Physical, Mechanical, and Other Properties of Five Hawaiian Woods
This report presents the results of recent Forest Products Laboratory evaluations of five timber species now being grown in Hawaii. The work was done in an effort to provide a more substantial basis for the development of the Hawaiian wood industry.

The research involved a comprehensive investigation of strength and related properties and an exploratory study of the veneer slicing and drying characteristics of ohia (Metrosideros polymorpha), a leading native timber species; a somewhat more limited investigation of the strength and related properties and an exploratory study of the veneer slicing and drying characteristics of eucalyptus (Eucalyptus robusta), a leading introduced species; and a limited investigation of the strength and related properties of three other introduced species, shamel ash (Fraxinus uhdei), Australian-redcedar (Cedrela toona var. australis), and redwood (Sequoia sempervirens). Limited exploratory investigations of the seasoning, machining, and treating characteristics of some of the woods were also made.

The results of this work indicate that these species should make a substantial contribution to the wood industry and general economy of Hawaii. The results also indicate the need for additional research in many areas to make possible more efficient utilization of the timber resources of Hawaii.

Introduction

In recent years, there has been increasing commercial interest in various timber species that are native to or cultivated in Hawaii. The increase

1 Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

2 This report was prepared in cooperation with Region 5 of the U. S. Forest Service, the Pacific Southwest Forest and Range Experiment Station, and the State Forester and Board of Agriculture and Forestry (now Department of Agriculture and Conservation), State of Hawaii.
in such interest has been part of a general increase in industrial
development associated with the recent inclusion of Hawaii as one of
the United States of America. The timber species of Hawaii that are of
greatest present or potential economic importance are different in many
respects from the timber species best known to the wood industry of the
Mainland. They are, in most cases, different botanical species from
those best known to the American trade. Also, the growing conditions in
Hawaii are such as to produce differences in timber growth that are re-
lected in the properties of the wood and its use characteristics.

The lack of information on properties of important Hawaiian timber
species has been a serious deterrent to their use and to the development
of the wood industry of the Islands. To provide such information, the
Forest Products Laboratory, in 1952, initiated a program of research
that has led to the development of basic data on many of the properties
of Hawaiian species. Most of the work was done in cooperation with the
Bernice F. Bishop Estate or the Board of Commissioners of Agriculture and
Forestry. Since the strength properties of wood are important in virt-
ually all of its uses, the evaluation of strength and related physical
properties was emphasized throughout the program. Exploratory investiga-
tion of veneer cutting, seasoning, treating, and machining characteris-
tics was also carried out on some of the material not needed for strength
tests.

The evaluation of the strength and related properties of ohia (Metro-
sideros polymorpha) was conducted essentially as outlined in American
Society for Testing Materials Designation D143-52, "Standard Methods of
Testing Small Clear Specimens of Timber" (1). The properties of other
species were evaluated on a more limited basis, by modifying the standard
number and distribution of specimens and confining the types of tests to
those considered most important for species evaluation. In all cases,
mechanical testing procedures were as specified in the ASTM Standard.
It is believed that the more limited testing schemes provided a reason-
able basis for estimating species characteristics, even though they did
not yield the complete information obtainable from the full ASTM selec-
tion and series of tests.

Ohia (Metrosidea polymorpha)

Ohia is an indigenous species of major importance from the standpoint of
volume and acreage. It is a dominant tree in large portions of the
Hawaiian forest, and forms large, almost pure stands in some areas. It
is one of the very few native trees of commercial importance for lumber
(6). In an effort to develop information that would aid in the

3 Underlined numbers in parentheses refer to Literature Cited at the end
of this report.

Report No. 2191 -2-
utilization of the species, the Board of Commissioners of Agriculture and Forestry entered into a cooperative agreement for the evaluation of ohia at the Forest Products Laboratory.

Material Evaluated

Two shipments of ohia were selected by representatives of the Board of Commissioners of Agriculture and Forestry and sent to the Forest Products Laboratory in 1957. One shipment was selected in Waiakea, a relatively level area at an elevation of about 5,500 feet, some 25 miles west of Hilo, Hawaii. Annual precipitation averages about 100 inches, and is fairly uniformly distributed throughout the year. The shipment consisted of six 8-foot bolts representing the c-d (8-16 foot) height in each of 6 trees, with additional bolts representing the a-b (0-8 foot) height and e-f (16-24 foot) height of 1 tree. The trees were 19 to 27 inches in diameter at breast height, with merchantable lengths of 24 to 35 feet.

The other shipment came from Kapua, a relatively level area at about 3,000 feet elevation, 100 miles southwest of Hilo, Hawaii. Annual precipitation averages about 60 inches, with no consistent seasonal distribution. This shipment consisted of c-d bolts from each of 5 trees and the a-b, e-f, and g-h bolts from 1 tree. The trees were 17 to 23 inches in diameter at breast height, with merchantable lengths of 34 to 51 feet.

Typical stands of ohia from which test material was collected are shown in figure 1. Figure 2 illustrates cross sections of two of the bolts from which test specimens were obtained.

Strength and Related Properties

Mechanical testing of ohia included the full complement of standard tests specified by the American Society for Testing Materials (1). Ohia was the only one of the Hawaiian species studied to be subjected to such a comprehensive investigation. The results obtained from the study on the c-d (8-16 foot height) bolts are presented in tables 1 and 2 as average values based on both of the shipments evaluated. The trees from the two shipments were essentially similar in their properties.

The average values in tables 1 and 2 indicate that ohia is the densest, and generally the strongest, of any of the Hawaiian species examined. It is substantially heavier than shagbark hickory, one of the heaviest of the commercial species of the Mainland, but is generally comparable to that hickory in many of its strength properties. The notable exceptions are its toughness, impact bending strength, and strength in compression perpendicular to the grain, in which it ranks far below hickory. Also, it has a tendency to shrink somewhat more than hickory, as would be
expected from its greater density. The strength properties of ohia are generally higher than those of white oak, another of the denser Mainland species of commercial importance.

The values in tables 1, 2, and 3 indicate that ohia is appreciably denser and stronger than Douglas-fir, a leading structural softwood in common use both on the Mainland and in Hawaii. Douglas-fir approaches ohia most closely in stiffness, an important factor in many structural applications. The weight of ohia, however, together with its high shrinkage and dulling effect on cutting tools, are likely to be detrimental to the use of the wood for some applications where it might otherwise replace Douglas-fir.

Nail-withdrawal tests on ohia, with sevenpenny plain sinker nails, indicated withdrawal loads for green material of 340 pounds from the radial surface, 320 pounds from the tangential surface, and 230 pounds from the end. Comparable tests on air-dry material indicated withdrawal loads of 360 pounds from the radial surface, 340 pounds from the tangential surface, and 340 pounds from the end. The withdrawal resistance of nails is affected by the specific gravity of the wood, the diameter and surface condition of the nail, depth of penetration, moisture condition of the wood, and other factors. Hence, the values obtained in these tests are applicable only to the conditions used. In general, the nail-withdrawal resistance of ohia appears to be somewhat less than would be exposed for its density.

Many of the strength properties of ohia are not as high as would be expected on the basis of its high density. This is probably attributable, at least in part, to the moderate spiral or interlocked grain included in some of the test material. This spiral or interlocked grain appeared to be a characteristic of the material studied, and may be characteristic of the species. Figure 3 illustrates some of the grain deviation observed.

Veneer Slicing and Drying Characteristics

Three of the ohia logs that supplied specimens for strength studies were also used in an exploratory evaluation of the veneer slicing and drying characteristics of the species. Quarter-log flitches 3 feet long were heated in water at 180° F. for about 23 hours. They showed no damage due to heating and there was no tendency for splits to open.

The flitches were sliced into 1/16- and 1/28-inch-thick veneer. Much of the sliced veneer had deep knife checks and was quite rough in the short-grained areas. The wood dulled the knife quite rapidly. Suggested slicer settings are presented in table 4. A ferric tannate stain developed on the flitch boards, but was not severe on the veneer sheets and was easily removed with warm dilute oxalic acid (4).
The veneer was dried in a roller-conveyor type drier by the schedules indicated in table 5 without development of drying defects.

The veneer had little figure except in the burls. The interlocked grain did not produce the expected well-defined ribbon-stripe figure such as is characteristic of mahogany. The most noticeable pattern in the veneer was due to the contrast between the sapwood and the darker red-brown heartwood.

The veneer was suitable for use as face veneer, but contained deep knife checks and required considerable sanding to remove all roughness. Plywood panels were made from the veneer with no serious difficulties. When sanded and finished, these panels had an attractive color, but very little figure (fig. 4).

Machining Characteristics

Twelve boards cut from the ohia sample bolts provided material for limited machining studies. The results are summarized and compared with averages for 25 Mainland hardwoods (2) in table 6. Ohia was better in shaping and boring and poorer in planing and turning than the average for the Mainland hardwoods. Because of the very limited sampling, these tests should be considered as only indicative of the machining properties of the species.

Seasoning Characteristics

Edgings from planks used for strength specimen material provided several pieces of ohia sapwood and heartwood, about 4 feet long, for an exploratory kiln-drying run. Sapwood pieces were 2-1/2 inches square, while heartwood pieces were 1 by 2-1/2 inches in cross section. The pieces were dried from the green condition to an average moisture content of about 9 percent in 30 days by Forest Products Laboratory schedule T3-C1 (11). Half of the pieces were endcoated with two coats of aluminized phenolic-resin varnish; the other pieces were not endcoated. In spite of the mild schedule, considerable checking and splitting developed in both heartwood and sapwood material. Most of the 2-1/2-inch-square sapwood sticks showed considerable end and surface checking, whether they had been endcoated or not. Some of the dry sticks were honeycombed almost full length. The smaller heartwood pieces showed less checking and splitting, but were severely distorted due to crook, bow, cup, and twist apparently associated with the grain deviation that is so prevalent in the wood.

This kiln run was entirely inadequate to serve as a basis for recommendations on the seasoning of ohia. It has merely served to emphasize the seasoning problem and point out the need for further research in that
area. Limited previous experience with drying of 1-inch-thick ohia has indicated that kiln drying of previously air-dried stock is likely to give better results than kiln drying stock green from the saw.

**Treating Characteristics**

A few pieces of air-seasoned ohia, 3-1/2 to 7 feet long, were pressure treated with coal-tar creosote on an exploratory basis. The results were not conclusive because of the limited number and source of the specimens treated. Good penetration could be obtained in the sapwood, but the heartwood was resistant to penetration.

**Utilization**

Ohia has many possibilities for use as a special-purpose wood. It is very strong and hard, yet can be machined fairly well and produces good veneer. As solid wood, it may find its best use for purposes where its high strength is an advantage without its weight and density being disadvantageous. Uses may be in such structural applications as poles, piling, or posts, or as crossties or certain types of heavy-duty flooring. The wood is reportedly being used successfully for keel and bilge blocks in connection with ship construction (12). It has been suggested for shuttles, pulleys, and cooperage (6). Although the wood machines reasonably well, it has a dulling effect on cutting tools. Thus, it may be well to emphasize uses that require a minimum of machining.

The wood has no outstanding figure when used as veneer, but may be suitable as a face veneer for certain types of cabinet work or paneling. Its good wearing characteristics may make it suitable for the exposed portion of plywood flooring.

It seems likely that the high density, abrasiveness, and drying difficulties of ohia will discourage its widespread use as a general-purpose wood.

**Eucalyptus (Eucalyptus robusta)**

*Eucalyptus robusta* is an introduced species that is showing considerable promise in plantation growth for its timber yield and utilization potential. Another planted eucalypt, *Eucalyptus saligna*, appears to have considerable potential in Hawaii, but it was not studied in the present investigation.
Material Evaluated

Two shipments of *E. robusta* were evaluated in cooperation with the Board of Commissioners of Agriculture and Forestry of Hawaii. Each shipment consisted of four 8-foot c-d or equivalent bolts from different trees and two 4-foot bolts from different heights in another tree. The two shipments came from two areas in Hawaii County; one near Puueo, where the annual rainfall averages 240 inches, and one near Pahala, Wood Valley, where the annual rainfall averages 84 inches. Except for this wide difference in annual rainfall, growth conditions in the two areas are quite similar. The trees sampled from the Puueo area were 32 years old and averaged about 28 inches diameter at breast height with about a 90-foot merchantable length. Those sampled from the Pahala area averaged about 23 inches diameter at breast height with about a 65-foot merchantable length.

Figure 5 illustrates cross sections of two of the *E. robusta* logs evaluated.

Strength and Related Properties

For the strength studies, the logs were ripped lengthwise into 2-1/2-inch-wide flitches that extended from bark to bark through the pith in two directions at 90° to each other. This provided a single cruciform pattern of test material selection rather than the double-width pattern ordinarily used in standard strength evaluations (1). Except for selection of test specimens, strength evaluations were made according to standard procedures (1).

Results of investigations of material from c-d or equivalent bolts of both shipments are presented as average values for the species in tables 1 and 2, and as comparative index values in table 3.

Eucalyptus was well below ohia in average specific gravity, but its average strength properties in the green condition compared quite well with those of ohia, except in hardness and toughness. The eucalyptus did not gain as much in most strength properties when dried to the air-dry condition as did ohia, so most of the values for properties of dry material are somewhat less than those for ohia. The shrinkage of eucalyptus is somewhat less than that of ohia, as would be expected from its lower density. The interlocked grain that is characteristic of eucalyptus produces considerable distortion in drying, however, and may also be responsible for the relatively small increase in some strength properties when the material is air dried.

Four important Mainland hardwoods, white ash, yellow birch, sugar maple, and pecan hickory, are generally comparable to *E. robusta* in density, and may be expected to provide a reasonable basis for comparison of other properties. Of the three Mainland species, pecan hickory compares most
closely with eucalyptus in specific gravity. Eucalyptus is higher than pecan hickory, on the average, in bending strength and stiffness and in maximum crushing strength, but lower than pecan hickory in hardness. Sugar maple, yellow birch, and white ash all average slightly lower than eucalyptus in specific gravity. While they are generally comparable to eucalyptus in bending strength, they are generally lower in stiffness as well as in compressive strength. Sugar maple is somewhat harder than eucalyptus, particularly in the air-dry condition, and all of the Mainland species mentioned exceed eucalyptus in their shock resistance characteristics, as shown by the index numbers in table 3. Yellow birch shrinks about the same as eucalyptus in volume, but shows less difference between radial and tangential shrinkage. Sugar maple, white ash, and pecan hickory all generally shrink less than eucalyptus.

When the strength and related properties of E. robusta as determined in this study are compared with those of ohia and of Mainland species for which data are based on a standard system of specimen selection, it should be kept in mind that the data for E. robusta are based on a more limited plan of specimen selection. Such comparisons should therefore be only general in nature, but may be helpful in classifying the use characteristics of Hawaiian E. robusta. It is believed that the data presented afford a reasonable, but possibly conservative, estimate of the quality of the material examined.

Veneer Slicing and Drying Characteristics

Four quarter-log flitches of E. robusta 3 feet long were used for an exploratory study of veneer slicing and drying characteristics. Heating for 25 hours in water at 180° F. appeared to be adequate for slicing 1/28-inch and 1/8-inch veneer. Two of the flitches were sliced into 1/28-inch veneer and the other two into 1/8-inch veneer. Suggested slicer settings for cutting good quality veneer are shown in table 4. No heating defects were observed either before or after the material was sliced. The 1/8-inch veneer was considerably rougher than the 1/28-inch veneer. Roughness appeared to be related to the orientation of the interlocked and curly grain to the slicer knife. Where the knife cut into the fibers the tear-out was pronounced, but where the knife was oriented parallel to the fibers the cutting was smooth.

The interlocked grain gave the veneer a ribbon-stripe figure. Small amounts of cross-ripple figure also appeared.

All 1/28-inch veneer was very tight, smooth, and free of splits. Dark blue stains similar to those which occasionally appear on oak veneer were noted on the veneer and on the knife. This stain was easily removed from the veneer with a warm, dilute oxalic acid solution (4).
The heartwood veneer was reddish pink; the sapwood was yellowish white before and light brown after it was dried. Drying schedules used for this veneer are presented in table 5.

Five-ply decorative panels were made with both 1/28- and 1/8-inch veneer for faces and backs. Crossbands and cores were 1/12-inch yellow-poplar. The veneer was conditioned to about 11 percent moisture content and assembled with Tego film glue. The panels showed no tendency to warp under uncontrolled indoor storage conditions.

After they had been sanded, the panels were filled with a light-colored filler followed by four coats of lacquer. This produced a very smooth finish on the 1/28-inch face veneer, but the 1/8-inch face veneer showed a slight ripple due to alternating bands of interlocked grain. The finished panels had a dull red-brown color. A filler that accentuates the natural red color of the wood would probably produce a more pleasing color in the finished panels.

Utilization

The results of this investigation indicate that the Hawaii-grown E. robusta may be suitable for many of the same uses as the naturally occurring ohia previously described. It is a heavy, hard wood probably most suitable for uses where its high strength can be utilized to advantage without its weight being a serious disadvantage. Some of the closely related eucalypts in Australia are used for flooring and for heavy construction (2). It may be possible to use this Hawaii-grown eucalyptus in the same manner, although its high shrinkage and interlocked grain lead to serious drying problems that must be overcome before maximum use of the wood will be possible.

The limited veneering studies included in this investigation indicate that the wood will make attractive face veneer that can be used successfully as plywood facings once it has been properly dried. Veneer must be dried carefully at low temperature, however, to avoid excessive loss due to collapse.

Shamel Ash (Fraxinus uhdei)

Shamel ash (Fraxinus uhdei) is a species introduced from Mexico that has shown considerable growth and utilization potential in Hawaiian plantations. The properties of the wood of this species were evaluated in cooperation with the Bernice P. Bishop Estate, Honolulu, Hawaii.

Report No. 2191
Material Evaluated

Study material was provided by an 8-foot bolt, presumably representing the 8- to 16-foot height, from each of five trees, from a 27-year-old plantation on the Bernice P. Bishop Estate, Honaunau, South Kona, Hawaii. The bolts averaged about 13 inches in diameter. The area is characterized by 100 inches or more of rainfall per year, poor drainage, and a temperature range from about 50° to 75° F. The trees in the stand were reported to have long straight trunks, well pruned, with a merchantable height of about 40 feet.

A section about 12 inches long was cut from the small end of each log for specific gravity and shrinkage specimens. The remainder was used for strength studies. An exploratory test of creosote penetration was conducted on some of the extra material.

Figure 6 shows a cross section of one of the logs from which material for this study was obtained.

Specific Gravity and Shrinkage

Specific gravity and shrinkage were measured on specimens prepared from successive 5-growth-ring increments taken each way from the pith in a 2-inch-wide flitch cut bark to bark across each 12-inch bolt section. Rings per inch varied from 2 to 9 in the specific gravity sections, but classes of 3 and 4 rings per inch were most common (fig. 6). The averages of ring width ranged from 3 to 5 for individual trees. One of the bolts received was characterized by severe lengthwise splitting that apparently resulted from internal stresses in the tree (fig. 7).

The research to evaluate the physical properties of Hawaii-grown ash indicates that the wood is intermediate in density between the Mainland white ash (F. americana) and the lighter ashes of the Mainland as exemplified by black ash (F. nigra), although it is generally more closely comparable in density to black ash than to white ash. The shrinkage of the Hawaii-grown ash, however, appears to be appreciably less than that of either white or black ash or other ash species native to the Mainland. Its shrinkage would be classed as moderately small.

Strength Properties

Static bending, hardness, and toughness tests were made on material that represented, as well as possible, all growth areas from pith to bark in each tree of shamel ash. Matched specimens were tested in the green condition and after they had reached an equilibrium moisture condition at 75° F. and 64 percent humidity. Although the scope of the study did not permit the standard selection of specimens (1), the specimen sizes and testing procedures were as specified in the primary standard of ASTM designation D143-52.
The results of strength studies are presented as average values in tables 1 and 2, and as index numbers for comparative purposes in table 3. The index numbers were calculated in the same manner as those listed for Mainland species, except that in some cases not all the strength data ordinarily used for such calculations were available. In any comparisons of actual average strength properties or index numbers computed from them, it should be kept in mind that specimens of Hawaii-grown ash were selected on a more limited basis than those of Mainland species or for ohia. It is believed, however, that the data for *F. uhdei* provide a reasonable estimate of the properties of the Hawaii-grown wood of the species.

Modulus of rupture (bending strength) and modulus of elasticity (stiffness) values for green wood are unusually high for the specific gravity of the wood as compared to values for various species of ash grown on the Mainland. For dry wood, however, these values are generally comparable to those of Mainland ash of the same specific gravity.

The relationship of shock resistance, as indicated by work values in static bending and by toughness tests, to specific gravity is quite variable among species. Comparisons with *F. uhdei* can thus be only very general. Work values for the Hawaiian ash (table 2) are generally comparable to those for black ash, and appear to be about what would be expected for the density of the wood. While no toughness values based on the size of specimen used in this study are available for Mainland ash species, comparison with toughness values for other Mainland hardwoods, including elm, hickory, oak, and birch, indicates that the toughness of the Hawaiian ash is at least as high as would be expected for its density.

Hardness of green and dry Hawaiian ash is also approximately what would be expected for its density, when compared with Mainland ash species.

In general, these tests show that the bending strength, shock resistance, and hardness of *F. uhdei* grown in Hawaii are at least as high as would be expected from ash of that density grown on the Mainland. Absolute density and strength levels are about the same as for black ash (*F. nigra*), and substantially lower than for the more widely known and highly regarded white ash (*F. americana*).

**Treating Characteristics**

A few 3-1/2- to 7-foot-long pieces of air-dried shamel ash were pressure treated with coal-tar creosote on an exploratory basis. The results were not based on enough research to be conclusive, but did indicate that this ash could be treated somewhat more effectively than either the ohia or the Hawaii-grown redwood. Complete penetration was obtained in the sapwood, and moderately good penetration was obtained in the heartwood.
Utilization

The properties of F. uhdei from Hawaii indicate that it could serve very well for many uses, except where exceptionally high strength and toughness are required. It should serve well for furniture and cabinet work and related interior uses, since it has relatively low shrinkage and would be expected to be machined rather easily. It should also be satisfactory for many other purposes for which a medium-density hardwood is commonly employed. Advantage could be taken of its easy treatability for some types of exposed uses that do not require extremely high strength.

Most of the material probably will not be suitable for high-grade handles or other similar items that require exceptional strength and toughness, since F. uhdei does not appear to be as good as the select types of white ash ordinarily preferred for such uses.

Australian-Redcedar (Cedrela toona var. australis)

Australian-redcedar (Cedrela toona var. australis) is one of the promising introduced species that is showing excellent growth potential in Hawaiian plantations. It grows rapidly and generally uniformly, and provides appreciable quantities of reasonably clear, straight-grained wood. Cedrela is a small genus, but commercially important species are found in many parts of the world, including tropical America, the Philippines, India, and Australia (10). It is a hardwood of the mahogany family (Meliaceae). A limited investigation of the strength and related properties of Australian-redcedar was conducted at the Forest Products Laboratory in cooperation with the Bernice P. Bishop Estate, Honolulu, Hawaii.

Material Evaluated

The specimen material for this study was supplied by five trees from a nearly pure, even-aged, 22-year-old stand near the northern border of the South Kona Soil Conservation District, Hawaii County, Island of Hawaii. The area is characterized by an average annual rainfall of about 100 inches, poor natural drainage, and a relatively constant temperature with a mean of about 70° F.

The trees selected averaged about 20 inches diameter at breast height, with an average merchantable height of slightly more than 60 feet. Four of the trees supplied 8-foot bolts from the usual 8- to 16-foot (c-d) height. These bolts provided material for evaluation of properties in static bending, compression parallel to grain, hardness, and toughness in both the green and the air-dry conditions. The other tree supplied two 4-foot bolts from above and below the c-d height for an evaluation of height effects in wood in the green condition only.

Report No. 2191 -12-
A section about 12 inches long was cut from the small end of each bolt for shrinkage studies. The remainder of each bolt was ripped to provide 2-1/2-inch-wide flitches, full length, that extended from bark to bark through the pith in two perpendicular directions. Specimens were selected in such a manner as to sample the inner, outer, and intermediate portions of each bolt and to provide good matching of specimens for tests in the air-dry and green conditions.

Cross sections of two of the trees, shown in figure 8, illustrate the rapid, even growth and the checking that characterized most of the material when received at the Forest Products Laboratory.

**Strength and Related Properties**

As was the case for most of the Hawaiian species investigated, the limited nature of the study of Australian-redcedar did not permit a complete standard selection of specimen material. It is believed, however, that the sampling provided a reasonable, and perhaps conservative, evaluation of the material selected for study that should be approximately comparable with results of tests conducted on a standard selection basis. Specimen sizes and testing procedures were as specified in the primary method of ASTM Designation D143-52 (1).

Average strength and related properties, as determined from the four c-d bolts, are presented in tables 1 and 2. Index numbers computed from those averages are presented for comparative purposes in table 3. The limited nature of the sampling should be kept in mind when comparing the values for Australian-redcedar with those of comparable Mainland species. The values should be considered as indicative rather than as precise estimates of species properties.

The Australian-redcedar grown in Hawaii appears to be generally comparable in density and in many strength properties to the red alder (Alnus rubra) native to the Pacific coast of the Mainland United States. Its shrinkage would be classed as large, and is greater than would normally be expected for its density. It shrinks about as much in volume as some of the denser ash, oak, maple, and hickory species of the Mainland, and appreciably more than the Hawaii-grown ash studied.

The bending strength, compressive strength, hardness, and shock resistance of the Hawaii-grown Cedrela compare reasonably well with those of red alder, but the Cedrela is lower in stiffness. The comparison of shock resistance is based on static bending work values. No comparable toughness values are available for red alder, but the toughness of Cedrela is somewhat less than that of Douglas-fir, a well-known moderately tough species.

Of the other Hawaiian species examined, the Australian-redcedar most closely resembles the plantation-grown redwood in density and strength.
The shrinkage of the Cedrela averages almost double that of the redwood, however, and the redwood is appreciably higher in toughness. On the other hand, the Cedrela is higher than the redwood in bending strength in the dry condition and stiffer in both the green and dry conditions.

There was a fairly well-marked gradation in properties from bark to pith in much of the Cedrela examined, with a general tendency toward decrease in density, shrinkage, and strength from bark to pith. Some of the wood showed very high longitudinal shrinkage, over 0.3 percent, which would probably cause difficulties in seasoning and in dimensional stability when used in association with normal wood.

Utilization

The wood of Hawaii-grown Australian-redcedar appears to be reasonably clear, with little evidence of grain distortion. It offers promise for paneling and for some types of furniture and cabinet uses. It is well known for such uses and for interior trim in areas where it is a native species. It does not appear suitable for applications that require high strength or hardness, but may be suitable for some types of construction uses, such as for siding. The high shrinkage of the wood indicates that satisfactory use for furniture and cabinet work would require very careful drying to a moisture content about in equilibrium with expected service conditions. Although the bolts received at the Forest Products Laboratory were severely checked, which reduced the yield of clear material, it is believed that careful handling and the shorter transport distance for use in Hawaii will largely eliminate much of this difficulty.

Redwood (Sequoia sempervirens)

Because of the similarity of growing conditions between some places in Hawaii and the redwood area of California, there has been some interest in the introduction of redwood (Sequoia sempervirens) into Hawaiian plantations. These redwood plantations have shown a growth rate generally comparable to that of open-grown second-growth redwood in California, as indicated by the material sent to the Forest Products Laboratory for study, and the Hawaiian redwood is reportedly quite similar in its growth characteristics to the young California material of the species.

A limited investigation of the strength and related properties of plantation-grown redwood from Hawaii was conducted in cooperation with the Bernice P. Bishop Estate, Honolulu.

Material Evaluated

The specimen material for this study was provided by five 8-foot redwood logs representing the 12- to 20-foot height of 5 trees from a 25-year-old
plantation in the Honaunau Forest Reserve, Kahaauloa, South Kona, Hawaii. The height of the trees at the time of sampling was reported to be approximately 80 feet. The average diameter of the sample logs was 13 inches. The area has an annual rainfall of about 100 inches, with a lateritic soil residual from volcanic ash.

When the logs arrived at the Forest Products Laboratory, a 14-inch section from the butt end of each log was removed for use in shrinkage and specific gravity studies. The remainder was used for strength evaluations. Cross sections of the sample bolts (fig. 9) show that the trees had grown rapidly in diameter, with an average of 3.2 rings per inch. The individual trees varied from 2.2 to 4.8 rings per inch in growth rate. The rate of diameter growth of these plantation-grown trees compares closely with an average of 3 rings per inch for open-grown second-growth redwood in California, and represents much more rapid growth than the average of 7 rings per inch previously observed for close-grown California redwood and the average of 29 rings per inch previously observed for virgin California redwood (7,2).

Shrinkage and Specific Gravity

Specimens for the determination of radial, tangential, and longitudinal shrinkage and specimens for the combined determination of specific gravity and volumetric shrinkage were selected from several locations in each short piece in such a way as to sample all portions of the cross section.

Hawaiian redwood averaged higher in density with respect to its growth rate than the California redwood previously tested. As shown in table 1, the redwood from Hawaii is denser than the open-grown second-growth California redwood that grew at about the same rate. The density of the Hawaiian material is intermediate between that of close-grown second-growth and virgin material from California.

The Hawaii-grown redwood averaged slightly higher than any of the California material in overall volumetric and tangential shrinkage, and was intermediate in radial shrinkage between the close-grown and the open-grown second-growth redwood from California. Longitudinal shrinkage of the Hawaii material was generally quite small, and should offer no serious problems in utilization of the species.

Strength Properties

Evaluation of the mechanical properties of plantation-grown redwood from Hawaii was confined to an abbreviated schedule of tests in static bending, hardness, and toughness. Specimens were selected in such a manner as to represent all portions of the cross section and to provide end matching between specimens for studies in the green condition and those for studies
in the air-dry condition. Toughness specimens to be tested in the tangential direction were side matched in the same growth rings with specimens to be tested in the radial direction.

The Hawaii redwood averaged higher than open-grown second-growth California redwood in bending strength (modulus of rupture) and stiffness (modulus of elasticity), as would be expected from its higher density. The Hawaii material was somewhat higher than close-grown California redwood in bending strength but not in stiffness, even though it is slightly denser than the close-grown material. Thus, the bending strength of the Hawaii redwood is about what would be expected for its density, but its stiffness is somewhat lower than would be expected for its density, on the basis of average values for California redwood.

The Hawaii redwood averaged appreciably higher than any of the second-growth California redwood in toughness and the closely related static-bending work values, as well as in hardness, and was generally higher than even the denser virgin redwood. The Hawaii redwood had higher values for these properties than its density would indicate.

Seasoning Properties

Fourteen 2- by 2-inch squares, which contained both heartwood and sapwood, were dried from the green condition in accordance with Forest Products Laboratory schedule T6-F4 (11). The trial was generally successful, except for a small amount of internal checking in one specimen. The specimen was considerably wetter than the others when the higher temperatures of the schedule were applied. Although the results of such a study may be regarded as no more than indicative, they suggest that the milder softwood schedule T3-F4 (13) may be required for such wet material. Further research is needed to establish the suitability of various schedules for items and sizes of more common commercial interest.

Treating Characteristics

A few 3-1/2- to 7-foot-long pieces of Hawaii-grown redwood were pressure treated with coal-tar creosote on an exploratory basis. The results were not conclusive, because of the extremely limited nature of the sample, but did indicate treating characteristics somewhat similar to California-grown redwood. Penetration was nonuniform in both sapwood and heartwood.

Utilization

The results of this evaluation indicate that plantation-grown redwood from Hawaii is generally somewhat denser and stronger than second-growth
California redwood. In its use characteristics, it may closely resemble the younger material from California that is grown relatively rapidly and does not develop the large amounts of clear wood common to old-growth California redwood. Because of the smaller size and lower heartwood content of the rapidly grown Hawaii material as compared with virgin California redwood, the Hawaii timber would be expected to be somewhat less decay resistant and produce less high-quality material. It may be valuable as a relatively low-density timber for many construction uses, however, and for general use as common lumber in applications where the denser, stronger hardwoods of Hawaii would be too heavy and cumbersome.
Literature Cited

(1) American Society for Testing Materials.  

(2) Davis, E. M.  

(3) Department of Scientific and Industrial Research (Great Britain).  

(4) Downs, L. E.  

(5) Drow, J. T., Markwardt, L. J., and Youngquist, W. G.  

(6) Gerry, Eloise.  

(7) Luxford, R. F., and Markwardt, L. J.  

(8) Markwardt, L. J.  

(9) Markwardt, L. J., and Wilson, T. R. C.  

(10) Record, S. J., and Hess, R. W.  
1943. Timbers of the New World. Yale University Press, New Haven, Conn.

(11) Torgeson, O. W.  
1951. Schedules for the Kiln Drying of Wood. Forest Products Laboratory Report No. 1791.
(12) Umyuem, A. K. W.  

(13) U. S. Forest Products Laboratory.  

(14)  

(15)  
Table 1.--Average physical properties of small clear specimens of five Hawaii-grown timber species evaluated at the Forest Products Laboratory, and comparable values for some Mainland species. Averages for all Hawaiian species except ohia are based on limited studies.

<table>
<thead>
<tr>
<th>Species</th>
<th>Trees tested</th>
<th>Moisture content (Percent)</th>
<th>Specific gravity</th>
<th>Weight per cubic foot</th>
<th>Total shrinkage (green to oven-dry) Percent</th>
<th>HAWAII-GROWN SPECIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash, shamel (Fraxinus uhdei)</td>
<td>5</td>
<td>46</td>
<td>0.47</td>
<td>53</td>
<td>3.5</td>
<td>7.4</td>
</tr>
<tr>
<td>Australian-redcedar (Cedrela toona var. australis)</td>
<td>4</td>
<td>109</td>
<td>0.35</td>
<td>46</td>
<td>4.3</td>
<td>9.8</td>
</tr>
<tr>
<td>Eucalyptus (Eucalyptus robusta)</td>
<td>8</td>
<td>88</td>
<td>0.60</td>
<td>70</td>
<td>6.1</td>
<td>10.7</td>
</tr>
<tr>
<td>Ohia (Metrosideros polymorpha)</td>
<td>11</td>
<td>67</td>
<td>0.70</td>
<td>73</td>
<td>6.9</td>
<td>12.1</td>
</tr>
<tr>
<td>Redwood (plantation grown) (Sequoia sempervirens)</td>
<td>5</td>
<td>156</td>
<td>0.35</td>
<td>56</td>
<td>2.3</td>
<td>5.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Species</th>
<th>Trees tested</th>
<th>Moisture content (Percent)</th>
<th>Specific gravity</th>
<th>Weight per cubic foot</th>
<th>Total shrinkage (green to oven-dry) Percent</th>
<th>COMPARABLE MAINLAND SPECIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alder, red (Alnus rubra)</td>
<td>6</td>
<td>98</td>
<td>0.37</td>
<td>46</td>
<td>4.4</td>
<td>7.3</td>
</tr>
<tr>
<td>Ash, black (Fraxinus nigra)</td>
<td>6</td>
<td>85</td>
<td>0.35</td>
<td>52</td>
<td>5.0</td>
<td>7.8</td>
</tr>
<tr>
<td>Ash, white (Fraxinus americana)</td>
<td>23</td>
<td>42</td>
<td>0.55</td>
<td>48</td>
<td>4.8</td>
<td>7.8</td>
</tr>
<tr>
<td>Birch, yellow (Betula alleghaniensis)</td>
<td>17</td>
<td>67</td>
<td>0.55</td>
<td>57</td>
<td>7.2</td>
<td>9.2</td>
</tr>
<tr>
<td>Douglas-fir (coast type) (Pseudotsuga menziesii)</td>
<td>67</td>
<td>38</td>
<td>0.45</td>
<td>39</td>
<td>5.0</td>
<td>7.8</td>
</tr>
<tr>
<td>Hickory, pecan (Carya illinoinensis)</td>
<td>5</td>
<td>63</td>
<td>0.60</td>
<td>61</td>
<td>4.9</td>
<td>8.9</td>
</tr>
<tr>
<td>Hickory, shagbark (Carya ovata)</td>
<td>24</td>
<td>60</td>
<td>0.64</td>
<td>64</td>
<td>7.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Maple, sugar (Acer saccharum)</td>
<td>22</td>
<td>98</td>
<td>0.56</td>
<td>56</td>
<td>4.9</td>
<td>9.5</td>
</tr>
<tr>
<td>Oak, white (Quercus alba)</td>
<td>20</td>
<td>68</td>
<td>0.60</td>
<td>62</td>
<td>5.3</td>
<td>9.0</td>
</tr>
<tr>
<td>Redwood (virgin) (Sequoia sempervirens)</td>
<td>16</td>
<td>112</td>
<td>0.38</td>
<td>50</td>
<td>2.6</td>
<td>4.4</td>
</tr>
<tr>
<td>(second-growth, open-grown)</td>
<td>6</td>
<td>146</td>
<td>0.28</td>
<td>43</td>
<td>2.0</td>
<td>4.4</td>
</tr>
<tr>
<td>(second-growth, close-grown)</td>
<td>8</td>
<td>112</td>
<td>0.32</td>
<td>42</td>
<td>2.4</td>
<td>5.0</td>
</tr>
</tbody>
</table>

1Based on weight when oven-dry and volume at test.
2Based on combined weight of wood and moisture and volume at test.
3Tests based on additional trees contributed to these averages for Mainland species.

Report No. 2191
Table 2.—Average strength properties of small clear specimens of five Hawaiian timber species evaluated at the Forest Products Laboratory, and comparable values for some mainland species. Averaged for all Hawaiian species except ohia are based on limited studies.

<table>
<thead>
<tr>
<th>Species</th>
<th>Moisture content</th>
<th>Static bending</th>
<th>Impact</th>
<th>Compression</th>
<th>Tension</th>
<th>Hardness</th>
<th>Toughness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HAWAII-GROWN SPECIES

<table>
<thead>
<tr>
<th>Species</th>
<th>Engineered P.s.i.</th>
<th>Engineered P.s.i.</th>
<th>Engineered P.s.i.</th>
<th>Engineered P.s.i.</th>
<th>Engineered P.s.i.</th>
<th>Engineered P.s.i.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
</tr>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
</tr>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
</tr>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
</tr>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
</tr>
</tbody>
</table>

COMPARABLE MAINLAND SPECIES

<table>
<thead>
<tr>
<th>Species</th>
<th>Engineered P.s.i.</th>
<th>Engineered P.s.i.</th>
<th>Engineered P.s.i.</th>
<th>Engineered P.s.i.</th>
<th>Engineered P.s.i.</th>
<th>Engineered P.s.i.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
</tr>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
</tr>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
</tr>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
</tr>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
</tr>
</tbody>
</table>

1Load required to embed a 0.444-inch ball to 1/2 its diameter.
2Specimen size 0.79 inch by 0.79 inch tested over a 9.47-inch span, except for values indicated by ( ), which are based on 5/8- by 5/8-inch specimen tested over 8-inch span.
4Forest Products Laboratory Report No. 2109, 1958 (3).
5Unpublished data for the following true hickories: Sand (C. pallida), mockernut (C. tomentosa), and pignut (C. alba).
Table 3.—Properties of Hawaii-grown wood species as represented by comparative index numbers, and comparable values for some Mainland species*

<table>
<thead>
<tr>
<th>Species</th>
<th>Volumetric</th>
<th>Bending</th>
<th>Compressive</th>
<th>Stiffness</th>
<th>Hardness</th>
<th>Shock resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HAWAII-GROWN SPECIES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash, shamel (Fraxinus uhdei)</td>
<td>104</td>
<td>95</td>
<td>149</td>
<td>79</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Australian-redcedar (Cedrela toona var. australis)</td>
<td>141</td>
<td>72</td>
<td>70</td>
<td>114</td>
<td>50</td>
<td>73</td>
</tr>
<tr>
<td>Eucalyptus (Eucalyptus robusta)</td>
<td>168</td>
<td>120</td>
<td>118</td>
<td>203</td>
<td>112</td>
<td>103</td>
</tr>
<tr>
<td>Ohia (Metrosideros polymorpha)</td>
<td>191</td>
<td>125</td>
<td>116</td>
<td>221</td>
<td>129</td>
<td>133</td>
</tr>
<tr>
<td>Redwood (Sequoia sempervirens)</td>
<td>82</td>
<td>68</td>
<td>87</td>
<td>49</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td><strong>MAINLAND SPECIES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alder, red (Alnus rubra)</td>
<td>123</td>
<td>76</td>
<td>81</td>
<td>139</td>
<td>48</td>
<td>72</td>
</tr>
<tr>
<td>Ash, black (Fraxinus nigra)</td>
<td>144</td>
<td>75</td>
<td>70</td>
<td>126</td>
<td>64</td>
<td>124</td>
</tr>
<tr>
<td>Ash, white (Fraxinus americana)</td>
<td>130</td>
<td>111</td>
<td>105</td>
<td>166</td>
<td>106</td>
<td>146</td>
</tr>
<tr>
<td>Birch, yellow (Betula alleghaniensis)</td>
<td>166</td>
<td>106</td>
<td>99</td>
<td>174</td>
<td>87</td>
<td>172</td>
</tr>
<tr>
<td>Douglas-fir (coast) (Pseudotsuga menziesii)</td>
<td>122</td>
<td>90</td>
<td>104</td>
<td>185</td>
<td>58</td>
<td>86</td>
</tr>
<tr>
<td>Hickory, pecan (Carya illinoinensis)</td>
<td>137</td>
<td>109</td>
<td>104</td>
<td>161</td>
<td>140</td>
<td>157</td>
</tr>
<tr>
<td>Hickory, shagbark (Carya ovata)</td>
<td>170</td>
<td>132</td>
<td>122</td>
<td>185</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maple, sugar (Acer saccharum)</td>
<td>147</td>
<td>114</td>
<td>104</td>
<td>178</td>
<td>115</td>
<td>137</td>
</tr>
<tr>
<td>Oak, white (Quercus alba)</td>
<td>153</td>
<td>102</td>
<td>97</td>
<td>153</td>
<td>108</td>
<td>127</td>
</tr>
<tr>
<td>Redwood (virgin) (Sequoia sempervirens)</td>
<td>69</td>
<td>82</td>
<td>102</td>
<td>136</td>
<td>54</td>
<td>66</td>
</tr>
</tbody>
</table>

1 Calculated according to procedures outlined in U. S. Department of Agriculture Technical Bulletin No. 158 (B). For all Hawaiian species except ohia, some property values normally used in such calculations were not available. Such calculations were based on available data only.

2 Values for Mainland species taken from U. S. Forest Products Laboratory Report No. 1169 (14).

Report No. 2191
Table 4.—Suggested slicer settings for cutting ohia and eucalyptus veneer

<table>
<thead>
<tr>
<th>Veneer thickness</th>
<th>Pressure bar settings</th>
<th>Pressure bar level</th>
<th>Slicer knife Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal opening</td>
<td>Vertical opening</td>
<td>Bevel °</td>
</tr>
<tr>
<td>OHIA (Metrosideros polymorpha)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/28 (0.0357)</td>
<td>0.032</td>
<td>0.030</td>
<td>12</td>
</tr>
<tr>
<td>1/16 (0.0625)</td>
<td>0.055</td>
<td>0.030</td>
<td>12</td>
</tr>
<tr>
<td>EUCALYPTUS (Eucalyptus robusta)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/28 (0.0357)</td>
<td>0.028</td>
<td>0.030</td>
<td></td>
</tr>
<tr>
<td>1/8 (0.125)</td>
<td>0.118</td>
<td>0.030</td>
<td></td>
</tr>
</tbody>
</table>

1 Rockwell hardness 62, flat ground.
Table 5.—Drying schedules and shrinkage values for ohia and eucalyptus veneer

<table>
<thead>
<tr>
<th>Veneer thickness</th>
<th>Dryer temperature</th>
<th>Drying time</th>
<th>Average final moisture content</th>
<th>Method of slicing</th>
<th>Average shrinkage of heartwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>OHIA (Metrosideros polymorpha)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/28 Inch</td>
<td>320 °F.</td>
<td>5 Minutes</td>
<td>3.5 Percent</td>
<td>Flat-to-quarter</td>
<td>10 Percent : 11 Percent</td>
</tr>
<tr>
<td>1/16 Inch</td>
<td>250 °F.</td>
<td>15 Minutes</td>
<td>3.3 Percent</td>
<td>Flat Quarter</td>
<td>6 Percent : 11 Percent</td>
</tr>
<tr>
<td>1/16 Inch</td>
<td>300 °F.</td>
<td>6 Minutes</td>
<td>4.2 Percent</td>
<td>Flat-to-quarter</td>
<td>8 Percent : 9 Percent</td>
</tr>
<tr>
<td>EUCALYPTUS (Eucalyptus robusta)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/28 Inch</td>
<td>200 °F.</td>
<td>10 Minutes</td>
<td>5-8 Percent</td>
<td>Flat-to-quarter</td>
<td>6 Percent : 7 Percent</td>
</tr>
<tr>
<td>1/8 Inch</td>
<td>200 °F.</td>
<td>5 Minutes</td>
<td>3.5-7 Percent</td>
<td>Flat-to-quarter</td>
<td>9 Percent : 8 Percent</td>
</tr>
</tbody>
</table>

Report No. 2191
Table 6.--Results of a limited evaluation\(^1\) of the machining properties of ohia

<table>
<thead>
<tr>
<th>Machining operation</th>
<th>Good to excellent samples</th>
<th>Comparative figure(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent</td>
<td></td>
</tr>
<tr>
<td>Planing</td>
<td>(\frac{3}{4},%)</td>
<td>61</td>
</tr>
<tr>
<td>Shaping</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Turning</td>
<td>22</td>
<td>79</td>
</tr>
<tr>
<td>Boring</td>
<td>92</td>
<td>89</td>
</tr>
<tr>
<td>Mortising</td>
<td>(5)</td>
<td>70</td>
</tr>
</tbody>
</table>

\(^1\) Based on samples from twelve boards representing an undetermined number of trees. Results should be considered indicative only.

\(^2\) Average for 25 Mainland hardwoods (2).

\(^3\) Defect-free samples.

\(^4\) Best cutting angle 20°; next best angle 10°.

\(^5\) Too hard to mortise with available facilities.
Figure 1. -- Typical stands of ohia (*Metrosideros polymorpha*) from which specimen material was collected for this study.
Figure 2. -- Cross sections of two of the ohia bolts from which specimen material was obtained.
Figure 4. -- A plywood panel faced with sliced ohia veneer.

Z M 114 684
Figure 5. -- Cross sections of two of the *Eucalyptus robusta* logs from which specimen material was obtained.

Z M 111 163
Figure 6. -- Cross section of one of the ash logs used in the evaluation of *Fraxinus uhdei* from Hawaii.
Figure 7. --Lengthwise splits in a log of Hawaii-grown ash (Fraxinus uhdei).
Figure 8. -- Cross sections of two bolts of Australian-redcedar (Cedrela toona var. australis) from which specimen material was obtained. The end and surface checks are characteristic of the material received for evaluation.
Figure 9. -- Cross sections of five plantation-grown redwood logs from Hawaii.