Carya - General - 44.

BULLETIN 480 MARCH, 1960

Tension Wood and Its Relation to Splitting in Hickory

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ACKNOWLEDGMENT

This study has been under way for a period of twelve years as a cooperative effort of the South Carolina Agricultural Experiment Station and the U. S. Department of Agriculture through the Southeastern Forest Experiment Station and the Forest Products Laboratory. Special recognition is given to M. Y. Pillow, Ralph Marts, and Ben Paul, of the Forest Products Laboratory, who have assisted at various times in field work and laboratory analysis. Industrial assistance was most helpful in the collection of field data, especially the fine help of the Poinsett Lumber and Manufacturing Company, Pickens, South Carolina, who participated in most of the field work.

Tension Wood and Its Relation to Splitting in Hickory

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INTRODUCTION

The efficient utilization of hickory (*Carya* spp.), as well as other commercially important hardwoods of the United States, has been impaired because of the severe end splitting which occurs in the logs. In many cases this splitting is so severe that it is impossible to chuck the log or bolt in a lathe, or to place the log on a saw carriage to produce lumber, (figure 1).

Splits of the type shown in figure 1, and many of lesser magnitude, appear first in the butt end of the tree immediately upon felling. As logs are bucked splits continue to develop in the ends of the logs. When a tree is being felled or bucked into logs, the sudden opening of these splits produces audible cracking or popping sounds.

Splitting is not confined to hickory and other woods of the United States. It is a problem which has faced foresters all over the world. European foresters have observed similar splitting in European beech (*Fagus sylvatica* L.), and the Australians observed it in eucalyptus (*Eucalyptus* spp.)

The phenomenon of end splitting in logs has been a topic of research over the past 40 years. Research indicates that these splits are the result of internal stresses that develop in a tree during growth, and that the splitting is in no way associated with seasoning stresses which develop during drying. Although the apparent cause of splitting is attributed to internal stresses developed in the tree, the mechanism by which these stresses develop has not been established. Several hypotheses dealing with this phenomenon have been proposed by various investigators.

In 1928, Martley observed changes in length of a plank cut through the center of a log, and he attempted to explain the dimensional changes by stresses which might be imposed from tree weight. He reasoned that as the tree increased in diameter growth the wood at the center of the tree would be subjected to a continually increasing compression load. He calculated pressures of 120 pounds per square inch at the central and lower parts of a large oak tree, and questioned that these pressures would ever reach a magnitude of 300 pounds per square inch. He concluded that it would be unlikely for stresses of such magnitude to have any measurable effect on the longitudinal dimensional change observed.

Figure 1.—Severe End Splitting in a Hickory Log.

Koehler (1933) made radial sawcuts into green discs, from the bark to the pith, and observed a contraction of the wood near the periphery of the disc and a widening of the sawcut near the center of the disc. From these observations he deduced that the outer part of a tree was in compression tangentially, and that this compressive force either produced or was the result of a radial tension stress. He hypothesized that the shakes and rift cracks found in trees were the result of transverse compression and tension stresses developed during growth, and he suggested three possible hypotheses to explain the development of these stresses:

(1) Circumferential growth greater than radial growth. This hypothesis suggests that as the tree grows in diameter, the circumferential growth is not exactly pi times the diameter growth. If the circumferential growth is greater than pi times the diameter growth, a circumferential compression stress accompanied by a radial tension stress may result and possibly cause an internal check to form.

(2) Reduced turgidity of the cells in the older tissue. This suggests that as the cells die and lose their turgidity, they decrease in size and thus set up tension stress in the heartwood.

(3) Chemical shrinkage of the older wood. Molecular changes which take place when sapwood turns to heartwood would cause contraction of the tissue and set up stresses.

The first quantitative measurements of longitudinal strain were made by Jacobs in 1938. He established the existence of a radial strain gradient from the bark to the pith around the entire tree. The pattern of this longitudinal strain gradient shows a zone of tension at the periphery of the tree and an interior zone of compression culminating at the pith.

Jacobs theorized that the outer layers of newly formed cells were laid down in a state of tension, and that the occurrence of these tension forces in the periphery zone gave rise to the cumulative compression force on the central part of the tree. To explain this zone of tension, Jacobs suggested that the newly formed cells had a tendency to shrink as they developed and this tendency to shrink was restricted by the interior cells to which they are attached. In 1945 Jacobs abandoned his first hypothesis on tension stress development in favor of the sap stream tension hypothesis. This hypothesis suggests that sap stream tension plays an important role in the development of growth stresses.

Boyd (1950a) confirmed the existence of the longitudinal strain pattern established by Jacobs. He pointed out that dimension changes, which may be observed when a green log is crosscut, are not caused by longitudinal stress alone, but are also related to longitudinal strain energy movements in the log. Calculated longitudinal stresses indicated values of about 3,000 pounds per square inch, while transverse stresses were of the order of 300 pounds per square inch. The stress values calculated by Jacobs were of similar magnitude. In subsequent work on stresses, Boyd (1950b) concluded that splitting was the result of the disturbance of the internal stresses when a tree was felled and bucked into logs. In standing trees, critical ring tension in the vicinity of the pith was the most important factor, but in felled trees failure was due primarily to conversion of longitudinal strain energy into transverse stresses. Boyd (1950c) reviewed the various hypotheses proposed regarding stress development and suggested a hypothesis similar to Jacobs' in 1938; that is, that stresses originate in the newly differentiated peripheral cells. This theory explains the formation of internal stress by the tendency of cells to shrink longitudinally and increase in cross section shortly after differentiation. The stresses that occur may result from the resistance to such shrinkage set up by the mature cells in the tree. Reason for the shrinking of these new cells is still not apparent.

Münch (1938), as reported by Boyd (1950c), suggested that the cell wall shortening mechanism was the reason for the rather high longitudinal stresses associated with tension wood, and Jacobs in the same year showed that tension wood displayed greater stresses than normal wood. Münch (1938), as stated by Clark (1939), suggested that the cell shortening is due to irreversible swelling of the fibrils when they are formed. Clark (1939) commented that this condition may prevail in normal wood and that tension wood may be an extreme condition of cell wall development.

In 1953-1954 Mayer-Wegelin and Mammen investigated a method for preventing splitting. This method consisted of making bore holes into the middle of the cross section of a log. This treatment did not reduce the formation of tension splits.

In 1948 the U. S. Forest Service,[1] in cooperation with the Clemson Agricultural College, Clemson, South Carolina, and the Poinsett Lumber and Manufacturing Company, Pickens, South Carolina, investigated methods of treating hickory trees to reduce or alleviate the internal stresses. The treatments investigated were:

(1) *Girdling*—trees were girdled to a depth of at least 1 inch around the entire tree and then they were left standing for 2½ months.

(2) *Leaf seasoning*—after trees were selected they were felled and permitted to season for 3 weeks (until foliage was wilted) with the leaves left on the fallen tree.

(3) *Controls*—no treatment; trees were cut into logs immediately after felling.

Leaf seasoning appeared to have a very slight influence on the degree of splitting which occurred in this study; however, no positive correlation between this factor and splitting could be definitely established. Girdling was ineffective in reducing the degree of splitting. There was no apparent difference in the degree of spitting between trees in diameter classes below 20 inches; however, splitting tended to be more severe in diameter classes above 20 inches. There appeared to be no relationship between the degree of splitting and species. In addition to the above observation, data were collected on specific gravity, moisture content, heartwood-sapwood ratio, rate of growth, precipitation, and temperature, A multiple regression analysis of these factors yielded no significant correlation between them and splitting.

In 1949, a second study was made to observe whether or not splitting was associated with season of the year. No significant relationship was observed between seasons and degree of splitting. At present there is no known treatment which can be used on trees or logs to prevent tension splits in the ends of logs.

[1] Smith, Walton R. Splitting in Hickory. 1949. (Unpublished office report, Southeastern Forest Experiment Station.)

TENSION WOOD IN SPLIT AND NON-SPLIT HICKORY

If we accept the hypothesis presented earlier that stresses in trees are caused by the growth mechanism, we can assume that all trees are under some degree of stress. However, because all trees do not split severely or to the same extent, it is reasonable to assume that the magnitude of the forces developed within trees may vary over a considerable range. It would follow then that some factor within the growth mechanism has a marked influence on the magnitude of the stress developed within trees. A factor which can be associated with the growth mechanism and which is believed by some investigators to be of some importance in stress development is the formation of tension wood. Tension wood is generally defined as an abnormal type of wood found on the upper side of branches and leaning trees and is characterized by the presence of gelatinous fibers. Jacobs in 1938 showed that tension wood develops greater tensions than normal wood. Mayer-Wegelin and Mammen (1953-1954) observed variations in the distribution of tension wood between severely split European beech and those less severely split. In the severely split trees, they noted that tension wood occurred in wide strips which included a rather large part of the circumference of the stem. The less severely split trees had the tension wood concentrated at the core of the tree near the pith.

In 1952 an exploratory study[2] on 3 severely split hickory trees and 3 non-splitters showed that the severe splitters contained a relative high proportion of gelatinous fibers and the non-splitters contained no gelatinous fibers.

In view of these findings, two studies were made in cooperation with the Clemson Agricultural College on the relationship of tension wood and splitting in hickory. The first study was started in 1955. The objective of this study was to determine whether or not the relative amounts of tension wood developed in hickory trees varied significantly between severely split trees and non-split trees.

The material for study consisted of 2-inch discs cut from the butt logs of 37 different trees. The discs were cut from logs at three veneer mills located in western North Carolina, eastern Tennessee, and western South Carolina, and consequently no tree history is available. Of the 37 samples collected, 19 were classified as severe splitters and 18 as non-splitters. Classification into splitter and non-splitter groups was based on the degree of splitting observed at the butt and top ends of each log. Severely split logs generally had at least one split which extended from the pith to the bark. Non-splitters contained none to very small star splits at their center. Figure 2 shows a typical splitter and non-splitter used in the study.

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[2]Unpublished study made at the Forest Products Laboratory, Madison, Wisconsin.

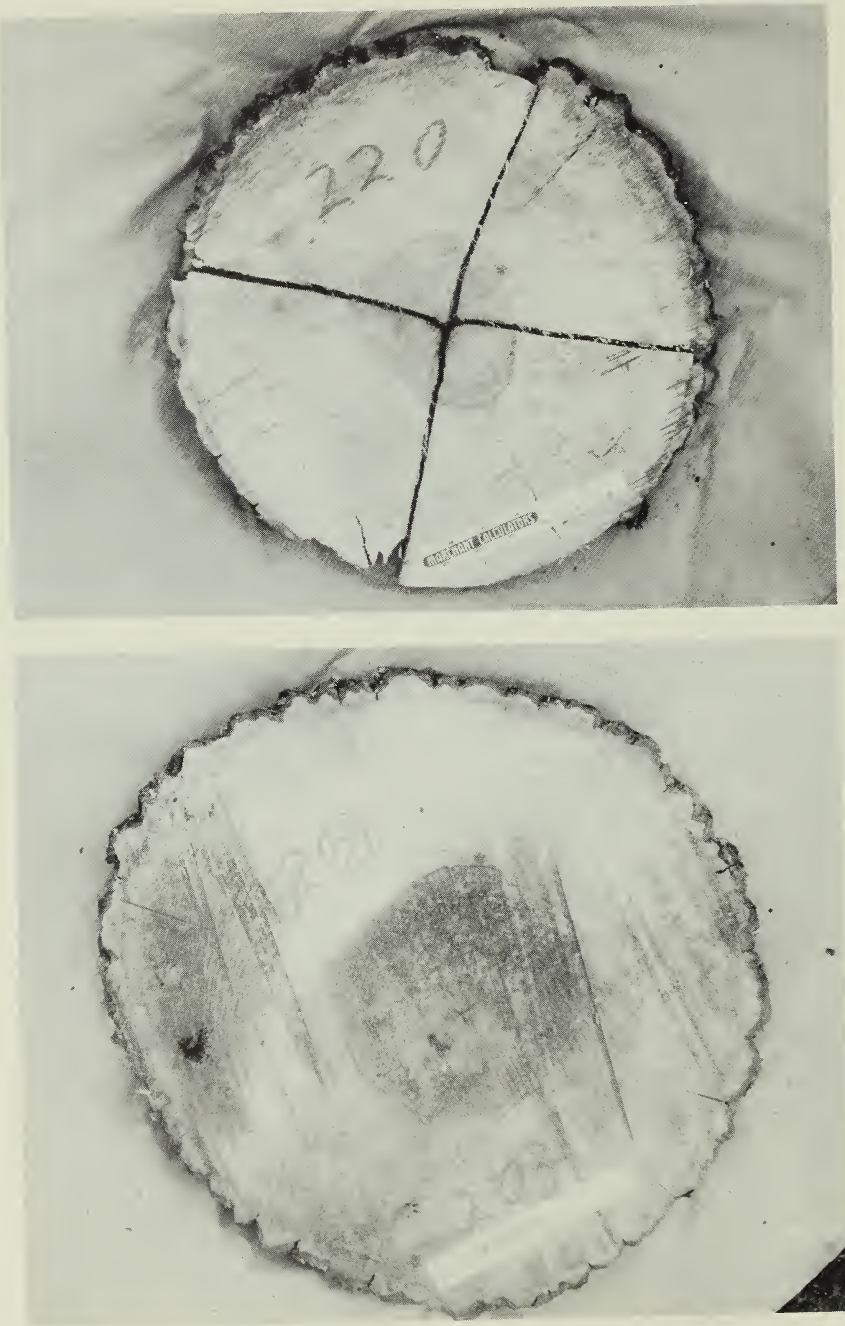


Figure 2.—Typical Split and Non-Split Hickory Under Study.

Table 1.—Percent of area occupied by gelatinous fibers on four radii of severely split and non-split hickory trees

SEVERE SPLITTERS

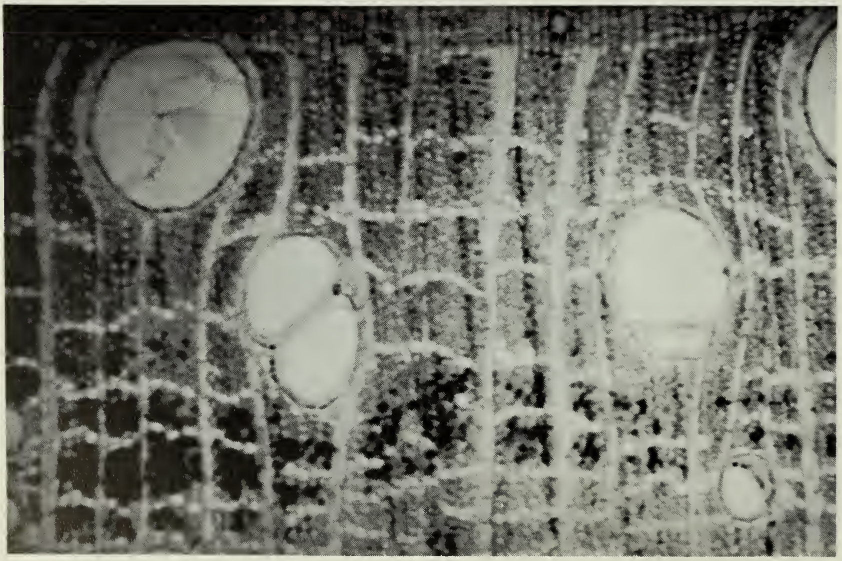
Tree number	Relative amount of gelatinous fibers				
	Radius 1	Radius 2	Radius 3	Radius 4	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
1	5	0	0	1	1.5
2	35	10	35	2	20.5
3	3	0	0	0	0.75
4	0	40	0	2	10.5
5	1	1	55	0	14.25
6	3	4	0	70	19.25
7	12	12	0	12	9.00
8	20	50	5	8	20.75
9	3	2	40	18	15.75
10	65	70	20	60	53.75
11	1	0	0	65	16.50
12	30	70	50	10	40.00
13	15	25	8	5	13.25
14	15	65	2	0	20.50
15	2	15	70	20	26.75
16	0	0	3	2	1.25
17	40	0	0	15	13.75
18	30	50	50	35	41.25
19	40	15	50	70	43.75
Average					20.16

NON-SPLITTERS

Tree number	Radius 1	Radius 2	Radius 3	Radius 4	Average
21	0	0	40	0	10.00
22	5	0	1	0	1.50
23	1	75	10	0	21.50
24	8	0	0	0	2.00
25	0	0	0	0	0.00
26	0	7	45	3	13.75
27	60	0	0	70	32.50
28	0	0	0	12	3.00
29	0	25	20	0	11.25
30	0	0	2	45	11.75
31	0	0	0	15	3.75
32	10	0	0	70	20.00
33	0	0	0	0	0.00
34	4	0	12	25	10.25
35	0	20	0	0	5.00
36	0	0	20	0	5.00
37	0	3	25	0	7.00
38	0	0	0	10	2.50
Average					8.93

Each disc was sampled randomly on four radii. Since no information was available regarding tree lean, the first radius was arbitrarily selected. The other three radii were installed at 90-degree intervals intersecting at the pith. A one-half inch sample block randomly selected was removed from each radius. These blocks were boiled in distilled water and stored in 70 percent ethyl alcohol until sectioned. Sections 15 microns thick were cut from each block on a sliding microtome and stained with chloriodide of zinc, as described by Pillow (1950). Immediately after staining, an estimate of the area occupied by gelatinous fibers was made with the aid of a stereoscopic microscope (75x). The estimated area was expressed in percent of the total area of the block. Values ranged from 0 percent to 75 percent. Values from 1 percent to 20 percent indicated the occurrence of relatively few isolated fibers or groups of fibers located in one or perhaps several rings; figure 3a shows this type of distribution. In the 20 percent to 50 percent level, the fibers occurred in bands of varying widths, (figure 3b). Above 50 percent the entire summerwood area generally contained gelatinous fibers, (figure 3c).

Table 1 shows the percent of area occupied by gelatinous fibers in each of the sample blocks analyzed for each of the trees. In the severe splitter group, gelatinous fibers were found to some degree in all of the trees analyzed. Forty-eight percent of the trees in this group had gelatinous fibers on all 4 radii, 21 percent on 3 radii, 26 percent on 2 radii, and 5 percent on 1 radius. In the case of the nonsplitter group 11 percent of the trees showed no gelatinous fibers.



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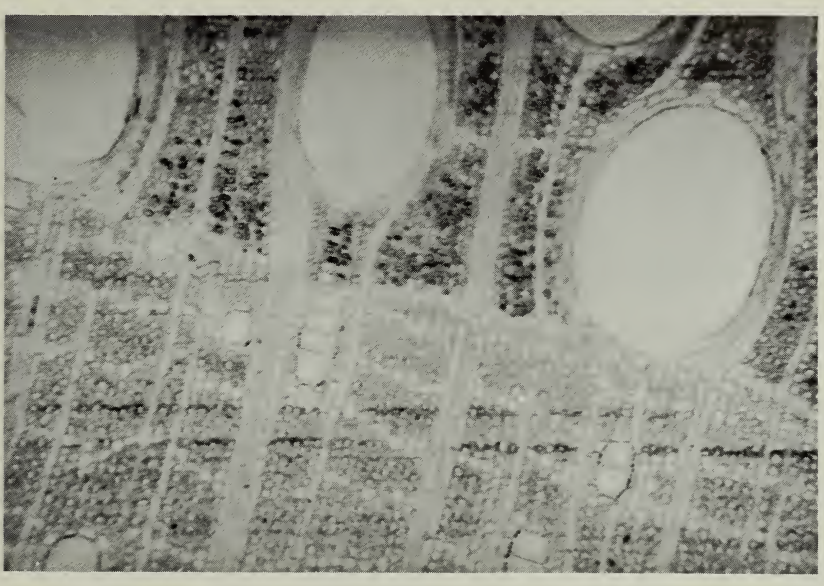

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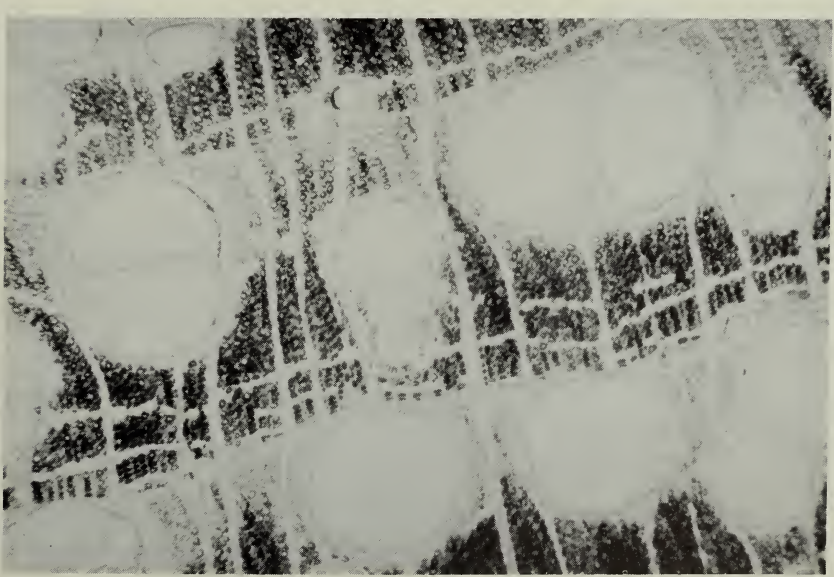

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Figure 3.—Grouping patterns of gelatinous fibers found in hickory. (a) Isolated individual fibers or groups of fibers, (b) bands of fibers within annual rings, (c) solid masses of fibers within annual rings.

None of the trees in the non-splitter group showed gelatinous fibers on all 4 radii, while only 11 percent had gelatinous fibers on 3 radii. Seventy-eight percent or the remainder of the trees in this group showed gelatinous fibers on 1 or 2 radii (39 percent of the trees had gelatinous fibers on 1 radius and 39 percent on 2 radii). If we compare the relative percentage of trees in each group having gelatinous fibers on 3 and 4 radii we find 69 percent in the splitter group and only 11 percent in the non-splitter group. This suggests the presence of a rather broad distribution of gelatinous fiber tissue in the splitter group.

The data shown in table 1 were transformed by $\sqrt{X + 0.5}$ and subjected to analysis of variance to establish the significance of the apparent difference in relative amounts of gelatinous fibers which appeared between the split and non-split groups. Results of this analysis are shown in the following analysis of variance tabulation.

Analysis of Variance

Source	D.F.	SS.	M.S.
Between split and non-split groups	1	367.74	367.74
Within groups	35	1226.05	35.03
Total	36	1593.79	

$F = 367.74/35.03 = 10.50^{**}$
**Significant at the one percent confidence level.

The F-ratio calculated in the analysis shows high significance, indicating that the difference in the ocular estimates of area occupied by gelatinous fibers is a true difference. This evidence, together with the trends shown by the data in table 1, that is, the broader distribution of gelatinous fibers (larger number of radii containing gelatinous fibers) and the obviously larger number of gelatinous fibers in the split trees, indicate very strongly that severely split trees have a greater proportion of gelatinous fiber tissue than non-split trees.

In view of Jacobs' work in 1938 regarding the development of higher tensions in tension wood than in normal wood, and the added evidence that severely split trees show greater amounts of tension wood than non-split trees, it is reasonable to conclude that gelatinous fibers play an important role in the degree of stress which develops in hickory trees and in the severe splitting which occurs.

DISTRIBUTION PATTERN OF TENSION WOOD IN SPLIT AND NON-SPLIT HICKORY TREES

The data of the study suggested the existence of different tension wood distribution patterns in severely split hickory and non-split hickory. Also the work of Mayer-Wegelin and Mammen (1953-1954) indicated variations in distribution of tension wood between severely split and less severely split European beech. In view of this, a second study was made to observe the distribution pattern of tension wood in severely split trees and non-split trees.

Three pignut hickory (*Carya glabra* (Mill.) Sweet) trees were selected: (1) a straight tree (1 degree lean) which split severely, (2) a leaning tree (6 degrees lean) which had little to no splitting, and (3) a straight tree (1 degree lean) which had little to no splitting. An outline of the physical measurements of these trees is listed in table 2.

Table 2.—Physical data of pignut hickory trees used in study of tension wood distribution

Tree number	Splitting character	Age	D.B.H.	Total height	Merchantable height	Lean	
						Amount	Direction
		Years	*Inches*	*Feet*	*Feet*	*Degrees*	
1 ----	Splitter	161	23.8	85	42	1	S70° W
2 ----	Non-splitter	201	12.9	60	30	6	South
3 ----	Non-splitter	131	15.0	68	34	1	North

Before felling, the north side of each tree was marked in order to facilitate proper orientation of the discs after they were cut from the tree. Tree lean was determined at breast height with a plumb-bob device developed by the U. S. Forest Products Laboratory. Beginning at the stump, 2-inch discs were cut at approximately every 8-foot interval up the tree to about the merchantable length of each tree. Immediately after bucking at each 8-foot level, each split which occurred was measured, and its location with respect to the north side of the tree noted. Table 3 lists the number of splits occurring at each 8-foot level and the total length in inches of all splits found at the respective levels immediately after bucking. The length of individual splits from tree 1 (severe splitter) ranged between 1.6

inches and 10 inches, while trees 2 and 3 had splits ranging from) 0.3 inch to 2.6 inches in length.

To examine the distribution pattern of tension wood in these trees, each disc was sampled on four one-half inch radial strips laid out at 90 degrees with respect to one another and intersecting at the pith. The strips were labeled 1, 3, 5, 7, representing north, east, south and west, respectively. Each radial strip was dissected into one-half-inch blocks from the pith to bark and the relative amount of gelatinous fibers was noted within each block. The same techniques used in the previous study for cutting, staining, and determining relative amounts of gelatinous fibers were also used in this study. In addition, the occurrence of gelatinous fibers within specific individual annual rings was also noted.

Table 3.—Number of splits and total split length occurring at various height levels in 3 pignut hickory trees studied

TREE 1 (SEVERE SPLITTER, 1 DEGREE LEAN)

Height level (feet)	Disc D.I.B.	Splits	Range of split length	Cumulative split length
	Inches	*Number*	*Inches*	*Inches*
2.8 (stump)	24.0	3	3.0 - 10.0	21.7
12.1	20.0	3	2.0 - 8.0	19.1
21.0	19.0	3	9.0 - 9.5	26.6
29.9	19.0	3	5.0 - 9.5	21.4
38.8	17.5	5	2.5 - 8.0	26.6
47.7	15.0	4	1.5 - 6.0	17.0

TREE 2 (NON-SPLITTER, 6 DEGREES LEAN)

Height level (feet)	Disc D.I.B.	Splits	Range of split length	Cumulative split length
1.2 (stump)	13.5	3	1.5 - 2.5	4.8
10.1	9.9	3	0.7 - 1.0	2.0
19.0	9.6	2	0.7 - 1.6	1.3
27.9	7.5	2	0.3 - 0.7	1.0
37.8	7.5	0	0	0.0

TREE 3 (NON-SPLITTER, 1 DEGREE LEAN)

Height level (feet)	Disc D.I.B.	Splits	Range of split length	Cumulative split length
2.7 (stump)	15.9	2	0.7 - 1.0	1.7
10.0	13.0	2	1.5 - 1.6	3.1
18.0	11.8	2	2.5 - 2.6	5.1

The largest amounts of gelatinous fibers were found in the straight, severely split tree. Table 4 shows the average relative amount of gelatinous fiber found on each radius and at each height level in each tree examined. The severely split tree shows values representing relatively high amounts of gelatinous fibers on each radius at each height level, whereas the leaning tree indicated relatively high amounts of gelatinous fibers on two radii which were associated with lean. All 4 radii of the straight, non-split tree showed either very small amounts or no gelatinous fibers at all, (table 4).

Table 4.—Relative amount of gelatinous fibers on 4 radii of severely split and non-split hickory trees

TREE 1 (SPLITTER WITH 1 DEGREE LEAN)

Disc number	Height above ground	Average relative amount of gelatinous fibers				
		North Radius (1)	South Radius (3)	East Radius (5)	West Radius (7)	Average
	Feet	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	2.8	25	35	33	27	30
2	12.1	45	43	38	34	40
3	21.0	32	35	44	31	35
4	29.9	32	49	20	35	34
5	38.8	33	51	39	28	37
6	47.7	33	51	15	23	30
Average		33	43	32	29	34

TREE 2 (NON-SPLITTER WITH 6 DEGREES LEAN)

Disc number	Height above ground	North Radius (1)	South Radius (3)	East Radius (5)	West Radius (7)	Average
1	1.2	15	2	0	1	5
2	10.1	36	22	5	20	20
3	19.0	22	15	6	15	15
4	27.9	13	31	9	1	12
5	37.8	49	52	4	8	30
Average		25	22	5	9	16

TREE 3 (NON-SPLITTER WITH 1 DEGREE LEAN)

Disc number	Height above ground	North Radius (1)	South Radius (3)	East Radius (5)	West Radius (7)	Average
1	2.7	1	2	4	5	3
2	10.0	1	1	10	13	6
3	18.0	0	12	8	4	5
Average		1	4	7	7	5

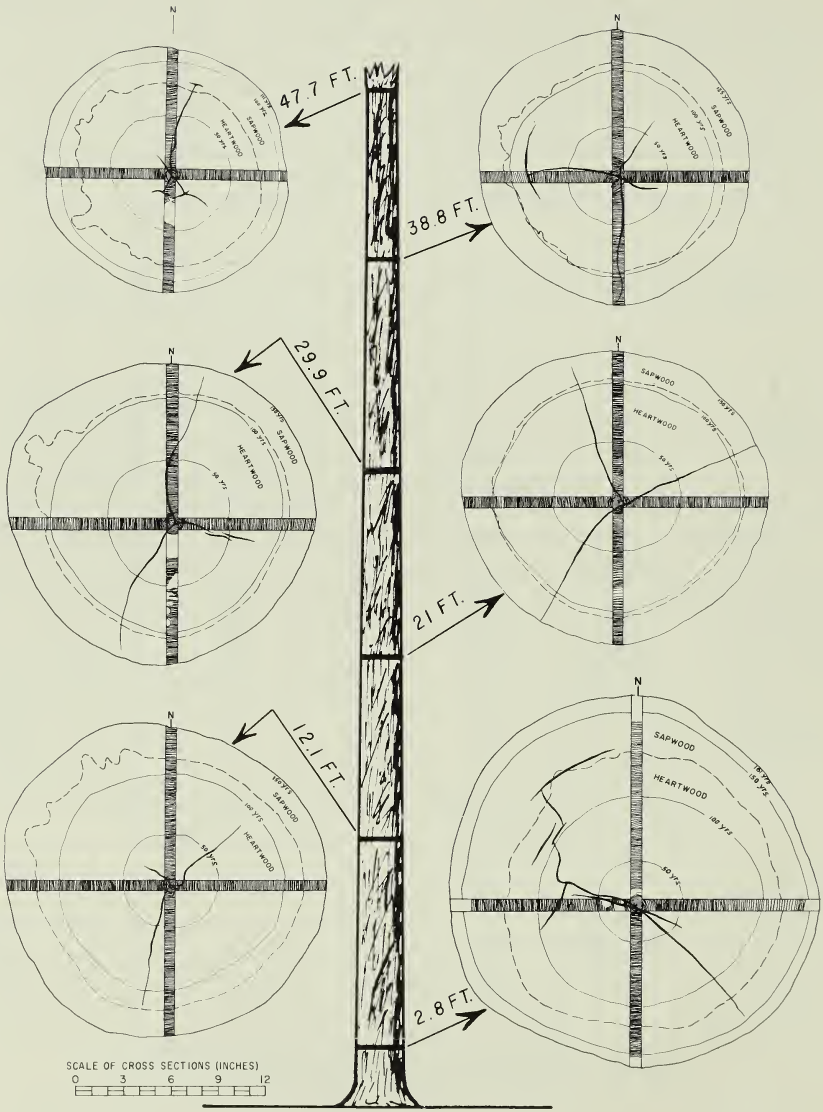

Figure 4.—Distribution Pattern of Tension Wood on Four Radii at Different Height Levels in a Severely Split, Straight Tree.

Figures 4, 5, and 6 show the distribution patterns of the four radii examined at each height for each tree. The fine lines within each radial strip denote the occurrence of gelatinous fibers in the individual annual rings. In the severely split tree (figure 4) 86 to 100 percent of the annual rings along each radius contained gelatinous fibers to some degree. In the 2 non-split trees, the percentage of annual rings containing gelatinous fibers varied considerably at all height levels in the tree and ranged between 0 to 100 percent. Tree 2 (leaning non-splitter, figure 5) shows the more or less typical distribution pattern generally observed in leaning trees where the gelatinous fibers are concentrated on the upper side of the lean. This tree leaned 6 degrees to the south; the gelatinous fiber concentration can be noted on the north radius. Tree 3 (straight, non-split tree, figure 6) had a pattern similar to that found in the leaning tree indicating that it may at one time have had more than one degree of lean displayed at the time of cutting.

The patterns of distribution observed in these trees indicate that gelatinous fibers distribution is different in split and non-split trees. In the case of severely split trees, the pattern disclosed suggests a rather uniform distribution over the entire cross sectional area throughout the trees, whereas in the non-split trees gelatinous fibers, when present in relatively high concentrations, are confined generally to a specific area on the cross section.

Terrell (1952) showed that gelatinous fibers may be found in any portion of the cross section of leaning trees; however, their greatest concentration was on the upper side of the lean. Kaiser and Pillow (1950) showed that the concentration of gelatinous fibers on the upper side of leaning trees at breast height was associated with the degree of lean. The findings of the second phase of this study agree in part with those pointed out by other researchers; that is, the occurrence and concentration of gelatinous fibers on the upper side of leaning trees. However, one point which this study has disclosed which does not coincide with the work of others is the occurrence of relatively large amounts of gelatinous fibers over the entire cross section and at various height levels in a straight tree. The occurrence of gelatinous fibers in branches and leaning trees is generally explained as a modification of normal cells in response to a gravitational stimulus. In a straight tree, however, there would be no gravitational force acting on the side of the tree as in the case of leaning trees, and it is, therefore, difficult to apply the theory of gravitational stimulus. This suggests that another mechanism or combination of mechanisms may be involved in gelatinous fiber formation.

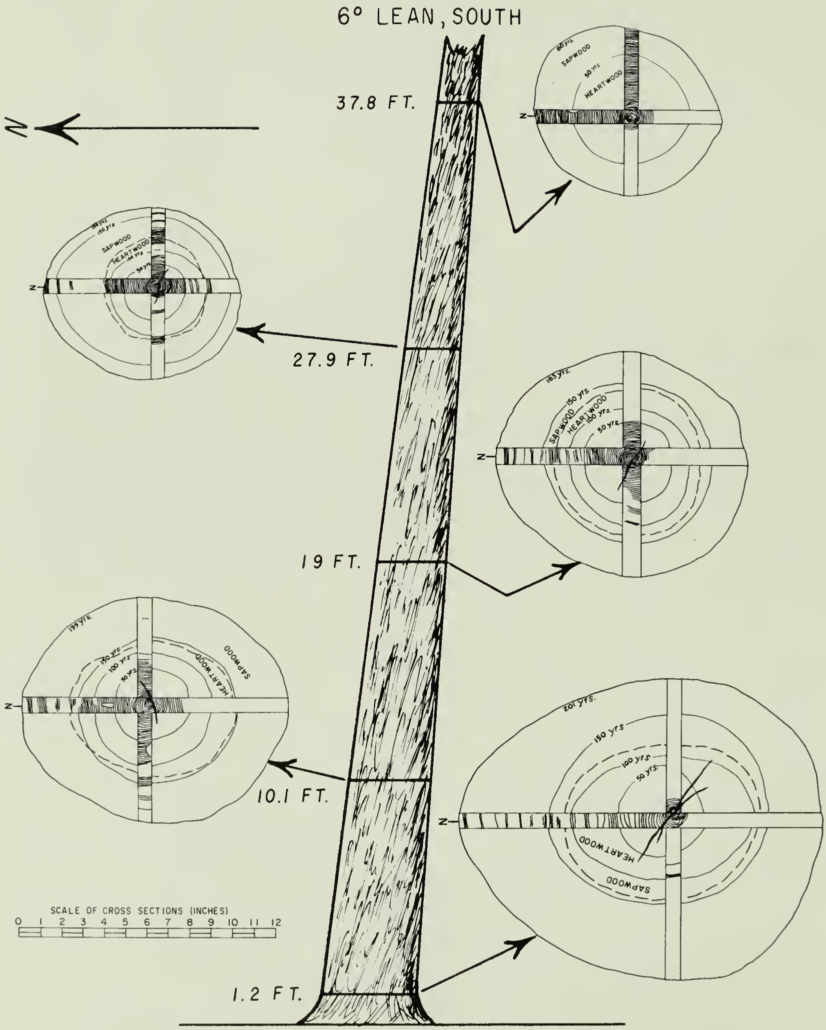

Figure 5.–Distribution Pattern of Tension Wood on Four Radii at Different Levels in a Leaning, Non-Split Tree.

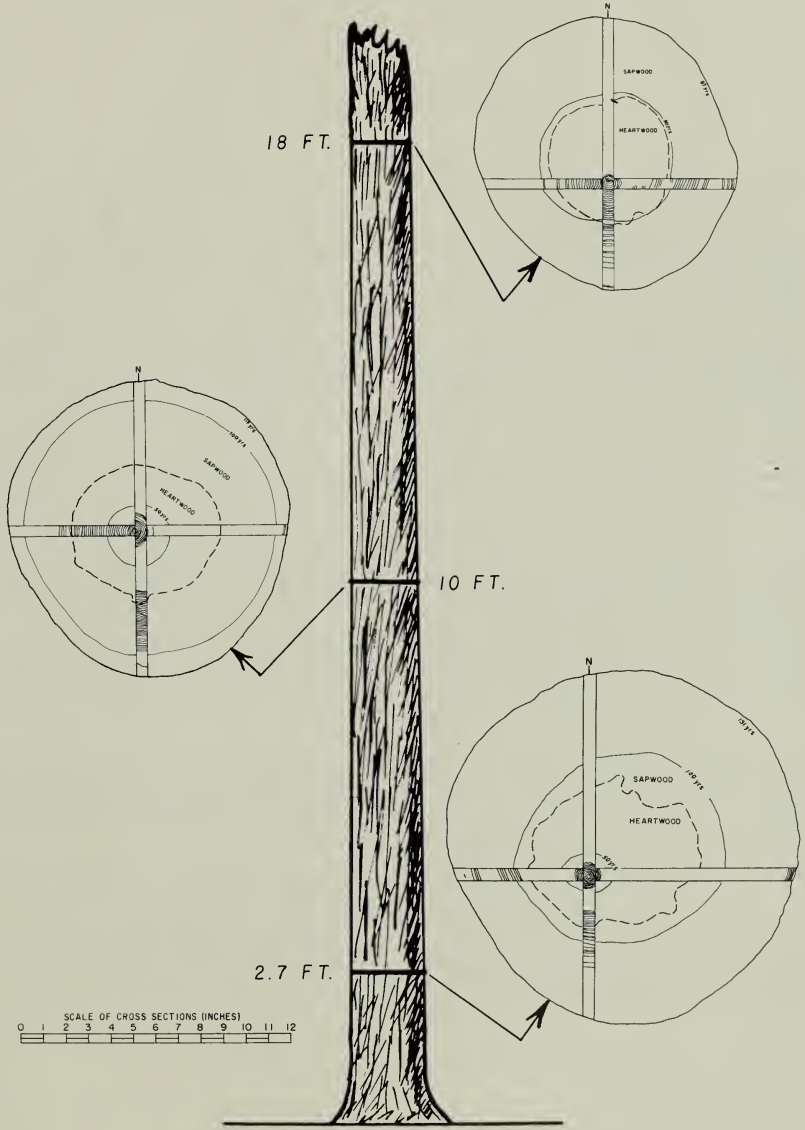

Figure 6.—Distribution Pattern of Tension Wood on Four Radii at Different Height Levels in a Straight, Non-Split Tree.

SUMMARY

The first study on tension wood and its relation to splitting showed that hickory trees which split severely contained relatively greater amounts of gelatinous fibers than trees which did not split. The differences in the relative amount of gelatinous fibers between severely split and non-split trees was statistically significant, indicating that the difference which occurred between the splitter and non-splitter groups was a true difference. This study also suggested that the distribution pattern of tension wood in split trees might be somewhat different from that encountered in non-split trees. A second study, undertaken to elaborate on the distribution pattern of tension wood in split and non-split hickory, revealed that gelatinous fibers in relatively large amounts can be found over the entire cross section of a straight, severely split tree. The four radii examined at each 8-foot interval up to the merchantable height showed gelatinous fibers in almost all annual rings on all four radii, at all levels except the stump. The non-split trees (one which leaned and one which did not lean) showed the typical distribution one expects to find in a tree which has a lean; that is, a concentration of gelatinous fibers on the upper side of the lean.

Jacobs (1938) showed that greater stresses are developed in tension wood than in normal wood. If this is true, then it is reasonable to assume that greater amounts of tension wood would tend to produce greater internal stresses.

It is, therefore, reasonable to conclude that the occurrence of relatively large amounts of gelatinous fibers, distributed relatively uniformly over the entire cross section of the tree, contribute much to the development of internal stresses which are of sufficient magnitude to cause severe splitting.

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