LONGITUDINAL SHRINKAGE OF WOOD

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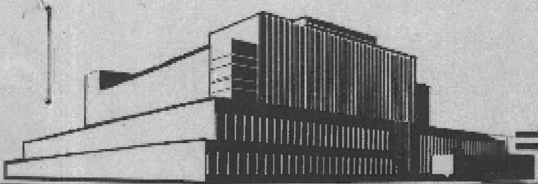

FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

LONGITUDINAL SHRINKAGE OF WOOD[1]

Forest Products Laboratory,[2] Forest Service
U.S. Department of Agriculture

Longitudinal shrinkage of wood ordinarily is so small as to be considered negligible, and, as a rule, no allowance is made for it. It has been found in investigations at the Forest Products Laboratory that there are certain types of abnormal wood, however, which shrink excessively along the grain and may cause serious trouble.

Shrinkage along the grain may be considered excessive under the following conditions:

(1) When it causes undue shortening in length so as to throw adjoining members into serious disalinement, as in posts and columns in buildings and in lookout and radio towers, and opening of butt joints, as in flooring and siding.

(2) When it causes crook, bow, twist, or cross breaks in lumber or waviness in veneer because of unequal shrinkage.

(3) When it causes stresses in lumber that result either in pinching of the saw in ripping or crosscutting, or in longitudinal cracking of boards in ripping or machine planing.

Variation in Longitudinal Shrinkage

The longitudinal shrinkage of wood normally ranges from 0.1 to 0.3 of 1 percent. (Unless otherwise stated, all shrinkage values given in this paper represent the total shrinkage from the green or soaked to the oven-dry conditions; that is, a condition of zero moisture content. In drying to an average air-dry condition of about 12 percent, the shrinkage would be about one-half as much.)

Cases have been observed in which the shrinkage along the grain was extremely large. The greatest longitudinal shrinkage so far recorded at the Forest Products Laboratory is 5.78 percent in wood from the lower side of a vigorous limb of ponderosa pine. This is more than the average

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[1]Original report dated August 18, 1930.

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

transverse shrinkage for the species. It is equivalent to a shortening of 11.1 inches in a 16-foot board. On the other extreme, slight elongation has been observed in certain woods in drying.

Figure 1 gives shrinkage values for 30 different kinds or types of wood at 3 different percentages of moisture content; namely, about 12 percent, about 7 percent, and at 0 percent. Shrinkage was assumed to have begun at a moisture content of 30 percent, which was taken as an average fiber-saturation point. Different types of wood were selected so as to give as wide a variation in shrinkage as possible; consequently, the values given in figure 1 are intended to represent averages for any species (4).[3]

No sharp limits can be set above which longitudinal shrinkage in wood may be called excessive. A total uniform shrinkage potential of 0.3 percent, however, is near the maximum permissible for most uses. Such a shrinkage would cause a shortening of 0.58 inch in a 16-foot board if it was ovendried. Fortunately, the shrinkage of most wood falls below this limit. If the longitudinal shrinkage is not uniform from side to side, an even smaller shrinkage may be objectionable, however, because of the curvature that it may produce.

Cause of Variation in Longitudinal Shrinkage

Optical, X-ray, and shrinkage phenomena indicate that the major portion of the cell walls of wood and numerous other plant materials is made up of relatively long cellulose molecules grouped together into micellar strands more or less parallel to each other but somewhat interlaced. These strands extend spirally around the cell cavity, as is indicated diagrammatically in figure 2. Individual cellulose molecules are very strongly held together within the strands by primary valences and less strongly to adjacent strands by secondary valences. Water absorbed by the cell walls is located between the micellar strands and, as the water leaves in drying, the strands draw closer together causing shrinkage of the cell walls and of the wood as a whole. Since the strands are many times as long as they are wide, the shrinkage is greatest at right angles to them and practically zero parallel to their longest dimension.

The slope that the spirally wound strands make with the long axis of the cells varies with different kinds of tissues and even in the same kind. For example, in commercial white ash trees grown under a variety of conditions, it has been found by microscopic examination to vary from between 5° and 15° in the summerwood fibers of upland trees to 35° in the summerwood from swelled butts of trees grown in periodically inundated

[3]Underlined numbers in parentheses refer to literature cited at the end of this report.

bottomlands. In the vessels, walls, or pores of hardwood species, the slope usually is greater than 45°. In normal summerwood of softwood species, the slope of the strands usually varies between 4° and 8° and in the springwood, between 20° and 25°; whereas in compression wood it ranges from 20° in summerwood to over 35° in springwood. With increasing slope of strands, the longitudinal shrinkage increases and the transverse shrinkage decreases, other things being equal. Springwood therefore tends to shrink more along the grain and less across the grain than summerwood, and certain types of abnormal wood shrink many times as much longitudinally as normal wood.

Although isolated fibers twist and untwist with changes in moisture content and presumably become longer as they dry out, in a piece of wood they are grown together tightly and cannot twist. In fact, so far as shrinkage is concerned, wood can more properly be regarded as being made of plates composed of two adjoining cell walls with the strands sloping in reverse directions in them, as at A in figure 2, the plates being securely fastened together all around.

Types of Wood in Which Excessive Longitudinal Shrinkage Occurs

Compression Wood and Tension Wood

Compression wood is a hard, heavy, brittle type of wood formed on the lower side of branches and leaning trunks of coniferous trees. It is characterized by rather wide annual rings containing wide summerwood that is not so dark and hornlike as in normal wood. Figure 3 shows a cross section of a pine log in which compression wood is well developed. Within any annual ring, compression wood is confined to one side of the pith; that is, it does not form continuously around the trunk during any year. It may be continuous from the pith to the bark in a sector, or it may occur in intermittent layers. In some annual rings it may be in one direction from the pith and in others in a different direction. Therefore, it frequently happens that boards or dimension stock have streaks of compression wood in them. Compression wood, having a greater tendency to shrink longitudinally than normal wood, usually causes bowing or crook of lumber in which it is unevenly distributed (fig. 4). Occasionally streaks of compression wood that adjoin normal wood will pull themselves apart so as to form tension breaks across the grain (fig. 5).

Compression wood is a source of considerable trouble in the drying and use of softwood lumber, principally on account of the bowing or crook which it produces. Sometimes the direct shortening causes trouble. For example, butt joints in redwood and cypress siding occasionally open up on account of the longitudinal shrinkage of compression wood in the siding (7) (fig. 6). If the siding is well dried before it is nailed down, however, there will be no occasion for any further excessive shrinkage to take place. No sharp line of distinction can be drawn between compression wood and normal wood; the two grade into each other imperceptably. Therefore, no fixed shrinkage value can be ascribed to compression wood. The maximum longitudinal shrinkage (5.78 percent) so far found in compression wood has already been given for wood from a limb of ponderosa pine. The maximum shrinkage so far determined for compression wood from a tree trunk is 5.42 percent in southern yellow pine. More often the shrinkage of compression wood is less than 1 percent but over 0.3 percent (10).

Tension wood is an abnormal type of wood formed on the upper side of branches and leaning trunks of hardwood trees. Like compression wood, it is characterized by relatively wide annual rings in a portion of the circumference. It is darker (or lighter) in appearance than normal wood and often causes saw cuts through it to be fuzzy. The longitudinal shrinkage of tension wood in English beech was found to range up to 1.7 percent of the green dimension when ovendried (1).

Just as with compression wood the longitudinal shrinkage of tension wood is highly variable. This is because of widely varying concentrations of the peculiar gelatinous fibers that characterize tension wood (fig. 7). As the relative numbers of gelatinous fibers increased from scattered ones to solid groupings, the longitudinal shrinkage also was found to increase in mahogany, aspen, and cottonwood lumber (11,12,13). In an eccentric cottonwood log from a leaning tree and containing tension wood on the side of the longest radius, it was found by an examination at the Laboratory that the shrinkage of the wood on that side varied from 0.16 to 1.55 percent. Tension wood is frequently responsible for bow and crook in lumber, waviness in veneers (fig. 8), and occasionally cross breaks as described and illustrated for compression wood (fig. 5).

Abnormally Lightweight Wood

Wood well below the average weight for a species shrinks more along the grain than heavier wood of the same species (4). This is shown in figure 1 for high- and low-density wood of longleaf pine (1 and 2), water tupelo (19 and 20), as (21 and 22), and for red oak of low density (26), which shrank over 0.8 percent. Figure 8, which shows the shrinkage of redwood of different specific gravities, clearly indicates a general trend toward a reduction in longitudinal shrinkage with an increase in specific gravity (4). All of the specimens represented in figure 9 above the 0.400 percent line consisted of compression wood. With this fact in mind, the downward trend of the remaining points, which represented normal wood almost entirely, is more apparent.

Even in balsa, which is an extremely light wood, the longitudinal shrinkage was found to vary inversely as the density. The average longitudinal shrinkage of balsa weighing from 12 to 15 pounds per cubic foot at 12 percent moisture content was found to be 0.18 percent, whereas that weighing 3 to 6 pounds per cubic foot when at the same moisture content had an average shrinkage of 0.37 percent. The complete range for individual specimens was from 0.105 to 0.634 percent of the length when soaked (8).

This peculiar relationship is due to the fact that in wood of normal weight the walls of most of the fibrous cells, or wood fibers, are constructed so that they do not shorten much in drying, as already explained; and since the wood fibers predominate, as a rule, they control the shrinkage of wood as a whole. In abnormally lightweight wood, however, either the wood fibers have a different type of structure or they are so scarce that the other kinds of cells predominate, particularly those that make up the vessels in hardwoods, which have a high longitudinal shrinkage potential.

The relationship between longitudinal shrinkage and density is just the opposite of what it is for transverse shrinkage and density; in general, the heavier the wood the more it shrinks across the grain. The relationship between density and shrinkage, whether longitudinal or transverse, results from the fact that the woods of low and high densities have different cellular structures, and not by the fact that there is a difference in the amount of wood substance present. It does not follow, however, that species of wood which normally are light in weight shrink more along the grain in general than heavy species of wood.

Springwood

In many species of wood each annual growth layer is differentiated into an inner, softer layer of low-density wood, springwood and an outer, harder layer of high-density wood, the summerwood. The springwood invariably shrinks more along the grain than the summerwood. This is easily demonstrated by whittling out of green wood with well-differentiated springwood and summerwood a splinter only one annual ring in thickness. Such splinters bow lengthwise of the grain as they dry, whereas splinters from wood in which the springwood and summerwood are not well differentiated, as basswood, remain straight or bow only slightly (6)(fig. 10).

The greater longitudinal shrinkage of springwood as compared with summerwood is indicated in figure 1 for southern yellow pine (3 and 4), abnormal southern yellow pine (5 and 6), Douglas-fir (7 and 8), and redwood (10 and 11). Figure 8 also shows that the specimens of redwood of lowest specific gravity, which consisted entirely of springwood, shrank considerably, whereas those of highest specific gravity, which consisted entirely of summerwood, shrank very little or even elongated. Figure 1 also shows that southern yellow pine summerwood (2) and Douglas-fir summerwood (6) elongated in intermediate drying stages. Elongation in the early stages of drying also has been observed in entire annual rings of western white pine (3), ponderosa pine (2), and some other species of wood.

Within a piece of wood several annual rings in width, the springwood, of course, cannot shrink more than the summerwood, since the two are so closely and alternately bound together. The difference in shrinkage potential, however, undoubtedly sets up some stresses in the wood.

In flat-grain lumber the greater longitudinal shrinkage of springwood frequently causes slivers to loosen and curve away from the surface, especially on the pith side (fig. 11). This condition, which occurs especially when the springwood has been crushed in planing with dull knives, frequently causes difficulty in flat-grain flooring. It can be largely avoided by using sharp knives and dressing pattern stock so that the face side is on the bark side of the piece; then the summerwood of each annual ring is toward the outside, and consequently the tendency of the annual rings to curve up is eliminated (6).

Rotary veneer occasionally happens to be cut so as to be one annual ring in thickness. Under such circumstances, any differences in shrinkage potential of springwood and summerwood may cause local curvature or undulations.

Wood Near the Pith of the Tree

Boards and planks of the southern yellow pine, ponderosa pine, and occasionally other species, which happen to be sawed lengthwise through the pith, frequently show cross breaks extending for a short distance at right angles to the pith. Such breaks are due to the greater longitudinal shrinkage of the wood near the pith. For this reason, narrow strips cut out so that the pith runs along one edge will bow or crook as they dry (2).

On the other hand, it has been reported that the wood on the bark side of some hardwood species shrinks more than the wood away from the bark and thereby causes bowing. The explanation probably is that the density of the wood in such pieces decreased toward the outside of the tree, as frequently is the case, and, as previously stated, low-density wood shrinks more longitudinally than that of high density of the same species.

Wood in Fast-Growing Conifers

In loblolly pine, slash pine, and redwood, relatively high longitudinal shrinkage has been found in second-growth trees with unusually wide annual rings containing summerwood that is not so dark and hard as in normal wood. Such wood resembles compression wood in some respects, but differs from it in extending entirely around the tree trunk and in some microscopic features. Wood of this type was found mostly in the butt portions of tree trunks. Probably it also occurs in other species than the ones mentioned. In loblolly and slash pine, particularly, it was found that when the annual rings are wider than one-fourth inch the longitudinal shrinkage usually is excessive (5,7,9) (fig. 12). At the Forest Products Laboratory edge-grain planks 12 feet long were cut from second-growth loblolly pine trees that had grown rapidly at first and later slowed down considerably. One cut edge was next to the pith and the other next to the bark. On drying to 10 percent moisture, these planks crooked so that maximum deviation from a straight line was 3.4 inches from end to end (fig. 13). The curvature was due to the greater longitudinal shrinkage of the wide-ringed wood near the center.

Cross-Grained Wood

In any piece of wood in which the grain does not run parallel with the long axis, there may be excessive apparent longitudinal shrinkage due to a transverse shrinkage component being effective along the length of the piece. If the grain ran at an angle of 45° across a board, it would shrink as much on a percentage basis along its length as in its width. Wood with spiral, diagonal, interlocked, wavy, or curly grain may have excessive apparent longitudinal shrinkage on account of the presence of cross grain. A knot along one edge of a narrow strip may cause bowing of the strip due to the cross grain which it produces.

Long Pieces of Wood

Although a long piece of wood should not shrink any more than a short one of the same kind on a percentage basis, the actual shrinkage is proportional to the length. The greatest shortening effect therefore would be expected in long boards, planks, timbers, or the like. The present tendency toward increased use of short lengths will help to break up the longitudinal shrinkage into smaller units, which will be particularly advantageous in keeping down the width of openings in butt joints in siding and flooring.

Relation of Longitudinal Shrinkage to Moisture Content

No attempt has been made by the author to determine the moisture content at which wood begins to shrink longitudinally in drying. It is hardly conceivable that it would be appreciably different from that at which transverse shrinkage occurs; namely, the fiber-saturation point, which averages about 30 percent moisture based on the moisture-free weight of the wood.

Although most of the points representing shrinkage for different percentages of moisture content in figure 1 are not in a straight line or characteristic type of curve for each kind of wood, they agree fairly well in pointing to about 30 percent as the moisture content at which shrinkage began.

Among the specimens of low shrinkage and elongation, there is a slight tendency to curvature in the shrinkage lines, indicating that the shrinkage rate increases and elongation decreases as the moisture content decreases. Some of the specimens showed no shrinkage; in fact some even elongated in the first and second stages of drying but, when all moisture was removed, they were shorter than when wet.

Summary

The longitudinal shrinkage of normal wood is so small as to be negligible for most uses. Certain types of abnormal wood, however, shrink and swell excessively along the grain, causing objectionable changes in the length of pieces, bowing, crooking, transverse breaks, opening of butt joints, and internal stresses.

Longitudinal shrinkage, like transverse shrinkage, depends on the change in moisture content below the fiber-saturation point. If wood is dried so that it will not change a great deal in moisture content when used, then it will not shrink or swell appreciably along the grain, no matter how abnormal its shrinkage potential may be. For uses in which the wood becomes alternately wet and dry, previous drying, of course, does not prevent subsequent changes in dimensions with changes in moisture content.

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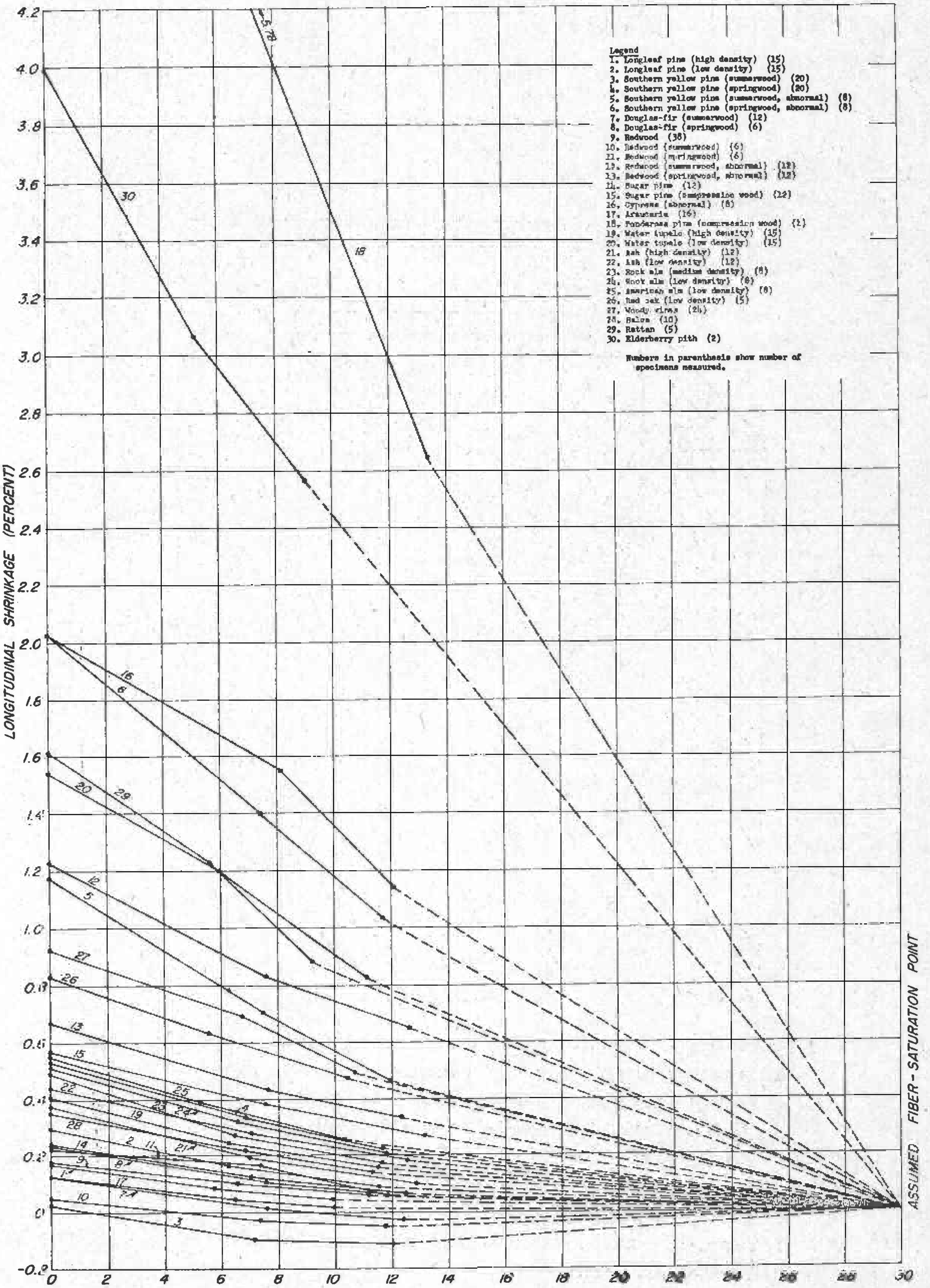

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Figure 1. --Shrinkage values for 30 species of wood at 0 percent, 7 percent, and 12 percent moisture content.

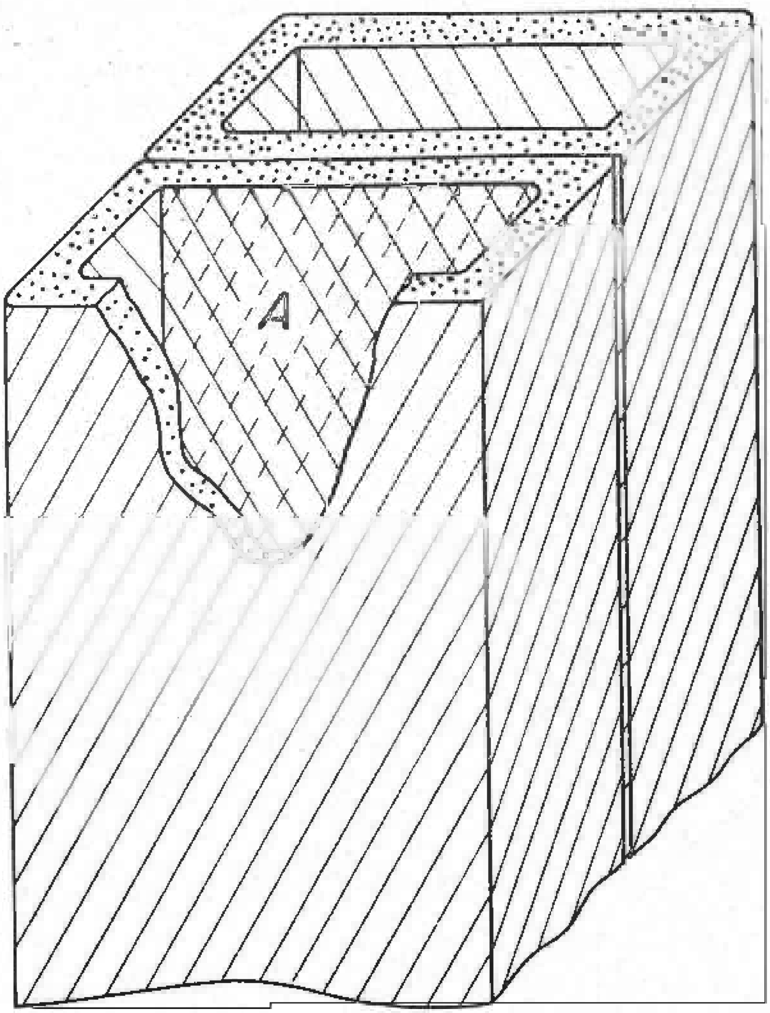

Figure 2. --Diagrammatic drawing of portions of two adjacent fibers showing micellar strands of cellulose as dots in the cross sections and as lines on the longitudinal walls. In the double wall between two fiber cavities, as at A, the strands slope in reverse directions, and the effective component shrinkage of the combined walls determines the extent of shrinkage of wood in different directions.

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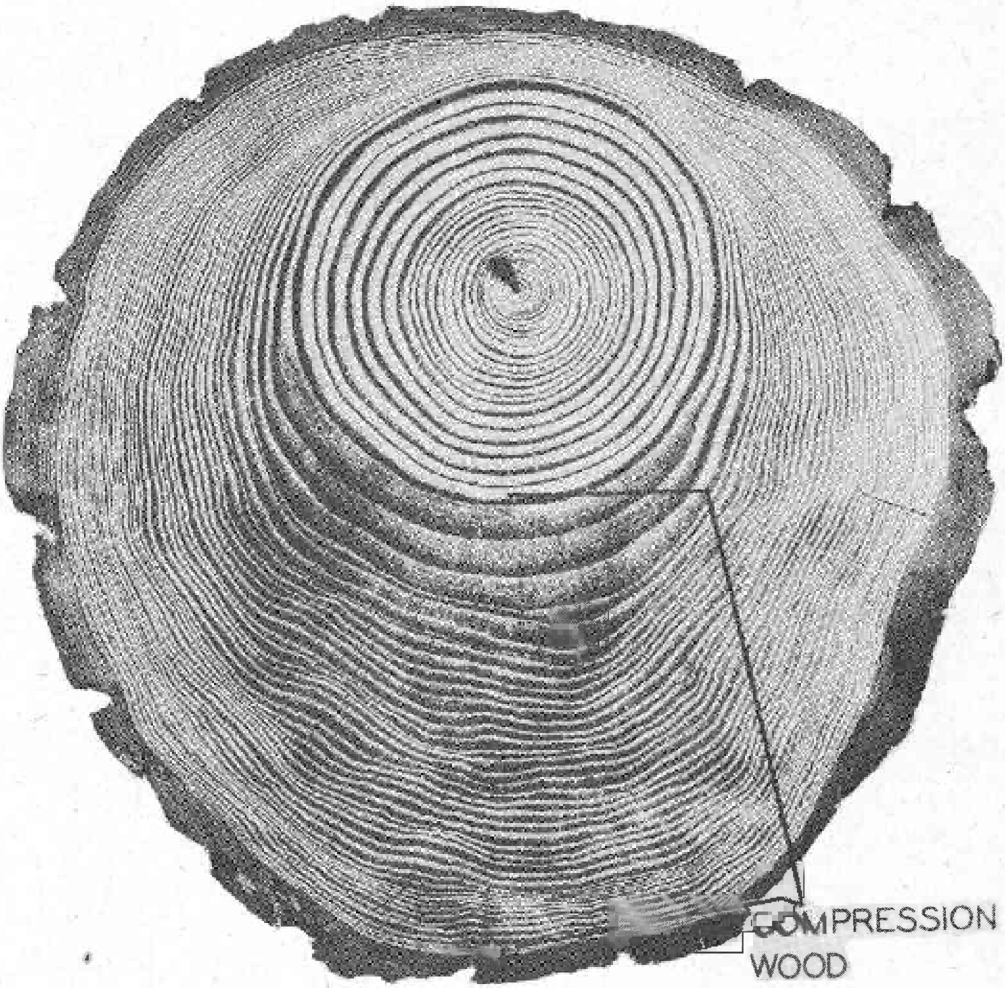

Figure 3.--Compression wood in a cross section of a loblolly pine log which grew vertically 24 years and then became inclined.

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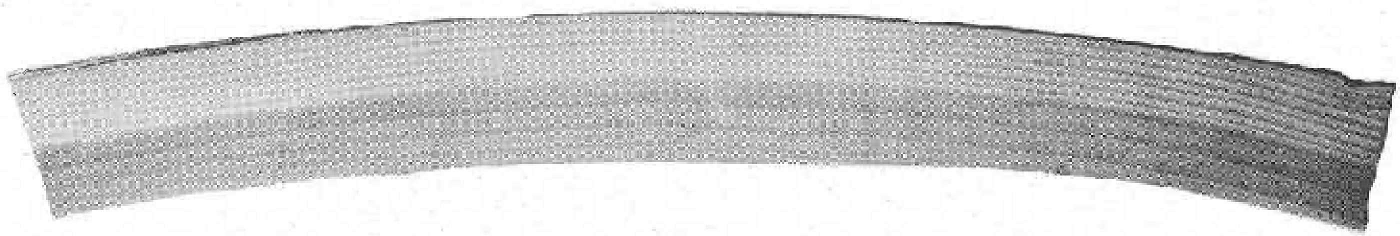

Figure 4.--Crook of loblolly pine slat as a result of excessive shrinkage of compression wood (darker portion) adjacent to normal wood. The piece was straight when green.

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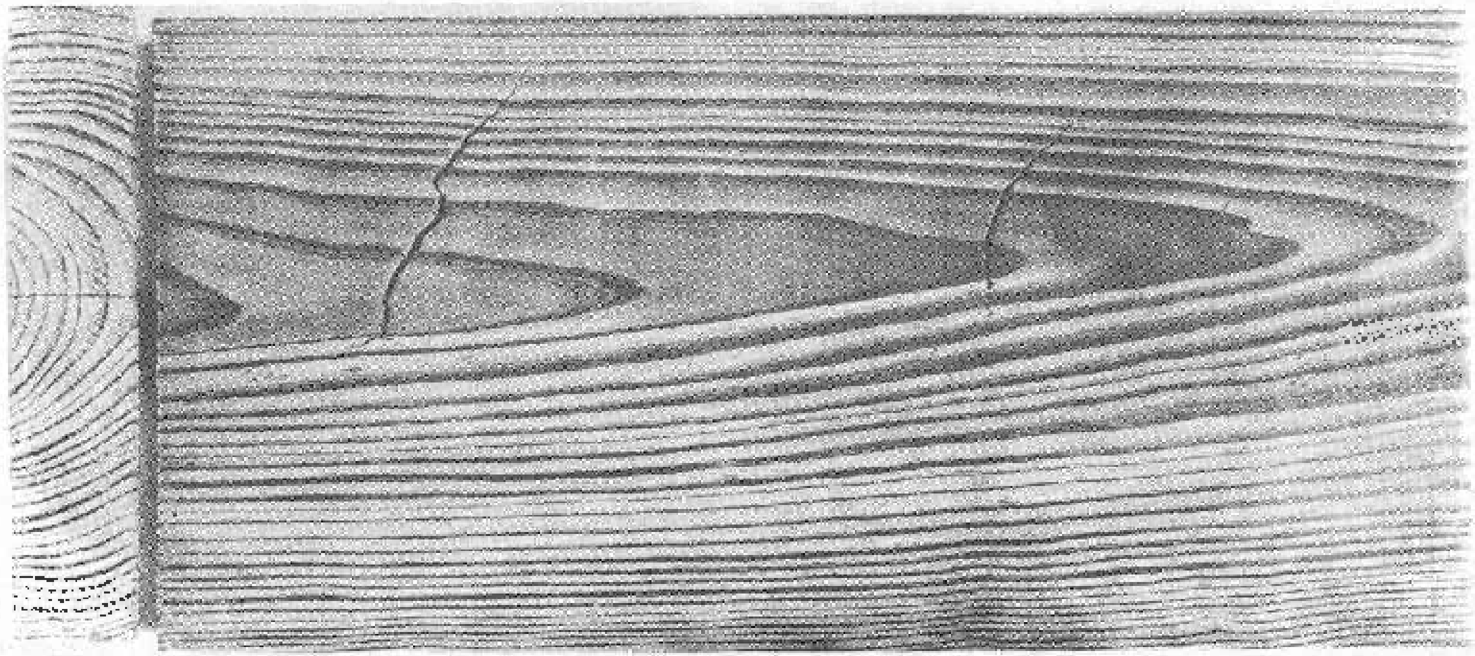

Figure 5. --Cross breaks in southern yellow pine due to longitudinal shrinkage of compression wood in the middle portion of the board.

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Figure 6. --Open butt joint in redwood siding due to shrinkage of compression wood. Note, only one out of five joints has opened up. The siding evidently was applied before it was sufficiently dry.

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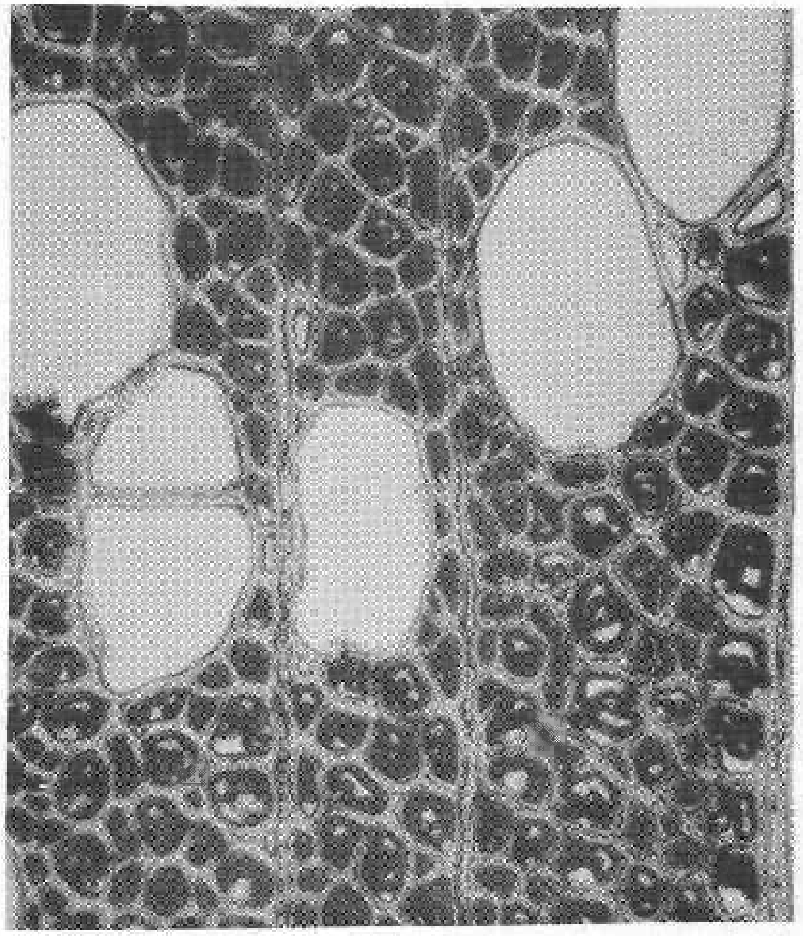

Figure 7.--Photomicrograph of a section of aspen, showing a solid grouping of gelatinous fibers with the buckled gelatinous layer clearly visible. X400.

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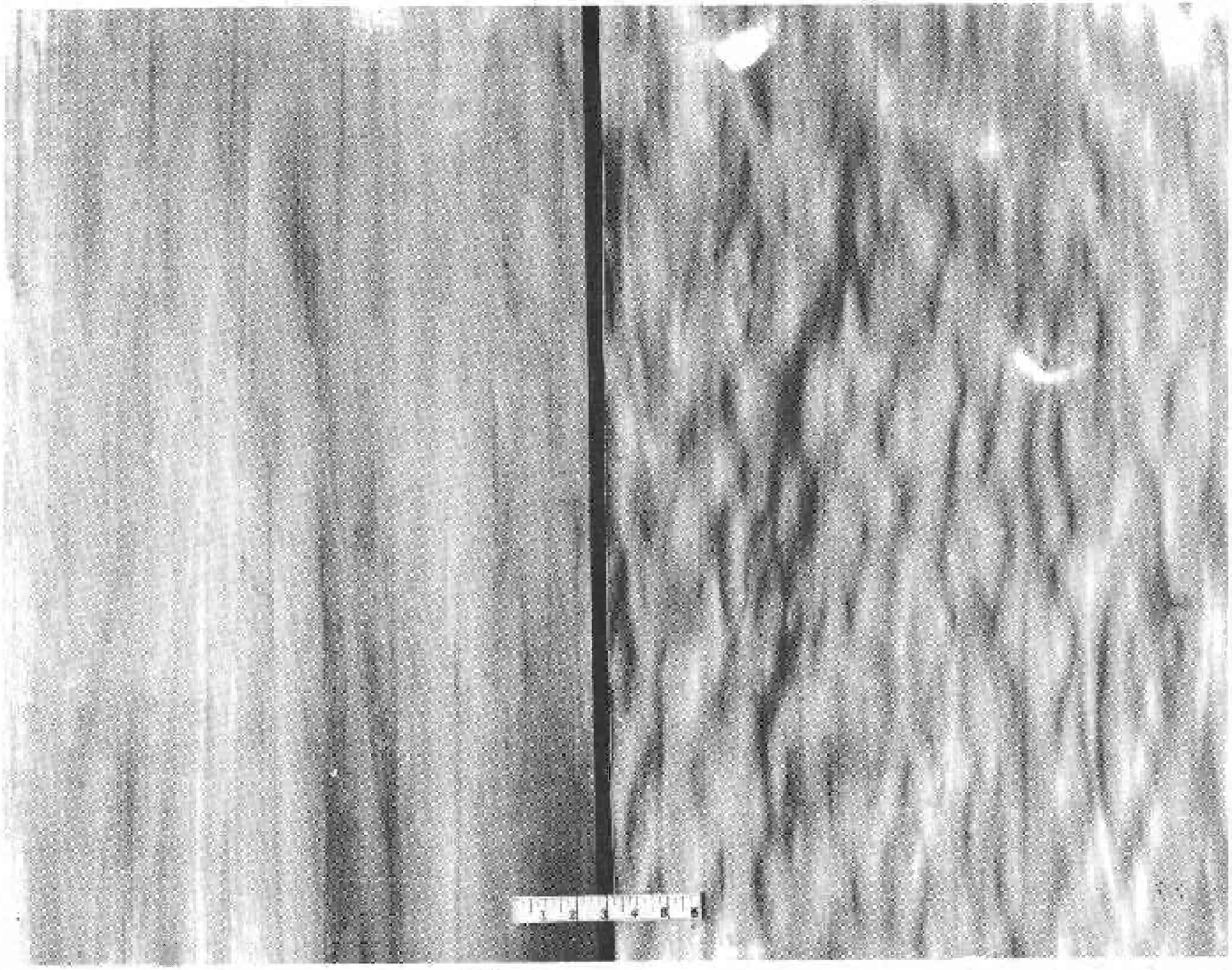

Figure 8. --Dried cottonwood veneer from an eccentric log. The smooth sheet (left) was cut from the side of the log with the shorter radius. The corrugated sheet (right) was cut from the side with the longer radius and presumably contains tension wood.

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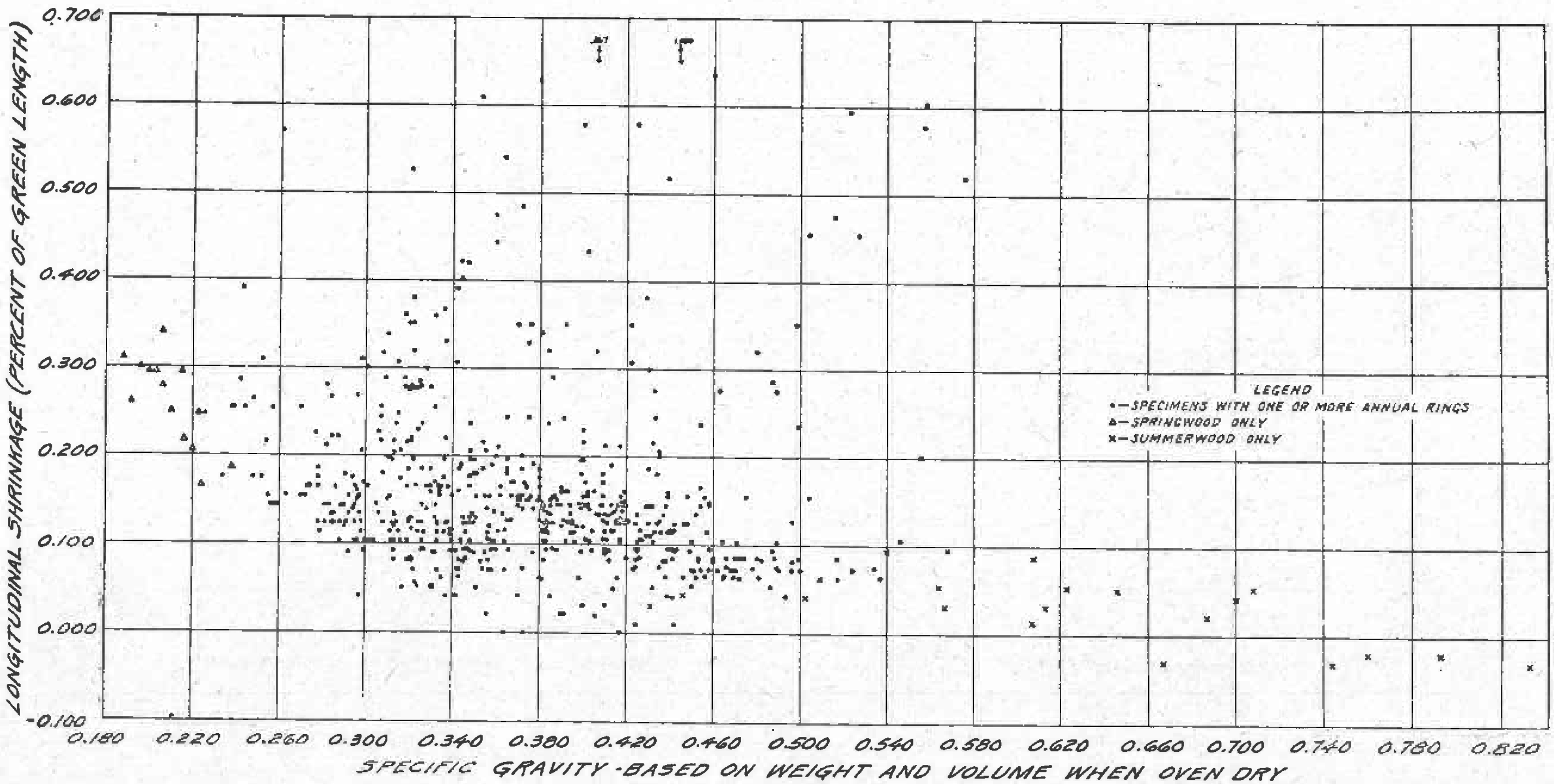

Figure 9.--Relation of longitudinal shrinkage of redwood to its specific gravity.

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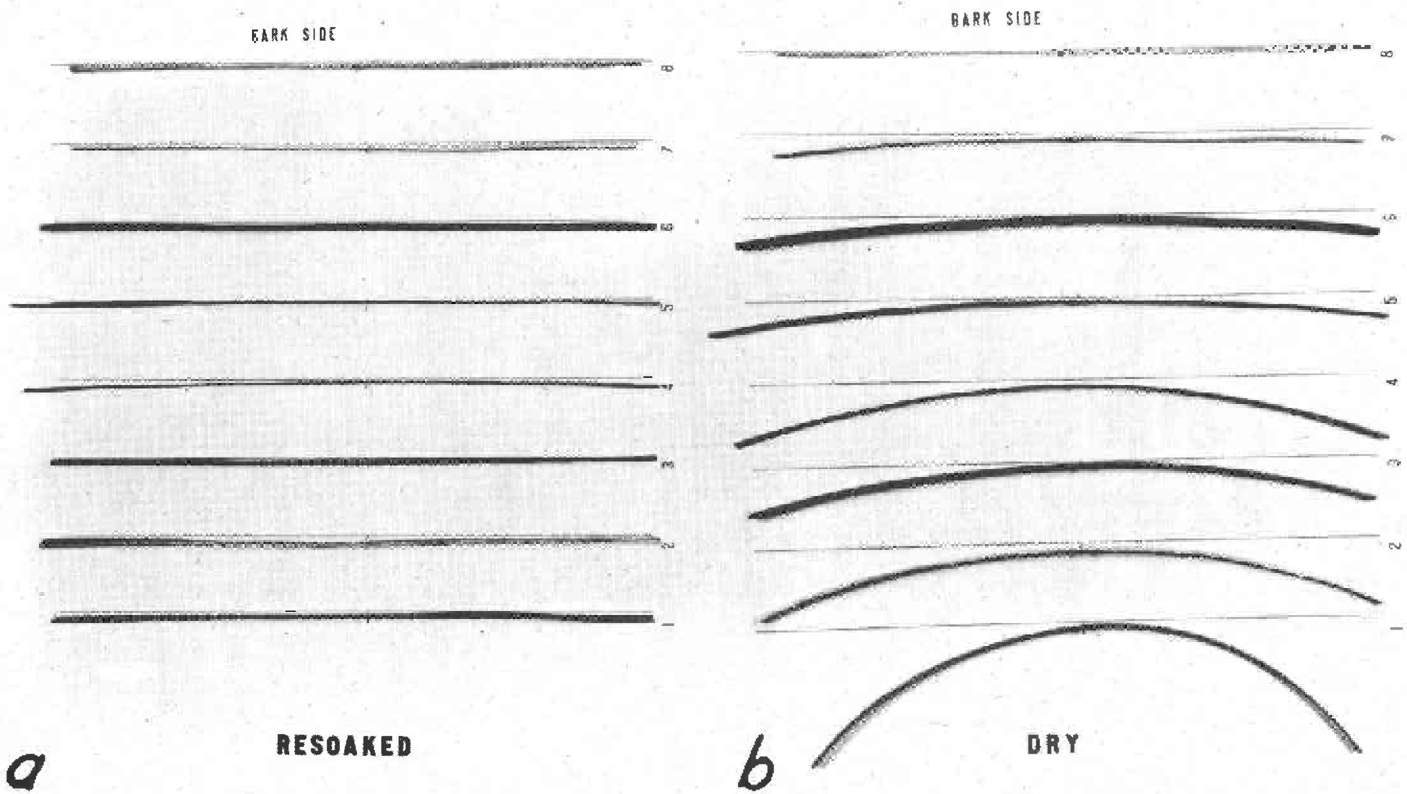

Figure 10. --Edge views of splints one annual ring in thickness whittled from straight-grained wood. Nos. 1 and 2 are ash, 3 is red oak, 4 is southern yellow pine, 5 and 6 are Douglas-fir, and 7 and 8 are basswood.

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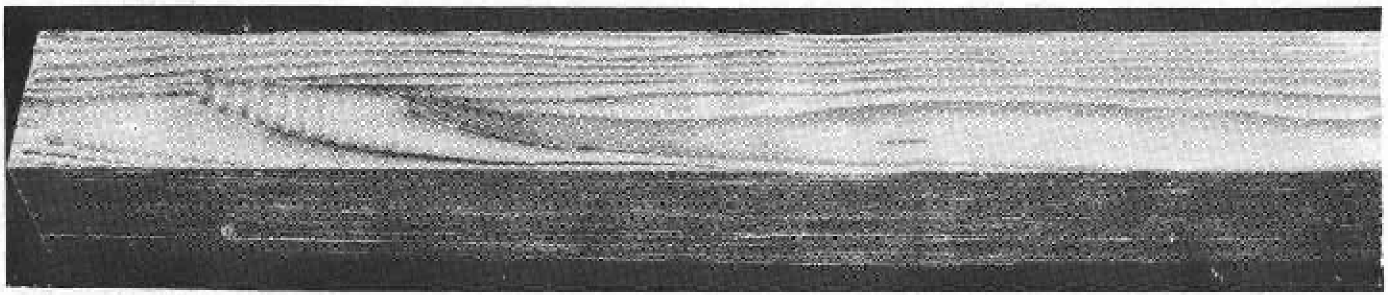

Figure 11.--Loosened grain in a softwood due in part to greater longitudinal shrinkage of the springwood.

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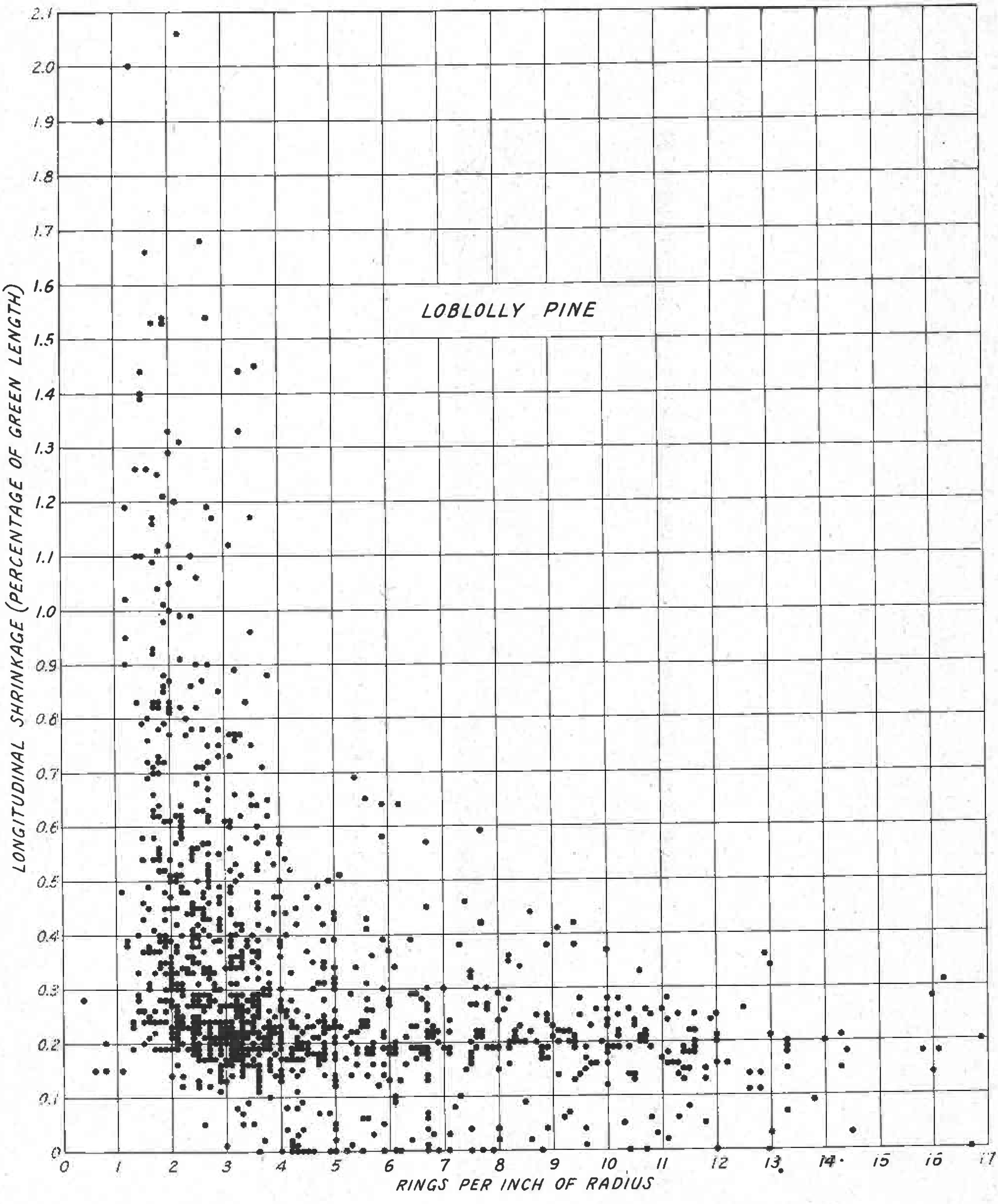

Figure 12.--Relationship of longitudinal shrinkage of loblolly pine to number of rings per radial inch.

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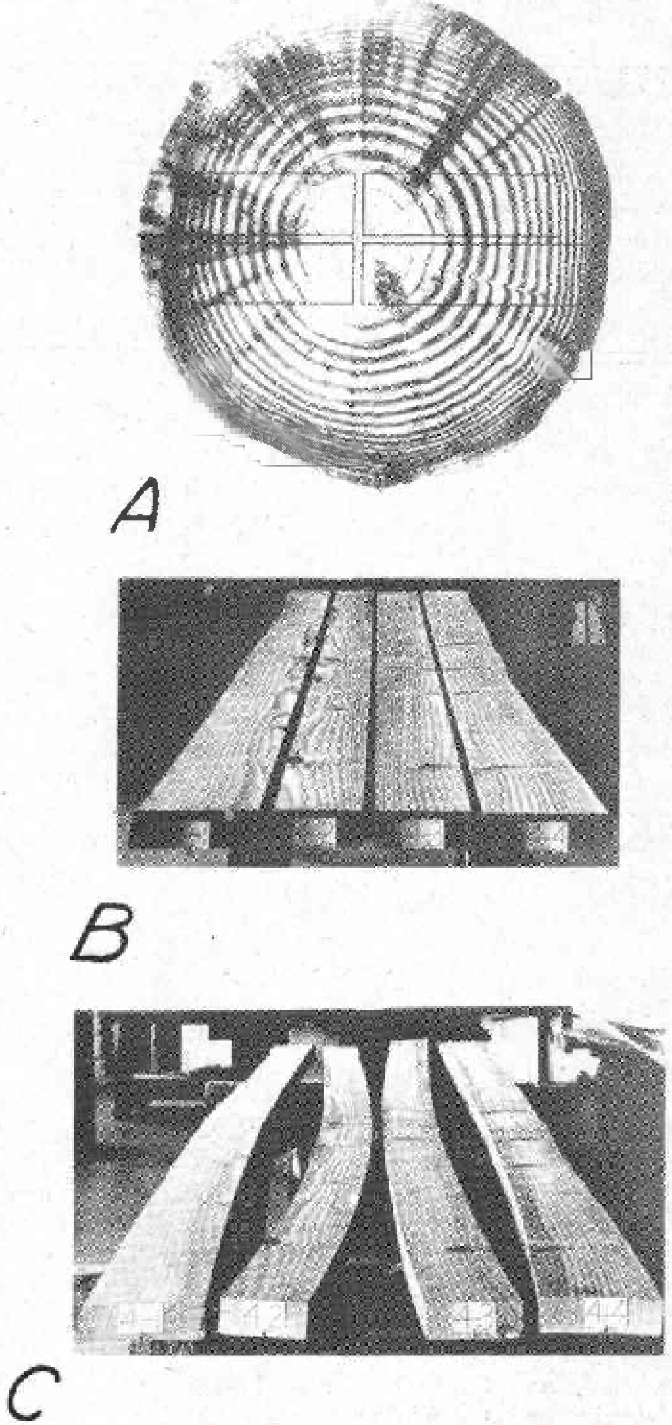

Figure 13. --Cooking of second-growth loblolly pine planks cut through the center of the trunk due to greater longitudinal shrinkage of the wide-ringed wood near the center. A, end of log showing how planks were cut out; B, the green planks; C, the planks after drying to 10 percent moisture content.

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