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A Comparison of Latewood Pits, Fibril Orientation, and Shrinkage of Normal and Compression Wood of Giant Sequoia*

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Summary

Giant sequoia latewood compression wood (CW) tracheids had pit canals that flared toward the lumen with extended poorly defined inner apertures that paralleled the fibrils in the S2 walls. Boiling and drying of CW and normal wood (NW) blocks induced split extensions at the CW pit aperture grooves but not at the NW pit apertures. These split extensions of the CW pit apertures were present also in longitudinal microsections. The mean fibril angle of 21 to 25 degrees of this well-defined CW was appreciably below the 45 degrees frequently reported. The CW tangential/radial shrinkage ratio of about 1 was distinctly lower than NW (1.6 and 2.1), and appeared to be the result of much lower tangential shrinkage. Both NW and CW specimens when dried quickly in an oven at 100° C had higher shrinkage (long., tang. and rad.) than when air-dried first at lower temperature and higher relative humidity.

Introduction

Although compression wood is a common growth defect in many coniferous species, it is not often found in giant sequoia [*Sequoia gigantea* (Lindl.) Decne.] because of that specie's consistent vertical growth pattern resulting from its usual dominant position in forest stands. When, therefore, two trees having an appreciable amount of compression wood were obtained during a study on physical properties of second-growth giant sequoia [Cockrell et al. 1971], it was decided also to make a study of comparative properties of compression and normal wood in that species. The present study describes variations observed in anatomical characteristics and shrinkage. A comparison of mechanical properties is presented in another report [Cockrell, Knudson 1913].

These two trees had grown on the bank of a stream in Whitaker's Forest, a 320-acre University of California research tract adjacent to the western edge of Sequoia National Park, at an elevation range of 5200 to 6200 feet. Judging from its growth ring pattern, one tree had leaned for 15 years toward the stream apparently because of bank undercutting by high water. Additional undercutting

* The SEM photographs were made in the Electronics Research Laboratory which is under the direction of Dr. T. E. Everhart who has a Cambridge Stereoscan Mark II SEM operated under NIH Grant No. G. M. 17523.

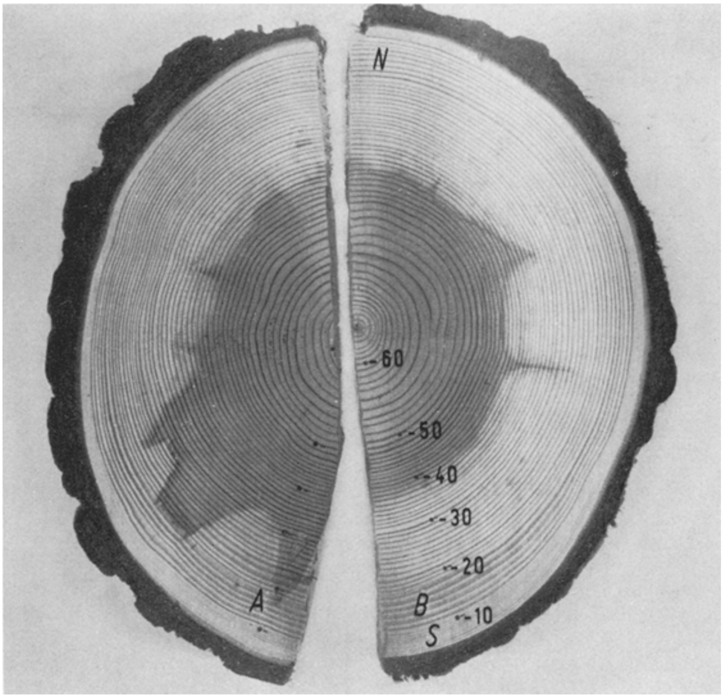

Fig. 1. Cross section of tree 1. Wide ring compression wood at *A* and *B*. Narrow ring compression wood at *S*

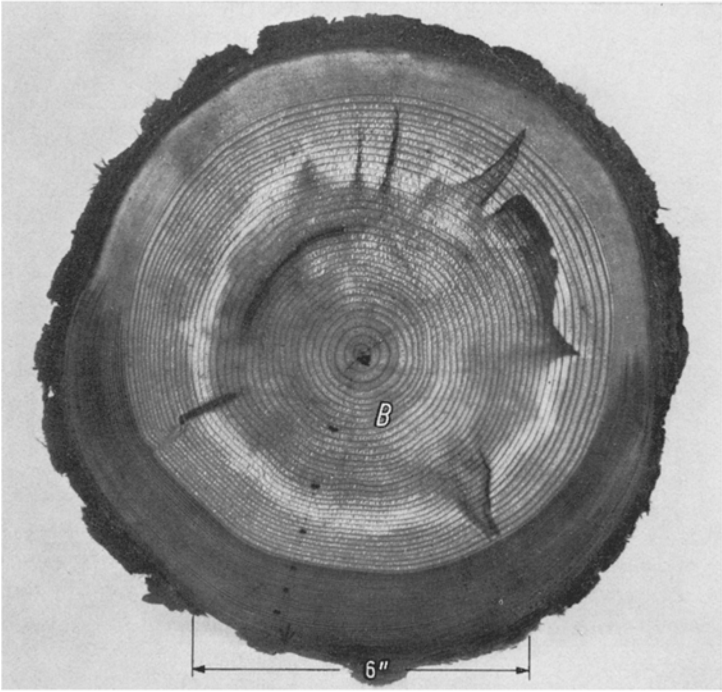

Fig. 2. Cross section of tree 2. Lower dark-colored semi-circular zone is compression wood

caused the bank to give way, and for 13 years prior to cutting the tree rested on its branches on the opposite bank and was almost horizontal. The other tree, growing about 100 yards downstream from the first, had also been undercut by the water and for 33 years had been lodged against a large ponderosa pine at an angle of 26 degrees from the vertical. Both had well-defined zones of compression wood from which test specimens of adequate size could be obtained. Figs. 1 and 2 show the cross sections of the trees, and Table 1 gives age and size data and height location of the test samples.

Table 1. Age and size of trees and location of samples

Tree number	Rings at stump	D.B.H.[1] (inches)	Total height (feet)	Height of sample (feet)	D.I.B.[4] (inches)
1	84	11.7	67[2]	5	10.8
				8	8.9
2	86	15.1	81[3]	7	11.4
				20	10.3
				30	9.9
				40	8.8

[1] Diameter outside bark 4.5 ft above ground
[2] Broken top
[3] Spike top resting against pine tree for 33 years
[4] Diameter inside bark

Procedure

Shrinkage blocks, all of sapwood, were selected from tree 1 at 5- and 8-foot levels above the ground. The blocks represented CW (compression wood) with wide rings, CW with narrow rings (formed after the tree had fallen across the stream), and NW (normal wood). Blocks were likewise selected from tree 2 at each of four height levels (Table 1) representing CW, TSW (tension side wood), and NW from the core inside the 33-ring outer zone. A few NW blocks entirely of heartwood were also prepared. The blocks were split out in order to insure straight grain, and surfaces were jointed and planed with rings aligned so as to permit exact measurements in tangential and radial directions. Dimensions were: 6-inches long, 1-inch tangentially, and 1-inch, or less, radially (the last-formed CW zone of tree 1 was about 0.4 inches wide, and the TSW of tree 2 was about 0.6 inches wide). Longitudinal, tangential, and radial measurements were taken to the nearest 0.001 inch for the green, air-dry, and oven-dry conditions. Green volume of the blocks was determined by immersing the blocks in water on a balance and weighing the force of displacement. Fibril orientation in the S2 layer was determined for the CW by means of striations and splits that occurred in the walls, and at the radial pit apertures, as a result of preparation of permanently mounted stained microsections cut from matching material of the shrinkage blocks (Fig. 3). For the NW and early wood of CW blocks, fibril orientation was determined by inducing iodine crystals, to form in the cell walls of radial sections by mounting in 40 per cent nitric acid [Cockrell 1946]. Fibril angle values are the average of 20 measurements made with a rotating microscope stage. The scanning electron micrographs were made on radial surfaces cut smooth with a microtome

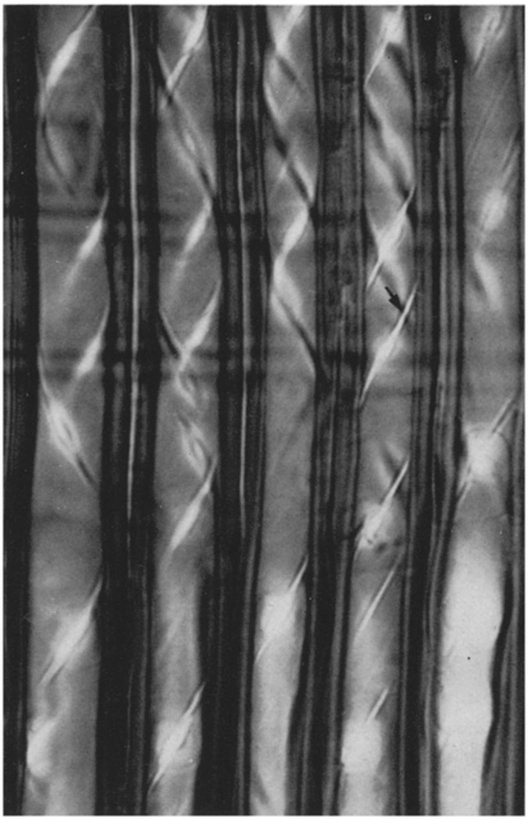

Fig. 3. Radial section of compression wood showing split extensions of pit apertures. 880 : 1

knife and coated with gold-palladium in a vacuum evaporator [Collett 1970]. As there appeared to be no variation in values related to height level of samples, the blocks were considered to be one population for each tree.

Results and discussion

Table 2 gives mean values for fibril angles, specific gravity, shrinkage percentages, and tangential to radial shrinkage ratios. Additionally, four CW and four NW sapwood blocks (one each from each height level) from tree 2 were dried

Table 2. Mean values for fibril angle, specific gravity, and shrinkage

Wood type	Rings per inch	Latewood fibril angle deg.	Specific gravity	Shrinkage per cent green to oven dry S.D.[1]	Long.	S.D.	Tang.	S.D.	Rad.	S.D.	*T/R* Ratio	S.D.
				Tree No. 1								
CW (5)[2]	10	25	0.53	0.008	0.67	0.037	3.9	0.19	3.9	0.16	1.00	0.08
NW (4)	14	4—5	0.38	0.006	0.07	0.0	7.9	0.08	4.9	0.17	1.60	0.06
CWNR (2)[3]	36	20	0.44		0.33		4.0					
				Tree No. 2								
CW (12)	24	21	0.55	0.024	0.65	0.061	4.3	0.28	3.9	0.17	1.12	0.10
NW (12)	10	2—4	0.32	0.012	0.12	0.034	7.9	0.33	3.7	0.23	2.13	0.11
NWH[4] (5)	11	—	0.35	0.019	0.07	0.027	5.7	0.40	2.6	0.14	2.16	0.15
TSW (12)	36	2—4	0.29	0.012	0.16	.019	6.4	0.47	3.2	0.45	2.05	0.30

[1] Standard deviation
[2] Numbers in parentheses refer to number of specimens measured
[3] Compression wood with narrow rings
[4] Normal wood heartwood

immediately from the green condition at 100° C. Table 3 shows these values. As expected in view of the low longitudinal shrinkage values for both sapwood and heartwood, the NW had minute latewood S2 fibril angles. The long axes of included inner apertures of the pits of latewood tracheids had about the same steep orientation as the S2 microfibrils, and as reported earlier [Cockrell 1973] neither wood-drying nor preparation of microsections produced split extensions of these

Table 3. Tree 2 samples quickly dried at 100 °C[1]

Shrinkage % G-OD

Wood type	Specific gravity	Standard deviation	Long.	S.D.	Tang.	S.D.	Rad.	S.D.	T/R Ratio	S.D.
CW (4)[2]	0.56	0.013	0.84	0.022	5.3	0.22	4.8	0.43	1.10	0.057
NW (4)	0.34	0.028	0.37	0.054	9.1	0.98	5.4	0.21	1.69	0.202

[1] Placed in oven immediately in original condition
[2] Number in parentheses refers to numbers of specimens measured

apertures. Earlywood fibril angles averaged only slightly greater than those of the latewood, but generally were much more variable and somewhat higher at the ring boundary.

Although the CW with wider rings of tree 1 appeared to be well developed CW (Figs. 4, 5), and the growth conditions were such as to produce pronounced reaction

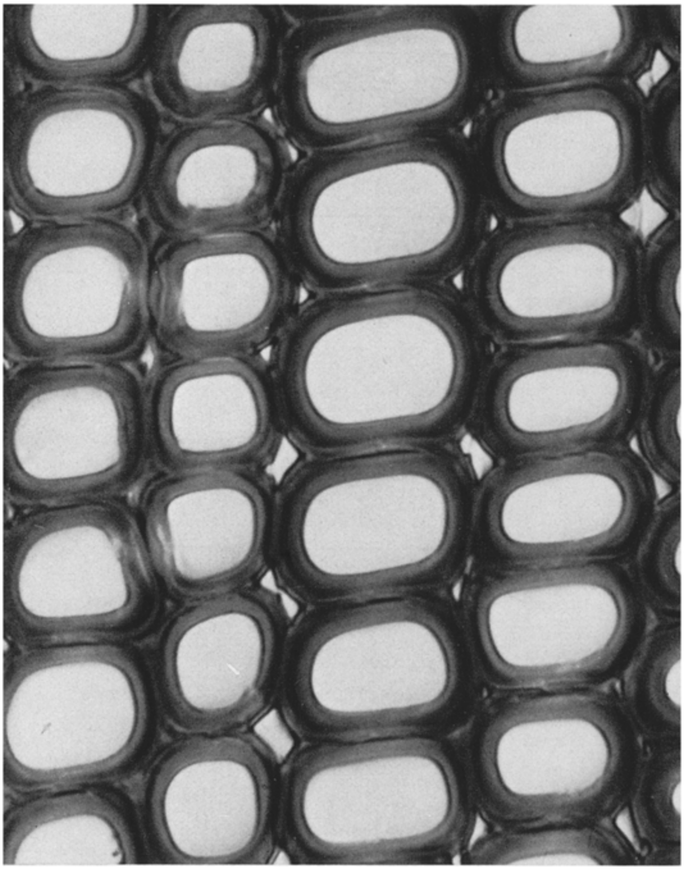

Fig. 4. Cross section of compression wood in zone *A-B* of tree 1. 440 : 1

wood, the axial shrinkage of 0.68 percent was not extreme (for CW), and the latewood S2 layer mean fibril angle of 25 (19 to 32) degrees was appreciably below the 45 degrees implied by many authors as generally characteristic of compression wood [Jane 1970; Panshin, de Zeeuw 1970; Tsoumis 1968; Wardrop 1965]. In spite of having relatively narrow rings (24 per inch) the CW of tree 2 had similar axial shrinkage of 0.65 percent and latewood fibril angles averaging 21 (16 to 31) degrees. Pillow and Luxford [1937] reported average fibril angles for pronounced CW of four softwoods of 22.6 to 29.4 degrees. As with the NW, earlywood of these blocks of giant sequoia had somewhat larger angles than did the latewood. Latewood comprised slightly over half of the volume of the rings and, as the author pointed out in a previous study [Cockrell 1946], probably exerted the dominant influence on longitudinal shrinkage.

As shown in Fig. 6 and reported in more detail in a previous report [Cockrell 1973], the pit canals of the CW latewood tracheids are flared toward the lumen with extended poorly defined inner apertures roughly paralleling the fibrils in the

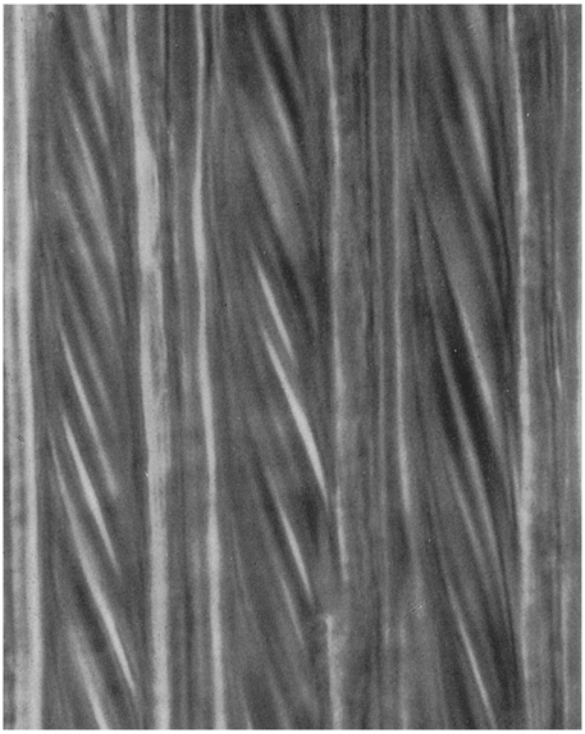

Fig. 5. Radial section of compression wood of tree 2 showing helical striations and splits. 750 : 1

S2 wall. The outer apertures (middle lamella side of border) are oval-shape, included, and their long axes are less steeply inclined than the inner apertures. The dry, smoothly cut surfaces of the wood observed in the scanning electron microscope revealed an intact warty layer without any splits on the surface or extending from the pit aperture grooves. Surface cut wet on boiled wood blocks and subsequently dried had many tracheids with splits and helical striations on the inner lumen, and had split extensions from the pit aperture grooves comparable to those present in all CW microsections prepared in this study (Fig. 6). Careful examination disclosed that isolated single tracheids were found with fibril angles of 45 to 78 degrees (Fig. 7) in some of the rings of most specimens of both trees. These tracheids occurred sporadically and could be found only by carefully scanning the radial sections of microslides.

Since the average air-dry longitudinal shrinkage of these samples was also determined, it is reported here. Because tree 1 samples were measured at 12 per cent moisture content and tree 2 samples at 15 per cent, they are presented separately. Values were: tree 1, CW (5 samples) 0.34 per cent (S.D. 0.03), NW (4 samples) 0.03 per cent (S.D. 0.0); tree 2, CW (12 samples) 0.23 per cent (S.D. 0.035), NW (12 samples) 0.0 per cent (S.D. 0.018).

The influence of manner of drying is a variable that should also be taken into account. The shrinkage from green to oven-dry of both CW and NW sapwood samples,

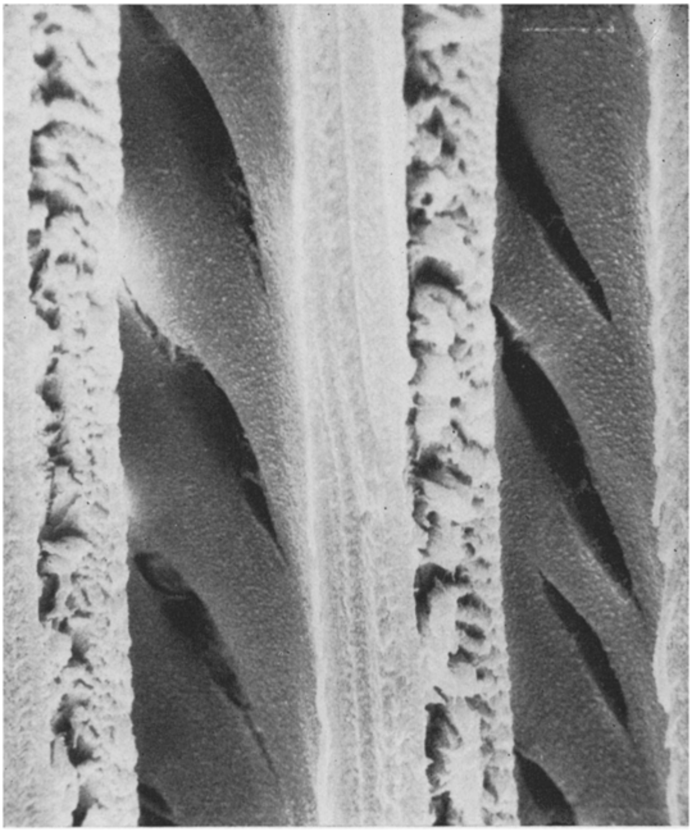

Fig. 6. Scanning electron micrograph of compression wood radial surface of a small block boiled for 1 hour before cutting. Note split extensions from pit apertures. 2800 : 1

subjected to immediate drying in an oven at 100° C, was appreciably greater than that of the samples first dried to constant weight and air-dry condition in a chamber with controlled temperature (21 degrees C) and humidity (Table 3). This was especially noticeable for the NW which had a value of 0.37 per cent, which was three times the axial shrinkage of the more slowly dried NW and places it in the lower range of compression wood shrinkage.

The lighter, last-formed CW of tree 1, (*S* on Fig. 1 and CWNR in Table 2) consisting of 13 narrow rings, each with one-third or less of the ring consisting of latewood with fibril angles of about 20 degrees, had only about half as much axial shrinkage but had the same reduced tangential shrinkage as the denser blocks. However, this wood as well as all the denser more typical CW fell within the usual range of axial shrinkage of "...less than 1 per cent but over 0.3 per cent." [Forest Products Lab. 1960].

The CW *T*/*R* ratios of 1.0 for tree 1 and 1.1 for tree 2 are distinctly lower than those for any normal softwoods as listed in Table 12—1 of Panshin and de Zeeuw [1970]. Table 2 shows that the tangential shrinkage percentage (G to O.D.) of the CW approaches half that of normal wood, whereas its radial shrinkage

Fig. 7. Radial section of tree 2 compression wood showing an isolated tracheid with fibril angles of about 55 degrees adjacent to tracheids with more common fibril angle of 20 to 25 degrees. 750 : 1

is almost the same as that of normal wood. The lower T/R shrinkage ratio therefore appears to be largely attributable to the much reduced tangential shrinkage. Pillow and Luxford [1937] report lower tangential and radial shrinkage for compression wood but do not give the T/R values. Harris and Meylan [1965] report lower tangential shrinkage with increasing fibril angle in compression wood, but they did not measure radial shrinkage. Since the T/R shrinkage ratio is an important physical property of wood, and a low T/R ratio is considered to be desirable, it is well to know the influence of compression wood on this property. Table 2 also gives shrinkage values for five NW heartwood specimens from tree 2. These had only about 70 per cent as much tangential and radial shrinkage as the sapwood, which is similar to the difference in coast redwood (*Sequoia sempervirens* (D. Don) Endl.) sapwood and heartwood, and Luxford [1932] attributes it to the high extractive content of the heartwood.

The manner of drying influences the values in transverse shrinkage as well as in axial shrinkage. Again (Table 3) it can be seen that both the tangential and radial shrinkage percentages of the samples dried quickly at 100 degrees C are much greater than for those dried first in a conditioned chamber to air-dry equilibrium. This is particularly the case for the radial shrinkage which is 46 per cent greater than the more slowly dried samples. As a result of this greater radial shrinkage, the T/R ratio is somewhat lower. This higher shrinkage agrees with that shown in a study by Espenas [1971] who found that Douglas fir, hemlock, and red alder wood shrinkage increased with increase in drying temperature.

In summary, although greater fibril angles of CW may be responsible for greater axial shrinkage and lower tangential shrinkage, they do not appear to influence radial shrinkage. The maximum latewood S2 fibril angle of 32 degrees for this clearly defined compression wood suggests that the value of 45 degrees reported in some recent literature needs qualification, and is better referred to as approaching a maximum of about 45 degrees. The low tangential-to-radial shrinkage ratio of the compression wood is an important physical deviation from normal wood. Because the magnitude of shrinkage is appreciably influenced by the manner of drying, all shrinkage data need to be accompanied by a description of the drying procedure used. For woods such as giant sequoia, coast redwood, and many cedars whose heartwood has reduced shrinkage because of high extractive content, it is also essential to indicate whether samples are sapwood or heartwood. The inner extended apertures of radial or tangential CW pits that are at an appreciable angle (16 degrees or more, in this study) with the cell axis are good anatomical indicators of the presence of compression wood.

References

Cockrell, R. A. 1946. Influence of fibril angle on longitudinal shrinkage of ponderosa pine wood. J. of Forestry **44** (11): 876–878.

Cockrell, R. A., Knudson, R. M., Stangenberger, A. G. 1971. Mechanical properties of southern sierra old- and second-growth giant sequoia. California Agric. Exp. Stat. Bulletin 854.

Cockrell, R. A. 1973. The effect of specimen preparation on compression wood and normal latewood pits and wall configurations of giant sequoia. Bulletin Internat. Assoc. of Wood Anatomists. 1973, No. 4.

Cockrell, R. A., Knudson, R.M. 1973. A comparison of static bending, compression and tension parallel to grain and toughness properties of compression wood and normal wood of a giant sequoia. Wood Sci. Technol. **7**: 241–250.

Jane, F. W. 1970. The structure of wood. 2nd Edition. Black, London.

Espenas, L. D. 1971. Shrinkage of Douglas fir, western hemlock and red alder as affected by drying conditions. Forest Prod. J. **21** (6): 44–46.

Forest Products Laboratory. 1960. Longitudinal shrinkage of wood. U.S.D.A., Forest Service, FPL Mimeo Rep . No. 1093.

Harris, J. M., Meylan, B. A. 1965. The influence of microfibril angle on longitudinal and tangential shrinkage of *Pinus radiata*. Holzforschung **19** (5): 144–153.

Luxford, R. F., Markwardt, L. J. 1932. The strength and related properties of redwood. U.S. Dept. of Agr. Tech. Bul. 305.

Panshin, A. J., de Zeeuw, C. 1970. Textbook of wood technology, Vol. I, 3rd Edition. McGraw-Hill, N.Y.

Pillow, M.Y., Luxford, R. F. 1937. Structure, occurrence, and properties of compression wood. U.S. Dept. of Agr. Tech. Bul. 546.

Tsoumis, G. 1968. Wood as raw material. Pergamon Press, Oxford.

Wardrop, A. B. 1965. The formation and function of reaction wood. p. 371–390. In: W. A. Côté (Ed.), Cellular ultrastructure of woody plants, Syracuse University Press.

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