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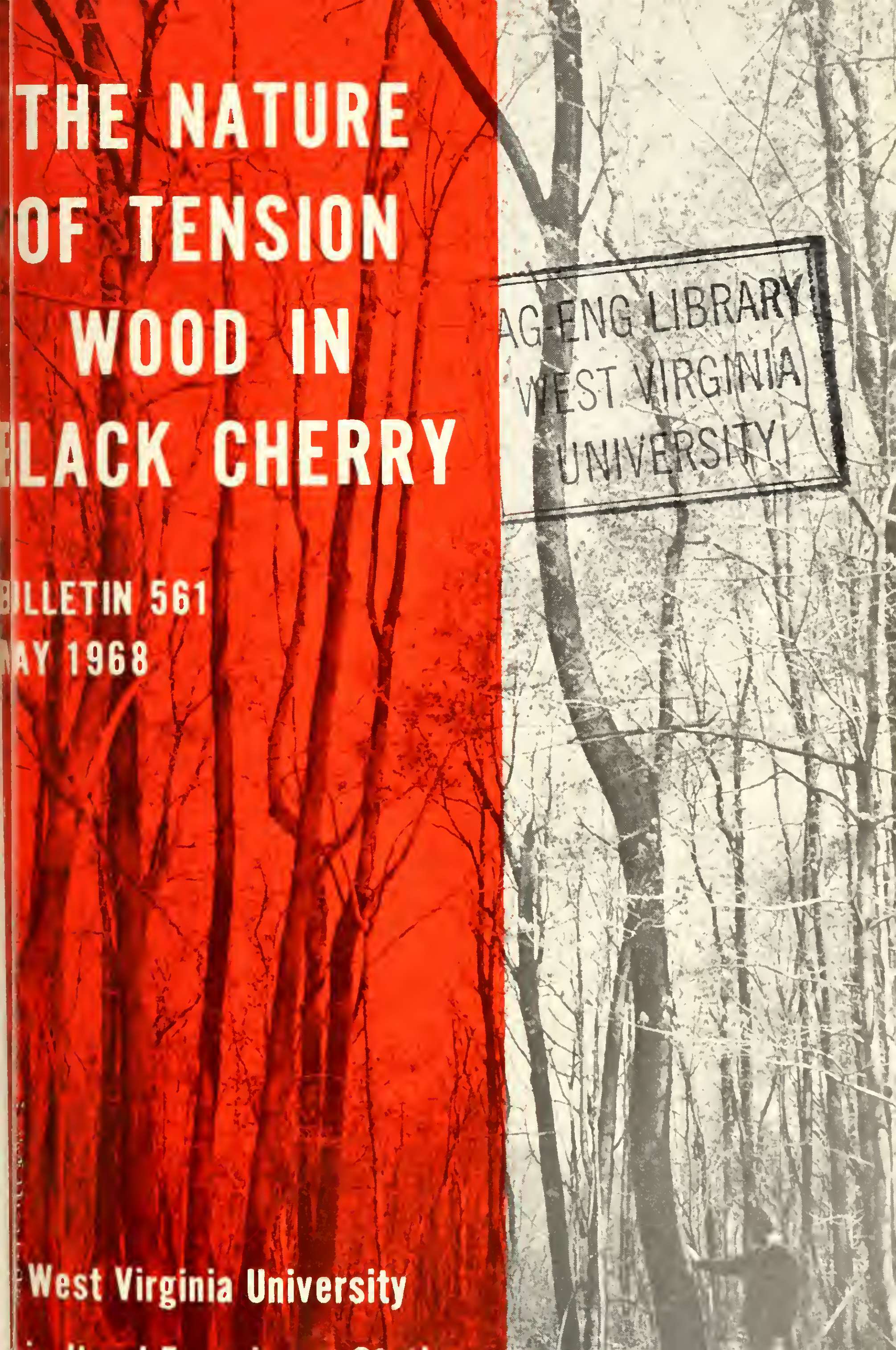

THE NATURE OF TENSION WOOD IN LACK CHERRY

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The Nature of Tension Wood in Black Cherry

C. B. KOCH, T. F. LI and J. R. HAMILTON

Introduction

BLACK CHERRY (*Prunus serotina* Ehrh.) is one of the most valuable species of the Appalachian hardwood forests. Even the common grades of cherry lumber command prices comparable to, or in excess of, those paid for the better grades of many other species. The wood is widely used in furniture manufacture because of its attractive figure and color. It is easy to season and, once dried, it exhibits considerable dimensional stability. For this reason, it is in considerable demand for printer's blocks, patterns, scientific instruments and other products.

As a result of the large demand for black cherry and past harvesting practices, much of the present volume of this species consists of trees of poor stem form which have originated mainly from sprouts. Such trees frequently exhibit considerable lean as well as excessive crook and sweep. It is significant, however, that many products for which cherry is particularly desirable do not require clear boards of large size. Thus trees with poorly formed boles may have considerable value if properly utilized, provided that the quality of the wood is satisfactory.

Crooked and leaning trees may contain abnormal wood which, in hardwoods, is termed tension wood. The occurrence of tension wood is often sporadic and unpredictable, but it is characteristically found on the upper sides of leaning stems and branches. It is generally associated with eccentricity of pith and the presence of fibers with unusual characteristics. When present, it constitutes a defect because it is difficult to machine smoothly and exhibits excessive longitudinal shrinkage.

This study was undertaken to assess the significance of tension wood and its effect on the utilization of poorly formed black cherry trees.

Literature Review

Classically, the term tension wood has been applied to wood located in the upper part of leaning stems and branches in hardwood trees. Contemporary usage of the term implies the presence of fibers which differ physically and chemically from normal fibers with little regard to specific location. These abnormal fibers are termed gelatinous fibers because of the existence of a greatly thickened cell wall

It is now generally accepted that tension wood is formed in connection with movements of orientation in woody plants (23). Associated with this phenomenon are significant changes in the anatomical, physical, and chemical characteristics of the wood (1, 5, 14, 20).

Macroscopic Features—Tension wood exhibits some characteristics which are readily visible without magnification. It is usually more lustrous than normal wood and exhibits a silvery sheen (2, 5), due, probably, to a higher proportion of cellulose and more perfect molecular alignment than occurs in normal wood. An abundance of projecting fibers, reportedly caused by a tearing rather than a cutting action during machining, frequently produces a wooly appearance in machined lumber (12).

The pith in leaning stems and branches is frequently displaced toward the lower side (4). An eccentric pith is not, however, universally present and is in fact one of the least reliable indicators of the presence of tension wood (10, 12, 18).

Anatomical Features—There are several anatomical differences between tension wood and normal wood. The most obvious abnormality in many species is the presence of fibers which have a markedly thickened wall, which, at times, replaces one layer of the normal wall or at other times occurs in addition to the normal layers. These unusual fibers are termed gelatinous fibers (G-fibers) and are typically concentrated on the upper sides of leaning stems and branches.

The structure of individual fibers in tension wood appears to be basically similar to that of normal fibers (22). If the normal cell wall layering is present in G-fibers, the microfibrilar arrangement is apparently unchanged. Optical studies have suggested (18), and X-ray diffraction studies have confirmed (20) that the molecular orientation in the G-layer is approximately parallel to the long axis of the cell.

The degree of lean and the frequency of these unusual fibers have been found to be highly correlated (3, 18). On the other hand, numerous exceptions to that which has been accepted as normal for tension wood may be found in the literature. G-fibers have been reported to occur on all sides of leaning trees but with a higher percentage on the upper side (17); to vary with height (3, 18); and to be randomly distributed throughout leaning tree boles (19). In some species, G-fibers are entirely absent (3) or only present in portions of increments (12). Other anatomical anomalies such as a reduction in vessel frequency and size (2, 3, 15), increase in fiber frequency and size (2, 15) and decreases in parenchymatous cells (15) have been noted. Vessel walls, isolated parenchyma cells and fibers which had not formed a G-layer have been observed to be distorted (3).

Growth stresses in tension wood are apparently of sufficient magnitude to cause minute compression failures. An increased frequency of such failures at right angles to the axial direction has been noted (2).

Physical Properties—Tension wood has been reported to contain smaller, less numerous vessels, less ray area and more fibers than normal wood. These conditions make for more wall substance per unit volume and, as a consequence, greater specific gravity. Many studies have confirmed that the specific gravity of tension wood is greater than that of normal wood, in some species by as much as 30 per cent (1).

There is considerable evidence to indicate that tension wood shrinks and swells more than normal wood in the longitudinal direction (7). A highly correlated linear relationship between the amount of longitudinal shrinkage and the percentage of refractory fibrous area has been noted by several authors (13, 17, 18, 19). In addition, collapse and other seasoning defects are often associated with tension wood (6, 22), thus suggesting the presence of unusual drying stresses.

In general terms, the strength of tension wood is less than that of normal wood, particularly when adjusted for specific gravity. The presence of high percentages of G-fibers adversely affects maximum crushing strength and tensile strength (1, 10). Cell wall failures appear to be of a gradual buckling nature in contrast to the typical compression failure. The toughness of tension wood, however, appears to be greater than that of normal wood (10, 14).

One of the major problems encountered in the utilization of tension wood is difficulty in machining. Turnings from tension wood come off in long unbroken ribbons, whereas, those from normal wood are in the form of short brittle chips (14). It is also reported that the failure of fibers to cut cleanly causes binding during sawing operations (12). Akins and Pillow (1) reported that the presence of abundant amounts of G-fibers in veneer caused buckling and splits to occur which would cause rejection for use as faces because of fuzzy appearance.

Chemical Properties—Tension wood in angiosperms has a higher cellulose content and less lignin than normal wood, a characteristic which is useful in its identification by means of differential histological stains (1, 9). Less xylan (9), higher ash, greater solubility in water, higher alpha cellulose content and lower pentosan content have been noted in tension wood than in normal wood (4). Chemical composition and X-ray diffraction examinations indicate an abnormally high ratio of crystalline to amorphous cellulose in tension wood (20).

Experimental Procedure

FIELD PROCEDURE

The trees from which the material for this study was obtained were located on the West Virginia University Forest, Monongalia County, West Virginia. This area was cut over about 35 years ago and is presently stocked with essentially even-aged stands of black cherry, yellow-poplar, red oak and associated species, mostly of sprout origin. The black cherry is generally of poor form and occurs in both sprout clumps and as single stems.

Four bolts, each 24 inches in length, two from one tree and one from each of two other trees were selected so as to provide material from two branches with approximately the same degree of lean, one leaning stem and one straight stem. After cutting, the bolts were marked on their upper side (as it occurred in the standing tree) and stored in a freezer until used.

LABORATORY PROCEDURE

Each bolt was sawed into discs of sizes appropriate for the tests to be performed and sanded smooth in order that the annual increments could be clearly delineated. Detailed laboratory examination was restricted to the bolts from the three leaning positions (bolts 2B, 5B and 1T), the bolt from the straight stem being examined in a more cursory manner.

Specific Gravity

The discs used for specific gravity determinations were marked into 16 equal angles with the pith as a common vertex. Sawing along the rays of the angles produced 16 pie-shaped specimens. Beginning at the periphery, each of these was divided into segments containing five growth increments. The segments were immersed in water and an intermittent vacuum applied until constant weight was attained. Saturated weights were determined after which the specimens were oven-dried and re-weighed. Specific gravities were computed by the method detailed by Smith (16), which results in values based on green volume.

Shrinkage

Three separate sets of specimens from each bolt were prepared for shrinkage determinations. One set was used to determine longitudinal and volumetric shrinkage, and the other two were to determine radial and tangential shrinkage respectively. An attempt was made to obtain specimens with matched increments from four diametrically opposite radial positions, but specimen size and eccentric growth prevented doing this in all cases. In each set of specimens, one radial position corresponded to the upper side, one to the lower side, and one to each of the two neutral sides of the bolt. Longitudinal shinkage specimens measured one inch in the tangential direction, no less than one-half inch in the radial direction and four inches in the axial direction, and were sawn as nearly as possible parallel to the grain. Radial shrinkage specimens measured one inch in the tangential direction, one inch in the axial direction and were as long in the radial direction as the eccentricity permitted. Tangential shrinkage specimens were centered about the four principal radii and were one inch wide in both the radial and axial directions. The tangential dimensions varied with proximity to the center but were as long as practicable.

The dimension of interest was measured to the nearest 0.0001 inch with a micrometer after the maximum volume of specimens had been obtained by immersion and also after the specimens were oven-dried. When oven-dry, the specimens were weighed, coated with melted paraffin, and the oven-dry volumes obtained by immersion. From the measurements obtained, the specific gravity (based on green-volume) and per cent shrinkage (based on green dimension) were computed for each specimen. Volumentric shrinkage was computed for only the longitudinal shrinkage specimens.

Anatomical Examination

Transverse sections 14 to 16 u in thickness were prepared from the outermost increment and from each successive five-increment interval along a strip which ran from the upper side, through the pith and through the lower side of each bolt. The sections were stained with safranin and fast green, a dye combination useful in studying tension wood because of the distinct color reaction with lignified and nonlignified tissues.

Each microscopic section was magnified 800x by means of a projection microscope. At each of ten randomly selected locations on each section, four vessels and eight fibers were selected for measurement. A calibrated rule was used to measure tangential vessel and fiber diameter and tangential fiber wall thickness. In addition, the width of rays across the diameter of the field of view of the projection microscope was measured and expressed as a percentage of the linear dimension. At each location, the number of vessels in the total field of view was recorded and later converted to the number per square millimeter. In addition to these measurements, each section was carefully examined for the occurrence of gelatinous fibers and color differences.

Results and Discussion

It was immediately apparent that eccentricity, with the pith displaced toward the lower side, is not a constant feature in leaning black cherry trees or branches. The growth pattern reported to be characteristic of tension wood in hardwoods was found in only one specimen — that which came from the slightly leaning stem. In the two specimens from branches with a growth angle approximately 45 degrees from the vertical, the widest increments were either on the lower or one of the neutral sides. The specimen from the straight stem exhibited little eccentricity. The literature suggests that one cause of increased radial growth on the tension side is the fact that tensile stresses are maximum in this area. However, it may be shown mathematically that if the neutral plane adjusts in bending, it is not necessary that eccentricity occur on the upper side to maintain stem and branch form (11).

Distinct differences in reaction to the differential stains were noted. In the bolts from the branches and leaning stem, the upper side invariably indicated a high cellulose-lignin ratio whereas the lower side reacted in the opposite way. The specimens from the straight stem exhibited no color difference between sides. These color reactions indicated that wood with one of the properties characteristic of tension wood — a change in the cellulose-lignin ratio — occurs on the upper sides of leaning stems even though typical eccentricity is not present.

Comparisons between the microscopic sections from the slightly leaning stem and the severely displaced branches confirm other studies (2, 18) which suggest that the intensity of tension wood formation is related to the degree of lean. A distinct deep green, indicating a high cellulose-lignin ratio, was noted in the branches and not in the leaning stem.

Differences in color reaction were also noted within increments in tension wood thus suggesting a within-increment alteration of the cellulose-lignin ratio. The outer portions of these increments were apparently lignified to the normal degree, whereas the earliest formed parts contained less than normal lignin and more cellulose. This phenomenon has been observed by Scurfield and Wardrop (15) who suggested that it reflects a decline in auxin production toward the end of the growing season. If auxin level is, in fact, involved in these color changes, then this evidence lends credence to the contention that tension wood formation is at least in part auxin moderated.

In general there is a considerable degree of inconsistency in vessel frequency when comparisons are made between the upper and lower sides of each bolt, between bolts and within increments in bolts (Table

TABLE 1

Means of Various Anatomical Characteristics of Black Cherry Wood from Leaning Stem and Branches

Bolt	Side	Increment from Periphery					
		1	6	11	16	21	
Vessel Frequency (number/mm²)							
2B	Upper	216.0	209.2	85.0	100.3	163.3	154.8 (116.4)
	Lower	103.7	51.0	85.0	144.6	192.2	115.3 (140.6)
5B	Upper	66.3	86.7	120.7	68.0	45.9	77.5
	Lower	47.6	107.1	129.3	71.4	39.1	78.9
1T	Upper	100.3	91.8	90.1	76.5	158.2	103.4
	Lower	124.1	171.8	148.0	98.6	132.7	135.0
Vessel Diameter (μ)							
2B	Upper	36.30	37.91	44.60	41.89	37.99	39.74
	Lower	53.98	48.53	46.99	44.31	40.94	46.95
5B	Upper	47.46	47.29	48.40	50.15	44.64	47.59
	Lower	55.73	58.78	56.20	55.12	48.69	54.90
1T	Upper	65.14	56.82	47.89	51.80	44.59	53.25
	Lower	57.08	51.00	49.10	50.64	44.97	50.56
Ray Percentage (linear measurement)							
2B	Upper	11.2	15.2	11.9	12.2	11.3	12.4
	Lower	18.8	24.4	19.5	15.2	16.3	18.8
5B	Upper	24.3	13.3	18.1	16.4	18.0	18.0
	Lower	28.3	20.6	17.0	24.5	30.6	24.2
1T	Upper	12.9	13.7	18.9	13.7	18.6	15.6
	Lower	10.6	15.4	10.8	15.4	17.2	13.9
Fiber Diameter (μ)							
2B	Upper	9.34	10.13	11.67	11.43	10.81	10.68
	Lower	13.05	13.58	12.53	11.64	11.64	12.49
5B	Upper	12.13	11.77	12.74	12.56	12.18	12.28
	Lower	13.67	12.83	13.05	12.10	12.54	12.81
1T	Upper	13.58	13.91	12.85	13.63	12.02	13.20
	Lower	13.37	12.96	12.77	12.68	12.94	12.94
Fiber Wall Thickness (μ)							
2B	Upper	1.54	1.84	2.38	3.26	2.53	2.31
	Lower	3.04	3.11	2.97	2.73	2.52	2.87
5B	Upper	4.09	3.54	3.32	3.90	4.19	3.81
	Lower	3.16	2.94	2.93	3.09	3.11	3.05
1T	Upper	2.79	3.05	3.32	2.67	2.90	2.95
	Lower	2.61	2.43	2.54	3.06	3.19	2.79

1). The inconsistency is reflected in the analysis of variance (Table 2), which indicates the effects of factors examined to be non-significant. A detailed examination of the data reveals an anomalous situation which affected the analysis. It may be noted (Table 1) that a comparatively large number of vessels were scored in increments one and six on the

TABLE 2

Summary of the Analyses of Variance of Four Anatomical Charateristics of Leaning Black Cherry Trees

Source	d.f.	Mean Squares				
		Vessel Frequency	Vessel Diameter	Ray Area	Fiber Diameter	Fiber Wall Thickness
Bolts (A)	2	8595.955*	225.53**	102.523**	6.03**	1.98**
Radial position (B)	4	767.186	65.99*	7.058	0.33	0.11
Sides (C)	1	37.600	112.36*	101.526*	3.63*	0.13
B X C	4	994.233	32.70	10.259	0.99	0.03

*Significant at the 0.05 level of probability.
**Significant at the 0.01 level of probability.

upper side of bolt 2B. A reexamination of the specimen material indicated that these two increments were unusually narrow. Although other contradictions may be noted when specific increments are examined, if the two abnormally narrow increments are not considered, the average vessel frequency of the three bolts was less on the upper than on the lower sides.

The afore mentioned narrow increments influenced vessel size to some extent (Table 1), but radial position, side and bolt proved to have a significant influence (Table 2). Vessel diameters in wood from the upper sides of the two branches averaged almost seven microns less than did those from the lower sides. This reduction was consistent from the center outward because it was found in each increment examined. Statistical analysis showed that these differences were significant (Table 3). In the leaning stem, vessel size was not consistently smaller on the upper side in the five increments examined. The average of the five increments showed vessel size to be in fact greater on the upper side than on the lower side (Table 1), but the difference was not significant (Table 3).

Somewhat analogous results were obtained when the percentage of the cross sectional area occupied by ray tissue was examined. The two bolts from the branches contained significantly less ray area on the upper than on the lower side (Table 3). The difference amounted to as much as 6.6 per cent (Table 1). With the exception of one increment, all those examined showed this relationship. Such was not observed to be the case in the bolt from the leaning stem in which the majority of increments contained less ray area on the upper than lower side.

Significant differences in fiber diameter between the upper and lower sides were recorded in only one bolt (2B), which was from a branch (Table 3). In this instance, reductions averaging 14 per cent were noted. The thickness of fiber walls differed significantly between

TABLE 3

Duncan's New Multiple Range Test for Differences Between Means of Certain Anatomical Characteristics of Leaning Black Cherry Stems

	Upper	Lower
1. Vessel Diameter (μ)		
(1) In bolt 2B	39.72	46.94*
(2) In bolt 5B	47.59	54.88
(3) In bolt 1T	53.27	50.42
2. Ray Area (%)		
(1) In bolt 2B	12.3	18.8
(2) In bolt 5B	18.0	24.2
(3) In bolt 1T	15.5	13.9
3. Fiber Diameter (μ)		
(1) In bolt 2B	10.69	12.49
(2) In bolt 5B	12.27	12.84
(3) In bolt 1T	13.19	12.94
4. Fiber Wall Thickness (μ)		
(1) In bolt 2B	2.32	2.81
(2) In bolt 5B	3.80	3.05
(3) In bolt 1T	2.90	2.76

*Any two means connected by the same line do not differ from one another at the 0.05 level of probability.

sides in one of the branch bolts (Table 3). The differences measured averaged less than one micron. Intensive microscopic examination failed to reveal the presence of a distinct G-layer in any of the fibers examined. Black cherry is apparently one of the species which does not form a greatly thickened wall layer in the fibers of tension wood.

The analysis of variance of specific gravity (Table 4) indicates that one of the branch bolts was significantly heavier than the bolts from the other branch and the stem and that the variation from the pith outward was also significant. However, no difference due to loca-

TABLE 4

Analysis of Variance of Specific Gravity

Source	d.f.	Mean Squares
Bolts (A)	2	0.2572*
Growth rings (B)	5	0.0497*
Circumferential position (C)	15	0.0028
B X C	75	0.0010

*Significant at the 0.01 level of probability.

tion with respect to the tension side was detected. The differences which occurred were small and no consistent pattern was evident.

The tension wood of most species has been reported to be one-third higher in specific gravity than that considered normal for the species (7). The increased density is reputed to be associated with smaller ray area, lower vessel frequency, smaller vessel diameter, higher percentage of fibers and the presence of the G-layer. While no G-layer was observed, it was anticipated that the significantly smaller vessel diameter and the lower ray area would result in a higher specific gravity in the tension wood. The effect of these factors was apparently over-ridden by the reduced lignification which was observed.

Mean longitudinal shrinkage values of wood from the tension side of the branches and the leaning stem were considerably higher than those from the opposite side and were generally higher than those from any of the other three sides (Table 5). This was also the case when the shrinkage values were adjusted for specific gravity (based on a linear relationship). Analysis of variance of adjusted values (Table 6) indicated that the effect of location in the bolt on longitudinal shrinkage was highly significant. A multiple range test indicated shrinkage of wood from the lower side to be significantly less than from the other three sides. It is possible that the differences in longitudinal shrinkage may be related to alignment of microfibrils. However, a more reasonable explanation, as suggested by Wahlgren (19), is that non-lignified secondary cell walls do not control longitudinal shrinkage. The remainder of the cell wall, which is more highly lignified and exhibits a greater

TABLE 5

Mean Longitudinal Shrinkage Values of Wood from Leaning Stem and Branches

Position	Bolt		
	2B	5B	IT
Upper	0.25	0.46	0.34
Neutral	0.40	0.37	0.30
Lower	0.16	0.07	0.04
Neutral	0.33	0.19	0.07

*Values are expressed as percentages of green dimension.

TABLE 6

Analysis of Variance of Adjusted Longitudinal Shrinkage Values

Source	d.f.	Mean Squares
Error	5	0.00000062
Side & error	8	
Side (adjusted)	3	0.0000054*

*Significant at the 0.01 level of probability.

nicrofibril angle, would then be essentially unrestrained longitudinally.

In all of the bolts examined, longitudinal shrinkage increased from the pith outward, a trend which was essentially the reverse of that of specific gravity. Since growth stresses also increase in a similar manner, it is possible that the two (longitudinal shrinkage and growth stresses) are related.

In general, the amount of radial, tangential and volumetric shrinkage was slightly but not significantly greater in wood from the tension sides of the bolts. This may be attributable to collapse which was evident n many of the shrinkage specimens containing tension wood.

Summary and Conclusions

It is apparent that black cherry produces wood in leaning stems and branches which has many of the characteristics of tension wood. The upper side of black cherry trees which are displaced from the vertical is made up of wood which has a higher than normal cellulose-ignin ratio, a reduction in number and size of vessels, reduced ray area and small diameter fibers. The net effect of these changes on a unit basis is an increase in the supportive tissues and a decrease in the conductive tissues in the wood subjected to the greatest tensile stresses.

Eccentricity of pith did not appear to be closely related to the ocation of tension wood. Hence, its use as a gross indicator of tension wood in logs and lumber is questionable.

The specific gravity of tension wood in the stems studied was not greater than that of normal wood. Although high specific gravities are generally associated with tension wood in other species, the predominant feature in black cherry appears to be a change in the cellulose-lignin ratio.

Longitudinal shrinkage of tension wood was abnormally high and increased with age of the tree. Since growth stresses also increase with age, it is possible that the two are related. The fact that wood from the upper sides of the bolts investigated exhibited slightly greater radial, tangential and volumetric shrinkage than that from the opposite sides was attributed to a greater tendency for tension wood to collapse during drying.

Most changes which were observed to be associated with lean were more pronounced in the two branches than in the leaning stem. These results suggest that logs from slightly leaning stems may be used with little concern about the effects of tension wood. On the other hand, the utilization of short bolts from severely displaced branches increases the possibility of encountering problems associated with tension wood.

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