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The Seasoning of Oregon Hardwoods

By
Leif D. Espenas



OREGON FOREST PRODUCTS LABORATORY
State Board of Forestry and School of Forestry,
Oregon State College, Cooperating
Corvallis

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LEIF D. ESPENAS¹

INTRODUCTION

PROPER SEASONING is an essential step in the preparation of wood for many of its final uses. The seasoning of hardwoods is generally a more exacting procedure than that of softwoods, because of the uses to which the wood is put and because hardwoods are more subject to seasoning defects. As hardwoods usually are used for interior construction where they are subjected to everyday use and observation, the wood should be nearly perfect in all respects.

In the manufacture of seasoned hardwoods, the visible defects resulting from poor seasoning practices can be cut out of the stock, but the invisible ones may not become evident until the finished product has been placed in use. The cutting involves a serious loss of material, but the defects that develop later mean added labor costs and produce dissatisfied customers.

It has been estimated that the State of Oregon has nearly 4.1 billion board feet of hardwood sawtimber (7).² The volume is small when compared with that of softwood sawtimber, but it is sufficient to maintain a larger hardboard industry than now exists. At the present time, some species are not in wide commercial use, largely because of the poor results from the drying practices employed and lack of information about improved ones. Species that are now in use commercially should not be especially difficult to season satisfactorily, yet the results have not been uniformly good. Poor manufacture, in addition to a low quality of seasoning, may contribute to the poor reputation of some hardwood lumber.

Because of the important role seasoning plays in the development of the hardwood resource, three of the most difficult woods to season have been studied by the Oregon Forest Products Laboratory. The information obtained should be applicable to other species as well. The purpose of this circular is not to present the detailed data obtained in these studies but to suggest practices that are based on the research results and on procedures used in other hardwood producing regions.

As already mentioned, hardwoods are used widely for interiors, where the moisture content is lower than that usually attained by

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² Numbers in parentheses refer to references listed at the end of this report.

air-drying. When the moisture content of air-dried lumber is lowered to that of its surroundings, the loss in moisture amounts to about 6 per cent, an amount sufficient to cause warping or end checking. Air-drying alone is not sufficient for the most satisfactory service and some kiln-drying should be contemplated.

SEASONING RESULTS MAY DEPEND ON OTHER OPERATIONS

FOR IDEAL seasoning, the wood should be received in an absolutely green, bright (free from stain), and well manufactured condition. Under such circumstances, all of the ill effects that may accompany drying would be subject to control in the seasoning operation. Unfortunately, very practical factors prevent this ideal condition. Other operations often are partly responsible for the condition of the dried lumber. It is not uncommon to find the final drying process blamed for a seasoning defect that actually developed in a preceding operation where corrective measures should have been applied. Once a seasoning defect occurs, the most careful drying procedures cannot remedy and frequently only aggravate it.

End checks may develop any time after the end grain of the wood is exposed, often occurring while logs are still in the woods. They may develop also in stored green lumber, especially when the ends are exposed to the sun. Once started, end checks are likely to extend further into the piece during seasoning.

Serious surface checks seldom develop in bark-covered logs, but peeled logs may surface check severely. Such checks can become so deep that lumber cut at an appreciable distance from the log surface will be affected. Cants for resawing, stored green lumber, lumber pulled along a green chain, and the top layers of uncovered kiln loads or unfinished air-seasoning piles also may surface check because of exposure to the sun.

In sawing lumber, it is important that the nominal thickness specified be closely adhered to, not only because of the saving of material but also because of the effect on seasoning. Lumber of nonuniform thickness cannot be piled properly; thin boards will not be held firmly by the stickers and therefore will be free to warp. The stickers, in turn, will not be firmly supported by the thin lumber and may allow warping of lumber in the next layer above or below. In addition, a lack of uniformity in thickness has a definite effect on drying time. Thicker lumber requires a longer time to reach a given moisture content; therefore, the drying time must

conform to the needs of the thicker stock. Meanwhile, the thinner lumber may become too dry. Final moisture-content uniformity can be achieved only at the expense of a prolonged equalization treatment.

Certain defects that develop in seasoning are related to natural defects or grain irregularities in the wood. In many instances, attempts to modify the drying procedure to eliminate seasoning defects fail because of the variations in shrinkage and rate of moisture loss that are associated with these natural defects and grain irregularities. Good milling practice endeavors to place these defects and irregularities in the lumber in such a manner that the resulting seasoning defects will have the least possible effect on the utility or grade of the lumber.

Stains of various kinds and decay may develop in stored logs or lumber. Seasoning will arrest the further development of stain- or decay-producing organisms, but chemical stains may occur in seasoning. In some species, evidence indicates that chemical staining is more severe in lumber that has been stored in the green condition or cut from logs that were stored prior to sawing.

SEASONING STUDIES ON HARDWOODS NATIVE TO OREGON

THE U. S. Forest Products Laboratory at Madison, Wisconsin, conducted a study (11) to determine kiln schedules for four western hardwoods, all native to Oregon. This study used test material 1 inch thick and 30 inches long. It was directed primarily toward the design of kiln schedules for green stock, but a few pieces of tanoak and chinquapin were dried first under simulated air-seasoning conditions. Observation of the test material led to the conclusion that the probability of successful kiln-drying is very good for green madrone and laurel (Oregon myrtle), less so for tanoak, and least for chinquapin. The tanoak and chinquapin which were air-dried first gave some indications that better results could be obtained by this method.

Studies on the seasoning of California black oak, also native to Oregon, were made recently at the California Forest and Range Experiment Station (9) (10). The first study dealt with the air seasoning and subsequent kiln-drying of $\frac{3}{4}$ -inch commercial-grade flooring strips in 3- and 6-inch widths. The results indicated that the strips could be air-dried, and the seasoning completed in a dry kiln without difficulty. Full 1-inch stock of random widths was used for the second study. Good results were obtained when this material was air-

dried to a moisture content of 20 per cent or less and then kiln-dried. The one attempt to kiln-dry a green charge of this material was not successful.

Studies at the Oregon Forest Products Laboratory on tanoak (4), madrone, and chinquapin compared kiln-drying green stock with kiln-drying air-dried stock. Both tanoak and chinquapin were air-dried at different seasons of the year and both madrone and tanoak at different levels of moisture content. One-inch, random-width, mill-run lumber was used in these studies. After being kiln-dried, the stock was graded, and a tally made of all areas 36 square inches or larger that were clear of all natural defects. Conclusions were drawn from the drop in grade and loss in clear areas when the seasoning defects were included in a second grading.

Because of possible variations in the species under investigation, some preliminary work was done to confirm the U. S. Forest Products Laboratory drying schedules, principally in the intermediate stages. Only minor differences could be detected.

With tanoak, the most favorable results were obtained by thorough air seasoning before kiln-drying. Using this procedure in the summer, the loss from visible surface defects was about one-half that which occurred when green stock was kiln-dried. Moreover, one-third or more of the kiln-dried green stock shrank so much in thickness that it probably could not be dressed to dimension without skips. Only 2 per cent of the stock that was air-dried first exhibited excessive shrinkage. Partial air seasoning gave results in proportion. Stock air-dried in winter checked somewhat more than that air-dried in summer.

Madrone does not appear to benefit by preliminary air seasoning. Warping is serious in this species even with close sticker spacing and heavy weights on the pile. Apparently, some of the lumber used in the study was sawn from logs too crooked for commercial mills, and the irregular grain caused excessive warping.

Results obtained in the chinquapin study resembled those obtained in the tanoak study.

GENERAL SEASONING PRACTICES

COMMON PRACTICE in the hardwood regions of the East is to air season lumber thoroughly before kiln-drying, especially thick stock and such species as oak, which are difficult to kiln-dry green. Although some of the reasons for this practice are of questionable

merit, preliminary air-drying has the following distinct advantages over kiln-drying green stock:

- Required kiln capacity is reduced and consequently the investment in equipment is less.
- Kiln performance requirements are less rigid than those for drying green stock. (The kilns at some woodworking plants are not designed for drying green material.)
- Better results are obtained from some species and for some manufactured items.

The principal disadvantages are:

- The large yard inventory and consequent carrying charges.
- The large yard area necessary.
- The additional handling charges.

The selection of a procedure for kiln-drying Oregon hardwoods seems to depend on the species to be dried and the personnel and equipment available for the operation.

Although schedules designed by the U. S. Forest Products Laboratory for green 1-inch tanoak and chinquapin require initial conditions difficult to attain in many good kilns, they were maintained in the studies on these woods at the Oregon Forest Products Laboratory. Even so, the results were much poorer than when the woods were air-dried first (4). Preliminary air-drying is therefore recommended for these two hardwoods.

All oaks are notoriously difficult to kiln-dry in the green state. California black oak proved to be no exception (9) (10). While it would seem reasonable to expect that Oregon white oak should be air seasoned first, good results were obtained in kiln-drying one small lot of green 1-inch material at the Oregon Forest Products Laboratory. However, since the time required probably would be excessive for a commercial operation, preliminary air seasoning is recommended.

The Oregon hardwoods that probably can be kiln-dried in either the green or air-dried state are red alder, cottonwood, Oregon ash, Oregon maple, madrone, and Oregon myrtle. Although less precision is required for drying red alder and cottonwood, all these woods demand good kilns and equipment and careful kiln operation. If these requirements are filled, kiln-drying of the green wood is more economical. The heavier cuts from some of these species, however, probably will require such a long kiln-drying period for

satisfactory seasoning that preliminary air-drying may be found economical.

The suggestions for air seasoning and kiln-drying in the following sections must be regarded only as starting points. Modifications must be made to suit the kiln, climate, season, and local variations in species characteristics. Indeed, any published schedule may need revision to meet local conditions.

AIR SEASONING

Yard site and layout

To air season hardwoods that are not particularly susceptible to such drying defects as surface checks, the yard site should be located on well-drained, high ground where each lumber pile will have unobstructed exposure to the prevailing winds. The Oregon hardwoods, however, should have some protection from direct sun, rain, snow, and prevailing winds. Whenever possible, it is preferable to air-dry these hardwoods in unheated, well-ventilated sheds where air movement can be controlled by the piling method and the lumber has complete protection from the elements. If such cover is impossible, the site should at least be well drained and in a sheltered location. Further protection from the elements can be provided by shielding and roofing the piles.

The yard layout should provide ample space for transportation and handling. Important factors often overlooked are adequate drainage of water from the yard site and ventilation. Yards located in low, wet sites where rain and snow water remain for long periods do not provide good drying conditions. The dampness in such locations invites attack by stain, decay, and insects. Proper air drainage from the piles is neglected even more often. Proper construction of the pile foundation and a well-engineered yard layout with ample spacing between the piles are necessary to prevent air stagnation, which is as detrimental to the lumber as the constant presence of water.

The location of the alleys in air-seasoning yards with respect to the prevailing winds is always a question. Actually, it probably is not so important as ample spacing between piles, since the latter will permit wind from any direction to remove moist air from all parts of the yard. The general shape of the yard also should be considered. Long, narrow yards allow better ventilation than square ones.

Figure 1 shows a section of a recommended small air-seasoning yard for hardwoods.

GENERAL LAYOUT OF AIR SEASONING YARD FOR DRYING HARDWOODS

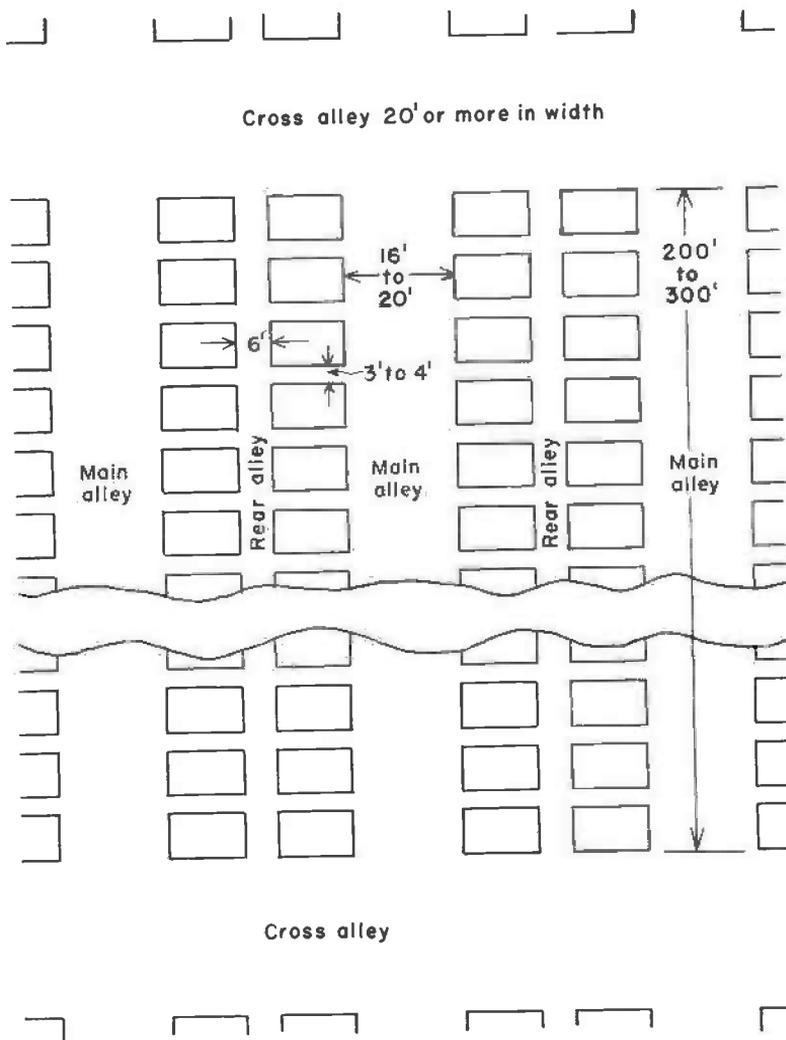


Figure 1.

Pile foundations

A prime requirement for pile foundations is free movement of air beneath the lumber. A retarded rate of drying in the lower portion of the pile will foster stain and decay, and necessitate an excessively long drying period to attain a reasonably uniform moisture content.

Pile foundations, which consist essentially of piers, stringers, and beams, must be firm and durable. Piers may be of masonry, concrete, or wood and must rest on substantial footings. Stringers should run from front to rear of the pile, resting on the piers, and may be steel I-beams, rails, or wood timbers. If wood is used for the stringers, piers, or footings, it should be either a naturally durable species (such as western red cedar) or wood pressure-treated with creosote or some other good preservative. The beams span the width of the pile and rest on the stringers. Where the sticker spacing is always the same, the stringers may be omitted and the beams allowed to rest directly on suitably located piers, but the close sticker spacing necessary for drying hardwoods makes the use of stringers more desirable.

For lumber piled by hand in the yard, the foundations should have a downward slope from front to back of about 1 inch per foot of pile length. Although the pile is sloped to drain off rain and melted snow, the stickers are at right angles to this slope and impede free drainage. Sloping the pile laterally would eliminate this difficulty and merits consideration.

Figure 2 shows a pile foundation of wood construction. The narrowness of the pile facilitates uniform drying, good segregation of stock, and rapid completion of the pile or of temporary covering when necessary.

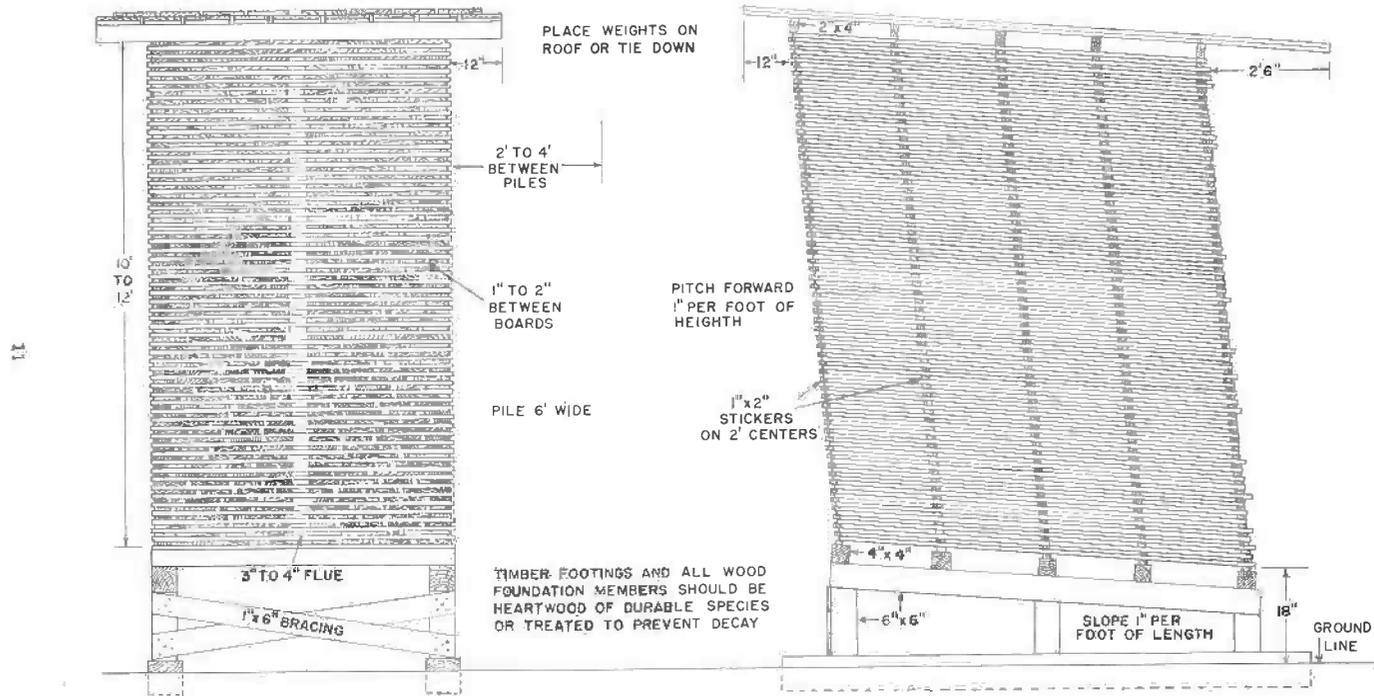
Figure 3 shows piles made with package units handled by fork lift trucks.

Piling

Good piling, necessary to control warping and maintain drying rates, depends primarily on careful design and workmanship. Lumber or remanufactured items should be sorted by thickness for seasoning, and each thickness piled separately. If the stock also can be sorted to length and each length piled separately, uneven ends can be avoided and sticker spacing can be uniform throughout the length of the pile. When this is not practicable, the lumber must be box-piled.

Several of the methods used to box-pile softwoods are not satisfactory for hardwoods, because of their greater tendency to warp.

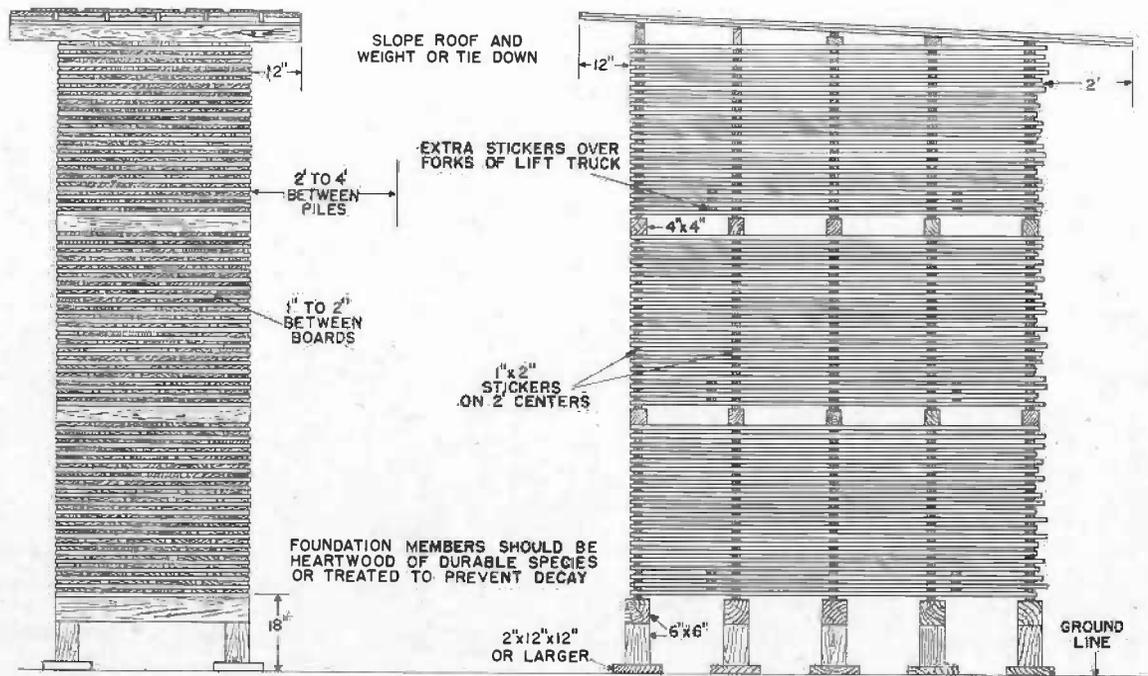
SUGGESTED PILING METHOD FOR AIR SEASONING OREGON HARDWOODS



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Figure 2.

SUGGESTED PILING METHOD FOR AIR SEASONING OREGON HARDWOODS
USING PACKAGE UNITS



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Figure 3. Unit package piling for air-drying.

To box-pile hardwoods properly, full-length boards are always placed at the outside edges of the pile, any extras being evenly spaced across the width of the pile. Short-length boards are fitted in between the full-length ones and pulled flush with the front and rear of the pile alternately across a layer. In the layer above, full-length and short-length boards are placed directly over those of like length to form vertical columns of lumber with the ends even. Stickers are placed to support the ends of the shorter-length boards, leaving little chance for distortion of either lumber or stickers. Figure 4 illustrates proper box-piling of random-length lumber.

In sloping piles, the front end of each layer projects slightly beyond that of the layer beneath, giving a forward pitch to the pile of about 1 inch per foot of height. This helps to prevent rain from entering the front of the pile.

When air circulates through a seasoning pile, it is cooled by evaporating moisture. Because cooler air is heavier, it settles down through the pile. The air movement should be aided by leaving from 1 to 2 inches between boards in a layer and by forming one or more flues or chimneys across the width of the pile. A flue or chimney is a vertical passage of wider spaces between boards extending through the height of the pile. Sometimes the flues are wide at the bottom and taper gradually to complete, or almost complete, closure at the top. The taper provides more air in the lower part of the pile where drying otherwise would be slower because of the cooler air. Piles, 6 feet wide or wider and of random-width lumber, should have one or more vertical flues (depending on the width of the pile) and a space between each board. In narrower piles, a space between each board is sufficient—unless rapid drying is possible without the occurrence of checking.

The danger of seasoning checks can be lessened by reducing the amount of air circulating through the piles, but this favors the occurrence of stain and decay. Proper control of air movement, therefore, must be designed to meet all local conditions.

The stickers, or crossers as they are sometimes called, should be uniform in thickness, properly spaced, well aligned vertically, and dry. Uniformity of thickness and proper spacing insure a firm, even bed that keeps the lumber straight, whereas the lack of either induces warping or fails to correct any natural tendency in that direction. For most 1-inch hardwood lumber, a sticker spacing of 2 feet is sufficient; for thinner lumber, or lumber especially liable to warp, it may be necessary to decrease the spacing to 15 or 18 inches. Stickers should be aligned vertically to follow the forward pitch of the pile, and so arranged that the weight of the pile is carried on

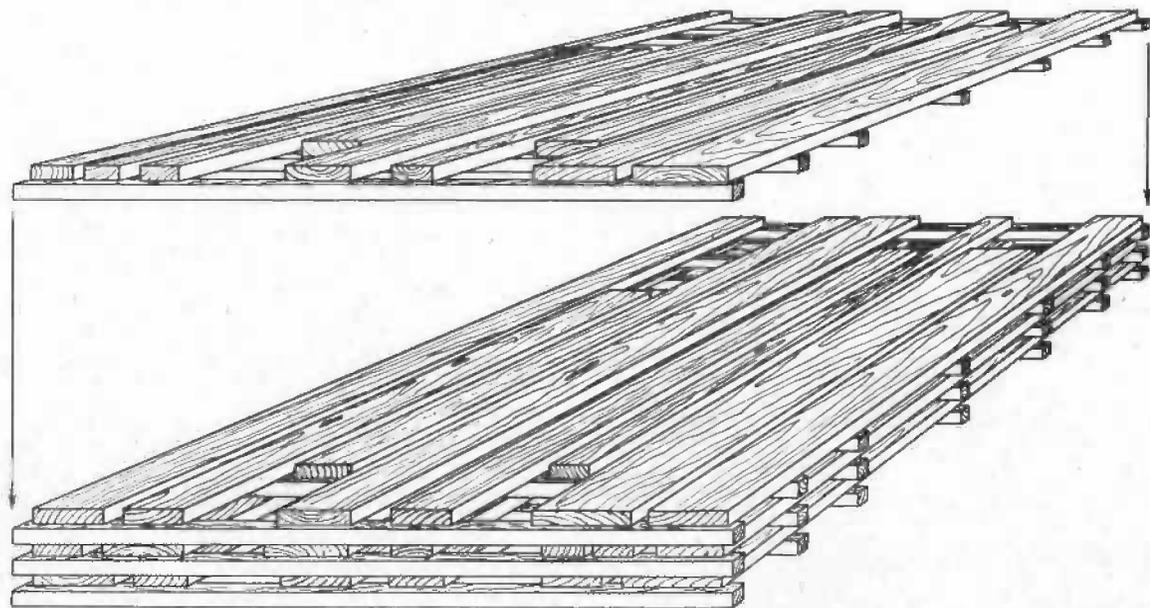


Figure 4. Proper method of box-piling random-length lumber. The following points should be noted: (a) full-length boards on outside tiers and surplus ones spaced across width of pile, (b) short-length boards alternately pulled flush to front and rear of pile in each layer, (c) boards of a given length directly over those of the same length in the layer below, and (d) varied sticker spacing at one end (or both ends) of pile to accommodate odd lengths.

solid columns of stickers and lumber. Stickers bearing on unsupported lumber will warp the latter, just as lumber on unsupported stickers or lumber that is already in the process of warping will distort the stickers. Dry stickers minimize the danger of stain and decay at points where they are in contact with the lumber.

Stickers for piling hardwood lumber usually are 1- by 2-inch, although somewhat wider ones are satisfactory for such species as red alder that do not surface check readily. The moisture in the lumber under the stickers must move to adjacent uncovered areas to be evaporated. This uneven drying causes exceptional stresses in these areas and at times produces surface checks that will later extend to the areas under the stickers, as shown in Figure 5. The narrower the stickers, the less is the likelihood of surface checking at these points.

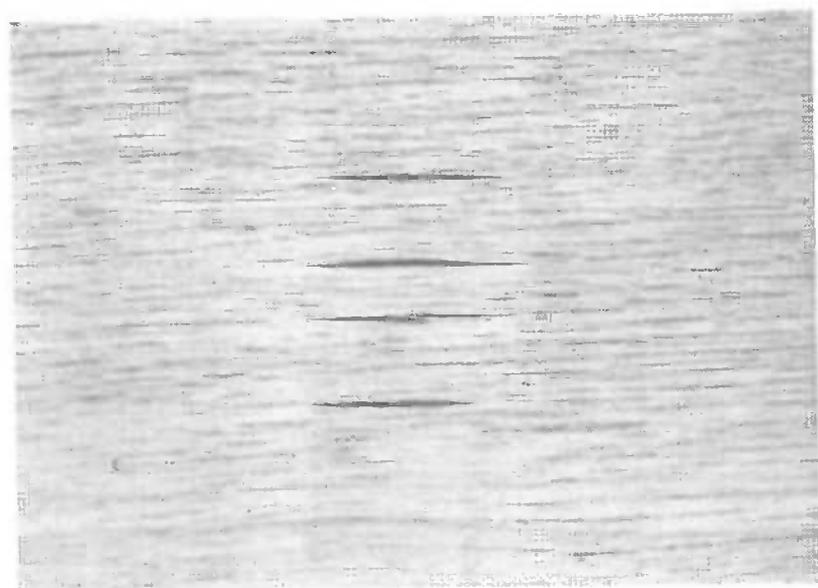


Figure 5. Surface checks in tanoak that developed beneath sticker crossings.

An air-seasoning pile should be protected from rain, snow, and direct sunlight by a roof with an overhang of at least 12 inches at the front and sides, and 24 inches at the rear. The roof can be two overlapping layers of low-grade boards, usually raised from 4 to 6 inches above the pile by thick stickers and held in place by weights, turnbuckles, or other mechanical devices. These means of keeping the

roof in place serve the additional purpose of holding the top layers of lumber flat, a matter that is accomplished in the lower part of the pile by the weight of the lumber itself. Figure 2 shows these details in a typical air-seasoning pile, but local conditions may necessitate changes in this general method.

Specific measures for the control of checking, stain, decay, and warping are as follows:

To decrease surface checking:

Use smaller spacing between boards; use fewer or smaller flues; decrease sticker thickness; decrease sticker width; cover the side of the pile with a loosely woven cloth; decrease spacing between piles; pile lumber in shed.

To decrease end checking:

Use end sealers; shield ends of piles from sun; allow half the width of the stickers to project beyond end of the lumber.

To decrease stain and decay:

Use larger spacing between boards; use more or larger flues; increase sticker thickness especially in lower part of pile; decrease sticker width; increase space between piles; use antistain chemicals; increase height of pile foundations; remove all ground cover and provide drainage for all water.

To decrease warping:

Decrease sticker spacing; use more weight on top of pile; be sure stickers are uniform in thickness and well aligned vertically; be sure lumber is uniform in thickness; improve milling practices.

Drying time

It is impracticable to predict the length of time required to air-dry lumber because it is influenced so greatly by the species, thickness of stock, method of piling, local climate, time of year, and desired final moisture content. In the studies at the Oregon Forest Products Laboratory, approximately 3 months were required in summer to air-dry 1-inch tanoak and chinquapin (4) to a moisture content below 20 per cent, whereas similar stock piled in the early fall took approximately 8 months. Although these woods were dried in piles much narrower than those ordinarily found in commercial yards, the times given for the two woods probably are approximately correct for most Oregon hardwood lumber of like thickness except when air-dried in the damp coastal region.

The progress of drying in an air-seasoning pile can be followed by using the same sampling methods as employed in kiln-drying, although this requires special equipment which often is not readily available. Since in most instances it is desirable to air-dry the lum-

ber to an average moisture content of about 20 per cent, the following simple test will determine when this point has been reached.

The moisture content at the midthickness of the lumber will be a few per cent below the fiber saturation point* when the average moisture content is 20 per cent. Therefore, some swelling along the midthickness should occur if its moisture content is raised. To perform the test, a sample approximately $\frac{1}{2}$ inch along the grain is cut about $1\frac{1}{2}$ feet from the end of an 8-inch or wider board. Preferably, more than one board should be tested, selection being made from those suspected of slower drying than the average. To escape the effect of excessive drying at the edge of the board, about $\frac{3}{4}$ inch is trimmed off both sides of the samples. A strip about $\frac{1}{4}$ -inch wide is then cut along the midthickness line, and its length carefully measured as soon as it is cut (the line along which the measurement is taken being marked). The strip is soaked in water for several hours and measured again. If measurable swelling of the strip occurs, the average moisture content of the original board is 20 per cent or less.

KILN-DRYING

Kiln requirements

A kiln for drying hardwoods should be designed to produce uniform temperatures throughout, and equipped for close temperature control. Air should circulate uniformly through the load, preferably with a velocity of 250 feet per minute or more. Although these are general requirements for kilns used to season either air-dried or green material, it must be remembered that the permissible variations in temperature and air velocity are much less in kilns drying green material. Uniform drying conditions cannot be expected from a kiln that is improperly designed or maintained. For good results, the conditions in the kiln should be periodically tested (5) and, if not uniform, any trouble corrected (8).

Piling

The general suggestions for sorting and box piling, and for sticker size and spacing for air-drying apply also to kiln-drying. These factors deal with the control of warping and with the provision of good air circulation, which greatly influences the uniformity of drying conditions and drying time. In kilns, however, air circulation generally is much greater than in air-drying and follows a dif-

* The moisture content of wood at the fiber saturation point is about 30 per cent (based on the oven-dry weight of the wood). It is the point below which shrinkage begins and strength increases, and at which swelling ceases when wood is absorbing moisture. When the midthickness moisture content is below the fiber saturation point, higher drying temperatures can be used with little danger of causing additional drying defects.

ferent pattern, depending on the particular kiln design. Circulation or design may necessitate more attention to details of piling. Since there are so many kiln designs in use, specific piling details are not given in this circular, but a few of the more general precautions are discussed in the following paragraphs.

In natural-draft kilns where circulation depends on the thermal displacement of air, the air moves vertically through the piles. Spaces between boards and flues extending through the entire height of the pile, as well as ample space outside the loads, are needed to facilitate circulation. Although such spaces decrease kiln capacity, the improved circulation, decreased drying time, and uniformity of moisture content should more than compensate for the loss.

In the modern internal-fan kilns with flat-piled loads, air from the fans travels vertically between the load and the walls, turning at right angles to enter the load. For these kilns, care must be taken to keep the edges of the load even, because projecting boards act as air scoops and cause a high air velocity through the sticker space on the upstream side with little or no air entering the first few downstream sticker spaces. This also is true for the sides of the "A" flue in loads piled for external-blower kilns.

All flat-piled loads in internal-fan kilns should be full height and extend the full length of the kiln. Voids cause the air to bypass the load and result in wasted electric power and decreased or uneven circulation through the lumber.

Care must be taken that the air passages through the loads are not blocked. Except in the case of severe warping, the occurrence of blocking is more common among kiln loads made up of unit packages where, through rough handling with fork lifts, stickers are knocked loose or boards are forced together, interfering with air circulation and causing warping. Additional stickers in the bottom layers where the packages bear on the forks will help prevent sticker displacement (see Figure 3). Also, various devices may be used on the end stickers or the ends of the package to clamp or bind the stickers in place while handling. A space of from 4 to 6 inches should be left between the vertical tiers of unit packages in a load because the stickers in adjacent tiers may not be in line horizontally.

Why kiln samples are needed

Kiln samples conveniently provide information on the moisture content of the lumber as it dries. This information is needed for successful control of defects that may develop in drying, for the application of a good kiln schedule, and for successful moisture equalization and stress-relief treatments.

Below certain moisture-content levels, the tendency for certain defects to develop becomes reduced or almost negligible because of the normal development of tensile and compressive stresses in the piece. It follows, therefore, that if a wood is susceptible to drying defects, safe drying conditions should be maintained until the chance of producing the defect is past. In other words, changes in drying conditions (the kiln schedule) should be based on the moisture content of the wood.

Kiln schedules based on moisture content have an additional advantage in that they are applicable to different kilns. Largely because of differences in air circulation, different kilns dry lumber at different rates even when the temperature and relative humidity are the same. It is impracticable, therefore, to formulate a kiln schedule on the basis of elapsed time in the kiln.

The moisture content of green wood as well as the rate of moisture loss during drying often varies appreciably. Consequently, there is usually a rather wide range in the moisture content of different pieces as the wood dries. Although the range narrows gradually as drying progresses, it is often desirable, especially with hardwoods, further to reduce the range at the end of the normal drying procedure. Data obtained from the kiln samples will indicate the need for this moisture equalization treatment as well as tell when it should start and how long it should be continued. Kiln samples also govern the stress relief treatments.

Preparation and use of kiln samples

A suggested procedure for preparing and using kiln samples is outlined below:

STEP 1. Select the boards from which samples are to be cut. For hardwoods, samples are taken from boards representing: (a) fast-drying stock (narrow, thin boards of less than normal density and green weight), (b) slow-drying stock (wide, thick, vertical-grain boards of greater than normal density and green weight), and (c) average stock.

STEP 2. Moisture-content sections and kiln samples are cut well back from the ends of the boards in order to avoid ends and wide faces that have been unduly dried by exposure. If one sample only is to be taken from a board, cut as in Figure 6,A to avoid unnecessary waste of material; otherwise, cut as in Figure 6,B. Number and mark the sections and samples in a convenient manner.

STEP 3. Weigh moisture-content sections to nearest 0.1 gram, or equivalent in pounds, *immediately* after cutting. Record weights on a convenient form.

STEP 4. Weigh the kiln samples to the nearest 0.01 pound or the nearest gram as soon as possible. Record weights on the form used for moisture-content sections.

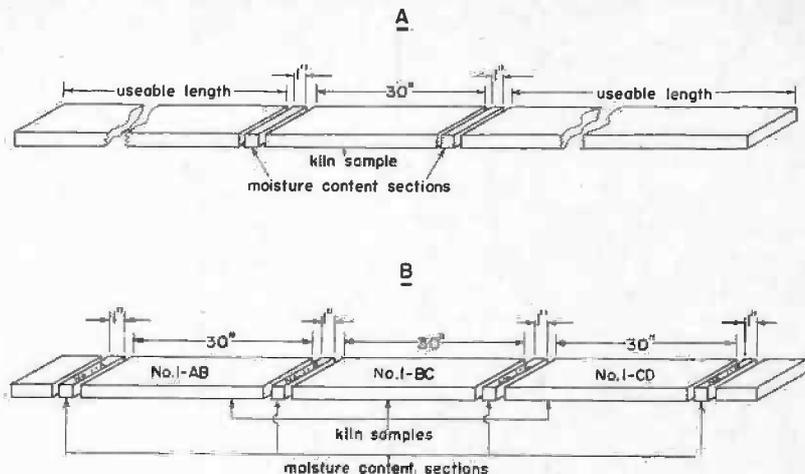


Figure 6. Methods of cutting kiln samples and moisture-content sections from lumber.

STEP 5. Coat both ends of the kiln samples with a good end-sealer (two coats of aluminum paint or filled, hardened gloss oil).

STEP 6. Dry the moisture-content sections in an oven maintained at from 212° to 220° F until successive weighings at 4-hour intervals show practically no loss in weight. Sections are weighed as they are removed from the oven. Record weights on the form.

STEP 7. Calculate the moisture content of the sections and, using the average moisture content of the two adjoining sections as that of the intervening kiln sample, calculate the oven-dry weight of the kiln samples. The following equations are used:

$$(1) \text{ Average moisture content in } \% = \frac{(\text{Green weight} - \text{Oven-dry weight}) \times 100}{\text{Oven-dry weight}}$$

$$(2) \text{ Oven-dry weight} = \frac{\text{Green weight}}{1 + \frac{\text{Average moisture content in } \%}{100}}$$

STEP 8. Place the kiln samples in pockets in the kiln loads (see Figure 7).

STEP 9. Weigh the kiln samples periodically during drying to the same accuracy as before. Record the weights on a convenient form and calculate current moisture content using the following equation:

$$(3) \text{ Current moisture content in } \% = \frac{(\text{Current weight of sample} - \text{Oven-dry weight}) \times 100}{\text{Oven-dry weight}}$$

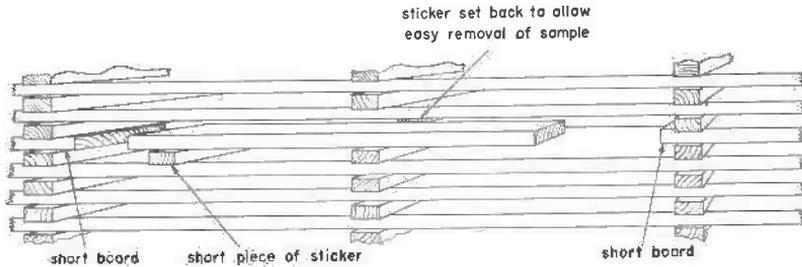


Figure 7. Pocket for kiln sample built into side of kiln load.

STEP 10. Variations in green moisture-content as well as errors in determining green weights frequently cause miscalculations of the oven-dry weight of kiln samples. These errors are made evident near the end of the drying period by obviously incorrect values for the moisture content of the samples. The moisture content may be checked, and corrections made, by cutting a 1-inch moisture-content section 6 to 8 inches from one end of the sample. The freshly cut end of the sample is coated and the sample weighed. Using equation (2), the oven-dry weight of the remaining portion of kiln sample is calculated by substituting the cut weight for "Green weight."

The following example will illustrate the calculations in steps 7, 9, and 10:

STEP 7. Assume the data in the following table have been obtained from a board cut as in Figure 6,B:

Sample number	Green weight	Oven-dry weight
1A	250.0 grams	100.0 grams
1AB	2.50 pounds	105.0 grams
1B	262.5 grams	105.0 grams
1BC	3.24 pounds	96.8 grams
1C	233.9 grams	96.8 grams

The moisture content of section 1A is calculated from equation (1):

$$MC\% \text{ 1A} = \frac{250.0 - 100.0}{100.0} \times 100 = \frac{150}{100} \times 100 = 150\%$$

The moisture content of sections 1B and 1C are calculated in a similar manner:

$$MC\% \text{ 1B} = \frac{262.5 - 105.0}{105.0} \times 100 = \frac{157.5}{105.0} \times 100 = 1.5 \times 100 = 150\%$$

$$MC\% \text{ 1C} = \frac{233.9 - 96.8}{96.8} \times 100 = \frac{137.1}{96.8} \times 100 = 1.416 \times 100 = 141.6\%$$

Next, find the average moisture content of the kiln samples by averaging the values of the two adjacent sections:

$$MC\% \text{ 1AB} = \frac{150 + 150}{2} = 150\%$$

$$MC\% \text{ 1BC} = \frac{150.0 + 141.6}{2} = \frac{291.6}{2} = 145.8\%$$

The oven-dry weight of the kiln samples now can be calculated from equation (2):

$$ODW \text{ 1AB} = \frac{2.50}{1 + \frac{150}{100}} = \frac{2.50}{1 + 1.5} = \frac{2.5}{2.5} = 1.00 \text{ pound}$$

$$\text{ODW 1BC} = \frac{3.24}{1 + \frac{145.8}{100}} = \frac{3.24}{1 + 1.458} = \frac{3.24}{2.458} = 1.32 \text{ pounds}$$

STEP 9. Assume that sample 1AB weighs 2.00 pounds after 48 hours drying. Its moisture content is calculated from equation (3):

$$\text{MC\%} = \frac{2.00 - 1.00}{1.00} \times 100 = \frac{1.00}{1.00} \times 100 = 100\%$$

If sample 1BC weighs 2.59 pounds after the same period of time:

$$\text{MC\%} = \frac{2.59 - 1.32}{1.32} \times 100 = \frac{1.27}{1.32} \times 100 = 96.2\%$$

STEP 10. Assume that after 14 days of drying, sample 1AB weighs 1.10 pounds, then:

$$\text{MC\%} = \frac{1.10 - 1.00}{1.00} \times 100 = 10\%.$$

However, it is desired to check this moisture and return the sample to the kiln for further drying. A 1-inch section cut from the sample shows the moisture content to be actually 12 per cent. Therefore, the moisture content based on the kiln sample is in error by 2 per cent. If the remaining portion of the kiln sample weighs 0.84 pounds, the oven-dry weight of the remaining portion of the kiln sample is:

$$\text{ODW} = \frac{0.84}{1 + \frac{12}{100}} = \frac{0.84}{1 + 0.12} = 0.75 \text{ pound.}$$

Time schedules

Most softwood dry-kiln operations in the West use schedules based on elapsed time in the kiln, but these are usually the outcome of intensive experience with specific kilns, species, and local conditions. A moisture-content schedule can be converted into a time schedule for lumber of a particular species, thickness, and type when actual experience has established a consistent relationship between moisture content and time. Any time schedule, however, should be verified occasionally with kiln samples because of variations in the characteristics of the wood and in kiln performance. As hardwoods in general are more sensitive to temperature and humidity changes in the schedule, the design of the time schedule must be sound, and frequent verification is necessary.

Application of kiln schedules

The schedules given in this circular indicate the kiln conditions that should be maintained through certain levels of moisture content. For example, if a load of green 1-inch red alder is to be dried, the initial conditions in the kiln are set at 140° F dry-bulb temperature and 134° F wet-bulb temperature. These conditions are maintained until the moisture content has been reduced to 40 per cent. At that time the dry-bulb temperature is raised to 145° F and the wet-bulb temperature to 136° F. These conditions are maintained until the

stock is dried to a moisture content of 30 per cent, when they are changed again, etc.

Because of the range in moisture content throughout the charges, there may be some question as to the exact meaning of the moisture-content values given in the schedules. The safest practice is to base the schedule changes on the highest moisture content in the kiln charge, i.e., govern the kiln schedule by the wettest and slowest drying kiln samples. This practice ensures safe conditions for the greatest part of the charge, and it is recommended as a general rule for most hardwoods. In drying the few hardwoods known to be resistant to drying defects, the rule can be relaxed. A schedule drawn up on the basis of average moisture content may produce good results with considerable saving in drying time.

Occasionally, it may be necessary to dry more than one item or species in a given kiln charge. In such cases, the kiln schedule should be selected and the kiln operated according to the species or item requiring the mildest drying conditions.

The rate of air circulation in a kiln is a large factor in the design of kiln schedules, because it affects the drying conditions at the surface of the wood, especially in the early stages, and the rate at which heat is supplied to the wood. As the air passes over a board, it tends to drag on the surface, leaving behind a dead layer of air. Rapid circulation and increased turbulence in the air stream will sweep away this dead layer more effectively, and the drying conditions then existing at the board surface become more closely equal to those indicated by the wet- and dry-bulb temperature readings. Where the circulation rate is low, the moisture in the dead layer remains behind, a condition not truly shown by the wet- and dry-bulb readings in the kiln. Kilns with high rates of air circulation require higher wet-bulb temperatures in the early stages of drying to keep lumber from checking than do those with low velocities. The schedules in the following sections are designed for modern kilns with good circulation. If applied to kilns with lower velocities, the indicated dry-bulb temperatures may be used, but wet-bulb temperatures should be lower during the first two or three steps of drying.

Published kiln schedules can only suggest drying conditions that should be modified later to suit a particular kiln and local conditions. These schedules are usually conservative, more attention being given to the condition of the dried lumber than to the length of drying time, although both are important in commercial operations. It is to be expected, therefore, that most changes will be toward more rigorous drying conditions.

Kiln schedules for green stock

RED ALDER AND COTTONWOOD. These native hardwoods are the easiest to season. Both are being processed at furniture and other remanufacturing plants with little difficulty, except in the case of 2½-inch or thicker red alder lumber. The drying schedules in use vary widely with the operating personnel, production requirements, and type of kilns in use.

Except for some work on sticker stain in red alder (4), no experimental work has been conducted at the Oregon Forest Products Laboratory in kiln schedules for these two woods. The tentative schedules which follow are based on present commercial practices and on the general pattern of drying schedules for hardwoods. Although the first steps in the schedule for stock up to 2 inches thick are more conservative than general commercial practice, they do not add greatly to total drying time and may give better results.

TENTATIVE SCHEDULE FOR RED ALDER AND COTTONWOOD
2 INCHES OR LESS IN THICKNESS

Moisture content of kiln samples	Temperature		Relative humidity	Equilibrium moisture content
	Dry bulb	Wet bulb		
<i>Per cent</i>	<i>°F</i>	<i>°F</i>	<i>Per cent</i>	<i>Per cent</i>
Green to 40	140	134	84	14.8
40 to 30	145	136	77	12.5
30 to 25	150	135	66	9.6
25 to 20	160	135	50	6.8
20 to final	180	130	26	3.3

TENTATIVE SCHEDULE FOR RED ALDER 2½ AND 3 INCHES
IN THICKNESS

Moisture content of kiln samples	Temperature		Relative humidity	Equilibrium moisture content
	Dry bulb	Wet bulb		
<i>Per cent</i>	<i>°F</i>	<i>°F</i>	<i>Per cent</i>	<i>Per cent</i>
Green to 40	120	115	85	16.1
40 to 30	125	118	80	14.0
30 to 25	130	118	69	11.0
25 to 20	140	118	51	7.5
20 to 15	150	118	38	5.5
15 to final	180	135	30	3.8

OREGON ASH. Green Oregon ash has been kiln-dried commercially with success but requires milder initial drying conditions than red alder. Eastern ashes, which closely resemble the local ash, are often kiln-dried green. The following is based on typical schedules for eastern species. One small lot of 1½-inch Oregon ash was dried on this schedule at the Oregon Forest Products Laboratory with good results.

TENTATIVE SCHEDULE FOR OREGON ASH 2 INCHES OR LESS
IN THICKNESS

Moisture content of kiln samples	Temperature		Relative humidity	Equilibrium moisture content
	Dry bulb	Wet bulb		
<i>Per cent</i>	<i>°F</i>	<i>°F</i>	<i>Per cent</i>	<i>Per cent</i>
Green to 40	135	130	86	15.9
40 to 30	140	132	79	13.3
30 to 25	145	131	67	10.0
25 to 20	150	124	46	6.7
*20 to 15	155	124	41	5.7
20 (15) to final	180	130	26	3.3

* Omit on lumber 1½ inches or less in thickness.

OREGON MAPLE. Oregon maple is similar to eastern maple and has essentially the same drying characteristics. It is now being dried at various manufacturing plants without much difficulty, although it too requires more care than red alder. Since Oregon maple is often cut from crooked logs or logs with irregular grain (both of which constitute additional problems to the control of warping), good piling is important. The following schedule, like that given for Oregon ash, is based on typical schedules for the eastern species.

TENTATIVE SCHEDULE FOR OREGON MAPLE 2 INCHES OR LESS
IN THICKNESS

Moisture content of kiln samples	Temperature		Relative humidity	Equilibrium moisture content
	Dry bulb	Wet bulb		
<i>Per cent</i>	<i>°F</i>	<i>°F</i>	<i>Per cent</i>	<i>Per cent</i>
Green to 40	130	125	86	16.0
40 to 30	135	128	81	13.9
30 to 25	140	126	66	10.0
25 to 20	150	125	48	6.8
*20 to 15	150	120	41	5.8
20 (15) to final	180	130	26	3.3

* Omit on lumber 1½ inches or less in thickness.

OREGON MYRTLE (CALIFORNIA LAUREL). The schedule developed by the U. S. Forest Products Laboratory, Madison, Wisconsin, is recommended for 1-inch myrtle. It also may be satisfactory for 1½-inch stock, but for heavier, more valuable stock it is probably advisable to use milder conditions in the first three steps of the schedule, and to insert a fourth step to be held until the average moisture content reaches 15 per cent. The schedule for 1-inch stock follows:

TENTATIVE SCHEDULE FOR MYRTLE 1 INCH OR LESS IN THICKNESS*

Moisture content of kiln samples	Temperature		Relative humidity	Equilibrium moisture content
	Dry bulb	Wet bulb		
<i>Per cent</i>	<i>°F</i>	<i>°F</i>	<i>Per cent</i>	<i>Per cent</i>
Green to 40	130	123	81	14.0
40 to 30	140	130	75	11.9
30 to 20	150	127	51	7.3
20 to final	180	135	30	3.8

* "Kiln Drying Schedules for 1-Inch Laurel, Madrone, Tanoak and Chinquapin," U. S. Forest Products Laboratory Report R1684 by O. W. Torgeson.

MADRONE. In a study of the seasoning of madrone at the Oregon Forest Products Laboratory, only minor improvements in results were obtained through various modifications of the schedule developed by the U. S. Forest Products Laboratory. Almost identical results are obtained (a) by air seasoning and then kiln-drying, and (b) by kiln-drying green. Control of warping in both air seasoning and kiln-drying is difficult, probably because of the irregular grain in the material used in the study. Since shrinkage in this wood is high and crookedness of grain characteristic, it is advisable to pay special attention to warpage control. Sticker spacing of 18 inches for 1-inch stock and heavy weights on the pile are suggested. The following schedule gave the best results in the study which was conducted only on 1-inch material:

TENTATIVE SCHEDULE FOR MADRONE 1 INCH THICK

Moisture content of kiln samples	Temperature		Relative humidity	Equilibrium moisture content
	Dry bulb	Wet bulb		
<i>Per cent</i>	<i>°F</i>	<i>°F</i>	<i>Per cent</i>	<i>Per cent</i>
Green to 50	120	116	88	17.4
50 to 40	120	113	80	14.1
40 to 30	130	110	52	8.0
30 to 20	140	109	37	5.7
20 to Final	180	130	26	3.3

CHINQUAPIN. In a study of seasoning 1-inch chinquapin, considerable collapse (excessive shrinkage in thickness) and checking occurred when green wood was kiln-dried—even when the drying conditions were closely controlled and the experimental kilns operated during the initial stages at the lower limits of commercial kiln performance (105° F dry bulb, 102° F wet bulb). On the other hand, good results were obtained when the material was first air-dried to a moisture content of 20 per cent or less. It is recommended that chinquapin be thoroughly air-dried before kiln-drying.

TANOAK. The results obtained in a tanoak seasoning study (4) indicate that it closely resembles chinquapin and that the material should be thoroughly air-dried before kiln-drying.

CALIFORNIA BLACK OAK. Since H. H. Smith's experiences (9, 10) with $\frac{3}{4}$ -inch and 1-inch California black oak resemble those described for chinquapin and tanoak, this species also should be air-dried before kiln-drying.

OREGON WHITE OAK. No detailed studies of the seasoning of Oregon white oak have been made by the Oregon Forest Products Laboratory although, as mentioned previously, one small lot of green 1-inch material was kiln-dried. While good results were obtained, the time required probably would be excessive. Moreover, the results with only one small lot cannot be considered a sufficient basis for establishing a schedule. Therefore, it is recommended that this wood be air-dried before kiln-drying.

Kiln schedules for air-dried stock

Air-dried stock for the kiln usually has a moisture content of 20 per cent or less. During the winter months, however, it may be necessary to kiln-dry stock that has not reached this moisture content, whereas in the middle or late summer months the moisture content may be as low as 10 or 12 per cent. Any kiln schedule designed for air-dried stock, therefore, should take into consideration the moisture content of the material at the time it goes into the kiln.

The drying schedules for green stock also can be applied to air-dried stock if the schedule of temperatures is designed for the moisture content of the wettest material at the time of charging into the kiln and subsequent temperature changes are made in accordance with the drop in moisture content of the drying material. The initial relative humidity should be that at which the wood was air-dried and then changed (in one or two steps, 24 to 48 hours apart) to that in the green stock schedules.

Since no schedules for green tanoak, chinquapin, California black oak, and Oregon white oak have been drawn up, the preceding suggestions cannot be applied to these woods. To be on the safe side, these woods should first be air-dried until the moisture content of the slowest drying stock is about 20 per cent, because seasoning defects may develop in boards with a moisture content above this figure. When there is not sufficient time for such thorough air drying, the initial kiln temperature should be held at 120° F or lower until the wettest material has been dried to 20 per cent moisture content. The temperature then may be safely raised to 180° F. As with other woods, the initial relative humidity should be nearly that to which the wood has previously been exposed, then lowered to about 40 per cent in one or two steps, and again decreased when the temperature is raised to 180° F. The following schedule is for these hardwoods when air-drying has not successfully brought the moisture content of the wettest material below 20 per cent:

Approximate duration	Temperature		Relative humidity	Equilibrium moisture content
	Dry bulb	Wet bulb		
	°F	°F	Per cent	Per cent
For one or two days*	120	110	72	12.1
For one or two more days	120	103	55	9.0
Until wettest material dried to 20 per cent moisture content	120	95	40	6.6
Until final moisture content reached	180	135	32	3.8

* Omit this step in dry summer months.

The following schedule is suggested for these woods when the wettest material has reached a 20 per cent moisture content:

Approximate duration	Temperature		Relative humidity	Equilibrium moisture content
	Dry bulb	Wet bulb		
	°F	°F	Per cent	Per cent
For first day*	180	168	75	10.1
For one or two more days	180	162	65	8.1
Until final moisture content reached	180	135	32	3.8

* Omit this step in dry summer months.

Moisture equalization and stress relieving treatment

When applied to lumber, the term "casehardening" refers to a condition of stress in which, when the moisture content is uniform and below the fiber saturation point through the thickness of the wood, the outer layers are under compression and the inner ones in tension. This is a condition of normally dried wood. Measures, such as intermittent steaming, should not be applied during the drying procedure to prevent it. The proper time to relieve casehardening is at the conclusion of the drying period.

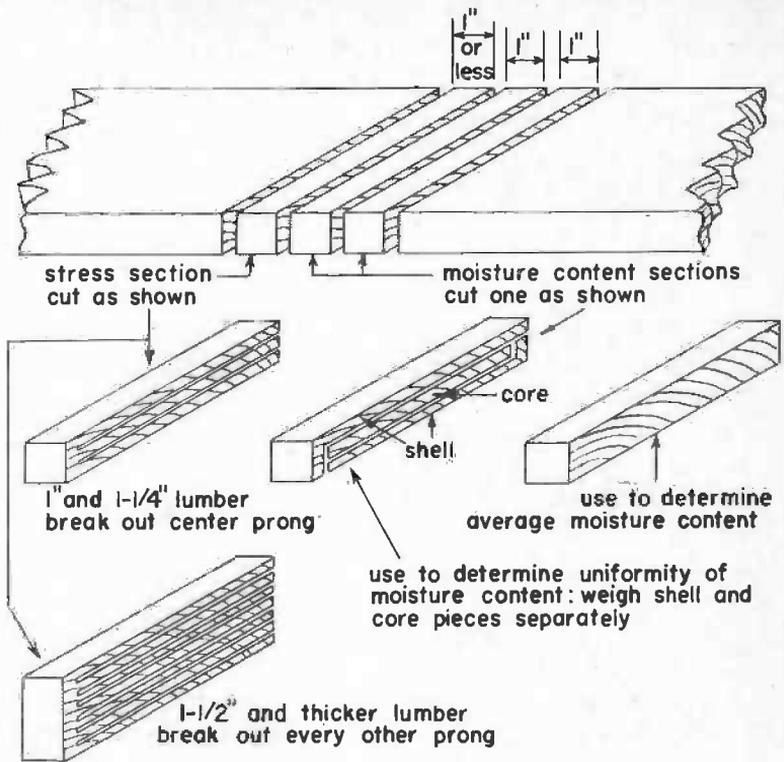
If lumber is not reworked, the casehardening stresses balance each other without distortion. If the stresses in remanufactured pieces get out of balance, the compressed layers become longer than those in tension, distorting the piece. A common example of this is the tendency of resawn lumber to cup toward the sawline. Other difficulties from this source are the cupping of lumber surfaced more heavily on one side than on the other; warping the pattern stock, saddle chair seats, and other carved items; splitting of stock coming from the planer; and end checking of freshly trimmed boards.

The method of testing lumber for casehardening is shown pictorially in Figure 8. Since it is often desirable to determine the average moisture content and the uniformity of moisture content at the same time, the method of cutting these test pieces is shown in the same figure.

Before the lumber is conditioned to relieve casehardening, which must be done effectively to the largest possible part of the kiln load for economic reasons, the midthickness moisture content of different boards must be brought to equality at the desired final moisture content. This treatment is known as "equalization." When this is to be done, the equilibrium moisture content in the kiln is so regulated that when the midthickness moisture content of the driest stock has reached the desired point, this material stops, but the wetter pieces do not stop drying. At the end of the "equalization" treatment, the midthickness moisture content values for most of the kiln will be about equal and at the desired final moisture content which is higher than the average moisture content.

At this point only, can the treatment for relieving casehardening be applied. The moisture content of the surface of the wood is raised to that at the midthickness. Care must be taken not to raise it beyond this point, because "reverse casehardening" may occur in which the stresses are reversed. No practical method of relieving this condition is known.

The moisture content at the midthickness of a piece of drying wood can be calculated fairly accurately from the average moisture



allow stress sections to dry before making conclusions

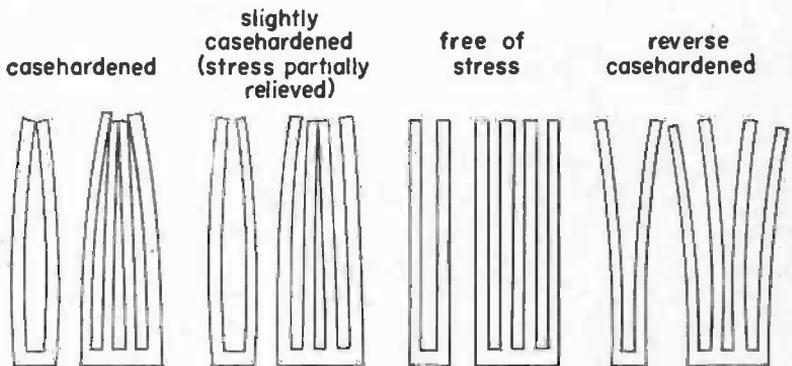


Figure 8. Method of cutting kiln samples of lumber to determine average moisture content, uniformity of moisture content, and presence of casehardening stresses.

content and the equilibrium moisture content of the atmosphere in the kiln. This eliminates guesswork in equalization treatments. The formulae used are:

$$(4) Y = \frac{3A - E}{2}$$

or, by transposition:

$$(5) A = \frac{2Y + E}{3}$$

Y is the moisture content at the midthickness, A the average moisture content, and E the equilibrium moisture content in the kiln.

In applying the formula, Y is the desired final moisture content, because the surface moisture content will eventually be raised to this point by the conditioning treatment. An equalization treatment is determined in the following manner:

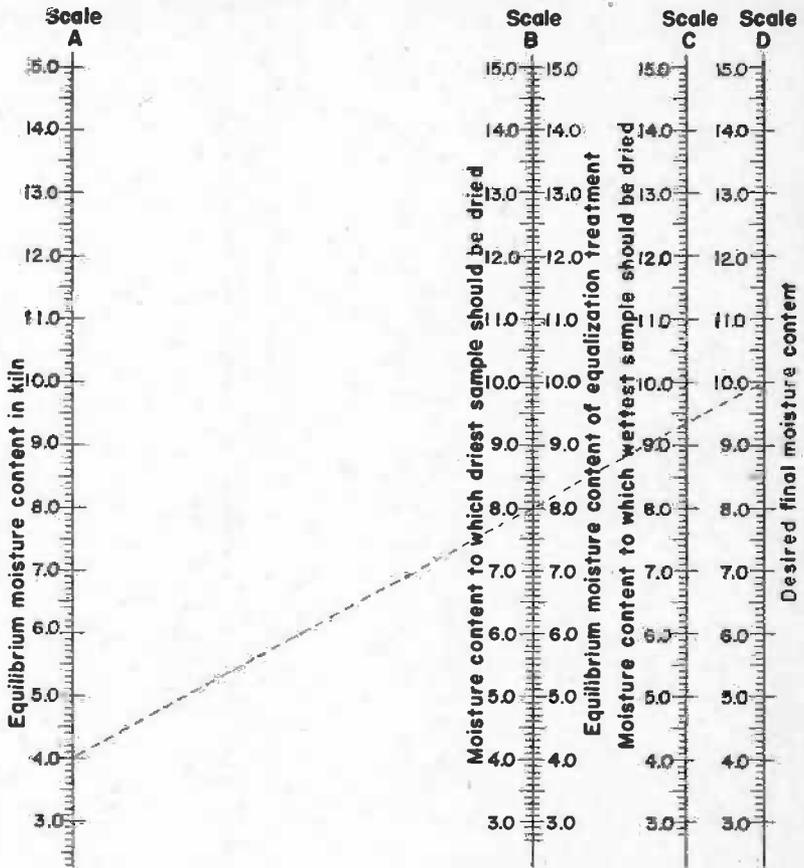
- (1) Calculate the average moisture content to which the material (kiln sample) must be dried to give the desired moisture content at the midthickness, using equation (5).
- (2) When the dried kiln sample reaches this average moisture content, raise the equilibrium moisture content to equal this average. This is the start of the equalization treatment.
- (3) Using the newly established equilibrium moisture content in equation (5), calculate the average moisture content necessary to give the desired moisture content at the midthickness. This is the moisture content to which the wettest sample should be dried.
- (4) Continue the equalization treatment until the wettest kiln sample has reached the calculated average moisture content. This completes the equalization treatment.

While the calculations for the equalization treatment are not difficult, it is much easier to use the alignment chart in Figure 9. The chart is based on equation (5).

An equilibrium moisture content chart is given in Figure 10.

It is characteristic of wood, when gaining moisture, to reach a lower moisture content at any given combination of temperature and relative humidity than when losing it. This is called the phenomenon of "hysteresis." Therefore, the equilibrium moisture con-

ALIGNMENT CHART FOR MOISTURE EQUALIZATION



Instructions:

Draw straight line from equilibrium moisture content in the kiln (Scale A) to desired final moisture content (Scale D). The intersection of this line on Scale B gives the moisture content to which the driest kiln sample should be dried and the equilibrium moisture content to be used for the equalization treatment. The intersection of the line on Scale C gives the moisture content to which the wettest kiln sample should be dried in the equalization treatment.

Example: desired final moisture content is 10.0% and equilibrium moisture content in kiln is 4.0%. See dotted line. Driest sample should be dried to 8.0% and equilibrium moisture content of equalization treatment is 8.0%. Dry wettest sample to 9.3%.

Figure 9. Alignment chart for moisture equalization treatment.

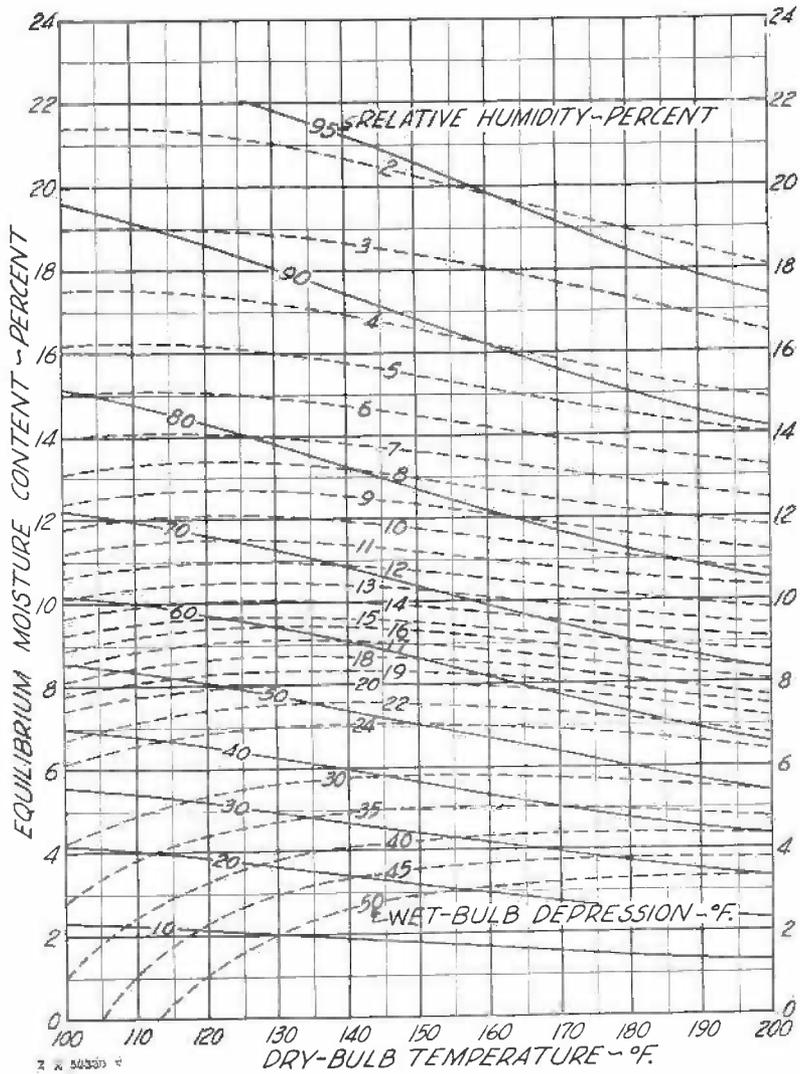


Figure 10. Equilibrium moisture content of wood as a function of dry-bulb temperature and wet-bulb depression. (Courtesy of U. S. Forest Products Laboratory.)

tent values in Figure 10 are high when applied to conditioning treatments. (In other words, the moisture content in the wood will be below that indicated in the chart.) A correction factor is necessary to determine the equilibrium moisture content under these conditions, but this factor in turn is affected by the density of the wood; the lower the density the smaller the correction. This corrected factor ranges from 1.2 for low-density woods, such as hemlock and ponderosa pine, to 1.4 for higher-density ones, such as tanoak. For example, if the midthickness moisture content of a charge of chinquapin (a wood of moisture density) is 8 per cent, the charge should be conditioned at an equilibrium moisture content of $8 \times 1.3 = 10.4$ per cent by the chart. For most Oregon hardwoods, a factor of 1.3 to 1.4 is used.

The following example illustrates a moisture equalization and conditioning treatment:

A charge of Oregon maple (a wood of moderate density) is to be dried to a uniform moisture content of 7 per cent and stress relieved, the final conditions in the kiln being 180° F dry bulb, 130° F wet bulb (50° wet-bulb depression). From Figures 9 and 10, it is found that the equilibrium moisture content is 3.3 per cent and that the driest sample should be dried to 5.8 per cent average moisture content. When this point is reached, the equilibrium moisture content should be raised to 5.8 per cent, a wet-bulb depression of 29° at 180° F dry bulb (151° wet-bulb temperature). This equilibrium condition is maintained until the wettest sample reaches 6.6 per cent average moisture content (same line in Figure 9) when conditioning should be started. The tabulated equilibrium moisture content for conditioning is $7 \times 1.3 = 9.1$ per cent which, according to Figure 10, requires a wet-bulb depression of about 15° at 180° F dry-bulb temperature.

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