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SPECIFIC GRAVITY VARIATION IN ROBUSTA EUCALYPTUS grown in Hawaii

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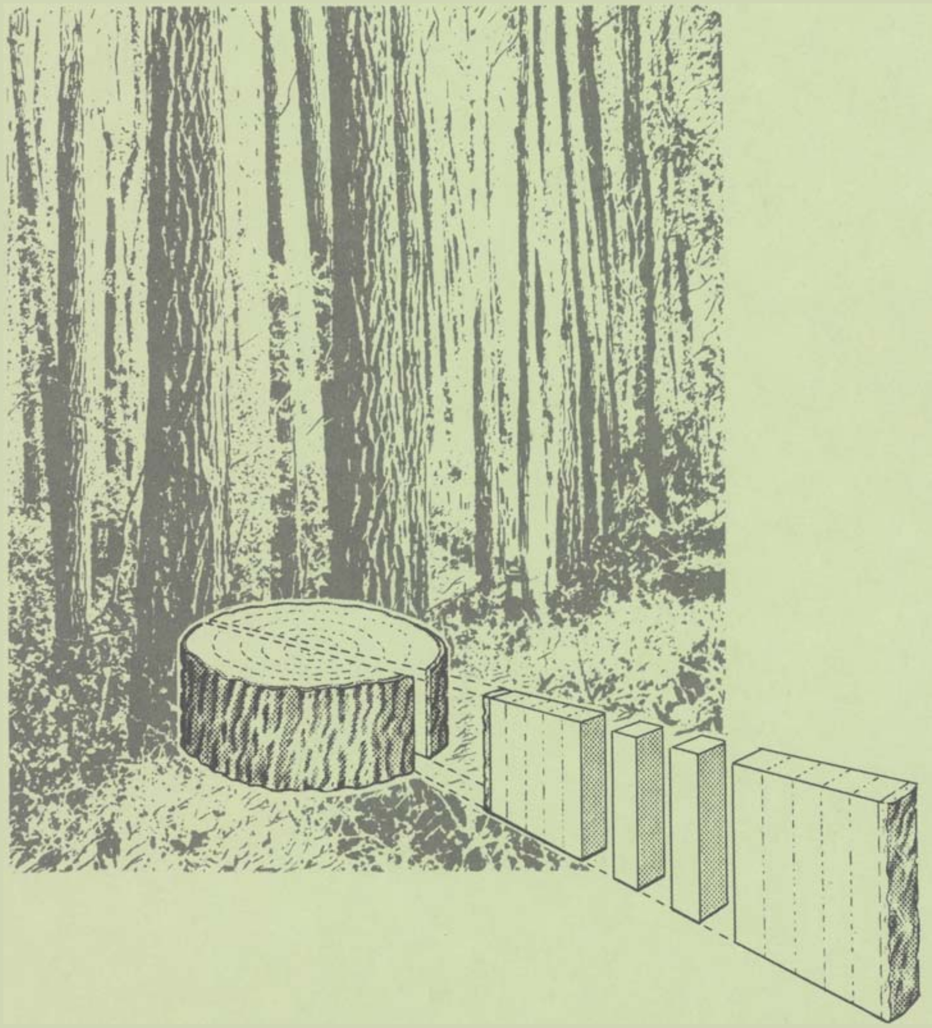

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The Author

ROGER G. SKOLMEN is on the staff of the Station's Institute of Pacific Islands Forestry, with headquarters in Honolulu, Hawaii, where he has been investigating the uses, properties, and processing of forest products. Native of San Francisco, he holds B.S. (1958) and M.S. (1959) degrees in forestry from the University of California, Berkeley.

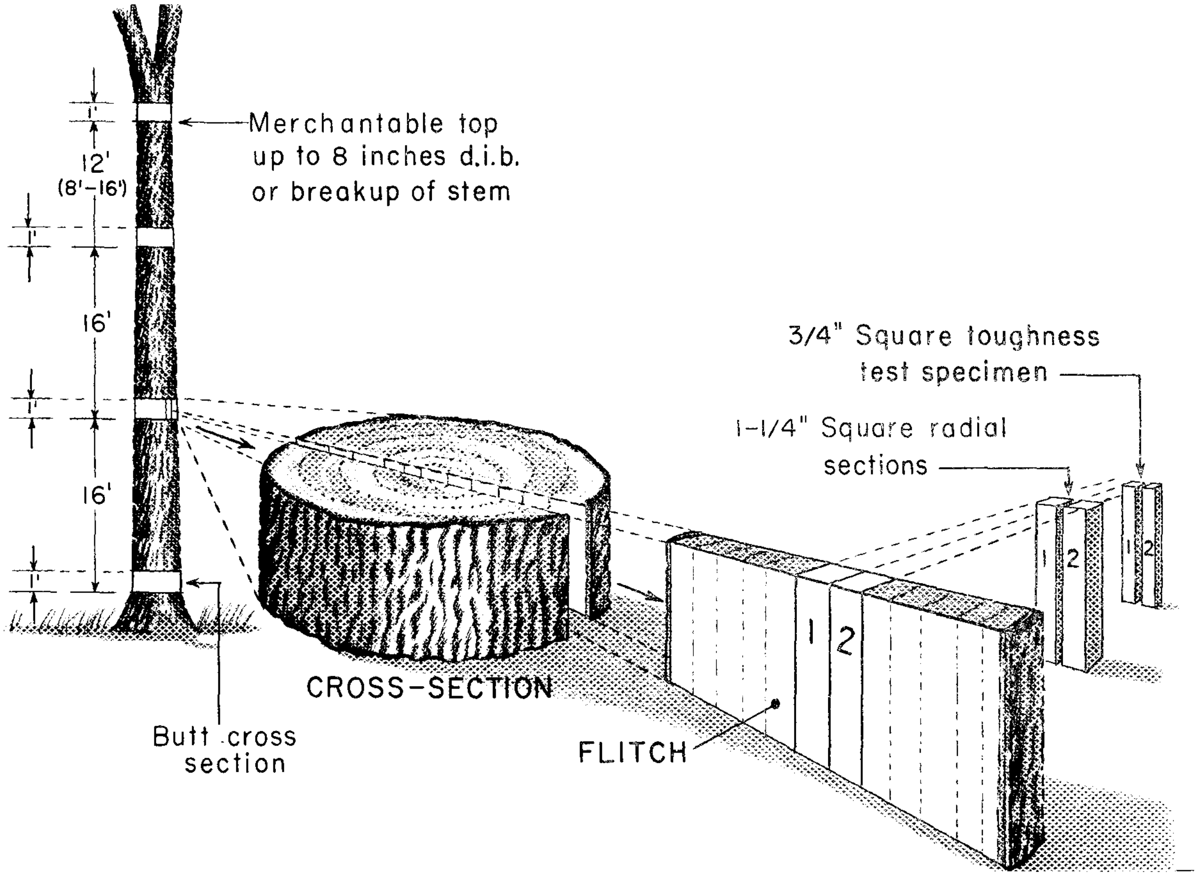
Robusta eucalyptus *(Eucalyptus robusta* Sm.) is an important timber species in Hawaii. The density, or specific gravity, of its wood has been measured in conjunction with standard physical and mechanical property tests (Gerhards 1963; Youngs 1960). It has also been measured as part of an exploratory investigation of brittleheart (brash wood near the pith) in the species (Skolmen and Gerhards 1964). These tests, as well as the general observations of most people who have worked with it, indicate that the wood varies widely in density, not only from one tree to another, but also in wood from one tree and even from one part of a board to another. Because most other properties of the wood are closely related to density, this variation causes many manufacturing problems.

This paper reports data on specific gravity gathered as part of a larger study to determine the extent of brittleheart in robusta. Because brittleheart was suspected to vary widely in volume from tree to tree, a relatively large sample of wood from 50 trees was gathered. This large sample made possible an intensive investigation of specific gravity variation.

PROCEDURE

Ten stands of robusta eucalyptus growing along the northeast coast of the island of Hawaii were selected for sampling. The stands represented the widest available range of age, elevation, and rainfall differences. Five trees at least 11 inches diameter breast height (d.b.h.) and containing at least one 16-foot log were randomly selected from each stand. Cross sections 1 foot long were cut from the large end of each 16-foot log in each tree and from just above the small end of the uppermost log. In some trees the uppermost log was only 8 or 12 feet long rather than 16 feet *(fig. 1)*. In the forest, 2-inch thick flitches with centered pith were sawn from the cross sections. In the shop, the flitches were sawn in line with the pith into 1-1/8 by 1-1/8-inch sticks, which, after air-drying, were further manufactured into 2- by 2- by 28-centimeter toughness test sticks. Each stick represented a certain multiple of 1-1/4 inches (1-1/8-inch green dimension and 1/8-inch saw kerf) of radius from the pith at a certain height in the tree.

The volume measurements for specific gravity were made by immersion, but the wood had been steamed after air-drying to 12 percent moisture content, in order to kill an insect infestation in the samples. This treatment caused the samples to recover some of the shrinkage that had occurred in drying, and raised their moisture content to an average of 14.6 percent. The specific gravity data are therefore a little lower than those determined for wood at 12 percent moisture content that has had normal shrinkage in drying, but they are valid for comparison.



RESULTS AND DISCUSSION

Specific Gravity of the Sample

The sample consisted of 1,759 toughness test sticks representing various radial segments at several heights in 50 trees. The grand mean specific gravity of these sticks was 0.603, with a coefficient of variation of 18.6 percent and a range among the sticks from 0.331 to 0.869. Specific gravity is obviously quite variable in the species; the usual coefficient of variation, based on tests of 50 United States mainland species, is 10 percent (U.S. Forest Serv., Forest Products Laboratory 1955).

Specific Gravity of Individual Trees

Mean specific gravity per tree ranged from 0.431 to 0.694 with a coefficient of variation between means of 10.4 percent. Only five trees of the 50 had a mean specific gravity of less than 0.5, and four of these were in one stand.

Specific Gravity of Stands

Among the 10 stands were several that had generally similar site characteristics, but specific gravity varied considerably between them *(table 1)*. The stand highest in elevation (No. 8), had abnormally short trees and a significantly lower mean specific gravity than the other stands. Stand 9, which had been planted on infertile, abandoned sugar cane land, was higher in mean specific gravity than the other stands, but only significantly higher than five of them. These two stands also had lower coefficients of variation than any of the others. The coefficient of variation between stand means was 8.7 percent.

Spacing of trees around the sample trees was also measured and analyzed, but had no obvious relationship to specific gravity. Stands 5 and 9 had a mean spacing of 8 by 8 feet. Stand 12 was spaced 14 by 14 feet. The other stands were spaced 10 by 10 to 12 by 12 feet.

Table 1–*Specific gravity of robusta, by stand and site characteristics*

Stand number	Age	Elevation	Rainfall	Mean dbh	Mean merchantable height	Mean specific gravity[1]	Coefficient of variation
	Years	*Feet*	*Inches*		*Feet*		*Percent*
1	44	1,300	250	18.1	60	0.654 ab	14.8
2	33	2,200	115	19.6	56	.620 abc	16.3
3	33	2,200	75	16.6	40	.591 bc	17.6
4	32	2,600	85	16.4	40	.576 c	18.6
5	34	2,000	100	16.9	48	.562 c	21.4
6	31	1,800	75	17.0	60	.616 abc	18.3
7	33	2,200	85	20.0	60	.578 bc	18.4
8	30	3,600	75	16.6	24	.480 d	13.7
9	35	1,600	225	16.2	44	.661 a	12.4
10	34	1,500	250	18.5	48	.624 abc	18.2
Over-all means				17.6	48	.603	18.6

[1] Values followed by the same letters do not differ significantly at the 5 percent level of probability.

Specific Gravity of Size Classes

The sample included trees ranging in d.b.h. from 12.3 to 25.9 inches and in merchantable height from 16 to 88 feet. To see if specific gravity varied with tree size, I grouped the trees into four size classes based on their diameter inside bark at the top of the first log. This measure allowed fairly uniform classes with a more nearly equal representation of stands and trees in each class than did the measurements of d.b.h. or the diameter inside bark at the butt.

The mean specific gravity of the class of larger trees was highly significantly different from the other three means *(table 2).* The other three means were not different from each other at the 5 percent level.

Except for two from stand 1, the trees in class 4 grew most rapidly in diameter, as indicated by the mean annual increment. Although this suggests that rapid growth produces wood of higher mean density than slow growth, probably the higher density value resulted from the greater proportion of dense, outer wood in the larger trees. The relationship does not hold for wood of stand 9, which though slowly grown in comparison to the other stands, had the highest mean specific gravity *(table 1).* Regression analysis using the ratio of diameter inside bark at the top of the first log to age of the tree as the dependent variable and mean specific gravity at the 16-foot height for each tree as the independent variable showed only a poor relationship between the two. It yielded a correlation coefficient of only -0.143.

Table 2–*Specific gravity based on diameter inside bark at top of first log, by size class*

Size class	Diameter range	Diameter growth per year[1]	Specific gravity[2]
	Inches		
1	7.6- 9.9	0.263	0.581 a
2	10.0-11.9	.322	.595 a
3	12.0-13.9	.390	.595 a
4	14.0-18.4	.444	.625 b

[1]Diameter at 16 feet divided by stand age.
[2]Values followed by the same letter do not differ significantly at the 1 percent level of probability.

Specific Gravity Variation Within Trees

Within trees, specific gravity was also quite variable. The coefficient of variation ranged from 7.8 percent for the least variable tree to 23.0 percent for the most. For only two trees was it below 10 percent.

Within a single tree, the largest range in specific gravity was 0.357 to 0.817, a difference of 0.460. The low value was from a sample at the butt of the first log next to the pith. The high value sample was 64 feet up the tree and 3 inches out from the pith. In the butt cross section of this same tree, the wood next to the pith was 0.357, and 6 inches from the pith it was 0.755, a difference of almost 0.4. This was the largest variation in a single cross section.

Most other trees were almost as variable, and differences of 0.3 and more between the highest and lowest value sample in a tree were quite common. Variation was usually greatest in individual cross sections from low in the trees–at the butt and at 16 feet. In many of these cross sections there were specific gravity differences of more than 0.3 between inner and outer wood.

In the consolidated data for all stands, a consistent trend of increase in specific gravity with distance from the pith and height is indicated *(table 3)*, although somewhat masked. When the data are grouped into the four size classes and when values based on only a very few samples are dropped, the trend is very clear *(fig. 2).*

Robusta does not produce growth rings in Hawaii, and so periodic growth cannot be determined from its wood. General observations, coupled with a few available periodic height and diameter measurements of robusta trees in plantations, indicate that growth is rapid for the first 10 years or so. Growth rate then gradually slows as the trees increase in age.

Table 3–*Specific gravity and sampling frequency, by radius and height in tree*

Height in tree (feet)	Number of samples	Mean specific gravity	Specific gravity and number of samples for each 1¼ inch radial increment [1]									
			1¼	2½	3¾	5	6¼	7½	8¾	10	11¼	12½
88	7	0.723	0.676(2)	0.706(2)	0.767(2)	0.763(1)						
80	18	.715	.666(6)	.722(6)	.754(5)	.771(1)						
76	6	.698	.641(2)	.684(2)	.768(2)							
64	101	.696	.635(28)	.693(28)	.739(26)	.735(15)	.724(4)					
60	12	.649	.531(4)	.666(4)	.749(4)							
56	22	.670	.600(6)	.657(6)	.727(6)	.710(3)	.704(1)					
48	223	.665	.573(60)	.644(60)	.719(56)	.742(34)	.750(13)	.662(1)				
44	13	.610	.456(2)	.555(2)	.628(2)	.652(2)	.656(2)	.671(2)	.694(1)			
40	15	.04	.527(4)	.655(4)	.694(4)	.808(2)						
32	354	.636	.538(88)	.604(88)	.678(85)	.712(55)	.732(28)	.723(10)				
24	18	.580	.528(6)	.589(6)	.646(5)	.514(1)						
16	438	.594	.492(98)	.548(98)	.625(98)	.664(76)	.686(44)	.677(17)	.662(6)	.701(1)		
Butt	531	.532	.436(100)	.461(100)	.527(99)	.579(93)	.620(70)	.632(38)	.616(16)	.664(10)	.644(4)	.610(1)
Total Mean	1,759	.603	.517(406)	.571(406)	.640(394)	.658(282)	.672(163)	.658(68)	.631(23)	.667(11)	.644(4)	.610(1)

[1] Distance of outer edge of sample from pith.

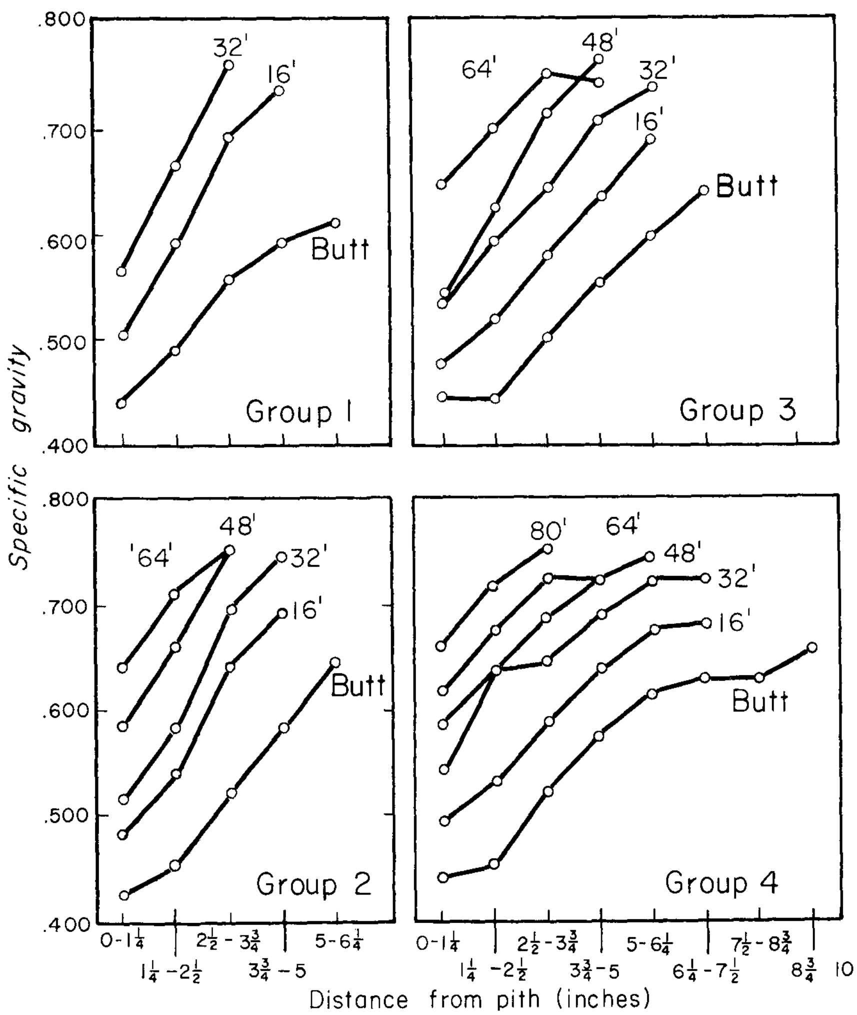


Figure 2–Specific gravity along radii of major cross sections, by height in tree and distance from pith, in four size classes determined by diameter inside bark at top of first log: Group 1, 7.6-9.9 inches; Group 2, 10.0-11.9 inches; Group 3, 12.0-13.9 inches; Group 4, 14.0-18.4 inches.

It is apparent that specific gravity of the wood produced is related to diameter growth rate. Diameter growth rate is in turn probably related to cambium age. When the tree is very young and very fast growing, low density juvenile wood is produced. Density increases as diameter growth rate decreases and mature wood is produced. The relation between cambium age and specific gravity increase is not so clear cut with regards to growth in height, because density increase with height is much greater than increase with diameter in wood produced by cambium of the same age. A 6-inch diameter robusta tree is usually over 40 feet tall. The specific gravity of wood 3 inches out from the pith at the butt of such a tree is usually less than that of wood at the pith at 32 feet up in the tree, even though the wood at this height in the tree was produced by the cambium at about the same time as the wood at the butt *(fig. 2).* This indicates that some of the increase in wood density with height is independent of the age, and possibly the reproductive rate, of the cambium.

Specific Gravity Variation Between Young Stands

To determine if there was any consistent propensity of certain stands to produce high or low density wood, I compared the mean specific gravity of each of the first three radial increments at the butt and 16-foot cross sections *(table 4).* Any increment from one stand should be similar in age and stage of growth to one from another stand, and the 1-1/4-inch increment at the butt section should be nearly identical in all stands.

Stand 9 produced wood that was significantly denser, even close to the pith, than the wood of all but one of the other stands *(table 4).* The greater mean specific gravity of trees in stands 1 and 9, when harvested *(table 1),* was already present in the butts of these trees when they were only about 6 inches in diameter at the butt. It would probably have been possible to predict that these stands would have denser wood on the basis of increment cores taken early in their life. There was not, however, a good early indication that stand 8 would have less dense wood than any other stand. The trend towards low density in stands 4, 5, 7, and 8 is present in most increments, but is not sufficiently consistent to provide a basis for prediction.

There is no obvious explanation for the initially denser wood in stands 1 and 9. As has been mentioned, stand 9 was growing on infertile soil of an abandoned sugar cane plantation. This soil may have been limiting in some nutrient essential to lower density wood production; stand 9 was obviously below normal size for its age. Stand 1, on the other hand, had grown at an impressive rate. It was on a shallow soil formed on a pahoehoe lava flow of Mauna Loa volcano and thus was different from all the other stands, which were on deep soils formed on Mauna Kea cinder deposits. Possibly stand 1 soil also had a nutrient makeup different from the others.

Table 4–*Stand mean specific gravity in descending order, for first three increments of radius at butt and 16-foot cross sections*

Stand number	1¼ inches from pith specific gravity [1]	Stand number	2½ inches from pith specific gravity [1]	Stand number	3¾ inches from pith specific gravity [1]
	BUTT CROSS SECTION				
9	0.515 a	9	0.587 a	9	0.653 a
10	.453 ab	1	.510 b	1	.578 a
2	.452 ab	2	.467 c	10	.553 b
6	.441 ab	10	.459 cd	6	.524 bc
8	.438 bc	6	.452 cd	3	.524 bc
1	.436 bc	3	.443 cd	2	.523 bc
3	.423 bcd	4	.435 cd	4	.517 bc
7	.419 bcd	5	.419 d	5	.486 bc
5	.393 cd	8	.418 d	8	.459 c
4	.388 d	7	.418 d	7	.456 c
	16-FOOT CROSS SECTION				
1	.550 a	9	.661 a	9	.720 a
9	.548 a	1	.624 a	1	.694 ab
2	.506 b	2	.567 b	6	.650 bc
3	.496 b	3	.563 bc	10	.639 bc
6	.490 bc	6	.548 bcd	3	.639 bc
10	.487 bc	10	.533 bcd	4	.616 c
7	.483 bc	4	.524 bcd	2	.607 cd
4	.468 bc	5	.508 cd	5	.597 cd
5	.449 c	8	.484 d	8	.543 d
8	.446 c	7	.477 d	7	.540 d

[1] Values followed by the same letters within each group do not differ significantly at the 5 percent level of probability.

Specific Gravity of Brittleheart and Sound Wood

Brittleheart is a core of brash wood near the pith. It is usually made up of rapidly grown, low-density juvenile wood. This wood is crushed by the long-term loading of longitudinal growth stress and is brash because it is full of minute compression failures. Such wood is essentially useless for lumber products and is usually discarded.

All the samples of this study were processed through a U.S. Forest Products Laboratory toughness testing machine. Those samples that had a brash type of failure were considered to be brittleheart.

Although brittleheart is formed of low density wood that is readily crushed, all low density wood is not brittleheart. Wood taken from near the pith of very young trees, though of low specific gravity, is not abnormally brash (Dadswell and Langlands 1934). It only becomes brash as the trees get older and larger, developing compression failures due to growth stresses. Specific gravity remains constant.

Nevertheless, one of the best means of segregating brittleheart from sound, normal wood is by weight, because in sawlog-size trees, there is a very strong relation between low density and brittleheart *(table 5).* There were 577 samples of brittleheart with a mean specific gravity of 0.503. This mean was found by the t test to be significantly (1 percent level) different from the mean of the 1,182 samples of sound heartwood and sapwood, which was 0.651. In each stand, brittleheart was significantly less dense than sound wood. But, illustrating that all low density wood is not brittleheart, the sound wood of stand 8 is quite close in specific gravity to the brittleheart of stands 2, 3, 4, 5, 6, 7, and 10.

Table 6–*Specific gravity of brittleheart, sound heartwood, and part or all sapwood, by size*[1] *class*

Item	Class			
	1	2	3	4
Diameter range (inches)	7.6-9.9	10.0-11.9	12.0-13.9	14.0-18.4
Brittleheart specific gravity[2]	.499 ab	.490 a	.500 ab	.522 b
Sound heart specific gravity[2]	.584 c	.614 d	.608 cd	.640 e
Sapwood and part sapwood specific gravity[2]	.691 f	.703 f	.707 f	.716 f

[1] Based on diameter inside bark at top of first log.
[2] Values followed by the same letters within each row and column do not differ significantly probability at the 1 percent level of probability.

Table 5–*Mean specific gravity of brittleheart and sound wood, by stand*

Stand number	Specific Gravity		
	All wood[1]	Brittleheart[1]	Sound wood[1]
9	0.661 a	0.572 a	0.693 a
1	.654 ab	.547 a	.691 a
10	.624 abc	.496 b	.674 ab
2	.620 abc	.499 bc	.657 b
6	.616 abc	.514 b	.655 bc
3	.591 bc	.494 bc	.627 d
7	.578 bc	.499 bc	.634 cd
4	.576 c	.487 c	.629 d
5	.562 c	.475 c	.653 bc
8	.480 d	.442 d	.496 e
Average	.603	.503	.651

[1] Figures followed by the same letters within each column are not significantly different at the 5 percent level of probability.

If the specific gravity values of brittleheart, sound heartwood, and sapwood or part sapwood are separated by size class *(table 6),* it is seen that the relation between brittleheart and sound wood specific gravity holds for trees of all sizes. Further, sapwood and part sapwood is significantly denser than sound heartwood. This is not surprising, since specific gravity has been shown to increase consistently with diameter and the three types of wood occupy distinct positions with respect to diameter.

It should be possible to control a considerable part of the variation in robusta wood density by sorting the wood into brittleheart, sound heartwood, and sapwood or part sapwood.

SUMMARY AND CONCLUSIONS

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1972. **Specific gravity variation in robusta eucalyptus grown in Hawaii.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Stn., 7 p., illus. (USDA Forest Serv. Res. Paper PSW-78)

Oxford: 176.1 *Eucalyptus robusta:* 812.31 [–015.26 + 812.712]
Retrieval Terms: Eucalyptus robusta; wood density; specific gravity; brittleheart; variation; Hawaii.

Tests on samples from 50 trees indicated that the specific gravity of robusta eucalyptus wood varies markedly within trees, between trees, and between stands. Mean specific gravity was 0.603; range was 0.331 to 0.869 for the entire sample. Most of the variation within trees results from a consistent increase in wood density with diameter and height increase. The range within one cross section was 0.357 to 0.755, and the largest range for a single tree was 0.357 to 0.817. Some of the variation between stands may be caused by site factors, because abnormally high or low specific gravity is related to the location where grown, or the stand, and shows up early in the life of the stand. Variation in specific gravity between stands is not obviously related to differences in growth rate between stands, although the slowest growing stand had the highest density wood.

Because robusta wood density is variable, the species is difficult to handle in many manufacturing operations. In seasoning, the denser wood loses and gains moisture much more slowly than the less dense wood. Wood cutting tools adjusted for average density may gouge low density wood and skip over or jam on high density wood. Gluing and finishing problems may also result from density variation.

To reduce the manufacturing problems, wood should be carefully sorted by weight during grading. This is already done to some extent when brittleheart and suspected brittleheart are removed on the mill floor and at the green chain. But considerable variation in wood density still exists in sound heartwood and sapwood. Because specific gravity increases with diameter, sorting sound wood into "all heartwood" and "part or all sapwood" would further decrease variation. Because specific gravity increases with height, sorting of logs into "butts" and "uppers" before sawing would also be a means of reducing variation. This would also have the effect of separating the stronger, high density wood of the upper logs from the weaker but more easily worked wood of the butt logs. Lastly, logs should be plain- or flat-sawed if possible, because boards so sawn contain less density variation than quarter-sawed boards.

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The specific gravity (air-dry volume, ovendry weight) of *Eucalyptus robusta* wood was tested within and between trees from 10 stands. Mean specific gravity was 0.603, but the range in individual samples for 50 trees was 0.331 to 0.869, and was 0.357 to 0.755 within one cross section. A consistent increase was recorded in all trees from pith to cambium and from butt to top. Mean for brittleheart (brash wood near the pith) was 0.503, considerably lower than that for normal wood at 0.651. Manufacturing problems caused by density variation could be reduced by sorting before sawing and during grading.

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