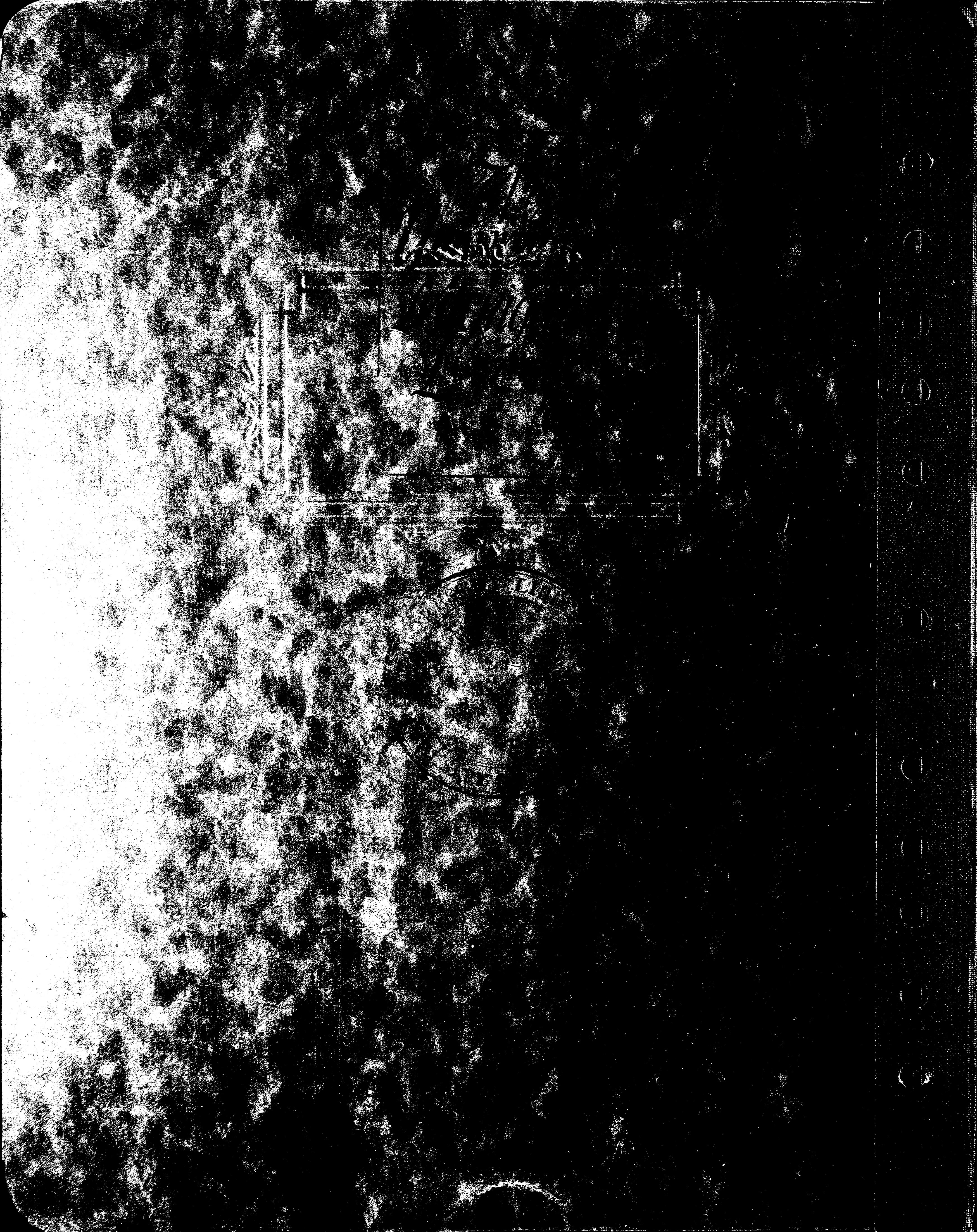
A COMPARATIVE STUDY OF THE PROPERTIES OF TENSION WOOD AND NORMAL WOOD FROM FOUR AMERICAN HARDWOODS

by
Robert A. McKay



University of Michigan

School of Conservation and Forestry

A COMPARATIVE STUDY OF THE PROPERTIES OF TENSION WOOD AND NORMAL WOOD FROM FOUR AMERICAN HARDWOODS

This report is submitted as partial fulfillment
for the degree of Master of Wood Technology.

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ACKNOWLEDGEMENTS

The results presented in this report were obtained at the Wood Utilization Laboratory of the University of Michigan School of Forestry and Conservation where the problem was executed under the supervision of Professor William Kynoch.

The author is indebted to Professor Kynoch for his interest, assistance, and encouragement. Gratitude is also expressed for the assistance so freely offered by many of the staff members, employees, and students of the University of Michigan.

INTRODUCTION

Gelatinous fibers have been recognized for over a century[1] and during that time considerable information has been accumulated concerning this abnormal anatomical feature which occurs only in deciduous trees. Very briefly, gelatinous fibers may be described as wood fibers which possess a loose, crinkly, jelly-like substance that forms somewhat of a tertiary cell wall (5, 16). It has been found that these abnormal wood fibers generally tend to occur on only one side of the stem (6, 16) and that the gelatinous material was less liquified than normal fiber walls (6, 16).

Originally it was the belief that this abnormal feature was associated with but a few species of trees such as black locust (Robina pseudoacacia) and osage orange (Toxylon pomiferum).[2] This concept has since been abandoned however, and at the present time it remains unknown whether or not there is any hardwood species in which gelatinous fibers never occur.

Extensive investigations of this phenomenon, particularly by Clarke (5, 6) and Rendle (16), revealed

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[1] First cited by Hartig but later described by Von Mohl in 1844.

[2] Related by Professor William Kynoch.

that an area which contained a large percentage of gelatinous fibers was tension wood,[3] another abnormal feature of which very little was known. Since then, gelatinous fibers have been considered the "anatomical index" to tension wood. This important association appeared to have provided the impetus for several thorough studies into one of the remaining void areas in the knowledge of wood structure.

One of the first important facts discovered concerning tension wood was that it generally occurred on the upper side (tension side, hence the name) of leaning trunks and large branches of decidous trees and was probably formed by the tree attempting to regain an upright position (7, 11, 12). Its presence in straight trunks was explained as being caused by the tree in maintaining an upright position (7). The information regarding the causes and position of tension wood associated it with compression wood, an abnormal feature found only on the under side of inclined coniferous trees (15). It has since been found that while the causes of tension wood and compression wood may be similar, the actual characteristics of these two unnatural tissues are in most instances diametrically opposite.

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[3] Also known as *Bois de tension*, *Zugholz* or *Weissholz*.

The following is a summary of the abnormal properties associated with tension wood:

1. Tension wood is not as strong in compression parallel to grain as normal wood (6, 7, 10, 16).
2. Tension wood is stronger in tension parallel to grain (16).
3. Tension wood has a very high longitudinal shrinkage and a high tangential shrinkage (3, 4, 6, 7, 10, 16).
4. Tension wood generally has a higher specific gravity than normal wood (1, 4, 9).
5. Tension wood is composed of a higher percentage of cellulose than normal wood (1, 6).
6. Tension wood obtains a fuzzy or woolly surface when it is machined on a lathe or saw (3, 6, 7, 8, 10, 13).

OBJECTIVE

Previous investigations of the characteristics of tension wood have been performed from more of an analytical than a practical standpoint. Although the unusual characteristics of tension wood have been well defined, the effect of tension wood upon the properties of an individual piece of lumber has not been fully investigated. Many of the studies were performed on only one cross-sectional disc or on one portion of a tree. The wood was usually tested at a moisture content of fifteen percent. It has also been the usual practice to compare the results of strength test on a basis of equal specific gravities, though it has been found that the specific gravity of tension wood is generally higher than that of normal wood (1, 4, 9).

It was the desire of the author to conduct a preliminary study of tension wood in four American hardwoods and simultaneously produce results that might qualify as answers to some of the questions arising concerning the effect of tension wood in wood of a moisture content similar to that at which the wood might be used.

In attempting to accomplish this objective it was necessary to obtain tension wood and to perform certain physical and mechanical tests on both tension wood and normal wood. These tests consisted of specific gravity and longitudinal shrinkage determinations and compression parallel to grain and tension parallel to grain tests. The following report will describe the progressive operations in the execution of this comparative study of tension wood and normal wood in four American hardwoods.

MATERIAL

The Procurement of Tension Wood

The work performed in this project may be divided into two main groups: (1) the detecting and collecting of a sizable quantity of tension wood and (2) the testing of the tension wood in order to determine some of the abnormal physical and mechanical properties that may be associated with it.

To obtain accurate and extensive results it was decided that two trees of at least three species should furnish the tension wood. Because the presence of tension wood has been found to be more common in leaning trees (2, 4, 6, 7, 11, 12), it was concluded that all trees cut should have an excessively inclined trunk.

Description of the Trees An extensive tour of some eight hundred acres of University of Michigan, City of Ann Arbor, Wayne County Training School, and privately owned wood lots revealed that the following species could be considered as likely sources of tension wood: (1) northern red oak (Quercus borealis var. maxima Ashe), (2) pignut hickory (Hickoria glabra Sweet), (3) white ash (Fraxinus americana L.), and

(4) box elder (*Acer negundo* L.). As the result of several examinations to be described later, the hickory was eliminated and in its place was substituted hard maple (*Acer saccharum* Marsh).[1]

The following is a description of each tree that was used in this project and its environmental conditions:

Red Oak (*Quercus borealis* var. *maxima* Ashe)

Tree designation	A	B
Date cut	May 3, 1947	May 3, 1947
Location	Stinchfield Woods	Stinchfield Woods
Diameter	11 inches	10.5 inches
Height	45 feet	47 feet
Inclination (from vertical)	18° ENE	15° E
Ground slope (from horizontal)	30° ESE	20° S
Crown class	dominant	dominant
Age	68 years	58 years

Box Elder (*Acer negundo* L.)

Tree designation	A	B
Date cut	July 10, 1947	July 23, 1947
Location	Saginaw Forest	Saginaw Forest
Diameter	11 inches	8.75 inches
Height	40 feet	50 feet
Inclination (from vertical)	25° E at 5 feet 45° E at 10 feet	27° SE at 10 feet 30° SE at 15 feet 18° SE at 25 feet
Ground slope (from horizontal)	level	level
Crown class	dominant	codominant
Age	30 years	38 years

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1. Obtained from the Biological Station on Douglas Lake in northern Michigan by Professor W. F. Ramsdell of the staff of University of Michigan School of Conservation and Forestry.

White Ash (*Fraxinus americana* L.)

Tree designation	A	B
Date cut	July 10, 1947	July 23, 1947
Location	Saginaw Forest	Saginaw Forest
Diameter	9.75 inches	8 inches
Height	35 feet	35 feet
Inclination (from vertical)	10° SE at 5 feet 30-35° SE at 15 feet	18° N at 10 feet 25-30° N at 20 feet
Ground slope (from horizontal)	10° SW	20° W
Crown class	dominant	codominant
Age	41 years	41 years

Hard Maple (*Acer saccharum* Marsh.)[2]

Tree designation	A	B
Date cut	July 1947	July 1947
Location	Biological Station Cheboygan County	Biological Station Cheboygan County
Diameter	8.5 inches	8.75 inches
Age	66 years	55 years

Logging Because it was necessary to know the orientation of any cross-sectional disc that might be cut from any tree, the under-side of each tree was marked at the butt prior to felling and afterward other marks were made along the stem as accurately as possible.

With the exception of the two maple trees, each tree yielded from two to four logs approximately seven feet in length. The maple consisted of one six foot butt log from each tree. After being carefully

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[2] Complete information unavailable.

marked as to species, tree designation, log number, and direction of lean, several discs approximately one inch thick were cut from each log and brought to the Wood Utilization Laboratory for analysis to determine the presence of tension wood.

Having obtained the logs from leaning trees completed the first major step in the procuring of tension wood. The final act was an examination of this wood to determine whether or not it contained tension wood and if so to what extent.

Preliminary Staining Procedure Primary in the identification of tension wood is the reaction produced when certain staining reagents are applied to the surface of freshly sawn wood. The distinction between tension wood and normal wood is due to the presence of the gelatinous substance in the tension wood. As has been mentioned before, the jelly-like material tends to possess a higher percentage of cellulose than does normal wood substance and therefore a contrast is produced between the two areas when stained. The nature of the contrast depends upon whether the stain is an indicator of cellulose or lignin. Previous research concerning the identification of tension wood has indicated that the most dependable macroscopic stains were chlor-zinc-iodide and phloroglucinol in hydrochloric acid (6, 7, 10). Baudendistel and Akins of the United States Forest Products Laboratory reported using these stains for making temporary microscopic mounts (3). Several formulas were obtained for the preparation of each stain, but after testing each the following mixing proportions were accepted as the most favorable:

Chlor-zinc-iodide (Herzberg stain)[3]

Solution 1	chloride of zinc	20 grams
	distilled water	10 grams
Solution 2	potassium iodide	2.1 grams
	iodine	0.1 grams
	distilled water	5.0 grams

Solutions 1 and 2 are mixed together. The chloride of zinc acts as a dehydrating agent on the cellulose which is in turn stained by the potassium iodide and iodine. After being applied to freshly felled wood and allowed to stand, the tension wood area assumes a dull purplish-brown color while the normal wood becomes a pale yellow. If the color is too strong, showing that excessive dehydration is taking place, a small additional amount of Solution 2 is added; on the other hand, if the color is too weak, more of Solution 1 is added.

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[3] Provided by Prof. William Kynoch.

Phloroglucinol in 12 percent Hydrochloric Acid[4]

phloroglucin	0.25 grams
12% hydrochloric acid	25.0 cc.

The above proportions produce a saturated solution which, when applied to wood, reacts with the lignin in such a manner as to produce a reddish-violet color.

The macroscopic staining operation was performed at two different times. The procedure that will be discussed at the present time was of a preliminary nature in that it was used only to determine whether the trees that had been felled would be of value in this project. The purpose of the second staining operation was to locate the exact area of tension wood after the approved logs had been cut into discs.

Preliminary Staining Results It is important to note that none of the one inch discs of oak, box elder, ash, or hickory that were brought in from the woods showed any visible signs of containing tension wood. This may have been due to a poorly cut surface and a high moisture content. The cross-sectional surfaces of the discs were sanded as described by Dadswell (7) in his report on tension wood in bollywood. The sanded surfaces were stained and the

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[4] As provided by J. D. Hale of the Forest Products Laboritories of Canada.

following results were noted:

Red Oak

Phloroglucinol in 12 percent hydrochloric acid was completely ineffective on discs from both trees. When chlor-zinc-iodide was applied a definite area became evident on the side of the disc opposite to the direction of lean. This area was a dull, dark brown in contrast with the dull, yellowish-brown of the remainder of the disc and comprised approximately one-eighth of the total area although there was no line of demarcation. The discs from both trees were eccentric but the widest portion was not opposite the direction of lean as is generally the occurrence in leaning hardwood trees. This, therefore, placed the tension wood in an area not possessing the widest growth rings but it definitely conformed to the upper side of the tree.

Box Elder

The chlor-zinc-iodide stain produced no noticable areas. Phloroglucinol stained the entire disc surface a light red but after standing for a day or two a very faint silver-blue was evident on the upper side of the discs from both trees; the red color of the remainder of the disc had faded to light pink. The silvery areas were located on the widest part of the eccentric discs and therefore contained the widest portion of some of the growth rings. A larger percentage of the cross-sectional area was included in the silvery portion of Tree B than of Tree A.

Ash

Here again the chlor-zinc-iodide stain was of no value. Phloroglucinol in 12 percent hydrochloric acid acted upon the ash in a manner similar to its action upon box elder, but more rapidly and to a greater degree of differentiation of the two areas. The normal wood became pink while on the widest portion of the eccentric discs there appeared a silvery area. This area comprised approximately one third of the total area and was located directly opposite the direction of lean.

Hickory

Application of the phloroglucinol solution in the hickory discs brought out no areas of interest. Chlor-zinc-iodide also failed to reveal a tension wood area on Tree A discs but when applied to discs from Tree B two dark brown, concentric, crescent-shaped areas were formed. The remainder of the cross-sectional area was stained a dull yellow as was the whole area of discs from Tree A. The inner-most band was approximately one inch across at its widest part and the outer band was about five eighths of an inch wide. They extended about one third the distance around the disc at the widest portion and were separated from each other by one quarter of an inch of normal wood. The two areas, with the exception of the narrow band of normal wood separating them, occupied the central portion of the widest part of the disc.

These areas were considered too small from which to obtain test specimens of a favorable size and quantity. Because of this and the lack of any abnormal areas in Tree A, it was decided that hickory should be abandoned as a possible source of tension wood. It must be remembered, however, that when Tree B was stained with chlor-zinc-iodide two areas became noticable that were similar in color, location, and shape to tension wood and although no actual tests were performed it can not be said that tension wood will not occur in hickory. If the tests on oak, box elder, ash, and maple that follow verify the staining results it may even be assumed quite definitely that tension wood does occur in hickory. This fact does not possess the importance that it might, because as stated before, tension wood is now being thought of as an abnormal feature that might be found in any hardwood tree if conditions permit.

Maple

It was at this time that the two bolts of hard maple were obtained. Thin discs were sawn from both logs to be used in the preliminary staining. After cutting the discs it was observed on the rough, unstained cross-sectional surface that approximately one third of the area had a very light cream colored appearance while the remainder of the disc was the color of ordinary maple. This area was located on the upper side of the very eccentric discs and its outline clearly defined. The inner boundary of this area in both trees was an arc concurrent with a growth ring about three inches from the pith and extending about half way around the disc. From the two extremities the area decreased in length around the discs and increased in thickness until it met the cambium on the upper side of the disc.

Phloroglucinol had no effect whatever upon the discs but when chlor-zinc-iodide was applied, the abnormal area just described became a dull brown while the remaining portion of the disc turned somewhat of a golden-yellow.

Thus the final phase of locating tension wood ended. With the exception of maple, the results were not substantiated by visible abnormalities on the surface of the discs.

Preparation of Test Specimens

It became necessary at this time to determine what size the test specimens should be made. This decision had been delayed until the approximate area of tension wood was determined in order that the specimens might be as large as possible. It was found that by cutting blanks with cross-sectional dimensions of 0.75 inch by 0.75 inch the finished specimen after shrinkage would be at least 0.5 inch by 0.5 inch which were the dimensions used by Dadswell (7) and Ingle (10).

The Cutting of Cross-sectional Discs To mark the logs where each cut would be made it was necessary to remove a strip of bark about three inches wide along the entire length. The strips were cut at least ninety degrees from the upper side of each log so that any checking that occurred would not damage the tension wood area and thus decrease the number of tension wood specimens. These strips also served to align all the discs from each log after they had been cut. Along the bare strip, marks were made at four and six inch intervals. An arbitrary ratio of about one six inch disc for four of the narrower discs was assumed. Upon the peeled area on each proposed disc was marked the species and disc number (see Fig. 1). The discs were numbered consecutively from bottom to top of tree with each species having a definite series of numbers as is outlined in Table 1.

TABLE 1

The Method of Marking Discs Before
Their Removal from the Trees

Species	Designations		
	Species	Tree	Disc No.
Red Oak	O	A	1-50
		B	1-50
Box Elder	E	A	101-150*
		B	101-150
Green Ash	A	A	151-200
		B	151-200
Hard Maple	M	A	201-250
		B	201-250

* Numbers 51-100 inclusive were designated for hickory which was later discarded.

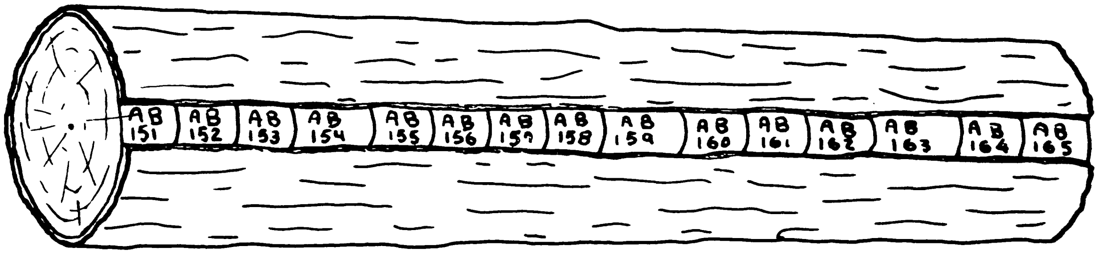


Figure 1.—Method of marking logs prior to sawing into discs. The second log of Ash Tree "A" is illustrated.

The discs were cut from the logs by means of a thirty-six inch buzz saw. Extreme caution was executed in this operation in order that each disc would have one cross-sectional surface that was as near perpendicular to its axis as possible. Two hundred and fifty discs were obtained. As the discs were cut they were placed on edge, in order, an inch apart, on two parallel slats to facilitate drying. All discs that contained gross defects such as knots, or cross grain, or had neither surface perpendicular to the grain were discarded.

<u>Observation of Unstained Discs</u> As the discs dried there became apparent on the rough sawn surface of most of them an area which possessed a texture, luster, and generally a color, that differed from that of the remainder of the surface. On all discs this distinctive area was fuzzy or woolly, indicating that the wood elements had not been cleanly severed. The color ranged from lighter to darker than the normal wood and had considerable luster.

This abnormal area occurred on the upper side of the discs. On the oak discs the area was somewhat darker than the remaining wood and had a dull luster. The fuzzy surface appeared as though it had been waxed and then lightly pressed toward the direction in which the saw teeth moved.

The peculiar portion of the cross-sectional surface of the maple discs had a faint silvery appearance which was very evident when reflecting light. When sanded the luster disappeared and the area became cream colored. Maple was the only species in which the tension wood area was distinctly outlined on the unstained surface. Each year's growth was separated from the next by a very fine line of normal colored wood. It was also noted that in both trees the heartwood was expanded in the tension wood area and thereby included more annual rings on the upper side of the tree than on the under side.

A silvery area was noticable on the ash discs but its limits were indistinct. Here again the heartwood was enlarged on the tension side of the stem. Due to early checking the discs had to be piled on end being separated from each other by a moist paper towel.to retard drying.

On the discs of box elder the abnormal wood appeared as concentric crescents of various thicknesses which occurred in a definite radial band from two inches to two and one-half inches wide. The areas were separated by a band of normal appearing wood. The crescents were fuzzy and silvery.

As explained before, there is no definite reason why the above mentioned areas, with the exception of those on maple, were not visible on the discs cut for the preliminary staining. This may have been due to faster and more regular sawing and a suitable moisture content.

Final Staining On the basis of the preliminary staining, the stain best suited for each species was applied to one surface of every disc. The results obtained were similar to those of the preliminary staining operation. After each area became visible it was outlined with either indelible pencil (on phloroglucinol) or chalk (on chlor-zinc-iodide) (see Figs. 2 to 9). The stains had been applied to the surface that was not perpendicular to the disc axis so that blank outlines drawn on that surface could be cut out while the bottom surface rested on the saw table.

Marking the Disc Surfaces In the outlined areas squares 0.75 inch by 0.75 inch were drawn in such a manner as to make two opposite surfaces tangent to the growth rings. On the opposite side of the disc a similiar number of squares was drawn. Though not always possible, it was the general procedure to place the latter squares within an area with growth

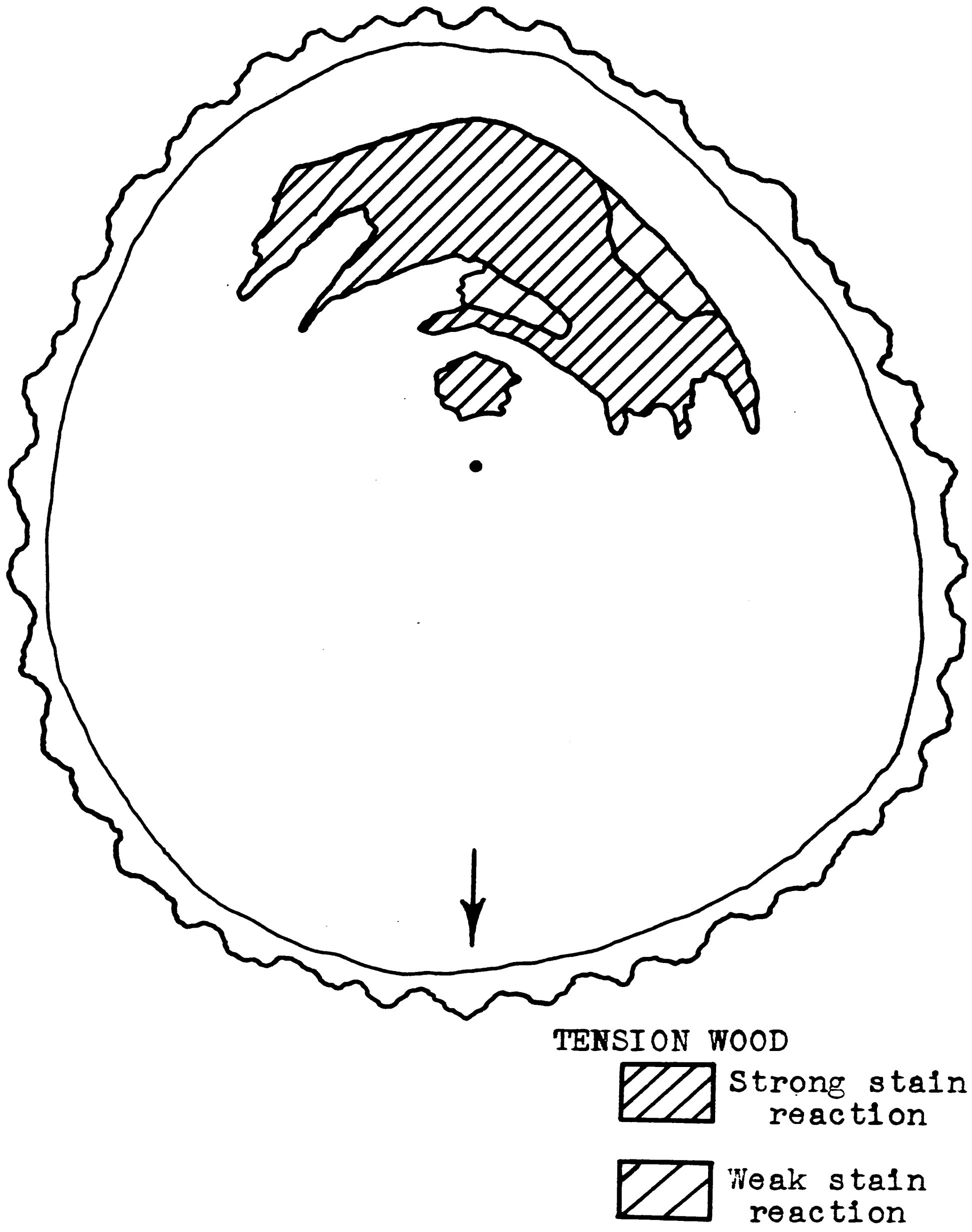


Figure 2.—An actual tracing reduced to one-half size of disc 15 from Oak Tree "A" with tension wood area shaded as was indicated by the reaction of chlor-zinc-iodide stain. The direction of lean is indicated by the arrow.

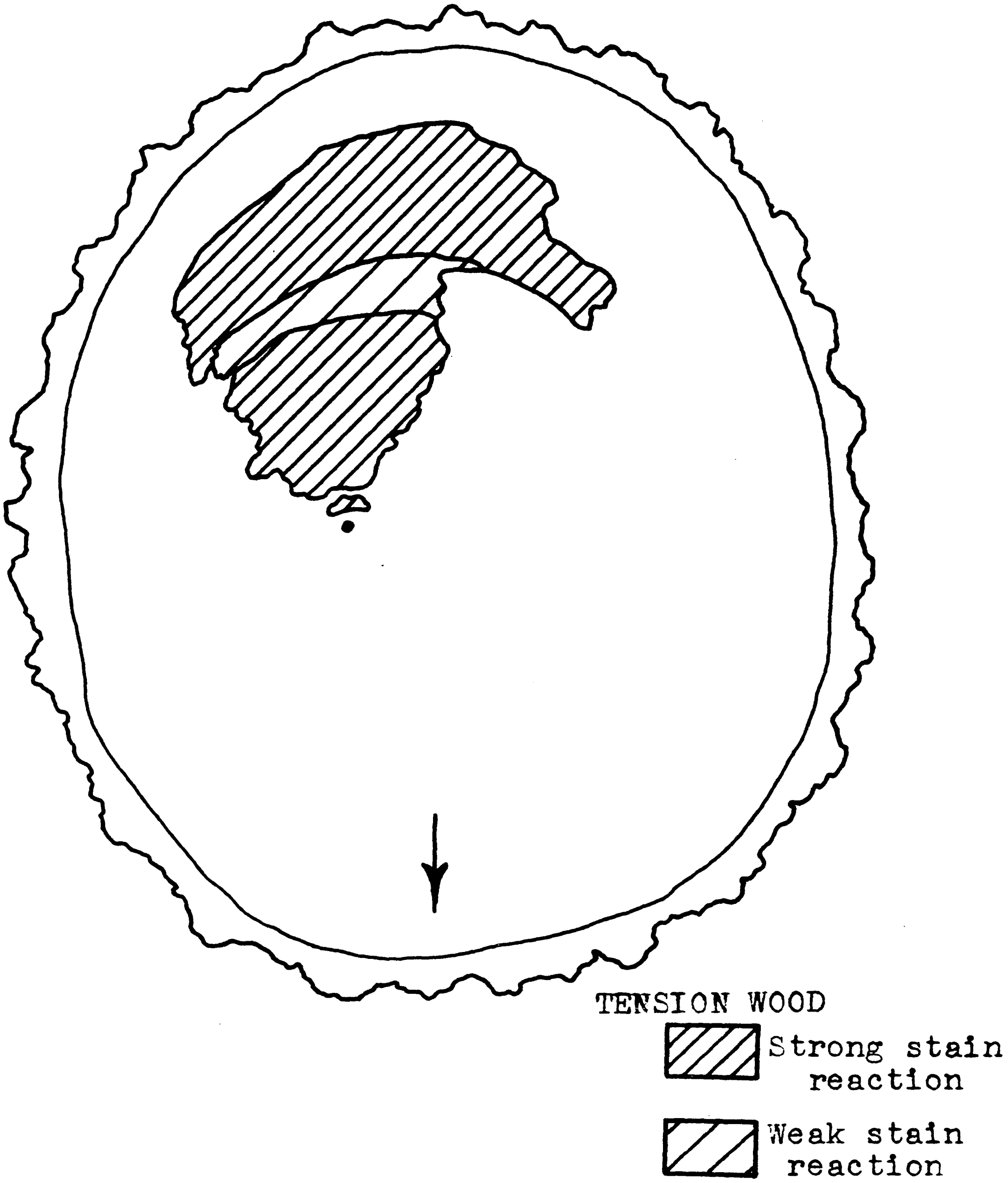


Figure 3.—An actual tracing reduced to one-half size of disc 19 from Oak Tree "B" with tension wood area shaded as was indicated by the reaction of chlor-zinc-iodide stain. The direction of lean is indicated by the arrow.

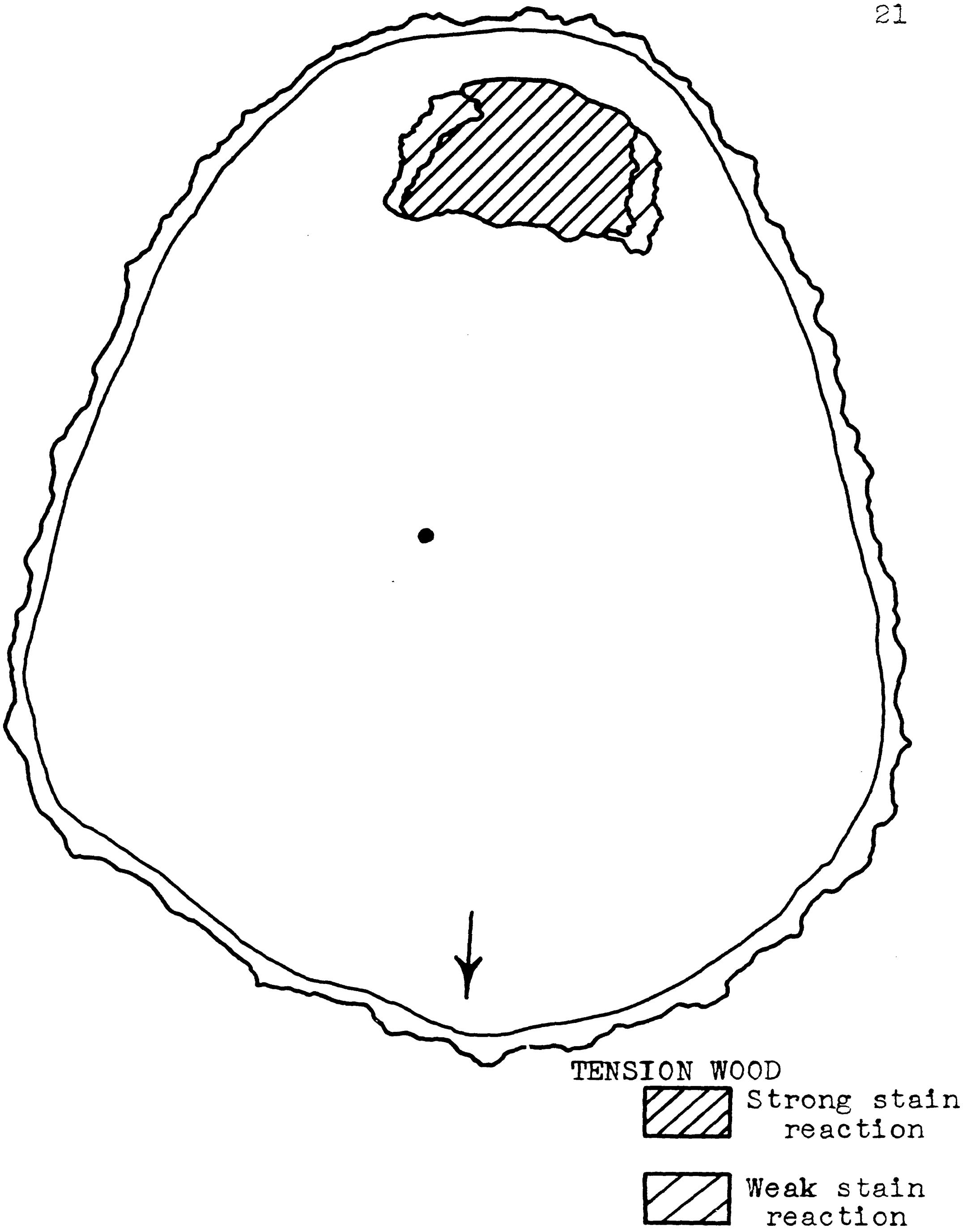


Figure 4.—An actual tracing reduced to one-half size of disc 116 from Box Elder Tree "A" with tension wood area shaded as was indicated by the reaction of phloroglucinol stain. The direction of lean is indicated by the arrow.

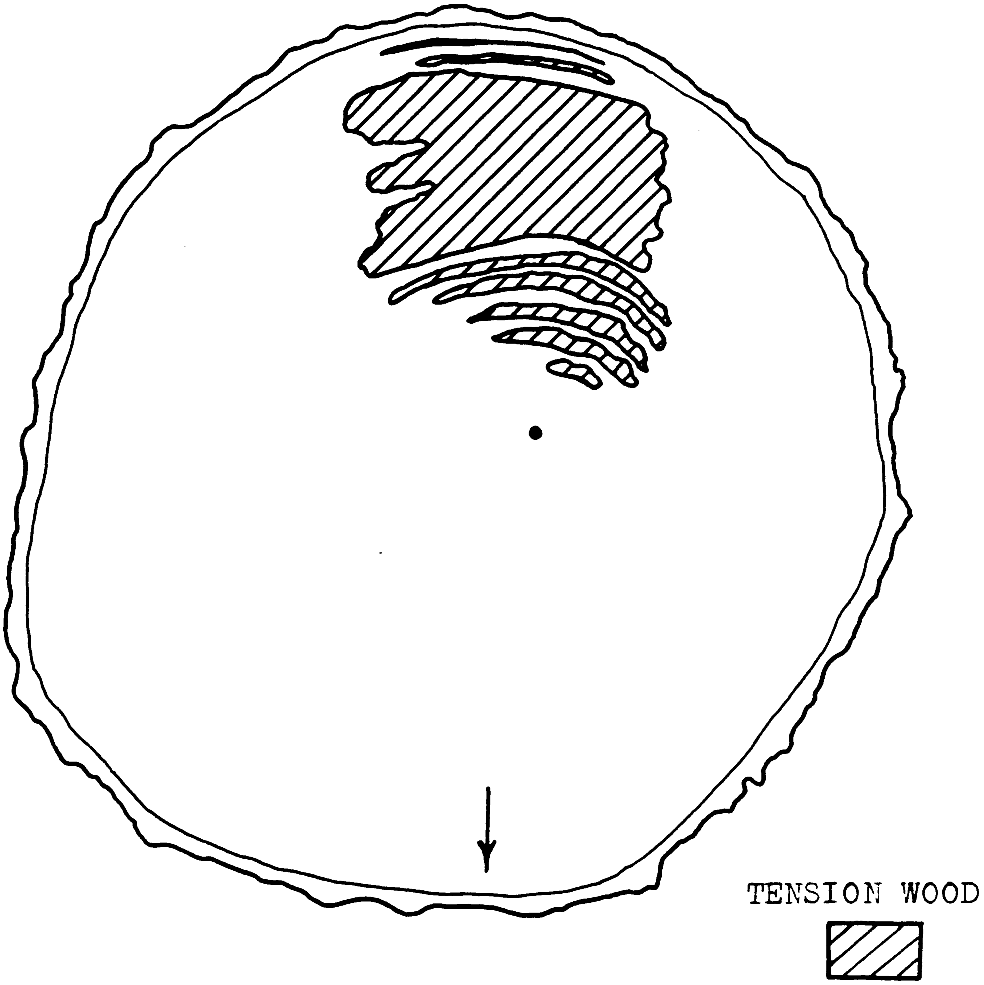


Figure 5.—An actual tracing reduced to one-half size of disc 117 from Box Elder Tree "B" with tension wood area shaded as was indicated by the reaction of phloroglucinol stain. The direction of lean is indicated by the arrow.

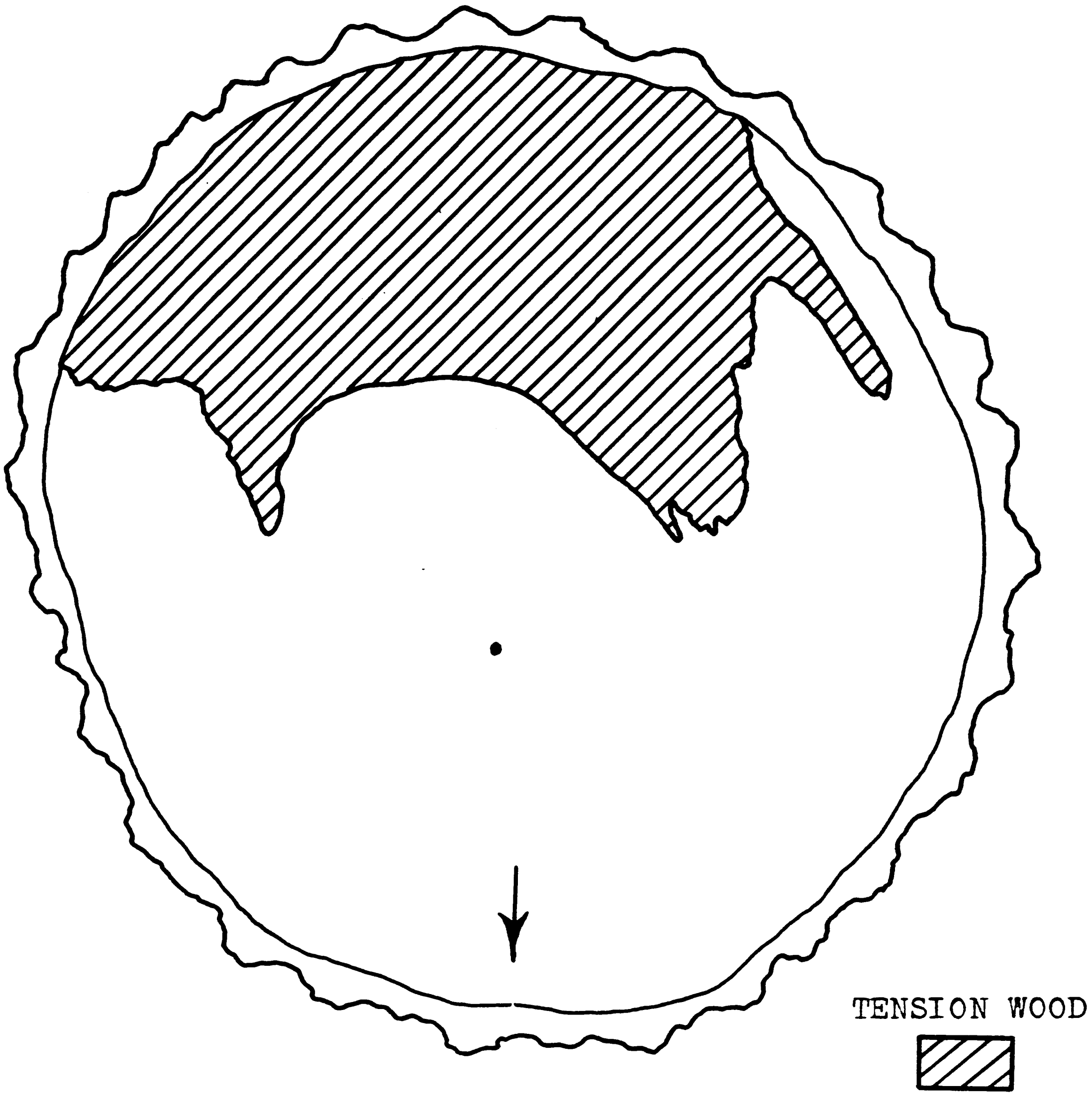


Figure 6.—An actual tracing reduced to one-half size of disc 179 from Ash **Tree** "A" with tension wood area shaded as was indicated by the reaction of phloroglucinol stain. The direction of lean is indicated by the arrow.

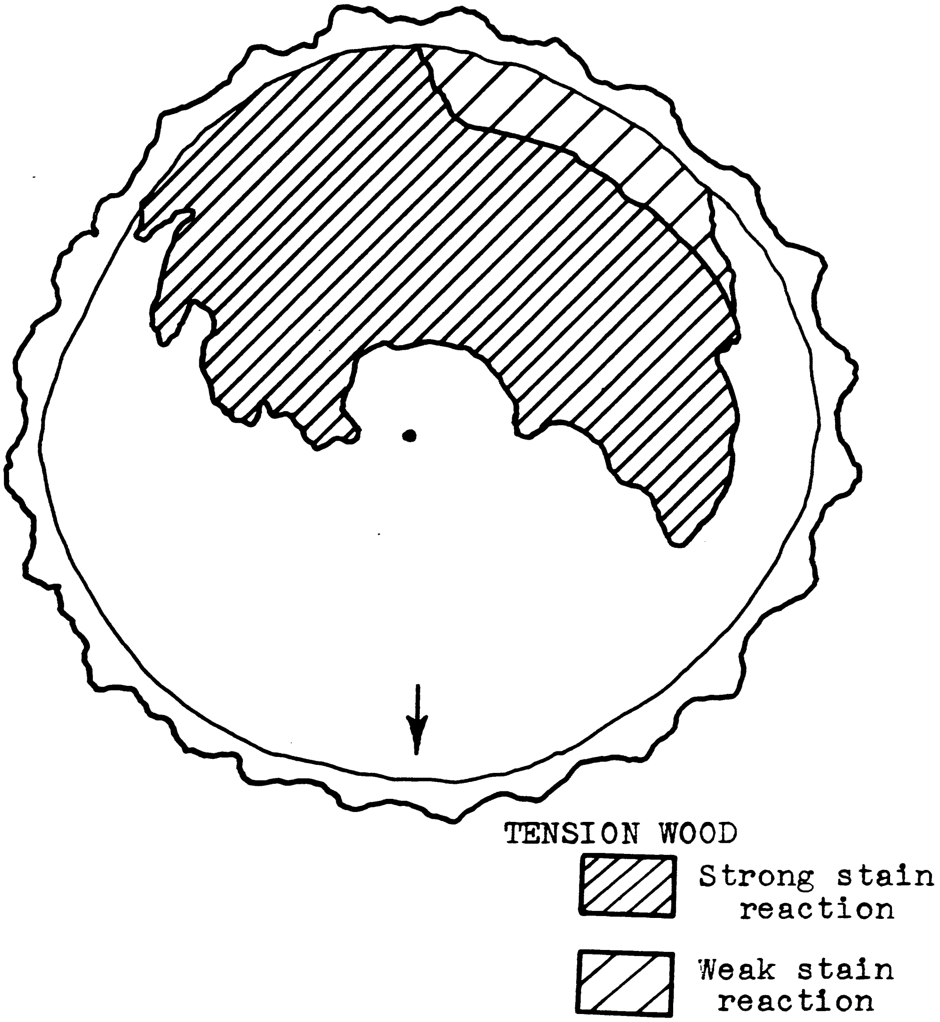


Figure 7.—An actual tracing reduced to one-half size of disc 158 from Ash Tree "B" with tension wood area shaded as was indicated by the reaction of phloroglucinol stain. The direction of lean is indicated by the arrow.

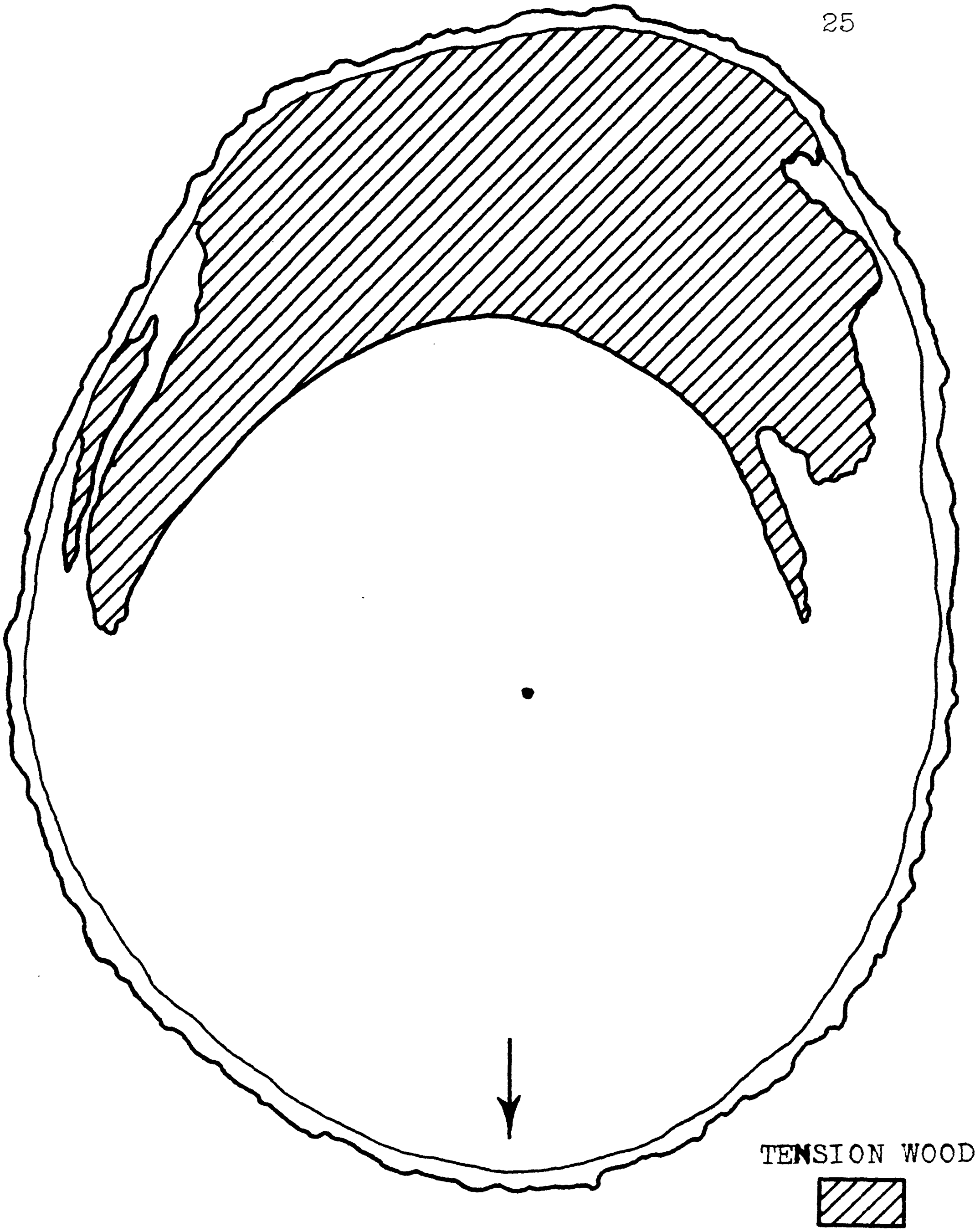


Figure 8.—An actual tracing reduced to three-quarter size of disc 208 from Maple Tree "A" with tension wood area shaded as was indicated by the reaction of chlor-zinc-iodide stain. The direction of lean is indicated by the arrow.

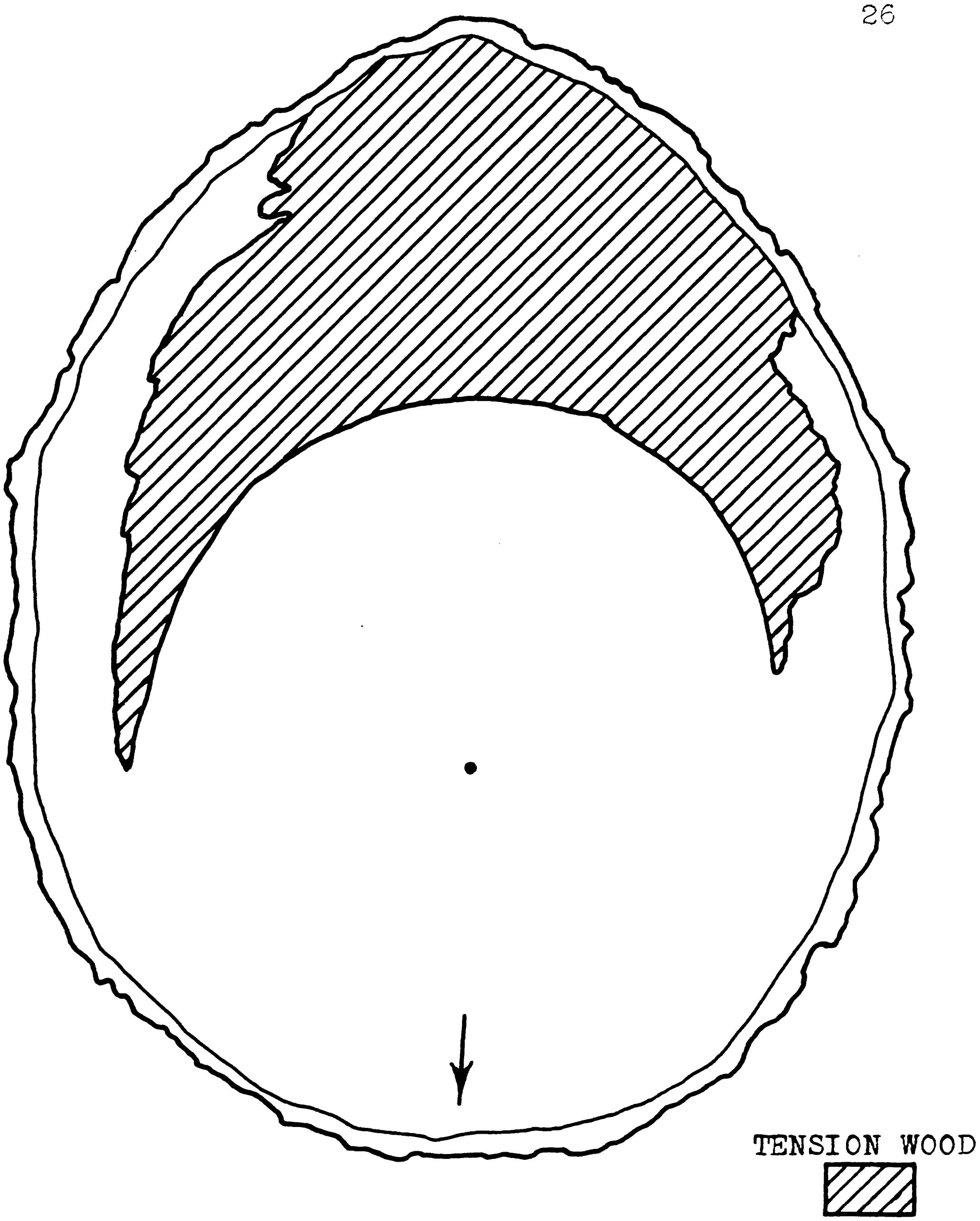


Figure 9.—An actual tracing reduced to three-quarter size of disc 208 from Maple Tree "B" with tension wood area shaded as was indicated by the reaction of chlor-zinc-iodide stain. The direction of lean is indicated by the arrow.

rings of similiar width to those in the tension wood area. Within each square was written the two letters identifying the species and tree, the disc number, and "N" or "T" denoting normal wood and tension wood. For consistency the markings were placed so that the bottoms of the squares were toward the pith (see Fig. 10).

Sawing Specimen Blanks from Discs The marked discs, after seasoning for over a week, were taken to the University of Michigan Plant Maintenance Shop where the specimen blanks were cut from the discs by means of a band saw. It was for this method of extracting the blanks that the staining and markings were made on the surface least perpendicular to the axis of the disc so that the true surface could be placed on the saw table.

During the sawing operation long, unbroken strands of wood were formed similiar to the condition Clarke found when tension wood was turned on a lathe (6). The long ribbons collected in the wheels, the cage, and in the saw guide to such an extent that they had to be frequently removed. This could easily have produced the same results described by Dadswell (8) in which the fibers clogged and damaged a circular saw by overheating when ripping logs containing tension wood.

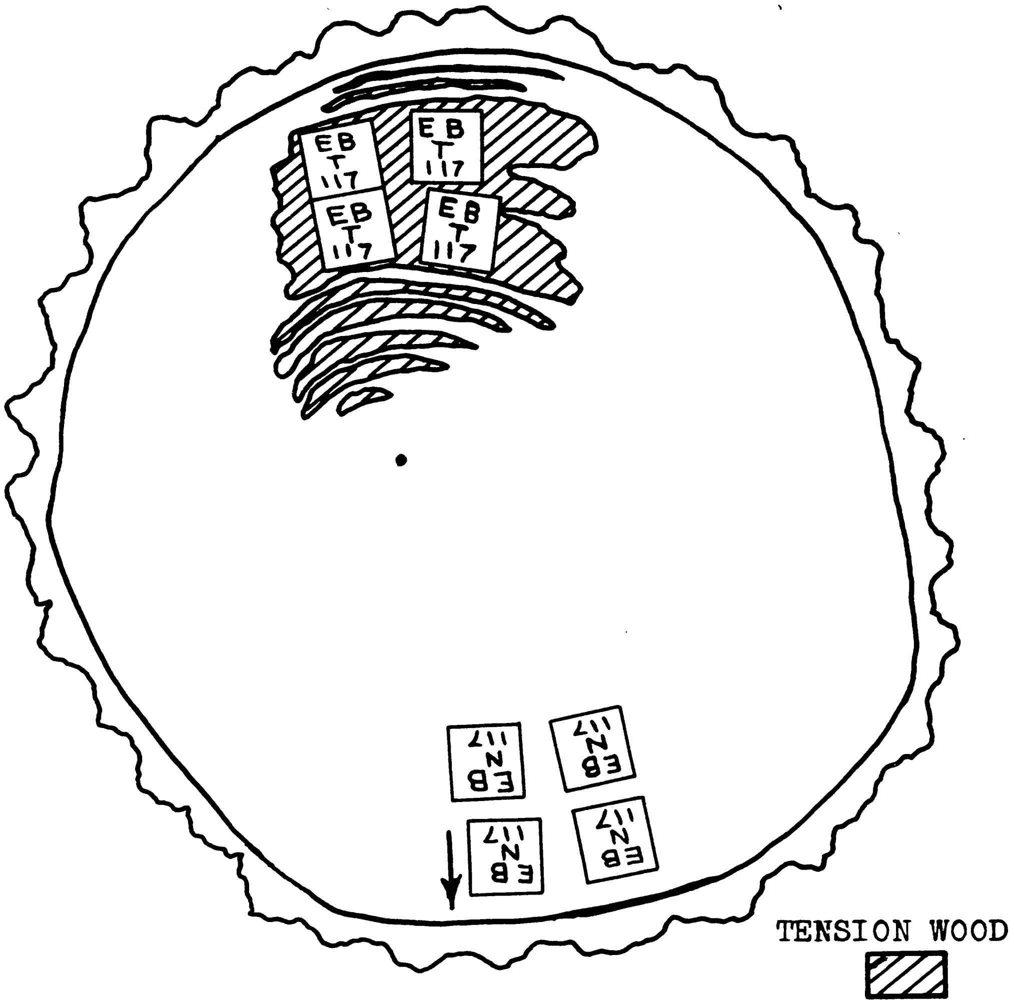


Figure 10.—Method of placement and marking of specimen blanks on disc cross-sectional surface.

The blanks from the upper side of the trees were generally very easy to distinguish from those on the opposite side; the tension wood pieces being fuzzy while the remainder were smooth (see Fig. 11). The fuzziness varied from a moderate amount to such an extent that it covered the entire piece. This woolly condition tended to be more intense on radial surfaces.

Shaping the Specimens The rough cut specimen blanks were carefully inspected; those containing knots, wavey grain, excessive cross grain, and any other obvious defects were discarded. The accepted blanks were allowed to season for several weeks. As their moisture approached 15 percent, approximately one third of the pieces were placed in the constant temperature and humidity room in which the conditions were controled for a calculated equilibrium moisture content of 15 percent. The remainder were allowed to season longer and were then placed in another room to obtain a moisture content of approximately 9 percent.

At this time the final cross-sectional dimensions were determined. The original measurments of the green pieces had decreased slightly due to shrinkage but the primary factor involved was slight cross grain that had been previously accepted. Straight grained

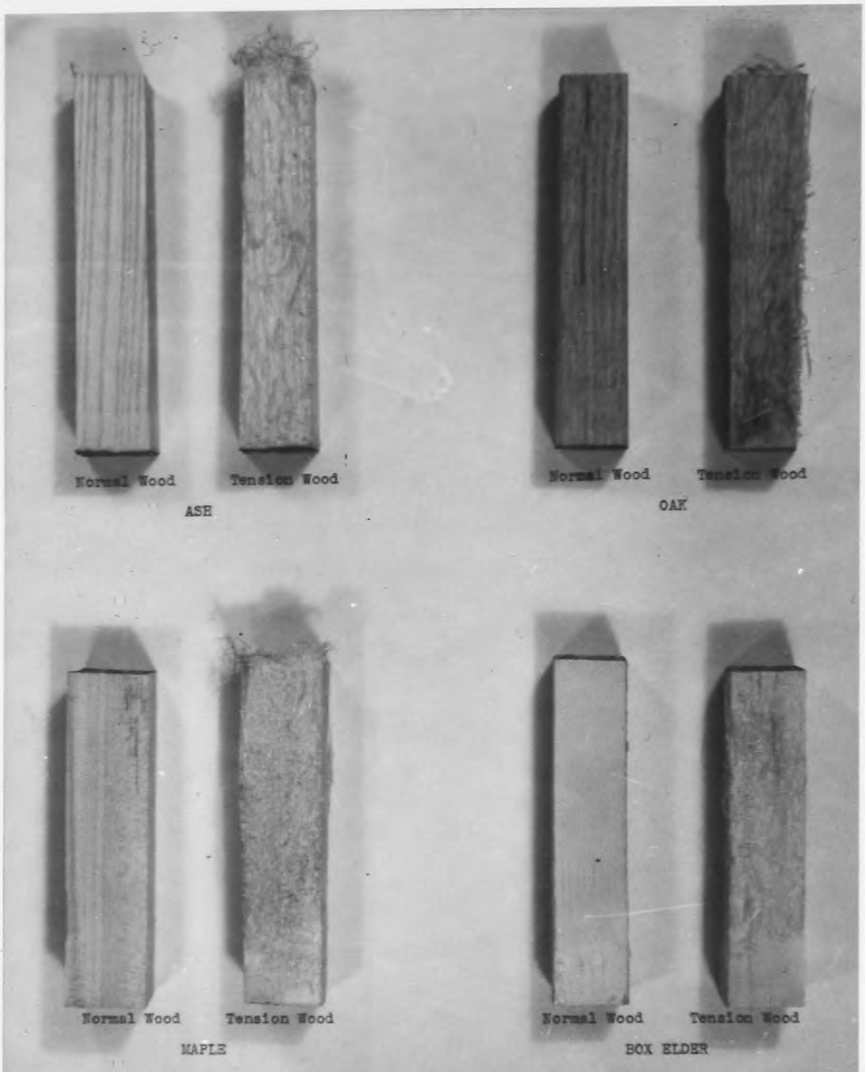


FIGURE 11.— Typical rough-cut specimen blanks showing the contrasting surface conditions of normal wood and tension wood. The pieces in each pair were sawn from opposite sides of the same disc.

specimens could be obtained by removing wood from opposite ends of opposite sides. It was found that by machining the specimens to 0.6 inch width and thickness a balance could be formed whereby it was possible to obtain the maximum number of test pieces and at the same time have these pieces as large as possible. The machining was performed on a disc sander in such a manner as to produce parallel opposite surfaces and right angles where adjacent surfaces met.

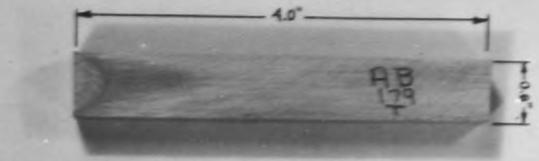
Using the same slenderness ratio, four to one, as is used in performing standard compressive strength tests at the United States Forest Products Laboratory at Madison, Wisconsin (14), the final dimensions for the compression specimens became 0.6 by 0.6 by 2.4 inches. When trial specimens with a 15 percent moisture content were tested, however, it was found that bending stresses developed. This difficulty was overcome by reducing the slenderness ratio to three to one. All the compressive specimens were cut to a length of 1.8 inches.

The shrinkage specimens were made 4.0 inches long in order that the available linear shrinkage micrometer might be used to measure the change in length. The same specimens that were used to determine the longitudinal shrinkage would serve for specific gravity determinations.

The dimensions for the tensile specimens were more difficult to determine than for the other specimens. Although the logs were marked to produce discs six inches thick for the tensile pieces, it was found that the length that would include all the specimens was 5.5 inches. It was obvious that specifications for standard tension parallel to grain test specimens (14) could not be reduced to such a short length, therefore, it was necessary to design a specimen that could be produced from blanks 5.5 inches long on the available machinery and tested with equipment that might be devised.

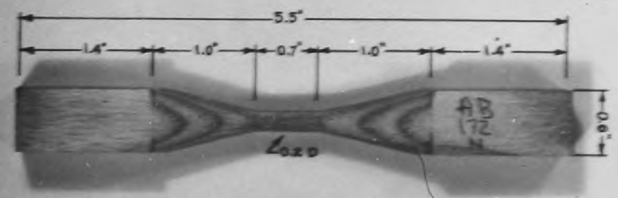
In order to obtain a small area in which to concentrate the load it was decided that turning the specimens on a lathe would produce the best results. The small section in the center was made 0.7 inch long with a diameter of 0.2 inch (see Fig. 12).

No noticeable differences were observed between tension wood and normal wood during the sanding operation. A contrast was evident, however, when the specimens were cut to length. The normal wood pieces were cut cleanly but the tension wood specimens had a pronounced burr on the edge. This occurred only where the saw was cutting as it came out of the



SPECIMEN FOR LONGITUDINAL SHRINKAGE AND SPECIFIC GRAVITY DETERMINATIONS

SPECIMEN FOR COMPRESSION PARALLEL TO GRAIN TEST



SPECIMEN FOR TENSION PARALLEL TO GRAIN TEST

FIGURE 12.—Dimensions of test specimens. The depth of the three pieces is 0.6 inch.

wood and was, therefore, prominent on two edges. The remaining two edges were smooth. It is regrettable that no definite observations were made concerning the turning characteristics of the two woods.

EXPERIMENTAL

Longitudinal Shrinkage Determination

After having been thoroughly conditioned in the constant temperature and humidity room to a moisture content of approximately 15 percent, the length of the shrinkage specimens was measured to one thousandth of an inch by means of a linear shrinkage micrometer. The specimens were weighed to one thousandth of a gram and then placed in a drying oven in which the temperature was maintained at approximately 215 degrees Fahrenheit. When their weight became constant, the pieces were weighed and measured once more. From the results obtained the moisture content and percentage of longitudinal shrinkage were determined by the following formulas:

$$\text{Moisture content} = \frac{\text{Original weight} - \text{Oven-dry weight}}{\text{Oven-dry weight}} \times 100$$

The moisture content thus obtained was expressed as a percentage of the oven-dry weight.

$$\begin{array}{c}\text{Longitudinal}\\ \text{shrinkage}\end{array} = \frac{\text{Original length} - \text{Oven-dry length}}{\text{Original length}} \times 100$$

The shrinkage thus obtained was expressed as a percentage of the original length (see Table 2).

Specific Gravity Determination

The oven-dry specimens obtained from the shrinkage determinations were used to determine the specific gravity. The specimens were dipped quickly in hot paraffin and reweighed in order to calculate the amount of paraffin on each piece. To determine the volume of the specimens, a container of water was placed on one pan of a balance and weights were added to the opposite pan until both were in equilibrium. By means of a small metal rod, the paraffin-coated specimens were immersed in the water causing more weights to be added to the weighted pan in order to maintain the original state of equilibrium. The increase in weight represented both the weight and the volume of the water displaced by the specimens.

It was found that 0.97 was the specific gravity of the paraffin used, but since a portion of the rod also displaced a small amount of water it was assumed that 1.0 might be considered as the specific gravity of the paraffin. Therefore, the volume of wood in each specimen was calculated by subtracting the weight of paraffin from the weight of the displaced water. Due to the small size of the specimens, it is believed that this method of correcting the indicated volume gave more accurate results than could be obtained from the usual procedure of disregarding the addition of paraffin on the specimen.

The specific gravity was determined by the following formula:

$$\text{Specific gravity} = \frac{\text{Weight in grams}}{\text{Volume in cubic centimeters}}$$

The specific gravities as determined by the above method were based upon volume oven-dry and weight oven-dry (see Table 2).

Compression Parallel to Grain Test

The compressive strength parallel to grain was determined for tension wood and normal wood from each tree at moisture contents of approximately 9 and 15 percent. The testing was performed on the Riehle 60,000 pound universal testing machine using a head speed of 0.011 inch per minute. Though this speed was not in proportion to that used in standard tests because of the very small specimens used, it was the slowest that could be obtained with the machine used.

Several methods of employing ball-and-socket attachments to insure uniform distribution of stresses were attempted without success. It was found that the best results were obtained by machining both ends of the specimens very accurately on a disc sander and using stationary plates on the head and table of the testing machine (see Fig. 13).

Prior to testing, the average cross-sectional dimensions of the specimens were measured by micrometer. The tests were carried out to failure with the maximum load and type of failure being recorded. The maximum crushing strength was obtained by the following formula:

$$\text{Maximum crushing strength} = \frac{\text{Maximum load in pounds}}{\text{Area in square inches}}$$

The results thus obtained are presented in Tables 2 and 3. Because of the small number of specimens available, the maple was tested at 9 percent moisture content so that the results would be more useful.

Tension Parallel to Grain Test

Because of the large number of rejects due to defects and to breakage in machining the specimens, it was decided that the tension specimens remaining should be tested at a moisture content of approximately 9 percent in order that the results would be of more practical value.

The testing was performed on the Riehle 60,000 pound universal testing machine using a head speed of

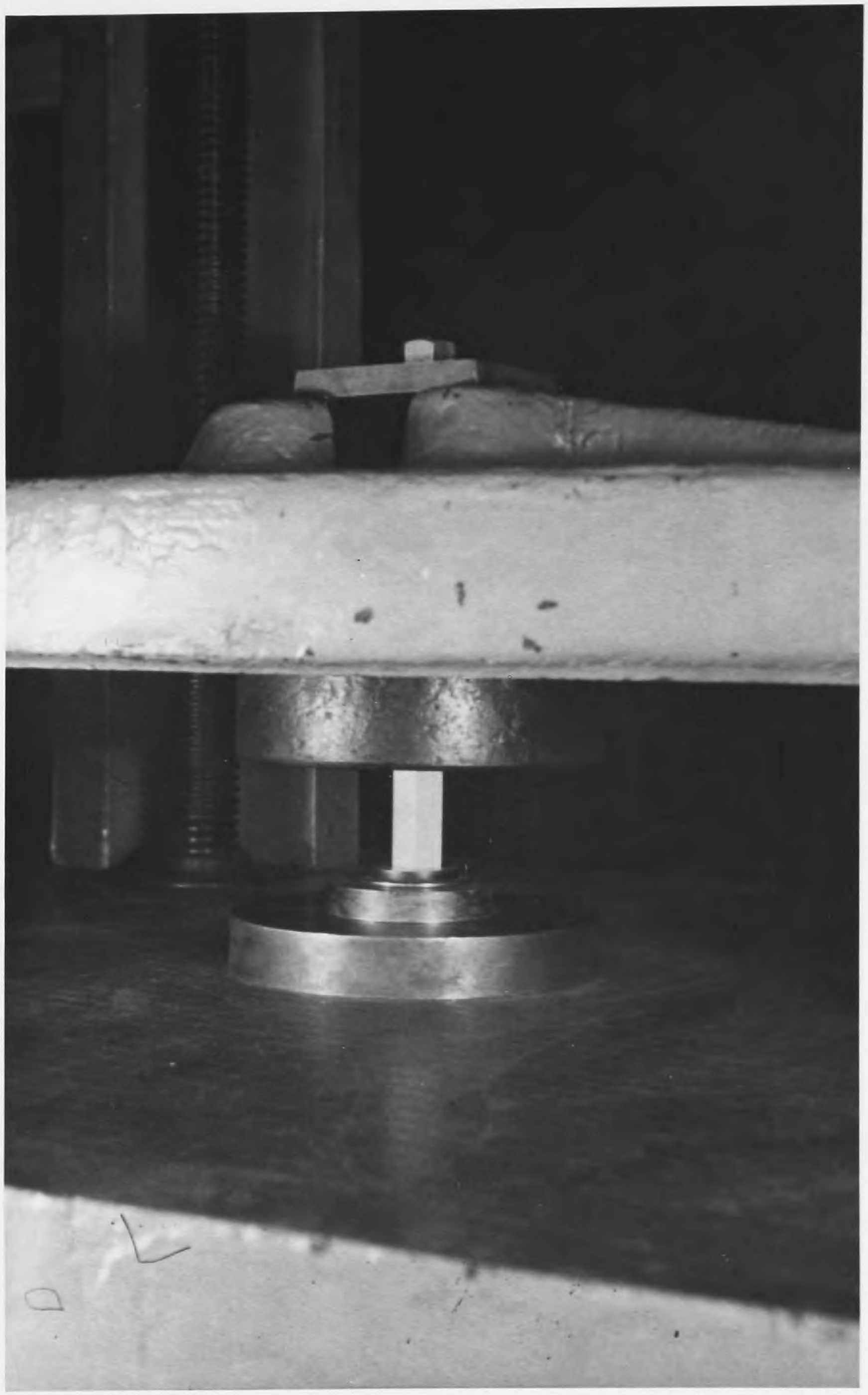


Figure 13.—Method of performing compression parallel to grain test.

approximately 0.011 inch per minute. In order to employ ball-and-socket action in the testing of the specimens, an apparatus was devised whereby the jaws and grips from a Dillon Model K Universal Tester could be used (see Fig. 14). Wood hand clamps were used to restrict the movement of the jaws rather than the customary metal ring which confined the maximum opening to less than the 0.6 inch necessary to accomodate the specimens.

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Prior to testing, the smallest average diameter of the narrow section of the specimens was measured by micrometer. The tests were carried out to failure with the maximum load being recorded. The maximum strength in pounds per square inch was determined by the formula as described in the preceding section (see Table 3).

Because of poor design, the tension specimens tended to fail in shear parallel to grain rather than in tension parallel to grain. The shear failure caused a cone-shaped piece of wood, a continuation of the section with the reduced diameter, to be removed from one end of the specimen. The number of failures of this kind was not extensive in specimens from both ash trees, but the presence of such a condition undoubtedly had some effect upon the results. All failures of the box elder specimens, however, were shear. Often the

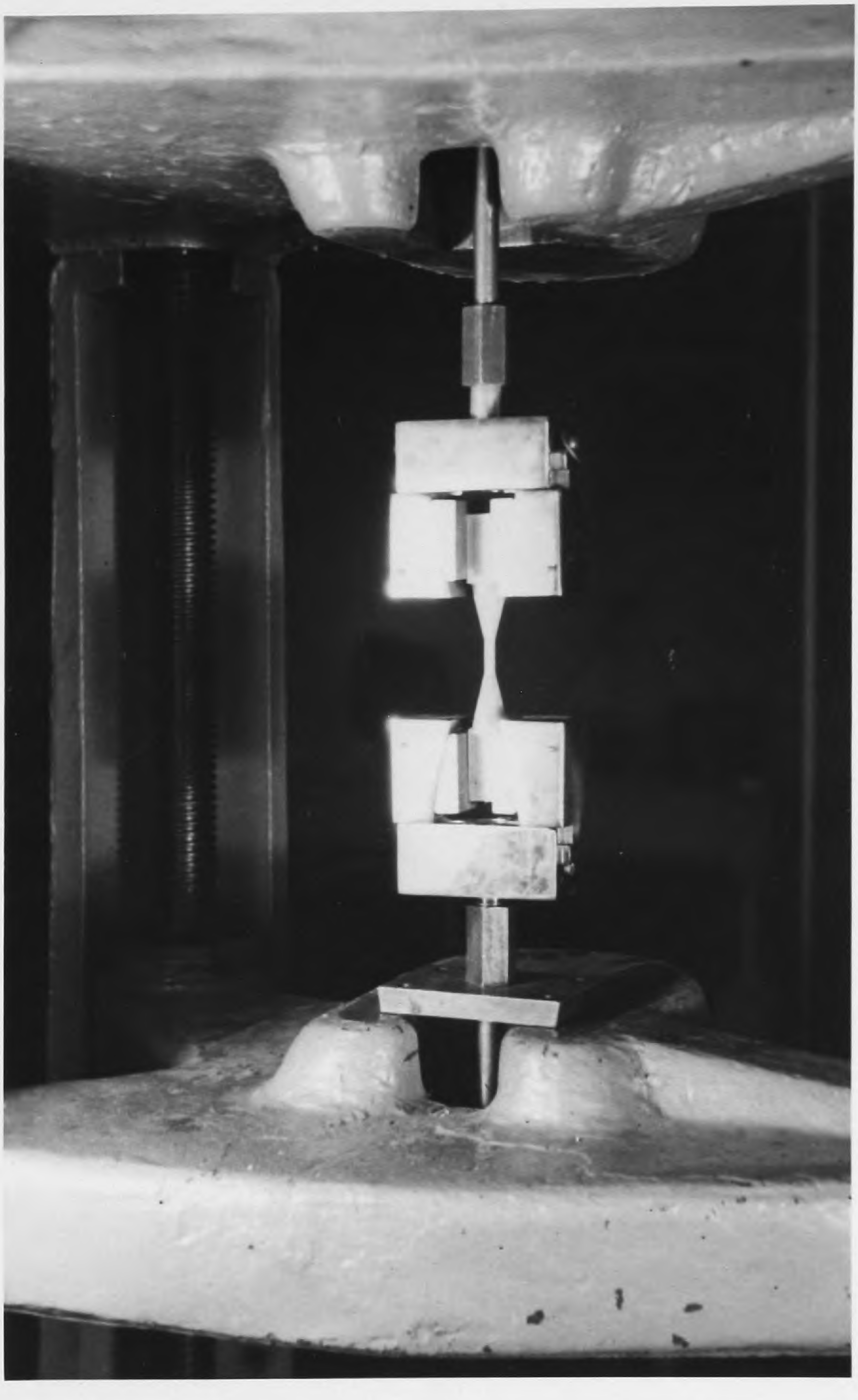

Figure 14.—Method of performing tension parallel to grain test. Wood hand clamps, not shown in photograph, restrict movement of jaws.

length of the slender cone of wood was so great that the removal of the cone left a hole completely through the center of the enlarged portion of the specimen. The length of the shear area was, therefore, 2.4 inches.

Because of the prevalence of shear failures, this test could not be considered as a true tension test. It did indicate that the average tensile strength parallel to grain was considerably greater than the average shear strength parallel to grain (see Table 3).

Microscopic Examination[5]

Specimens of tension wood approximately one quarter inch square and half an inch long were boiled in water until they became quite soft and tended to be somewhat rubbery. Cross-sectional slices approximately eighteen microns in thickness were cut from the ends of the softened specimens by means of a microtome.

After a twenty minute immersion in hematoxylin solution, the sections were washed in a series of alcohol solutions whose concentrations progressed from 50 percent to absolute alcohol. Following a final wash in xylene, the sections were mounted in balsam on a glass slide to be studied under a microscope. A solution of chlor-zinc-iodide was prepared as an

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5. Performed by Mr. Lino Tato.

alternate stain to check the results of hematoxylin if any uncertainty should arise.

RESULTS

It has been established that tension wood may occur in northern red oak, box elder, white ash, and hard maple. It may be considered that pignut hickory can also contain this abnormal wood. In the eight trees that were studied and the one tree of hickory that gave a positive stain reaction, the tension wood occurred on the upper side of the trunk which was the side with the greatest growth.

Phloroglucinol in 12 percent hydrochloric acid and chlor-zinc-iodide were effective macroscopic stains for indicating the presence of tension wood. Chlor-zinc-iodide reacted best on oak, maple, and hickory; phloroglucinol gave the best reaction on box elder and ash.

Tension wood was easily distinguished from normal wood by its fuzzy or woolly surface condition after having been machined by a saw. This contrast was much more prominent after ripping than after cutting across the grain.

The color and luster of tension wood were different than that of normal wood. Generally tension wood was more lusterous and its color ranged from darker to lighter than that of normal wood.

No conclusive information was obtained concerning the specific gravity of tension wood. In the six trees with the lowest average specific gravity, the specific gravity of the tension wood from each tree was as high or slightly higher than that of the normal wood from the same tree. The normal wood from both maple trees, however, had a greater specific gravity than the tension wood (see Table 2). It was considered that the results of this test, with the exception of box elder B and maple B, were not definite enough to be of any practical value other than indicating that the specific gravity of tension wood is generally greater than that of normal wood, particularly in the lighter woods.

The longitudinal shrinkage determinations provided definite evidence that tension wood shrinks much more along the grain than does normal wood. The maximum average shrinkage of tension wood was 0.54 percent whereas the greatest average shrinkage of normal wood was only 0.33 percent (see Table 2). The shrinkage of tension wood exceeded that of normal wood by a low of approximately 41 percent in oak A up to a high of 187 percent in maple B.

When tension wood and normal wood specimens with a moisture content of 15 percent were subjected to the

TABLE 2

Average Results of Tests Performed on Tension Wood and Normal Wood at 15 Percent Moisture Content

SPECIES	TREE DESIGNATION	TENSION WOOD			NORMAL WOOD		
		SPECIFIC GRAVITY[1]	LONGITUDINAL SHRINKAGE[2] (Percent)	MAXIMUM CRUSHING STRENGTH PARALLEL TO GRAIN[3] (Lb. per sq. in.)	SPECIFIC GRAVITY[1]	LONGITUDINAL SHRINKAGE[2] (Percent)	MAXIMUM CRUSHING STRENGTH PARALLEL TO GRAIN[3] (Lb. per sq. in.)
Red oak	A	.710	.45	4,876	.710	.32	5,391
Red oak	B	.656	.44	4,879	.631	.30	5,287
Box elder	A	.520	.54	4,757	.517	.27	5,155
Box elder	B	.561	.47	5,036	.502	.33	5,264
White ash	A	.660	.41	5,417	.660	.24	5,671
White ash	B	.737	.35	5,943	.712	.24	6,148
Hard maple	A	.730	.40	--	.745	.19	--
Hard maple	B	.725	.46	--	.787	.16	--

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1. Specific gravity based on volume oven-dry and weight oven-dry.

2. Longitudinal shrinkage from approximately 15.5 percent moisture content to oven-dry.

3. Maximum crushing strength parallel to grain adjusted to 15 percent moisture content.

TABLE 3

Average Results of Compression and Tension Tests Performed on Tension Wood and Normal Wood at 9 percent Moisture Content

SPECIES	TREE DESIGNATION	TENSION WOOD			NORMAL WOOD		
		MAXIMUM CRUSHING STRENGTH PARALLEL TO GRAIN[1]	MAXIMUM TENSILE STRENGTH PARALLEL TO GRAIN[2]		MAXIMUM CRUSHING STRENGTH PARALLEL TO GRAIN[1]	MAXIMUM TENSILE STRENGTH PARALLEL TO GRAIN[2]	
		(Lb. per sq. in.)	Stress (Lb. per sq. in.)	Moisture Content (Percent)	(Lb. per sq. in.)	Stress (Lb. per sq. in.)	Moisture Content (Percent)
Red Oak	A	7,893	--	--	7,559	--	--
Red Oak	B	7,581	--	--	7,287	--	--
Box elder	A	6,615	--	--	6,810	--	--
Box elder	B	6,880	19,954	10.7	6,915	16,762	10.8
White ash	A	7,716	23,767	10.2	7,756	18,138	10.2
White ash	B	9,189	23,733	10.5	9,442	16,221	10.4
Hard maple	A	7,938	--	--	9,802	--	--
Hard maple	B	8,716	--	--	10,240	--	--

1. Maximum crushing strength parallel to grain adjusted to 9 percent moisture content.

2. Because no method of moisture-strength adjustment was available the actual average moisture contents were entered in the table.

compression parallel to grain test, it was found that in the six trees studied the maximum crushing strength of tension wood was lower than that of normal wood. (see Table 2). The greatest difference occurred in oak A where the normal wood was approximately 11 percent stronger than the tension wood. In oak B and box elder A the difference was more than eight percent. Unfortunately, the lack of test specimens prevented testing maple. A study of the average strengths of normal and tension wood indicated that there was a definite tendency for the maximum crushing strength of both types of woods to increase slightly with an increase in the height of growth in the tree.

The compression parallel to grain test performed on specimens with a moisture content of 9 percent indicated that the maximum crushing strength of normal wood was again generally greater than that of tension wood although the difference in strength was somewhat less noticeable than when tested at 15 percent (see Table 3). Tension wood from oak A and B was found to be stronger at a 9 percent moisture content than normal wood. The normal wood of the remaining six trees was stronger. The strength of the normal wood exceeded that of the tension wood by 25 percent in maple A and by 17 percent in maple B.

There is no definite explanation why the tension wood from oak A and B was stronger than the normal wood. Dadswell (7) and Ingle (10) state that the difference in the maximum crushing strength of tension wood and normal wood when tested green is very great, but at 15 percent moisture content it was considerably less. Perhaps this condition continues as the moisture content decreases until the strength of both woods is the same. Based upon that dubious assumption, the increase in strength of the tension wood from oak might be attributed to the hardening of the jelly-like substance that nearly fills the lumen of the gelatinous fibers.

As explained before, the tension parallel to grain test tended to develope shear strength parallel to grain rather than tensile strength. For box elder the strength indicated in Table 3 is definitely shear strength. The results of the test indicated, however, that the shear strength of tension wood is greater than that of normal wood. The strengths obtained from subjecting specimens of ash to the test were primarily tension parallel to grain. The tension wood from ash A was 31 percent stronger and that from ash B was 46 percent stronger than the normal wood from the same trees.

It was unfortunate that the design of the specimens was such that the tendency to fail in shear rather than in tension was so strong. The only corrective measure would have been to obtain longer specimens though that was almost impossible. Further reduction of the diameter of the narrow portion of the specimen would have increased the possibility of error particularly since some of the trees had growth rings that were wider than the tension area of the specimen would have been.

The microscopic examination of stained sections from the four species revealed that gelatinous fibers are definitely associated with tension wood. The hematoxylin solution produced excellent staining reactions in oak and box elder; its reactions in maple and ash were somewhat less distinct. The color reactions of gelatinous fiber walls were as follows: (1) middle lamella dark purple to black, (2) secondary wall unstained, and (3) tertiary wall purple. The gelatinous tertiary wall was generally attached to the secondary wall although sometimes they were separated around part of the cell. Often the cell lumen was of irregular outline as though the gelatinous layer had developed bulges and folds due to swelling.

Because this examination was not extensive, no attempt was made to associate the number of gelatinous fibers in a unit area with the properties of that area.

The descriptions that follow pertain only to the sections that were prepared and studied under a microscope and not to the entire tension wood area from each tree. Gelatinous fibers in oak were larger and more numerous than in the other three woods. The tertiary walls were several times as thick as the secondary walls and the lumina were reduced to small holes. In maple and ash the tertiary walls were not as thick as in oak. Gelatinous fibers in the sections of box elder were widesly scattered and the tertiary walls were quite thin.

Based upon those observations and the results of the physical and mechanical tests, it has been assumed that the intensity of tension wood, in the same manner as that of compression wood, varies from negligible to a very great amount. The intensity is dependent upon the concentration of gelatinous fibers, the degree to which the gelatinous tertiary wall has been formed, and the size of the tension wood area. These factors are controlled by environmental conditions during the life of the tree.

SUMMARY

Tension wood was found by staining cross-sectional discs that had been cut from the trunks of eight leaning hardwood trees. Specimens sawn from the tension wood area and from the opposite side of the disc were subjected to compression parallel to grain tests at moisture contents of 15 percent and 9 percent, and tension parallel to grain tests at 9 percent moisture content. Specific gravity and longitudinal shrinkage determinations were also made. The results of these tests indicated that those physical and mechanical properties studied are generally not alike in both types of wood. The following is a summary of the results of observations and tests performed in this study:

1. When tested at 15 percent moisture content, tension wood was lower in maximum crushing strength than normal wood. With the exception of oak, tension wood was also weaker at 9 percent moisture content.
2. Although the tension parallel to grain test was not very accurate, it was observed that

the tension wood in the two species tested was stronger in tension parallel to grain and in shear parallel to grain when loaded in tension.

3. Tension wood shrank more along the grain than normal wood.
4. The specific gravity of tension wood from the six trees of lowest weight per cubic foot was the same or greater than normal wood, whereas the normal wood in maple had a higher specific gravity.
5. Gelatinous fibers were found to be associated with tension wood.
6. Chlor-zinc-iodide and phloroglucinol in 12% hydrochloric acid were effective stains in indicating the presence of tension wood on freshly sawn cross-sectional discs.
7. The difference in luster and color and the woolly surface condition generally made tension wood easily distinguishable from normal wood.

CONCLUSIONS

This comparative study of the properties of tension wood and normal wood from four American hardwoods has revealed that, although the properties that were tested differed in the two dissimilar types of wood, the differences were generally not great enough to be of much practical importance. In this problem the tests and determinations were performed on specimens that were either completely tension wood or completely normal wood. It is unlikely that in the general use of wood a piece of pure tension wood would ever be produced. However, in light construction with low factors of safety and in which strength was of major importance, tension wood would undoubtedly be an undesirable element. In ordinary sizes of boards there would generally be enough normal wood to tend to decrease the detrimental effect of the tension wood present.

In view of the fact that well designed structures have high safety factors and that in ordinary construction over-size pieces of wood are generally used because of custom or style, it appears that the shrinkage of tension wood might be its greatest disadvantage. Although the longitudinal shrinkage of tension wood was considerably greater than that of normal wood, its shrinkage remained small compared with normal radial and tangential shrinkages. However, a board with tension wood on one edge or side and normal wood on the opposite would undoubtedly warp in drying. The amount of distortion and weakness that could be permitted would naturally depend upon the manner in which the piece would be used. Wood containing tension wood should be thoroughly dried before being machined or utilized so that further shrinkage would not take place. Tension wood would be undesirable in light plywood construction using adhesives which would raise the moisture content of the wood to the extent that stresses would develope in the redrying and conditioning processes.

The woodworking properties of tension wood may possibly be considered as defects though further studies remain to be made concerning these characteristics. The exceedingly woolly surface observed in this problem occurred on green wood when sawn parallel to the grain. As the moisture content lowered, the amount of fuzziness produced in sawing was also decreased. It is believed that when machined in the seasoned condition, the surface will be smooth enough that only light sanding will be necessary to obtain a surface fit for furniture. However, in the manufacture of veneers in which high moisture contents are necessary to facilitate cutting, the woolly condition described by Baudendistel and Akins (3) definitely produces a poor product. It is also possible that weak glue joints would be formed because of reduced mechanical adhesion due to the tertiary wall considerably reducing the size of the cell cavity. It is also possible that machining will separate the gelatinous layer from the secondary wall causing it to be loose and further weaken the mechanical adhesion.

Perhaps someday tension wood may be used to advantage as shear and tension members.

It must be remembered that the trees studied in this project were not of merchantable size and that larger leaning trees would have correspondingly larger areas of tension wood. This study has indicated that tension wood may occur in any degree of intensity and since the results obtained were averaged for each entire tree, the figures in Tables 1 and 2 cannot be considered as representative but rather as indicative. That is to say, if many trees had been examined and the trees with the greatest amount of tension wood studied thoroughly, the results from tests upon those trees would better represent the abnormal properties of tension wood. This line of thought is necessary since tension wood is an inconspicuous defect and much more needs to be known about the extreme cases. It is safe to conclude that after more extensive studies have been made, wood from leaning hardwoods will be treated with the same caution as is now being given to wood from leaning coniferous trees. Where strength, with the possible exception of shear and tension parallel to grain, is of primary importance wood containing more than a slight amount of tension wood should be eliminated.

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