STRENGTH AND RELATED PROPERTIES OF
BALSA AND QUIPO WOODS

Information Reviewed and Reaffirmed

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

Before the war, balsa (Ochroma lagopus) attained commercial importance because of its exceptionally light weight and its insulating properties. Primitive logging and transportation facilities at the source provided sufficient supplies for peacetime markets. Now, however, the use of balsa as core material in "sandwich" construction for aircraft and for other war uses has greatly increased the demand for this wood and resulted in efforts to increase the supply by improving the production facilities in Ecuador and other producing regions and to find possible substitute species.

One of the species which has been proposed as a substitute for balsa is quipo (Cavanillesia platanifolia), also known as bongo, a wood of comparable low specific gravity that is reported to exist in sufficient quantity and size to meet commercial requirements. A series of tests were run, therefore, at the Forest Products Laboratory to determine and compare the various strength and related properties of these two woods. These tests and the resulting information determined will be discussed in this report.

Summary

The average specific gravity of the balsa and the quipo tested was approximately the same. That of the balsa was 0.13 with a range from 0.06 to 0.24

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1 This is one of a series of progress reports prepared by the Forest Products Laboratory relating to the use of wood in aircraft. Results here reported are preliminary and may be revised as additional data become available.

2 Maintained at Madison, Wis., in cooperation with the University of Wisconsin.
for the individual specimens; while the quipo had an average specific
gravity of 0.12 with a range from 0.07 to 0.20. The specific gravity of
the quipo was less variable within individual pieces than that of the
balsa, which is an advantage when the selection of material with uniform
weight and strength is required.

The average moisture content of the quipo specimens at test was from 1 to
3.3 percent higher than that of the balsa specimens. Since no data upon
the moisture-strength relations for these light-weight species were avail-
able, average moisture adjustment factors as previously found for other
species were applied. This approximation effects only a minor change of
values and does not appreciably alter the comparisons between the species.

The balsa was generally bright and free from decay; whereas the quipo was
badly stained, and decay was present to such an extent that specimens con-
taining decay had to be accepted to provide a full schedule of tests. Since
the effect of decay on strength properties, however, is likely to be quite
variable without a corresponding effect on specific gravity, the closeness
of correlation between several of these properties and specific gravity
indicates that the values for quipo may not have been seriously affected.

Comparing the results obtained from specimens of similar specific gravity,
the balsa gave the higher values in static bending, compression parallel
to the grain, and toughness; the quipo was superior in compression per-
pendicular to grain when loaded on the tangential face; and the two species
were approximately equal in compression perpendicular to grain with load
on radial surfaces, tension perpendicular to grain, shear parallel to
grain, and hardness.

Description of Material

Balsa

Balsa (*Ochroma lagopus*) is a tropical tree, widely distributed throughout
the West Indies, Mexico, Central America, and northern South America, with
the Republic of Ecuador furnishing the greater percentage of the world's
commercial supply. Its growth is rapid, attaining a size of commercial
value in 4 to 6 years. Fast-growing trees between these ages produce the
lightest wood, while in slow-growing and older trees the wood becomes
heavier and less adaptable to commercial uses.

The balsa tested was obtained from a commercial supplier and arrived at
the Laboratory in January 1943. The entire shipment was of wood produced
in Ecuador and consisted of bundles containing approximately 1,500 board
feet of kiln-dried lumber of various dimensions.
The wood was clear, bright and in a dry condition. It was faintly pink in color with a silky luster and velvety feel. The sapwood usually was not clearly defined, and growth rings were absent or indistinct. The rays, readily visible, were conspicuous on the radial surface and usually distinct on the tangential surface. The wood required careful handling as it was soft, light, and easily indented or injured. It was porous, non-resinous, tasteless, and odorless.

The major portion of the material was free from checks, decay, and discoloration, indicating that it had been effectively seasoned after cutting. Decay and small worm holes were present in some of the boards. A few pieces contained pith. No knots or shakes were noted, but compression failures of varying degrees were prevalent.

Quipo

Quipo (Cavanillesia platanifolia), sometimes known as bongo, is a tropical species of wood found chiefly in Central America. It has had little or no commercial exploitation up to the present time. Its growth is slower than balsa, averaging about 30 years to attain a useful size. The wood is white or yellowish in color, often has brown streaks scattered throughout, and is without the silky luster found in the balsa. The texture of finished surfaces is coarse and harsh. The wood is soft, of pithlike consistency when green, but harder when dry. It is said to have no pith core or water heart such as is found in some balsa trees. Growth rings are not distinct but are more evident than those in balsa wood. Pores are numerous and appear as small pinholes longitudinally through the wood. The rays are rather coarse and are conspicuous on a radial surface although indistinct on a tangential surface. The bark is light in color, hard, about 1-3/4 inches thick, and underlain with coarse fibrous material. The wood is light with an average density equal to or less than that of balsa.

Two shipments of quipo, both in lumber form and originating in the Province of Darien, Republic of Panama, were received for the purpose of this investigation. According to information from Panama,² both shipments were cut during the rainy season, and an attempt was made to season the material by air drying. Part of the first shipment was dried under cover, but due to the wet conditions the seasoning was not effective. The wood was in a damp condition, and blue stain was prevalent throughout when it reached the Laboratory. A large part of the second shipment was discarded at the source because of excessive decay. The remaining portion was blue-stained and showed evidence of decay but as a whole was in better condition than the first shipment.

²Letter from Terance O. Ford, Compania Ford, S. A., Panama, R. de P. November 27, 1942.
The individual pieces of balsa and quipo were numbered, measured, weighed, and loosely piled in the Laboratory to condition to a uniform moisture content, preliminary to the cutting of specimens from them. Each species was sorted into groups according to density. Each group had a range of 1 pound per cubic foot, such as 4-1/2 to 5-1/2 pounds per cubic foot, 5-1/2 to 6-1/2 pounds per cubic foot, and so on. The lightest and heaviest groups included insufficient material for a full series of tests and were not used.

Ten clear pieces from each of the six groups ranging from 5-1/2 to 11-1/2 pounds per cubic foot were selected for test. The general method of cutting is shown in figure 1. Approximately 37 percent of the quipo specimens, all in the three lower density groups, were from the first shipment in which the boards were not of sufficient thickness to produce specimens of standard size. It was necessary to glue together pieces of the same density and with the growth rings matched as closely as possible to form specimens for the compression perpendicular to grain, shear, tension, and cleavage tests.

The specimens were placed in a humidity room at 70° F. and 64 percent relative humidity until check weights of representative samples indicated that equilibrium moisture content had been attained.

The tests were conducted according to the methods of A.S.T.M. standard D-143-27 with the following exceptions and additions: (1) the machine speed was reduced from 0.024 to 0.011 inch per minute for the tests of compression perpendicular to the grain in order to obtain readings at smaller increments of load for a better stress-strain curve; (2) for the tension and cleavage tests the machine speed was reduced from 0.25 to 0.16 inch per minute; (3) a complete series of tests of both tangential and radial loading was performed in compression perpendicular to the grain, tension, cleavage, shear and toughness; and (4) an additional test in compression perpendicular to the grain was performed on 2-inch cubes with the entire top surface of the specimen loaded.

Shrinkage

Shrinkage in drying is proportional to the moisture lost below the fiber-saturation point and is usually expressed as a percentage of the green dimensions, which represent the natural size of the piece.

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The toughness test and machine are described in reference (1).

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As no green balsa or quipo material on which to make shrinkage determinations was available, specimens 1 inch long in the direction of the grain by 1 inch thick by \(\frac{4}{4}\) inches wide, the width being tangential in half of the specimens and radial in the other half, were cut from the dry material and soaked in water for a period of 18 days. The specimens were weighed occasionally during the soaking period, and the average rates of moisture absorption are shown in figures 2 and 3. From this soaked condition, the specimens were dried slowly until oven-dry; they were weighed and measured frequently during the process. Shrinkage values corresponding to various moisture contents were computed as percentages of the dimensions of the soaked specimens. The minimum and maximum shrinkage values observed are given in table 1. Average moisture-shrinkage curves are shown in figure 4.

### Explanation of Figures

Figures 5 to 25 show the specific gravity-strength relationships of balsa and quipo wood. The open circles and triangles in these graphs represent the individual tests, and the closed circles and triangles the averages of the several tests that came within each density group (4-1/2 to 5-1/2 pounds per cubic foot to 11-1/2 to 12-1/2 pounds per cubic foot). The specific gravity is based on the oven-dry weight and the volume at time of test. The average relationships between the strength properties and specific gravity are indicated by empirical curves of the straight line type, shown as solid lines, the regression of the strength property on specific gravity having been computed by the method of least squares.

Specific gravity values of the cleavage, shear and tension perpendicular to the grain specimens were not determined, and the specific gravity values for individual specimens represented in figures 18 to 25 were obtained by averaging the specific gravity values of specimens taken from the same stick for other tests.

### Moisture Adjustment

The dashed line shown on some of the figures represents the density-strength relation after a moisture correction was applied to the equation. This line gives an approximation of the strength properties that would be expected if the specimens had been tested at 12 percent moisture content. In the absence of specific data on moisture strength relations for balsa and quipo, average moisture adjustment factors\(^2\) that had been derived for other species were used.

\(^2\)Described in reference (1).

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Analysis of Results

Specific Gravity

Tests of other woods have shown that specific gravity, or density, is an index of the strength properties, and this is true also of balsa and quipo wood. While there may be considerable differences in strength values between species of the same density there is a relatively small range of strength for pieces of like density of the same species. This makes it possible to select material to meet a given requirement. Since balsa and quipo each have a considerable variation of density, even within pieces cut from the same tree, this factor can be used in establishing specifications for the material required for a particular use.

Moisture Content

The moisture content of balsa and quipo differed, although both were conditioned together under 64 percent relative humidity and 70° F. The difference in moisture content of the two woods at equilibrium under these conditions was presumably due to the fact that the balsa, having been kiln-dried, approached moisture equilibrium from below, whereas the quipo, being at much higher moisture content, approached from above.

Decay

In using these results for comparisons between species, consideration should be given to the blue stain and other disolorations present in the quipo wood. Examination of several samples of both shipments revealed that these samples were badly stained and contained a considerable amount of decay, while in some of them there were even nematodes present. These findings indicated that the samples had been exposed to severe conditions.

Although strength properties of wood increase in general with increase in specific gravity, there is always some variability among pieces of the same specific gravity. Such variability is increased by variations in the effect of any decay that may be present. The properties of quipo as derived from static bending (figs. 5 to 7), compression parallel to grain (figs. 8 to 10), hardness (figs. 15 to 17), and toughness (figs. 24 and 25) tests are correlated with specific gravity to a degree that indicates that decay did not enter to any large extent as an additional variable.

5These studies were made by the Division of Forest Pathology, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture, conducted in cooperation with the Forest Products Laboratory at Madison, Wisconsin.

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Shrinkage

Data on shrinkage from the green condition are not available, but the present tests indicate that after they are dried and soaked balsa and quipo do not differ significantly in shrinkage. The data do not show any consistent relationship between density and shrinkage for either species. The moisture absorption studies that were made on the same specimens as the shrinkage measurements show that the quipo absorbed considerably more moisture the first 2 days of soaking and from then on the difference was maintained by practically the same absorption by the two species. In all specimens there was a distinct density-moisture absorption relationship in which the percentage of moisture absorbed increased as the density decreased. The difference between the two species in absorption is rather remarkable in view of the fact that the specimens were only 1 inch in dimension in the direction of the grain.

Cleavage

All the balsa cleavage specimens split along the side from a point where the grip was attached to the specimens rather than through the section of minimum length. The boring of the hole in preparing specimens of the required form may have created irregularities causing this result.

Compression Failures

Many compression failures were found in pieces of the balsa wood during the first inspection and when specimens were being prepared. These were avoided in cutting the individual specimens, but it is possible that undetected compression failures were sometimes present and affected the test results. The worm holes that were present in some of the balsa specimens were of such size and location that they did not materially affect the test results. No compression failures were detected in the quipo wood.

Conclusions

1. The results show that balsa and quipo of like density are of approximately the same strength in compression perpendicular to the grain when loaded on a radial face, in end and side hardness, shear parallel to the grain (tangential), and cleavage (tangential and radial)(figs. 12, 14, 15, 16, 17, 18, 20, and 21).

2. The balsa was definitely stronger than the quipo of like density in static bending, compression parallel to grain, and toughness. It was slightly higher in shear parallel to grain (radial) and tension perpendicular to grain (tangential and radial)(figs. 5, 6, 7, 8, 9, 10, 19, 22, 23, 24, and 25).

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3. The quipo gave higher values than the balsa of like density in compression perpendicular to the grain when loaded on tangential face (figs. 11 and 13). The greater strength of quipo in that property may be due to its prominent medullary rays.

4. Strength values of both balsa and quipo can conveniently be related to density, and appropriate simple equations may be constructed showing their relationship.

5. Since the quipo contained a considerable amount of stain and decay, the strength values shown in this report may be slightly lower than would be obtained for properly seasoned material in a sound condition.

6. Little is known regarding the growth, cutting, seasoning and handling of either species before it reached the Laboratory. Just how representative the material tested is of the species as a whole is therefore unknown, and additional tests may result in slight changes in the average values.

7. Large variations of density were found in both species, not only between pieces from different locations in the tree but also within an individual piece. The quipo, however, showed less variation within individual pieces than the balsa. This lesser variability would be advantageous when it is desired to obtain material within a limited range of density.
Bibliography

(1). Markwardt, L. J. and Wilson, T. R. C. - 1935
Strength and Related Properties of Woods Grown in the United

(2). Markwardt, L. J. - 1914
Compression Failures as Defects. Hardwood Rec. 39 (1): 24-25
illus.

(3). American Society for Testing Materials - 1933
Standard Methods of Testing Small Clear Specimens of Timber.
A. S. T. M. Designation D 143-27.
408-444, illus.

(4). Tiemann, H. D.
Report No. 257 Proj. 134-11 Forest Products Laboratory. What
Causes the Difference in Radial and Tangential Shrinkage?
Some Experiments with Quiro and Sheel Oak with a Study of the
Structure of Quiro by Polarized Light. Also, Reduction of
Shrinkage by Drying Wood in the Frozen Condition.

(5). Tiemann, H. D.
Report 258, Proj. 134-11, Forest Products Laboratory. "Heart
Break" or Cross Breaks in Balsa.

(6). Price, A. T.
A Mathematical Discussion on the Structure of Wood in Relation
to Its Elastic Properties.

(7). Draffin, J. O. and Muhlenbruch, C. W.
Mechanical Properties of Balsa Wood, From the Proceedings of

(8). Carpenter, R. C.
The Properties of Balsa Wood. From the transactions of A.S.C.E.

(9). Koehler, A. - 1933
40 pp., illus.

(10). Brush, W. D. - 1942

(11). Record, S. J., and Hess, R. W.
Timbers of the New World.

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Table 1.—Range of shrinkage values for balsa and quipo wood.

<table>
<thead>
<tr>
<th>Direction of shrinkage: Shrinkage from soaked to oven dry condition, percent of soaked dimension</th>
<th>Balsa</th>
<th>Quipo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tangential</td>
<td>3.4 to 7.0</td>
<td>3.7 to 5.8</td>
</tr>
<tr>
<td>Radial</td>
<td>1.4 to 2.1</td>
<td>1.7 to 2.9</td>
</tr>
<tr>
<td>In volume</td>
<td>5.1 to 9.3</td>
<td>5.5 to 8.5</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>SPECIMEN NUMBER</th>
<th>TYPE OF TEST</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>COMPRESSION PERPENDICULAR TO GRAIN (TANGENTIAL)</td>
</tr>
<tr>
<td>2</td>
<td>COMPRESSION PERPENDICULAR TO GRAIN (RADIAL)</td>
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<tr>
<td>3</td>
<td>COMPRESSION PERPENDICULAR TO GRAIN (TANGENTIAL)</td>
</tr>
<tr>
<td>4</td>
<td>COMPRESSION PERPENDICULAR TO GRAIN (RADIAL)</td>
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<tr>
<td>5</td>
<td>SHEAR PARALLEL TO GRAIN (TANGENTIAL)</td>
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<tr>
<td>6</td>
<td>SHEAR PARALLEL TO GRAIN (RADIAL)</td>
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<tr>
<td>7</td>
<td>TENSION PERPENDICULAR TO GRAIN (TANGENTIAL)</td>
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<tr>
<td>8</td>
<td>TENSION PERPENDICULAR TO GRAIN (RADIAL)</td>
</tr>
<tr>
<td>9</td>
<td>COMPRESSION PARALLEL TO GRAIN</td>
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<td>10</td>
<td>STATIC BENDING</td>
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<tr>
<td>11</td>
<td>CLEAVAGE (TANGENTIAL)</td>
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<tr>
<td>12</td>
<td>CLEAVAGE (RADIAL)</td>
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<td>13</td>
<td>HARDNESS</td>
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<tr>
<td>16</td>
<td>SPECIFIC GRAVITY AND VOLUMETRIC SHRINKAGE</td>
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<tr>
<td>17</td>
<td>TOUGHNESS (TANGENTIAL)</td>
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<tr>
<td>18</td>
<td>TOUGHNESS (RADIAL)</td>
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<td>19</td>
<td>SHRINKAGE (TANGENTIAL)</td>
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<tr>
<td>20</td>
<td>SHRINKAGE (RADIAL)</td>
</tr>
</tbody>
</table>

Figure 1.—General method followed in cutting test specimens from stick.
Figure 2.—Rate of moisture absorption in soaking. Specimens were 1 by 1 by 4 inches. The 4-inch dimension was tangential.
Figure 3.—Rate of moisture absorption in soaking. The specimens were 1 by 1 by 4 inches. The 4-inch dimension was radial.
Figure 4.--Moisture shrinkage curves.

LEGEND:

O-BALSAPoINTS REPRESENT AVERAGE OF:
TANGENTIAL-11 SPECIMENS
(AVERAGE SPECIFIC GRAVITY .135)
RADIAL-12 SPECIMENS
(AVERAGE SPECIFIC GRAVITY .124)
Δ-QUIPO-POINTS REPRESENT AVERAGE OF:
TANGENTIAL-8 SPECIMENS
(AVERAGE SPECIFIC GRAVITY .128)
RADIAL-7 SPECIMENS
(AVERAGE SPECIFIC GRAVITY .115)
Figure 5.—Static bending, stress at proportional limit.
Figure 6.—Static bending, modulus of rupture.
Figure 7.--Static bending, modulus of elasticity.

LEGEND:
- BALSA (10.6 PERCENT M.)
- QUIPO (13.6 PERCENT M.)
- GROUP AVERAGE
- GROUP AVERAGE
Figure 8.—Compression parallel to grain, stress at proportional limit.
Figure 9.--Compression parallel to grain, maximum crushing strength.
Figure 10.—Compression parallel to grain, modulus of elasticity.
Figure 11.—Compression perpendicular to grain, stress at proportional limit. The specimens were 2 by 2 by 6 inches and were loaded on tangential faces.
Figure 12.--Compression perpendicular to grain, stress at proportional limit. The specimens were 2 by 2 by 6 inches and were loaded on radial faces.
Figure 13.--Compression perpendicular to grain, stress at proportional limit. The specimens were 2 by 2 by 2 inches and were loaded on tangential faces.
Figure 14.—Compression perpendicular to grain, stress at proportional limit. The specimens were 2 by 2 by 2 inches and were loaded on radial faces.
Figure 15.—End hardness.
Figure 16.—Tangential hardness.
Figure 17.—Radial hardness.
Figure 18. --Shear parallel to grain, tangential.
Figure 19.—Shear parallel to grain, radial.

LEGEND:
- BALSA—(9.7 PERCENT M.)
- QUIPO—(13.0 PERCENT M.)
- GROUP AVERAGE
- GROUP AVERAGE
Figure 20.—Cleavage, tangential.
Figure 21. Cleavage, radial.
Figure 22.--Tension perpendicular to grain, tangential.
Figure 23.—Tension perpendicular to grain, radial.
Figure 24.--Toughness, tangential.
Figure 25. -- Toughness, radial.