COMPRESSION WOOD IN WESTERN HEMLOCK *TSUGA HETEROPHYLLA* (RAF.) SARG.[1]

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ABSTRACT

The anatomical structure of the wood of western hemlock was studied for trees with different lean angles. Fibril angle, tracheid length, and lignin content are reported here for different positions across the outermost growth ring and positions around the stem for each lean angle. No significant difference in fibril angle or tracheid length was formed across the ring in the control tree of zero lean angle. Differences were found for all characteristics measured for positions around the stem of leaning trees. Compression wood had larger fibril angle, shorter tracheid length, and higher lignin content than either side wood or the control tree. Opposite wood was very variable for different lean angles. For compression wood, the fibril angle and lignin content increased for lean angles from 0 to 20°, then remained relatively constant for larger lean angles. Tracheid length showed a similar but inverse change with lean angle.

Keywords: Compression wood, opposite wood, fibril angle, microfibril angle, tracheid length, lignin content, across-ring variation, around-stem variation, wood anatomy, *Tsuga heterophylla.*

INTRODUCTION

Compression wood in coniferous species has been of interest to the wood scientist for a number of years as it has an effect on the processing and use of wood. Westing (1965, 1968) did a comprehensive review of the literature and discussed compression wood characteristics encompassing many publications. Timell (1982) more recently reviewed the research concerning the chemistry of compression wood. There has been little reported about compression wood in western hemlock, *Tsuga heterophylla.* Kellogg and Warren (1979) observed the relationship of compression wood in lumber to branch formation. Wellwood (1956) reported on compression wood adjacent to areas of the stem of western hemlock that had been invaded by mistletoe, *Phoradendron* Nutt. Dinwoodie (1965) compared some of the anatomical characteristics of normal and compression wood of western hemlock to pulp properties. There is a lack of information about the variation of

[1] This research was conducted when the senior author was in residence at the College of Forest Resources, University of Washington, and is part of his Ph.D. dissertation.

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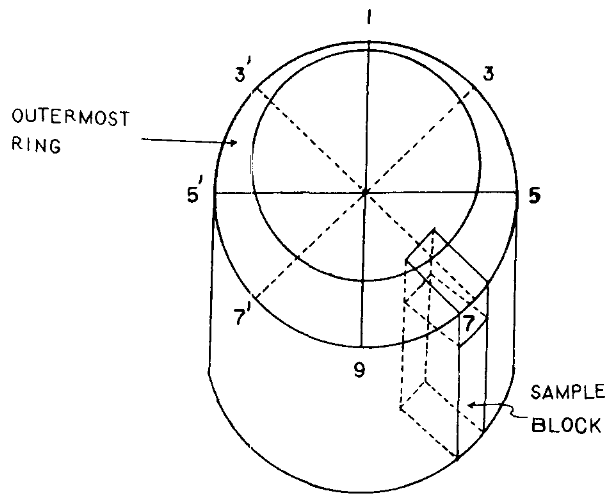

FIG. 1. Method of cutting test samples from tree sections. Line 1 to 9 extends from the upper side to lower side of the leaning stem. Position 9 is compression wood, 1 is opposite wood, 5 is side wood.

anatomical characteristics with respecct to lean angle and various positions around the stem in western hemlock.

Western hemlock is a tree that shows considerable variation in the characteristics of the growth rings—some appearing to be abrupt transition from earlywood to latewood, while other adjacent rings may show a gradual transition. The apparent density of the ring due to differences in color is often quite variable. This variability makes it difficult to tell whether a given ring or group of rings is a less severe type of compression wood unless microscopic examination is undertaken. Even then there is a question of what are the best criteria for defining an abnormal condition that would result in problems such as abnormal shrinkage or a strength reduction in the product.

The objective of this research was to determine the difference in the anatomical structure of the wood in the stems of western hemlock with apparent different degrees of compression wood. It was determined how the anatomy varied across the growth ring and also around the tree from the underside to the top side of stems with different degrees of lean. This report gives only the results for differences in lignin content, tracheid length, and fibril angle.

MATERIALS AND METHODS

Five trees were selected from a single stand. All were chosen between 36 and 43 years of age to avoid the characteristics of juvenile wood. One tree was selected for each of the lean angles 0, 5, 20, 45, 75°, the angle of the stem axis with respect to gravity. After felling, a 12-in.-long stem section was cut between 4 and 5 ft height above the ground. In the laboratory, the stem sections were subdivided into three sample discs 4 in. longitudinally and stored in a freezer at −4 C to prevent biodegradation before analysis.

The sample discs were marked and numbered with nine diameter lines spaced at even intervals of 22.5° around the center of the disc. Because of time constraints, only positions 1, 3, 5, 7 and 9 were sampled by removing sample blocks

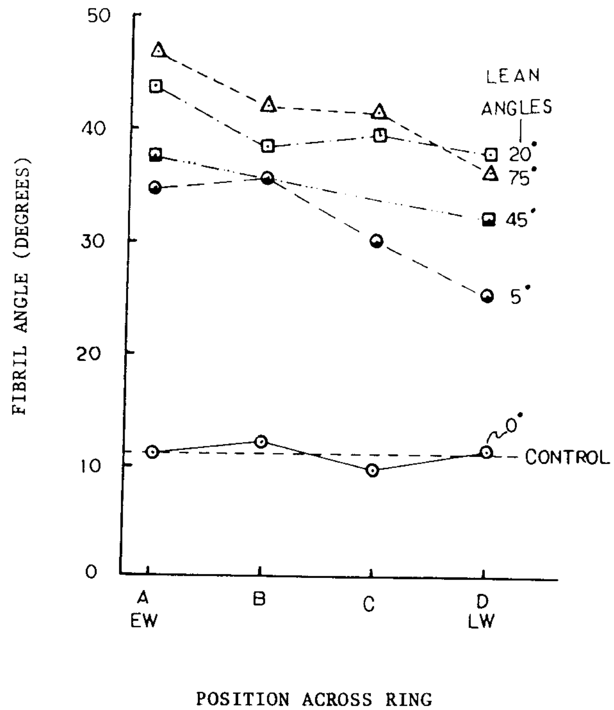

FIG. 2. The variation of fibril angle with position across the growth ring for different lean angles. The points for the control tree with 0° lean are an average for all positions around the stem. The control value is the overall average of all measurement for the control tree.

as in Fig. 1. The subsamples for the various anatomical studies were obtained from these sample blocks such that they were effectively end-matched to minimize variability between studies.

On the sample disc, Fig. 1, the 1–9 line was drawn from the uppermost point on the top side of the leaning stem to the lowest point on the underside of the stem. This point had been carefully marked on the standing trees before it was cut in the field. The 1–9 line is therefore perpendicular to the central axis of the stem and in the same plane as that of both the stem axis and the line of gravitational direction. Position 9 is what would be the compression wood side, position 5 the side wood, and position 1 the opposite wood with positions 3 and 7 transitional positions. Only the outer growth ring (increment) was used for the studies as this was the only growth ring for which the lean angle of the tree could be determined with confidence.

Studies of the anatomical characteristics were made both for positions across the growth ring from earlywood to latewood and for positions around the stem from position 1 to 9, for each lean angle. For the straight upright tree of zero lean angle, which will also be referred to as the control tree, the 1–9 line was arbitrarily assigned to establish the sampling distribution pattern and does not have any relation to gravitational direction as in the leaning trees.

Fibril angle was measured by the polarized light technique described by Preston (1934, 1952). The technique of Leney (1981) was used to prepare the microscope

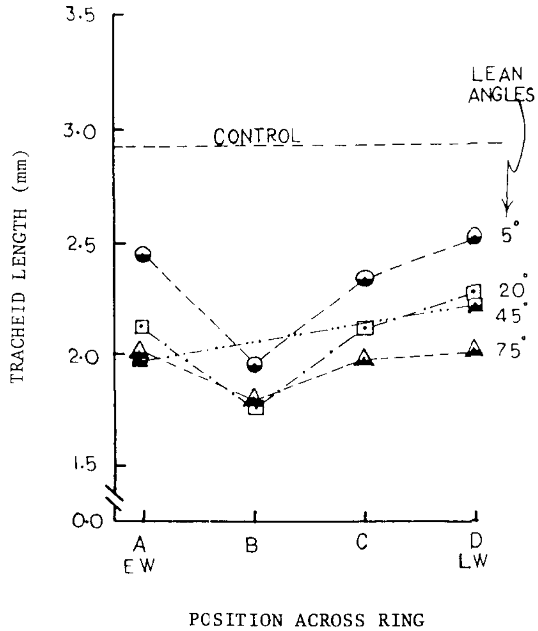

FIG. 3. The variation of tracheid length with position across the growth ring for different lean angles compared to the control.

slides of half fibers necessary so the polarized light passed through only a single cell wall. Tangential sections were cut from the desired position in the growth ring and macerated to produce the half fibers for measurement of fibril angle in the tangential wall.

To determine variation across the growth ring, sample sections were cut in both earlywood and latewood using a sliding microtome. To avoid possible error of sampling at the ring boundary, the sectioning was started 150 μm from the boundary. The first earlywood is designated as sample position A and last latewood as D. Sample positions B and C were distributed between A and D. For narrow rings, C or both C and B were omitted. In compression wood rings with wide latewood, position B was located in the transition zone between earlywood and latewood.

To measure tracheid length, thick microtome sections were cut at each sample position within the ring for all sample blocks. The sections were carefully cut to be truly parallel to the longitudinal direction and were macerated in a warm solution of equal parts glacial acetic and 30% hydrogen peroxide. Slides with a random distribution of tracheids were made by a sedimentation method adapted from Echols (1961). The tracheids were dried on the slide, and a random sample of 30 was measured by a projection method using a calibrated measuring device.

The determination of lignin content was based on TAPPI Standard Method T13M-54 modified so that the entire analysis was accomplished in a fritted glass crucible similar to the procedure of Erickson (1962). Microtome sections 25 μm thick were used rather than the usual ground wood particles. By using sections

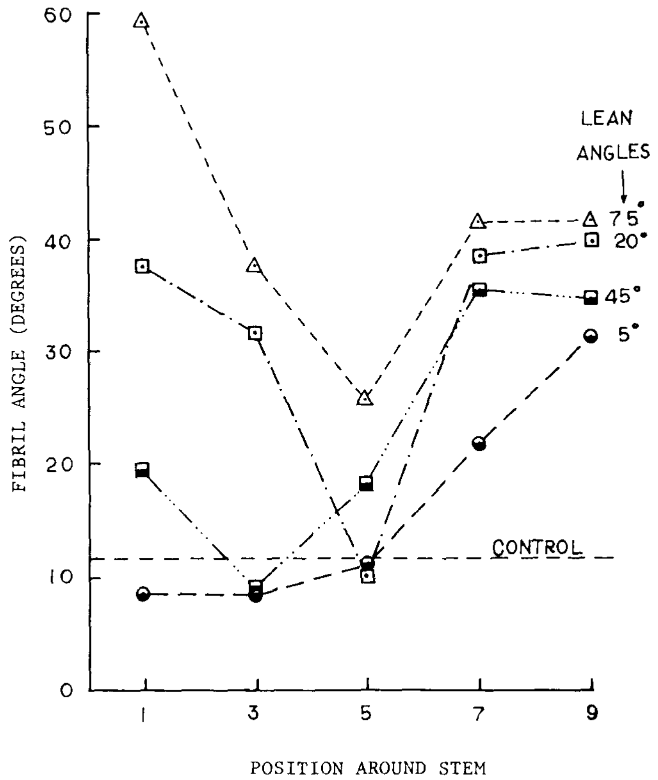

FIG. 4. The variation of fibril angle with position around the stem for different lean angles compared to the control.

for chemical analysis, there is no loss of the fine particles that are generated when using a Wiley mill. The fines may be preferentially generated from a particular portion of the cell wall so their loss would bias the sample.

RESULTS AND DISCUSSION

Changes across the growth ring

The lower part of Fig. 2 shows the fibril angle for positions across the ring from earlywood A to latewood D of the tree with zero degree lean angle (control). The points are averages of the five positions around one side of the stem. Little difference of fibril angle from earlywood to latewood is evident. Statistical analysis showed no significant difference in fibril angle between earlywood and latewood in this normal tree of hemlock. The overall average of 11.35 is used as a control value for comparison with trees of various degrees of lean angle.

This lack of difference between earlywood and latewood is contrary to what one would expect, as Panshin and deZeeuw (1970) report others generally report latewood to have a smaller fibril angle than earlywood. However, Wellwood (1962) measured fibril angle along with other properties of western hemlock. His data showed that as the ring age approached 27 years there was little difference between

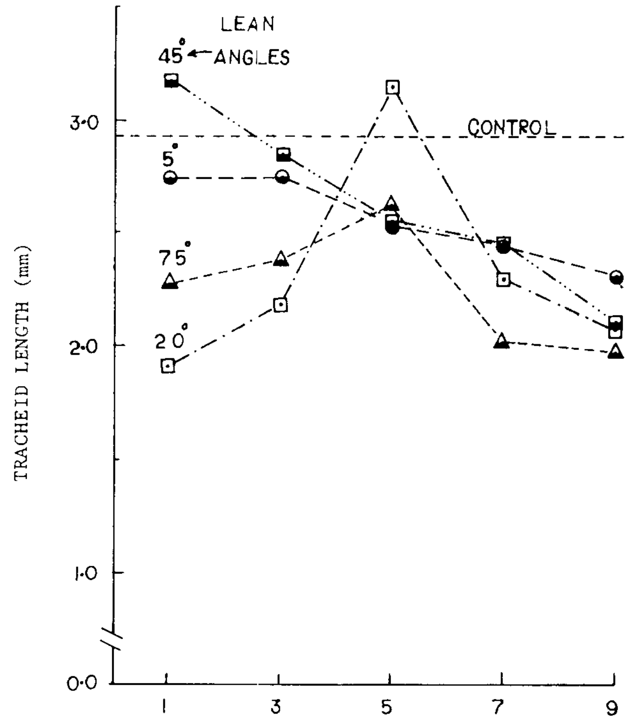

FIG. 5. The variation of tracheid length with position around the stem for different lean angles compared to the control.

the fibril angle of earlywood and latewood. As the results reported here were for rings of 36 to 43, finding no significant difference in the fibril angle of earlywood and latewood is not surprising.

The upper part of Fig. 2 shows the change of fibril angle across the ring at position 9 (compression wood) for trees with different lean angles. There is a similar decrease in fibril angle from earlywood to latewood for all lean angles, and the fibril angle is much greater than for the control tree.

The change of tracheid length across the ring in the control tree showed too much variation to indicate a significant trend. The maximum change across the growth ring for the different positions around this tree with zero lean angle was less then 0.4 mm. As for fibril angle, the difference in tracheid length across the ring was not statistically significant.

Figure 3 shows the variation of tracheid length across the compression-wood ring at position 9 for trees of various lean angle. There is a consistent reduction in length at position B, which was in the zone of transition from earlywood to the thicker walled latewood. Statistical analysis, however, showed that there was no significant difference in tracheid length between earlywood at position A and latter part of the latewood at position D. This same pattern was found for position 7.

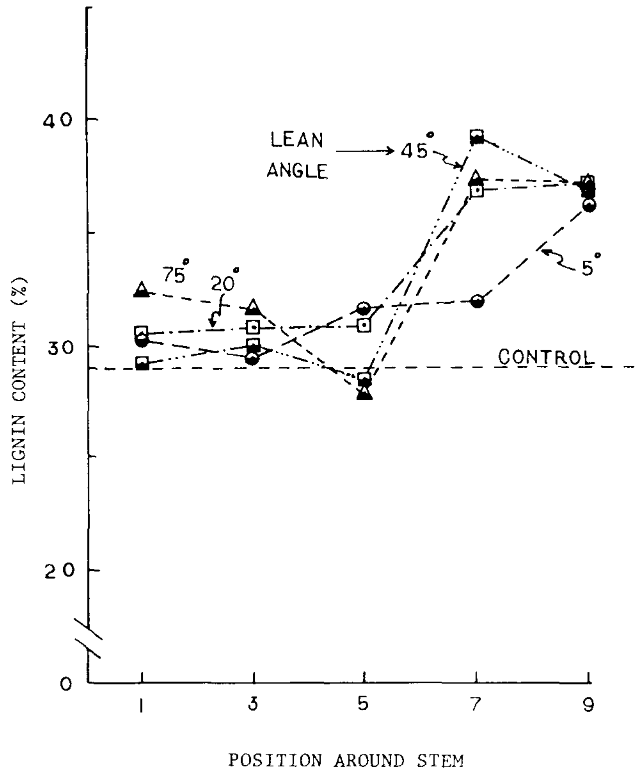

FIG. 6. The variation of lignin content with position around the stem for different lean angles compared to the control.

Changes around the stem

An average of all fibril angle measurements across the ring was used for comparison of fibril angle at different positions around the stem. For the control tree the average fibril angle varied between 10.59 and 12.51°, and showed no statistically significant difference for various positions around the stem. Figure 4 shows the difference in fibril angle for positions around the stem of the leaning trees. For lean angles 20, 45, 75°, there is similar large fibril angle at both position 7 and 9. Both these positions also showed cells rounded in cross section, which is characteristic of compression wood. For 5° lean angle, position 7 did not show this characteristic compression-wood cell formation.

At position 5 (side wood) the fibril angle is at or approaching a minimum. Except for the small lean angle of 5°, there is a tendency for the fibril angle to increase as position 1 (opposite wood) is approached. However, it is not consistent with the lean angle, as the 45° lean angle shows a smaller fibril angle than 20° lean angle. When compared to the control, however, this change around the stem shows that the fibril angle on the side of the tree approaches normal wood and is larger again in opposite wood for the larger lean angles. More trees would need to be sampled to determine whether the variation at position 5 compared to the control is due to influence of lean angle or is natural between tree variation. The

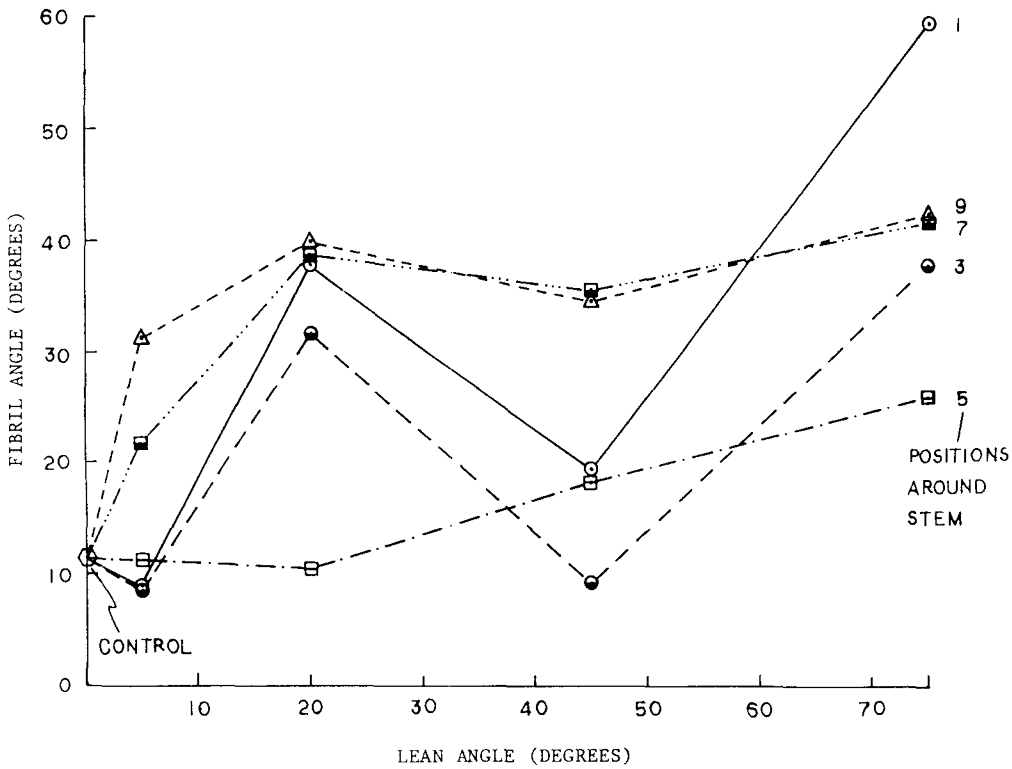

FIG. 7. The relationship between fibril angle and lean angle for different positions around the stem.

larger fibril angle in opposite wood (position 1) has been reported for *Pinus radiata* (Harris 1977); *Larix laricina* and *Picea rubens* (Timell 1973b).

Figure 5 shows the relationship of tracheid length and position around the stem of the leaning trees as compared to the overall average tracheid length of the control tree. Position 1 (opposite wood) shows great variability among the different lean angles. Position 9 (compression wood) shows a consistent shorter tracheid length than for the control tree and for position 5 (side wood), which is considered to be the most normal wood in the stem. As mentioned above, variation of side wood can be expected to show the normal variation between trees. The difference for the tree with 20° lean angle would tend to show that there is no relationship between compression wood formation as such and the anatomical characteristics of the side wood.

The lignin content for the position around the stem of the control tree ranged between 28.4 and 29.8%. The average of 29.07% is used as a control in discussion of results. Lewis (1950) reported 28.8% lignin content for western hemlock, while Wilson and Wellwood (1965) reported 32.8%. Figure 6 shows some variation between trees at positions 1, 3 and 5, but all are distinctly lower in lignin content than positions 7 and 9 where compression wood is well developed. Position 7 for the 5° lean angle has a lower lignin content, which agrees with the lack of compression-wood development at that position as determined by other characteristics.

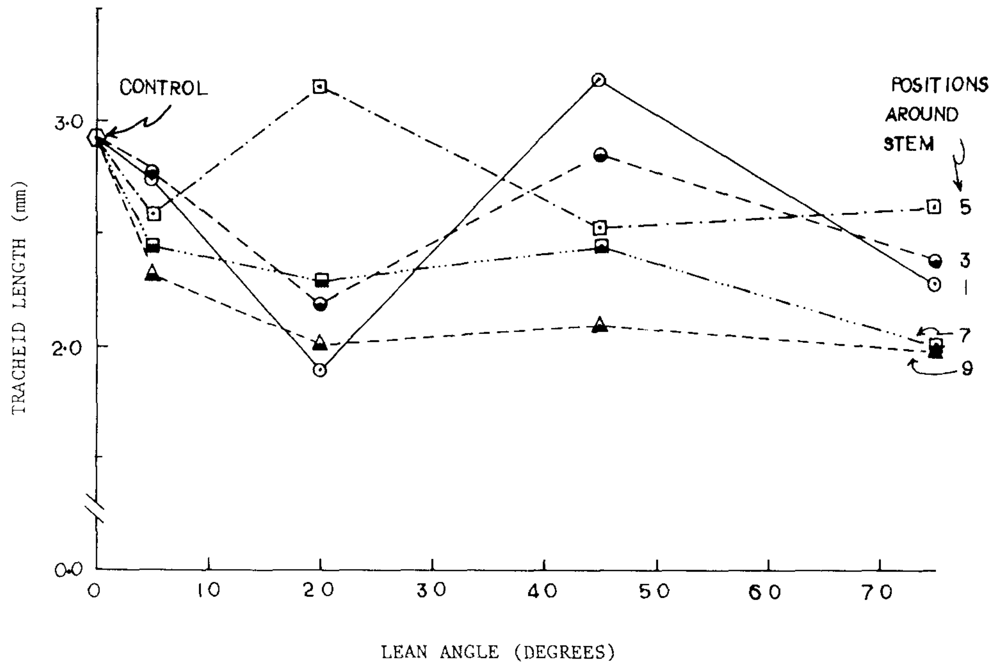

FIG. 8. The relationship between tracheid length and lean angle for different positions around the stem.

According to the Newman-Kents multiple range test, there was no significant difference between side wood at position 5 and opposite wood at positions 1 and 3 except for the 75° lean angle, which shows a higher lignin content in opposite wood. Other than this exception, there is agreement with the findings for the 5 different species studied by Timell (1973a).

Changes for different lean angle

Figure 7 shows the variation of fibril angle with lean angle for various positions around the stem compared to the control tree average of 11.35. The lack of any trend for positions 1 and 3 is evident. For position 5 there is a gradual increase with lean angle. It must be emphasized that for position 5, this could be a normal between-tree variation rather than the effect of lean angle. Of particular interest, the fibril angle for positions 7 and 9 shows a large increase up to the 20° lean angle and then constancy of this large fibril angle for larger lean angles. It would appear that there may be a critical angle between 5 and 20° lean angle where the fibril angle becomes maximum with little change at larger lean angles. Further studies with respect to the effect of lean angle on fibril angle should be done using larger sample size to confirm and refine this information for lean angles of less than 20°.

The tracheid length variation with lean angle is expressed in Fig. 8. This emphasizes the lack of any relationship for the opposite and side wood at positions 1, 3 and 5. However, it is interesting that the average tracheid length of the

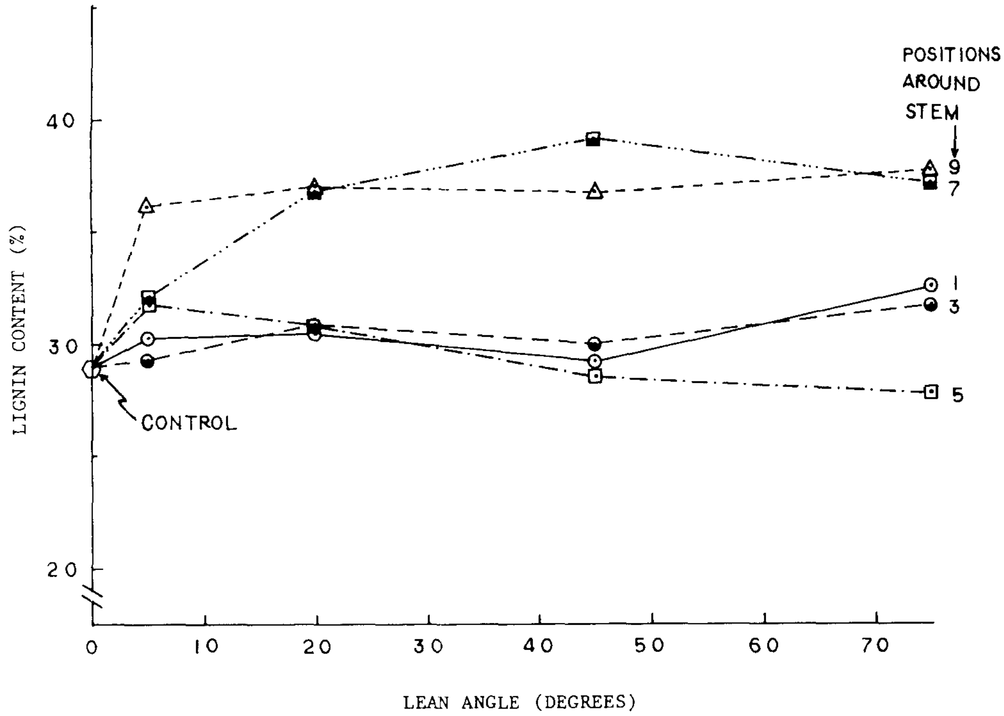

FIG. 9. The relationship between lignin content and lean angle for different positions around the stem.

compression-wood side of the stem (positions 7 and 9) has a reduced tracheid length which is more or less constant for the different lean angles.

For position 9 where distinct compression wood was found for all trees with some degree of lean, Fig. 9 shows that the lignin content increases significantly from the normal wood of the control and then remains at a reasonably constant high level for all lean angles. Position 7 is similar except for the lean angle of 5° which is discussed above. Opposite wood at position 1 and 3 and side wood at position 5 show distinctly lower lignin content with little relationship to lean angle.

SUMMARY

For the western hemlock trees studied, there was no significant difference in fibril angle or tracheid length from earlywood to latewood in a normal upright tree with zero degree lean angle (control tree). For the compression-wood ring, there was a distinct decrease in fibril angle from earlywood to latewood. The tracheid length, for the compression-wood ring, decreased from the first earlywood to the transition region between earlywood and latewood, then increased into the latewood to be about the same or longer than the earlywood.

For measurements made at various positions around the stem, the fibril angle of compression wood was significantly larger than the normal wood of the control. Fibril angle decreased from compression wood to side wood and increased again in opposite wood but with considerable variability between trees. For two lean

angles, the opposite-wood fibril angle was as large as, or larger than, on the compression wood side. The tracheid length of compression wood was distinctly shorter than the control tree and showed some increase going to side wood. The tracheid length of opposite wood was very variable and showed no relation to the conditions on the compression wood side.

The lignin content for compression wood was distinctly greater than side wood, opposite wood, and the control. With one exception, there was no significant difference between side wood and opposite wood and these are little different from the control.

When the effect of lean angle is compared for the trees studied, an interesting pattern is evident. Fibril angle of compression wood increases rapidly from 0 to 20° lean angle, then remains relatively constant for larger lean angles. A similar trend is seen for lignin content except that the point of constancy is at about 5° lean rather than 20. Tracheid length shows a similar but inverse change with lean angle where it decreased and then remained fairly constant at lean angles of 20° and greater. This suggests that there is a critical lean angle between 5 and 20° beyond which the cell characteristics of the compression wood are reasonably constant.

The limited sample size of this study prevents generalizing for the species but the results indicate relationships which should be confirmed by a study using a greater number of trees.

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