samples using the water immersion method. Rate of growth as indicated by the number of annual rings per radial inch was taken while the specimens were at approximately 12% moisture content.

Correlation analysis and a stepwise multiple regression analysis were performed to develop equations and to obtain an estimate of the accountable variation in the average ring fibril angle ascribable to each of the following independent variables: radial position, height in the tree, latewood percent, specific gravity, rings per inch, and north-south orientation.

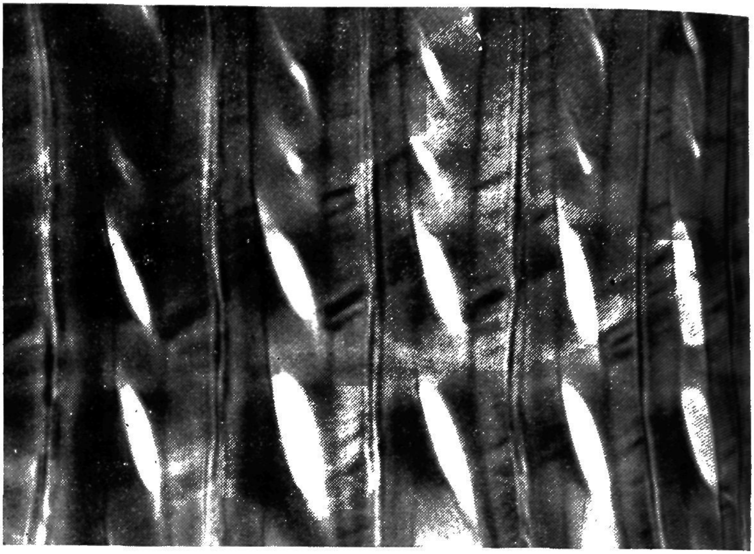

FIGURE 3. Alignment of bordered pits located between ray tracheid cells and longitudinal tracheids can be seen in upper half of micrograph. Half-bordered pits located between ray parenchyma cells and longitudinal tracheids can be seen in lower half of micrograph. Alignment of both types of pitting is nearly identical.

Radial section; upper level; north side; radial position 2; latewood, 1880x.

## Results

A summary of values obtained on wood physical characterictics studied is shown in table 2. Latewood fibril angle values average 20.7 degrees and ranged from 3 to 44 degrees, while earlywood fibril angle values averaged 40.1 degrees and ranged from 11 to 62 degrees. Although not evident from the data presented in this paper it was observed that latewood and earlywood fibril angles usually varied in direct proportion.

Table 3 summarizes the average physical characteristic values of wood obtained from selected radial positions at each of the three height levels investigated. Several patterns of variation already reported in the literature are obvious. Average ring fibril angle weighted by percentage of latewood decreased as distance from the pith increased and generally increased as height above stump height increased. Maximum fibrillar orientation was observed in specimens adjacent to the pith at the butt level (figure 1). Fibrillar orientation decreased as distance from the pith increased (figure 4) to a minimum value in wood from the butt section adjacent to the bark. At any given height, specific gravity, latewood percent, and rings per inch increased as distance from the pith increased. Observed differences attributable to radial position diminished as height

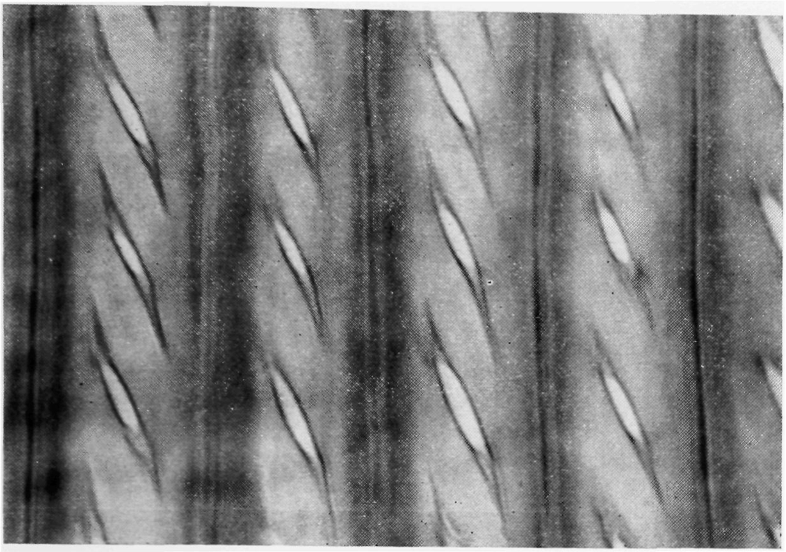

FIGURE 4. Alignment of half-bordered pits located between ray parenchyma cells and longitudinal tracheids. Alignment indicates the decreased fibril angle found at position 2 as compared to position 3 which is adjacent to the pith.

Radial section; butt level; north side; radial position 2; latewood; 1880x.

Table 2
Summary of Values for Physical Characteristics of Wood from Plantation-Grown Red Pine[1]

| Physical Characteristics | Mean | Standard deviation | Range |
|---|---|---|---|
| Earlywood fibril angle[2] | 40.06 | 2.44 | 11.0 – 62.0 |
| Latewood fibril angle[2] | 20.69 | 4.40 | 3.0 – 44.0 |
| Latewood percent | 16.75 | 6.42 | 6.65 – 34.58 |
| Specific gravity[3] | 0.401 | 0.035 | 0.347– 0.516 |
| Growth rate[4] | 8.2 | 2.3 | 4.5 – 14.0 |

[1] Based on sixteen, 48-year old red pine trees.

[2] In degrees; based on 3,411 observations.

[3] Based on oven-dry weight and volume.

[4] In rings per inch.

above ground increased. Correlation coefficients are presented in table 4, illustrating that those variables relating average fibril angle to rings per inch, specific gravity, latewood percent, and radial position are highly significant (0.99% level). North-south orientation and height in the tree evidently lack significance in their effect on average fibril angle as determined in this study.

Equations relating average ring fibril angle to other factors considered are shown in table 5. The coefficients of determination indicate the percentage of variability in the fibril angle accounted for by the regression equation. The accuracy of the equations is indicated by the standard error of the estimate. The best single variable regression is that of fibril angle on latewood percent which accounts for 68.4% of the variation in fibril angle. The addition of radial position, rings per inch, and height above ground accounts for 76.2% of the collective variability in the fibril angle.

Table 3

Average Physical Characteristic Values of Wood from Various Positions[1] in Plantation-Grown Red Pine

| | Butt level | | | Mid level | | | Upper level | |
|---|---|---|---|---|---|---|---|---|
| Physical Property | Pos. 1 | Pos. 2 | Pos. 3 | Pos. 1 | Pos. 2 | Pos. 3 | Pos. 2 | Pos. 3 |
| Fibril angle[2] | 32.4 | 37.0 | 42.1 | 34.0 | 36.9 | 38.7 | 37.1 | 38.[illegible] |
| Latewood percent | 27.6 | 16.8 | 9.1 | 21.8 | 14.1 | 8.9 | 15.2 | 13.[illegible] |
| Specific gravity[3] | .465 | .388 | .374 | .424 | .378 | .366 | .396 | .37[illegible] |
| Growth rate[4] | 11.5 | 10.0 | 5.8 | 10.3 | 7.9 | 6.1 | 6.9 | 5.[illegible] |

[1] Position 1 is adjacent to the bark and contains annual rings 18-31. Position 3 is adjacent to the pith and contains annual rings 3-8. Position 2 is midway between position 1 and position 3 and contains annual rings 9-18. In the case of the upper level, position 1 was non-existent due to the small diameter of the stem at this point.

[2] Average ring fibril angle in degrees; based on 6,822 observations.

[3] Based on oven-dry weight and volume.

[4] In rings per inch.

Table 4
Correlation Coefficient For Several Factors in Plantation-Grown Red Pine

| | Fibril angle[1] | Radial position[2] | Height in tree[3] | Latewood percent | Specific gravity | Rings/ inch | N-S orientation |
|---|---|---|---|---|---|---|---|
| ıtation | +0.057 | +0.111 | +0.045 | –0.110 | –0.112 | –0.062 | +1.000 |
| s/ | –0.746** | –0.584** | –0.536** | +0.804** | +0.793** | +1.000 | |
| ific ity | –0.767** | –0.719** | –0.388** | +0.913** | +1.000 | | |
| wood ent | –0.827** | –0.761** | –0.331** | +1.000 | | | |
| ght ree[3] | +0.137 | –0.178 | +1.000 | | | | |
| ial tion[2] | +0.760** | +1.000 | | | | | |
| il e[1] | +1.000 | | | | | | |

ignificant at the 99% level.
Multiple $R^2 = 0.76$ for the listed significant variables.
Distance from the bark in inches.
Height above stump level in feet.

Table 5
Average Ring Fibril Angle Regression Equations, Coefficient of Determination, and Error of the Estimate

| ression equation | Coefficient of determination[1] | Standard error of the estimate |
|---|---|---|
| Simple Regression (1 Variable) | | |
| = 30.536 + 3.5625RP | 57.6 | 2.33 |
| = 43.897 – 0.4236LW | 68.4 | 2.01 |
| = 65.360 – 70.7635SG | 58.8 | 2.29 |
| = 45.441 – 1.0592GR | 55.7 | 2.38 |
| Multiple Regression (4 Variables) | | |
| = 46.428 + 0.4628RP – 0.2538LW – 0.5881GR – 0.0812HT | 76.2 | 1.76 |
| = 52.572 + 1.0883RP – 27.0147SG – 0.6853GR – 0.0681HT | 73.4 | 1.86 |

nple and multiple regressions are significant at the 99% level of probability.
ıriable symbols:
Y, average ring fibril angle
RP, radial position as inches from bark
LW, latewood percent
SG, specific gravity; oven-dry weight and volume
GR, growth rate in rings per inch
HT, tree height in feet above stump level

## Discussion and Conclusion

Unlike most previous studies which have investigated the interrelationship of only latewood fibril angle with selected wood properties, this investigation has taken into account average ring fibril angle. Clearly, of the wood properties studied, latewood percent appears to provide the best single indicator for variation of average ring fibril angle. This is in agreement with Hiller (1964c) who concluded that age and latewood percent account for 72% and 70%, respectively, of the latewood fibril angle variation in 20 to 25 year old slash pine.

A multiple correlation coefficient of 0.87 was obtained in the multiple regression analysis of average ring fibril angle and the significant independent variables of latewood percent, radial position, rings per inch, and height in the tree, indicating that together these factors explain approximately 76% of the variability of the average fibril angle. Correlation coefficients for the wood features investigated and their significance (table 4) suggest, however, that most of the features are interrelated. Specific gravity, although significantly correlated with average fibril angle, did not significantly contribute to the explained variation in the average fibril angle because of its extremely high correlation with percent latewood.

A definite pattern of decreasing fibril angle was observed at all height levels with increasing distance from the pith. This pattern is also typical of latewood fibril angle obtained for southern pines (Pillow, *et al.*, 1959; Hiller, 1964a). The effect of height in the tree stem upon the average fibril angle was neither as pronounced nor as consistent as was the effect attributable to radial position within the stem (table 3). Average fibril angle of wood adjacent to the bark (position 1) exhibited a progressive increase with increased height above the ground. Average fibril angle determined for position 2 remained comparatively uniform at butt and mid levels in the tree, while average fibril angle for wood adjacent to the pith (position 3) exhibited a decrease from butt level to upper level. These patterns of variation were most likely attributable to corresponding variations in the percent of latewood as illustrated by the high degree of correlation between average fibril angle and the percent of latewood. North-south orientation within the tree stem had no significant influence on any of the physical characteristics of the wood examined. This is in agreement with Cooper (1960) who found north-south orientation had no significant effect on specific gravity in red pine.

Several other relationships of potential significance are illustrated in table 4 that seem worthy of speculation and may suggest further areas for research. Both Brunden (1964) and Cooper (1960) have indicated that crown closure in a developing plantation reduces the amount of crown-formed wood which is considered to be inferior to stem-formed wood. For example, Brunden (1964) reported the specific gravity of crown-formed material to be 10% less than stem-formed wood in red pine. Table 4 indicates a significant positive correlation between rings per inch and both specific gravity and percent latewood. A highly significant negative relationship is also evident between rings per inch and fibril angle, and relatively small fibril angle values are commonly associated with strong, thick-walled fibers. It may be desirable, therefore, to establish red pine plantations with dense initial spacing, to induce early crown closure, followed by controlled thinning to sustain an adequate growth rate (Baker, 1969) of approximately 10 rings per inch (Shumway, 1969), in order to improve the overall quality of the wood produced.

## Literature Cited

Baker, G. 1969. Influence of tree spacing in a red pine plantation on certain wood and tree qualities. Maine Agr. Exp. Sta. Bull. No. 668, Orono, Maine.

Berlyn, G. P. 1964. Recent advances in wood anatomy. For. Prod. Jour. 14(10): 467-476.

Brunden, M. N. 1964. Specific gravity and fiber length in crown-formed and stem-formed wood. For. Prod. Jour. 14(1):13-17.

Cooper, G. A. 1960. Specific gravity of red pine as related to stem-formed and crown-formed wood. Iowa State Jour. Sci. 34(4):693-708.

Fujisaki, K. 1964. Studies on factors affecting the modulus of elasticity of wood on the relation between the inclination of micellar orientation and modulus of elasticity (Part I). Bull. Ehime Univ. Forest 1:34-37.

Hiller, C. H. 1959. Variations in fibril angles in slash pine. U.S. For. Prod. Lab. Rept. 2003, Madison, Wisconsin.

Hiller, C. H. 1964a. Correlation of fibril angle with wall thickness of tracheids in summerwood of slash and loblolly pine. TAPPI 47(2):125-128.

Hiller, C. H. 1964b. Pattern of variation of fibril angle within annual rings of *Pinus attenuradiata*. U.S. For. Ser. Res. Note FPL-034, Madison, Wisconsin.

Hiller, C. H. 1964c. Estimating size of the fibril angle in latewood tracheids of slash pine. Jour. For. 62(4):249-252.

Hiller, C. H. 1969. Technologist, Structure-Property Relations Research, Division of Wood Quality, U.S. Forest Products Laboratory, Madison, Wisconsin. Personal communication.

Kramer, J. G. 1951. The effects of three factors upon the cross-breaking strength and stiffness of red pine. Sta. Bull. No. 560, Purdue Univ. Agr. Exp. Sta., Lafayette, Indiana.

Mark, R. E. 1967. *Cell Wall Mechanics of Tracheids.* Yale University Press, New Haven, Connecticut.

Meylan, B. A. 1968. Cause of high longitudinal shrinkage in wood. For. Prod. Jour. 18(4):75-79.

Pillow, M. C., B. Z. Terrell, and C. H. Hiller. 1959. Patterns of variation in fibril angles in loblolly pine. U.S. For. Prod. Lab. Rept. 1935, Madison, Wisconsin.

Shumway, R. S. 1969. Evaluation of selected mechanical properties of plantation-grown red pine. Unpublished M.S. Thesis, School of Forest Resources, University of Maine, Orono, Maine.

Wellwood, R. W. 1961. Tensile testing of small wood samples. University of British Columbia, Res. Pap. 46, Vancouver, British Columbia.

Wiksten, A. 1946. Metodik vid matning ay arsringens varved och hostved kap. III Differentiering ay var-och histved genom fargning. Skogsforsoksanstalt 34:476-488.