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TRENDS OF FIBRIL ANGLE VARIATION IN WHITE ASH

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ABSTRACT

The variation of the fibril angle within the trunk of a fast-grown white ash and the association of the fibril angle with ring width, fiber length, radial fiber diameter, and fiber wall thickness were studied.

No consistent trends in fibril angle variation from pith to bark were found at any level in the tree; however, the average fibril angles of comparable growth rings were larger at the base of the trunk than the fibril angles at heights above 9 feet. The larger fibril angles at the base of the tree seem to be associated with the thickness of the fiber wall.

There were no indications of any relationship between fibril angle and ring width or fiber length when the trends of variation of these three features were compared, but a significant negative correlation was found between fiber length and fibril angle when both of them were measured on the same fiber.

TRENDS OF FIBRIL ANGLE VARIATION IN WHITE ASH

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INTRODUCTION

In a study of the wood structure and strength properties of white and green ash, Pillow[2] found that the fibril angle in the S_2 layer of fiber walls was inversely associated with basic strength properties, particularly stiffness. He also demonstrated that white and green ash trees grown in excessively moist soil have large fibril angles and correspondingly weak wood, Pillow further noted that the fibril angle in ash decreases at heights above 8 to 12 feet and suggested that the large fibril angles at the base of the trunk were associated with low density wood characterized by comparatively thin fiber walls and large lumens.

To date, there has been no information to show whether white and green ash exhibit systematic trends in fibril angle sizes as does loblolly pine.[3] Knowledge of. such trends is necessary for further studies of the effect of external conditions on the size of the fibril angle.

The purpose of this study was to see whether or not systematic trends in fibril angle existed within the trunk of a white ash tree, and to explore the association of fibril angle with other anatomical characteristics of the wood such as width of the growth rings, percentage of latewood, and fiber dimensions.

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Pillow, M. Y. Characteristics of Ash from Southern Bottomlands. Southern Lumberman 159 (Dig. 15): 131-136. 1939.

[3] Pillow, M. Y., Terrell, B. Z., and Hiller, C. H. Patterns of Variation in Fibril Angles in Loblolly Pine. U.S.D.A. Forest Serv. FPL Rep. 1935. Forest Products Laboratory, Madison, Wis. 1959.

MATERIAL

One fast-grown white ash was cut for sampling in May 1966 in southern Wisconsin, Dimensions were: Total tree height, 78 feet; length of the trunk to the second fork in the crown, 32 feet; crown length, 46 feet; and crown diameter, 29 feet.

Disks of 4-inch thickness were removed at approximately the midpoint of every yearly height increment from the ground to the second fork in the crown. The height above ground at which each disk was taken and the number of growth rings within each disk are given in table 1.

Table 1.--Height above ground of sampled disks and number of growth rings within each disk

Number of growth rings	Height above ground[1]	Number of growth rings	Height above ground[1]
	Ft.		Ft.
51	1.2	41	13.2
50*	2.2	40*	14.7
49	3.6	39	16.2
[2]48	---	38	19.6
47	4.2	37	22.2
46	4.9	36	25.7
45*	6.2	35*	28.2
44	7.2	34	31.6
[2]43	---		
42	9.2		

*Disks sampled for fibril angle determinations.

[1]Measured to the lowest edge of the disk.

[2]The height increment could not be located.

METHODS OF STUDY

On selected growth rings, measurements were made of the following anatomical features: Width of the growth ring and of earlywood and latewood; length of latewood fibers; diameter of earlywood and latewood fibers; single wall thickness of earlywood and latewood fibers; and the fibril angle in the S_2 layer of earlywood and latewood fibers,

All features were measured in the same specimens from growth rings at several locations in the trunk, but not all of the features were measured in every ring sampled.

The selection of rings for fibril angle determinations was based on the three sequences of cambial activity that were analyzed by Duff and Nolan.[4] Four disks were chosen that had a total ring number of 50, 45, 40, and 35. These disks were located at heights of 2.2, 6.2, 14.7, and 28.2 feet above the ground,

The fibril angles were measured in every fifth growth ring, from pith to bark along three randomly chosen radii on each disk. Considering the total number of rings in the disks, the selection of samples made it possible to compare: (1) The mean fibril angle of rings laid down in different calendar years at the same height (horizontal sequence); (2) the mean fibril angle of rings laid down in different calendar years and located at different heights but at the same distances from the pith (vertical sequence); and (3) the mean fibril angle of rings laid down in the same calendar year at different heights and located five rings apart from each other in consecutive disks (oblique sequence),

The widths of the rings as well as the width of earlywood and latewood were measured at the same growth rings.

In addition, three complete oblique sequences progressing through every annual height increment were sampled. The sequences had been formed in 1955, 1945, and 1935. They represented fast-, intermediate-, and slow-diameter growth. Features determined for these three sequences were: The width of the annual rings; the width of earlywood and latewood zones: the mean fibril angle; and the mean length of the latewood fibers. Measurements were made along three randomly chosen radii on each disk.

Possible differences in fiber diameter and wall thickness related to position in the tree were explored by sampling specific growth rings in the three oblique sequences (1935, 1945, and 1955). The sample rings were located 4.9 and 25.7 feet above the ground. Here, too, measurements were made along three randomly chosen radii.

[4]Duff, G. H., and Nolan, J. J. Growth and Morphagenesis in the Canadian Forest Species. I. Controls of Cambial and Apical Activity in Pinus resinosa Ait. Can. J. Bot. 31(4): 471-513. 1953.

Micro-Techniques and Methods of Anatomical Determinations

Ring width.--The widths of the growth rings and of their component parts, earlywood and latewood, were measured on hand-smoothed surfaces of the green disks, using a dual linear micrometer developed at the Forest Products Laboratory.[5] Because most of the fibers associated with the large vessels formed early in the growing season are thin walled, the boundary between earlywood and latewood was defined to be immediately behind the large vessel area.

Fibril angle.--Fibril angle determinations were made of specimens 1/2-inch wide tangentially by 3/4-inch longitudinally. The specimens were boiled in water to soften the wood and to remove the air, and stored in 70 percent ethanol. One radial section, 14 microns thick, was cut from each of the three specimens, stained with Bismarck Brown Y, and permanently mounted. Fibril angle determinations were made by measuring the deviation of the elongated pit apertures from the longitudinal axis of the fiber with polarized light using an eyepiece goniometer. For each section, 15 fibril angles were measured in the earlywood and latewood, giving a total of 90 angles for the growth ring (45 in the earlywood and 45 in the latewood).

Fiber length.--Fiber length measurements were made of macerated latewood fibers, After sectioning, the latewood was trimmed from the remainder of the specimen, split into pieces the size of matchsticks, and macerated in Jeffrey's fluid. One hundred cubic centimeters concentrated nitric acid were added to 125 grams chromic acid dissolved in distilled water. Then distilled water was added to obtain a total of 1,000 cubic centimeters. The fibers were stained with safranin and mounted in water. Length measurements of whole fibers were made with a maptracer on their projected image. A total of 100 fiber length determinations were made in each of the selected growth rings.

Fiber diameter and wall thickness.--The average diameter and wall thickness of fibers were calculated from determinations made on cross-sections of the selected growth rings. The 14-micron-thick sections were stained with Bismarck Brown Y and permanently mounted. A point-counting procedure was followed using an integrating eyepiece fitted to a compound microscope.[6] The eyepiece is provided with a graticule containing 25 points asymmetrically arranged within a circle. The points are connected by straight lines to facilitate counting. By rotating the eyepiece, as many measuring positions as desired may be obtained within the same sampling field.

Determinations were made in 100 sampling fields in a growth ring. Two measuring positions were chosen in each field. Of the sampling fields, 50 were in the latewood and 50 in the earlywood. The fields were evenly distributed over the entire earlywood and latewood areas in a specimen.

The proportion of the fiber area occupied by fiber walls was estimated by dividing the number of points falling on fiber walls by the total number of points falling on the fiber area,

The average cross-sectional fiber diameter in the earlywood and latewood was determined by counting fibers at every measuring position along the interval length (in millimeters) between points of the graticule. The total of the interval lengths from all determinations in the growth ring was then divided by the total number of fiber traversed.

With these determinations, average thickness of the fiber wall in the earlywood and latewood of the growth ring was approximated using the formula given by Smith:[5]

$$W = \frac{D}{2}\left(1 - \sqrt{1 - \frac{4A}{\pi}}\right)$$

where W = average single wall thickness of fibers,
D = average fiber diameter, and
A = proportion of fiber area in wall,

[5] Smith, Diana M. Microscopic Methods for Determining Cross-Sectional Cell Dimensions. U.S.D.A. Forest Serv. Res. Pap. FPL 79. Forest Products Laboratory, Madison, Wis. 1967.

[6] Henning, August. Kritische Betrachtungen zur Volumen-und Oberflächenmessung in der Mikroskopie. Zeiss-Werkzeitschr. 6: 78-86. 1958.

DISCUSSION OF RESULTS

Ring width and fibril angle.--The patterns of ring widths (horizontal sequence) found at four heights are shown in figure 1. These trends are also representative of the trends in percentage of latewood, since it was found that percentage of latewood increases with ring width. After an initial period of suppressed growth, lasting about 10 years, the radial growth rate of the tree reached a maximum and then decreased. The ring widths are essentially the same at all height levels for the last 30 years of the tree's life,

In contrast to ring width, variation in average fibril angle of the entire ring did not follow any systematic trends from pith to bark (fig. 2). However, the average fibril angles in the two lower disks were larger than the fibril angles in the two higher disks for corresponding growth rings. The same trends were observed €or the average fibril angles of the earlywood and of the latewood, but the average fibril angle of the late-wood fibers was always smaller than that of the earlywood, the differences ranging from 0.5° to 9.0° with a mean difference of 4°. In figure 2 the average fibril angle of the entire ring is presented weighted by percent of latewood.

The vertical sequences are shown in figures 3 and 4. Here ring width and fibril angle have been

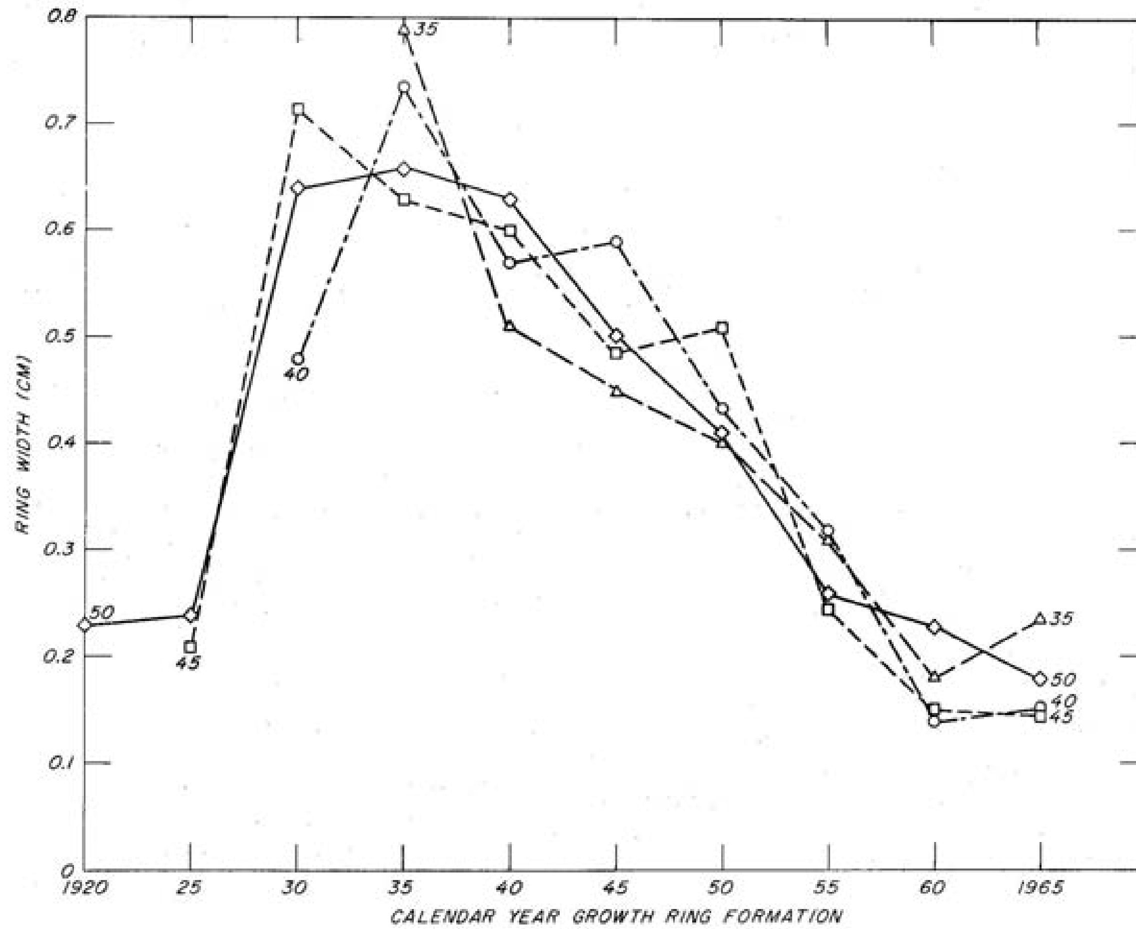

Figure 1.--Ring widths of four disks taken at 2.2, 6.2, 14.7, and 28.2 feet from the ground. Disks are designated 50, 45, 40, and 35 according to the number of growth rings they contain. Each point represents a single growth ring taken at five-ring intervals from pith to bark.

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plotted over height above ground with each line representing a different number of rings from the pith,

For a given number of rings from the pith, ring width tends to decrease with height above ground. Two exceptions were the 5th and 10th rings, whose reversed trends are caused by the initial suppressed growth of the tree. Since ring width at all heights decreases from pith to bark (fig. 1) there is a decrease in ring width from the 15th to 45th ring sequences (fig. 3).

In all of the vertical ring sequences, the average fibril angles (fig. 4) are larger at the lower levels than at the higher levels. There is no order of magnitude between sequences as found for ring width.

The trends of fibril angle variation in the three complete oblique ring sequences are given in figure 5. In all of them the largest fibril angles are confined to the lower end of the trunk to a height of about 9 feet, which coincides with the initial suppressed height growth of the tree (see table 1). The width of the increment sheath does not seem to have any effect on fibril angle size. Neither does age, since the rings of the three sequences are located at different distances from the pith at a given height level.

Judging by the patterns of variation of ring width and fibril angle, there is no indication of any direct association between them--the differences in average fibril angles within the trunk apparently cannot be explained by ringwidth alone. Since the amount of latewood in the annual rings is correlated with ring width, it also may be inferred that fibril angle and latewoodpercentage are not directly associated.

Fiber dimensions and fibril angle.--The results of past studies, mainly of softwoods, have indicated that the fibril angle in the tracheid walls is correlated with the dimensions of the tracheids (length, diameter, and wall thickness). Therefore, it seemed to be a reasonable assumption that the differences in fibril angles along the trunk of the ash could be explained by differences in fiber dimensions at the base and top of the trunk,

The relationship between fiber length and fibril angle was explored first. The length of latewood fibers was determined for the same

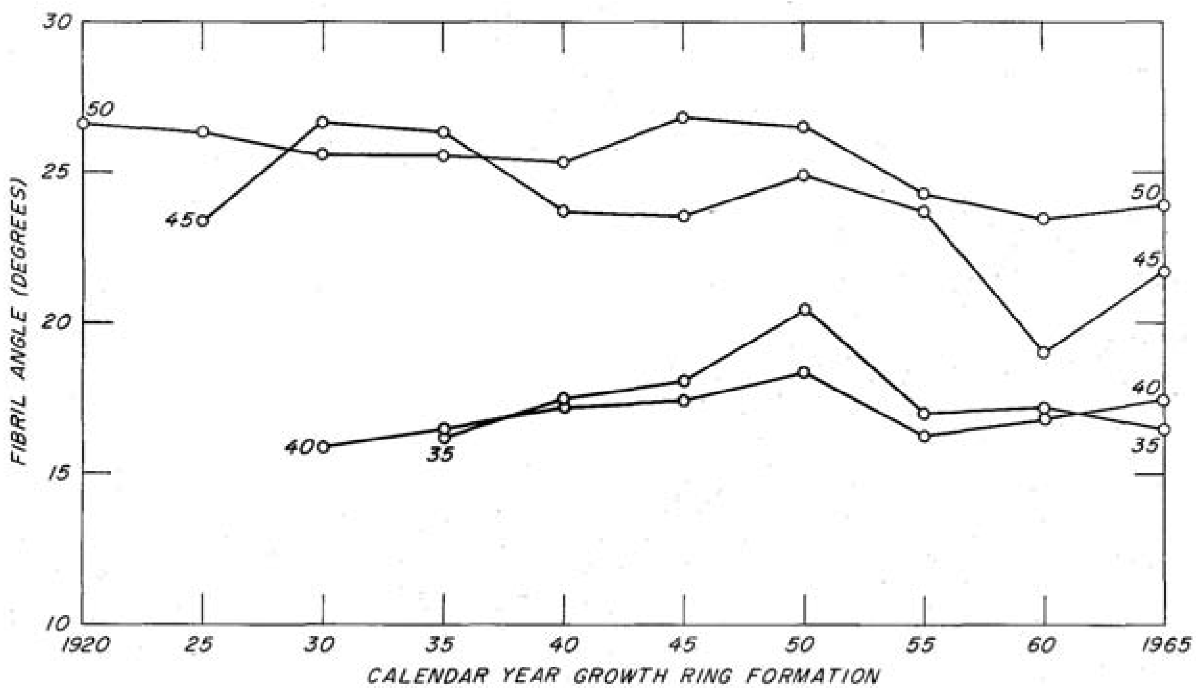

Figure 2.--Average fibril angles in four disks taken at 2.2, 6.2, 14.7, and 28.2 feet from the ground. Disks are designated 50, 45, 40, and 35 according to the number of growth rings they contain. Each point in the graph represents the average fibril angle of a single growth ring.

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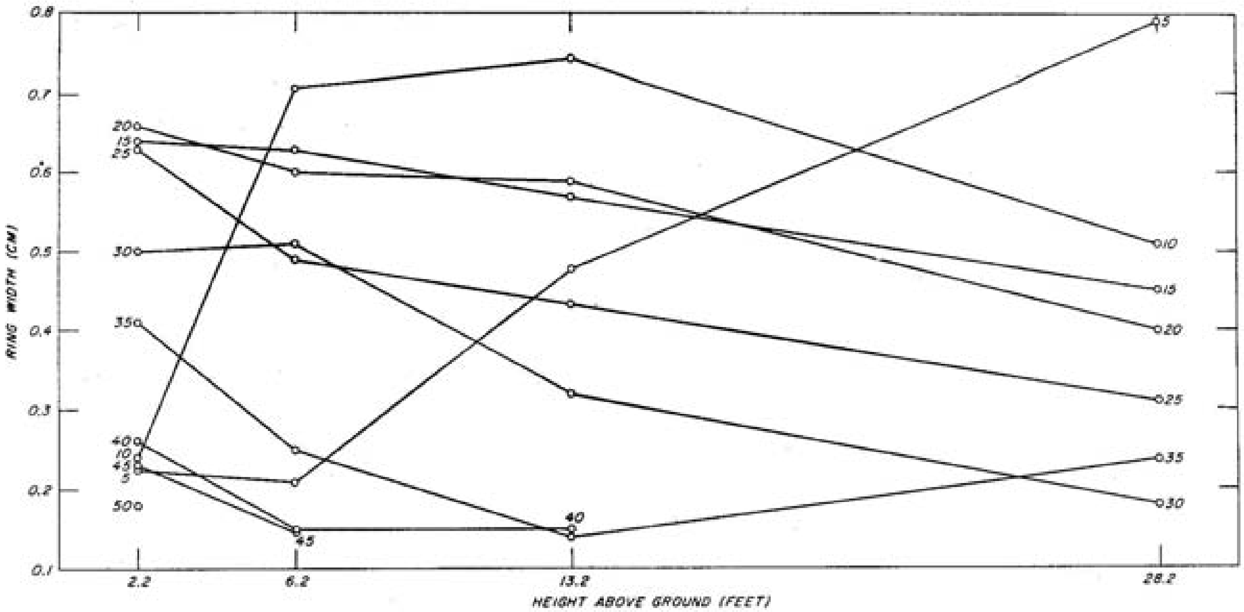

Figure 3.--Widths of growth rings located at the same number of rings from the pith at four heights (vertical ring sequences).

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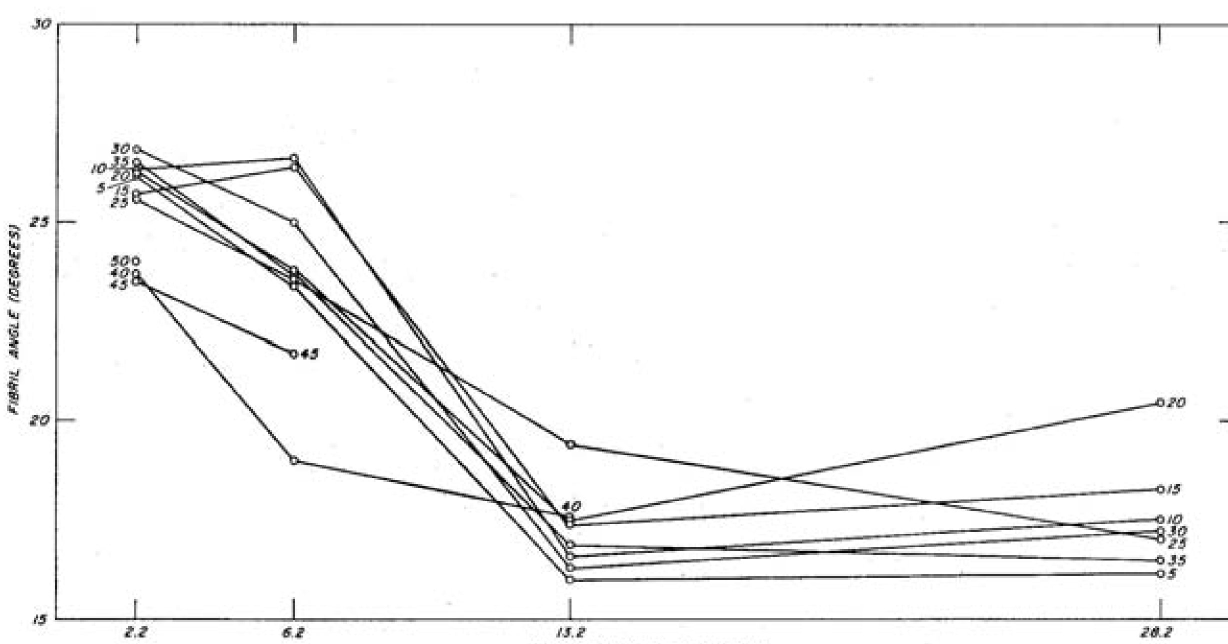

Figure 4.--Average fibril angles of growth rings located at the same number of rings from the pith at four heights. Each point represents the average fibril angle of an entire ring weighted by percentage latewood.

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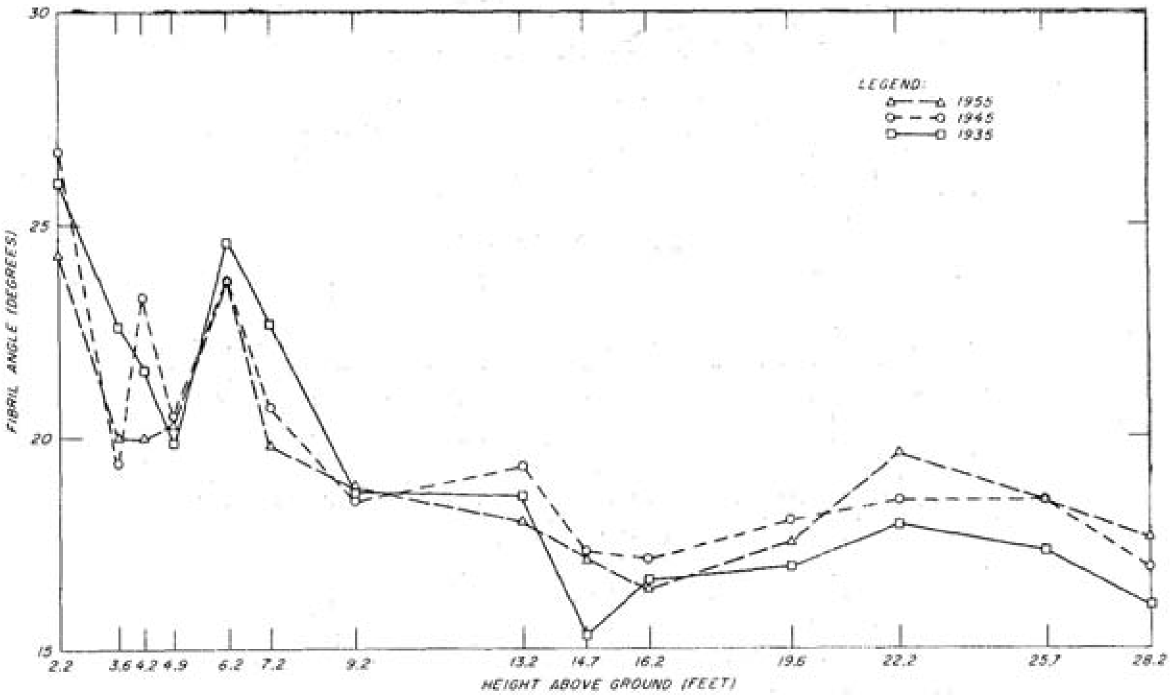

Figure 5.--Average fibril angles of growth rings formed in the same calendar years in consecutive disks from the lower to the upper end of the bole. Each point represents the average fibril angle of an entire ring weighted by percentage latewood. M 134 791

complete oblique sequences presented in figure 5 for fibril angles. It was found that fiber length varied only by 0.1 millimeter within these sequences and that the trends in fiber length were not consistent among sequences. A comparison of the fibril angle and fiber length trends indicated no direct association between these two anatomical features. However, a significant negative correlation was found when fiber length and fibril angle were measured on the same macerated latewood fibers. The measurements were made on 30 each of the largest and of the shortest fibers within the 1955 growth increment sampled at 4.9 and 25.7 feet above the ground.

The regression equations and pertinent statistics are assembled in table 2.

To explore the relationships between fibril angle and the diameter and wall thickness of the fibers at the bottom and top of the tree trunk, three increment sheaths were sampled at 4.9 and 25.7 feet above the ground. The increment sheaths had been formed in 1935, 1945, and 1955. The average measurements of the three anatomical features are given in table 3. For either fiber diameter and fiber lumen diameter in the earlywood or in the latewood, there was no consistent

Table 2.--Relationship between fiber length and fibril angle

Sample location (Height above ground in feet)	Regression equation (Y = fibril angle, X = fiber length)	Number of fibers	Standard deviation from regression	Coefficient of correlation
4.9	Y = 25.9 - 9.11X	30	4.40	-0.41*
25.7	Y = 22.1 - 7.02X	30	3.12	-.56**
Combined heights	Y = 23.01 - 7.15X	60	3.84	-.44**

*Significant at the 5 pct. level.

**Significant at the 1 pct. level.

difference between the averages at the two heights sampled. The difference in average fibril angles between the two heights, therefore, does not seem to be associated with fiber diameter or fiber lumen diameter.

On the other hand, the average thickness of the single fiber wall differs between the two heights. Both the earlywood and latewood fiber walls are thicker at the 25.7 than at the 4.9-foot height. When the data are combined and fibril angle is plotted against wall thickness, a curvilinear relationship is indicated between the two features. It shows that the fibril angle decreased with increasing wall thickness.

Table 3.--Average values of fibril angle and fiber anatomical features in the earlywood and latewood of three increment sheaths sampled at 4.9 and 25.7 feet above the ground

Type of tissue	Year of increment formation	Number of rings from pith	Fibril angle (degrees)	Thickness of single fiber wall (microns)	Fiber lumen diameter (microns)	Fiber diameter (microns)
			4.9 feet above ground			
Earlywood	1935	16	23.2	2.9	10.0	15.8
	1945	26	24.6	3.1	10.8	17.1
	1955	36	21.8	3.0	10.4	16.5
Average			23.2	3.0	10.4	16.4
Latewood	1935	16	19.0	3.2	7.5	14.0
	1945	26	19.1	3.2	8.4	14.7
	1955	36	19.5	3.2	8.2	14.7
Average			19.2	3.2	8.1	14.5
			25.7 feet above ground			
Earlywood	1935	6	19.2	3.3	9.4	16.0
	1945	16	21.8	3.1	10.5	16.8
	1955	26	21.1	3.1	12.3	18.5
Average			20.7	3.2	10.7	17.1
Latewood	1935	6	16.8	3.7	7.3	14.8
	1945	16	16.8	3.2	7.8	14.2
	1955	26	16.0	4.0	7.1	15.0
Average			16.5	3.6	7.4	14.7

CONCLUSIONS

No consistent radial trends were found in the average fibril angles of growth rings taken at five ring intervals from pith to bark and at four heights in the tree. The average fibril angles varied little in size over a span of 50 growth rings. These observations contrast with those made of loblolly pine where the average fibril angles of consecutive rings decrease consistently and markedly from pith to bark.–

In the vertical sequence, the average fibril angles of comparable growth rings were larger at the base of the ash trunk than the fibril angles at any height above 9 feet. This agrees with observations made of loblolly pine, The average fibril angles in the earlywood and in the latewood followed the same trends, except that the fibril angles of the earlywood were always larger.

Comparisons of trends in average fibril angle with trends of ring width, and the averages of fiber length, fiber diameter, and fiber wall thickness indicated that only fiber wall thickness may be associated with the fibril angle. However, a significant negative correlation was found between fiber length and fibril angle when both features were measured on the same fibers.

The larger fibril angles at the base of the trunk in comparison with the top of the trunk may be associated with fiber wall thickness, since earlywood and latewood fibers at the base level had thinner walls than those at the higher level in the trunk.

The results of this study confirm Pillow's observation that average fibril angle in white ash decreases at heights above 8 to 12 feet. The results go further by showing no age effect in the radial trends of fibril angle and including measurements of fiber dimensions and associations between fibril angles and these dimensions.

This study provides information for the selection of ash for critical applications since fibril angle and stiffness are so closely related.