Seasoning Defects of Western Softwoods

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The subject which we are to consider today is entitled "Seasoning defects in western softwoods." To an audience of dry kiln operators and lumber manufacturers this topic has a specific meaning and application. It might, however, not be so clearly understood by some more general audience and a closer analysis of our definitions should be helpful.

The word **defect** is used in the English language with a variety of flavors—generally indicating, however, an appreciable and often important lack of a desirable property or usefulness. Webster's dictionary defines the word **defect** thus: "An imperfection, a blemish, a fault, in timber any irregularity which may impair the strength or utility." Another definition states: "Defect—a want of something necessary for completeness."

Lumber is used for both strength and beauty. Any irregularity which impairs either strength or appearance could, therefore, be called a defect. Many irregularities develop in the growing tree. For example, tree branches, growing into heavy limbs, result in large knots in the sawed lumber. The cross grain of the knot and the distorted wood around it do not furnish any significant bending strength to the piece of lumber. If they make up a considerable portion of the board, it has less strength. The consumer also considers a knot or knot hole as a blemish when appraising the appearance of the board. A knot is definitely a defect in his estimation. For certain uses an architect may capitalize on the unique appearance presented by a board containing sound knots in a pleasing pattern and a premium product may be created out of an otherwise defective one. Yet he considers a knot to be a defect.

The use of the term **defect** implies that somewhere in the manufacture of lumber a measure of quality has been lost. Since knots, for example, develop in a growing tree, it might be considered that a full measure of quality never was present and therefore such implication of the word **defect** is untrue. Lumber merchandisers have replaced the term **defect** with the term **characteristic** and have thereby relieved some of the stigma implied by the former term. So now we may speak of knots, knot holes, pitch pockets, distorted grain, irregular color, etc. as growth characteristics in discussing western softwoods. While the physical properties and appearance of the wood remain unchanged by the use of this term, market acceptance of the lumber is improved. In our discussion today we will not include growth characteristics as defects.

There is a second group of defects in lumber which I will likewise pass by today—those which are the result of mismanufacture. Dog holes in lumber, which are the result of mechanical handling of the log, cant, or board; narrow or thin boards, which were not cut large enough to meet the industry commercial standards; blue stain, which is present in the log when it enters the mill; are examples of such defects in lumber which are not the immediate responsibility of the dry kiln operator.

I wish, rather, to consider those changes in lumber quality which reduce the strength, appearance, or usefulness from that originally available in the freshly cut lumber. These changes developed during drying either in the yard or in the kiln and in subsequent surfacing. Our principal interest here is the field of kiln drying lumber and we will confine ourselves to it, even though air drying is accompanied by similar development of defects. Specifically, I wish to discuss those defects which develop in the kiln drying process as the result of (1) poor drying control, (2) lack of understanding of the behavior of wood drying, and (3) plain neglect. The ability and efficiency of a dry kiln operator can be evaluated by the extent to which he can minimize or avoid the development of seasoning defects.

What are these seasoning defects? The most important one is surface checking. Surface checking primarily affects that appearance of the lumber. It seldom affects the structural strength of the piece to any significant degree. It is highly objectionable in the clear finish grades of lumber, which incidentally carry the highest unit price, and thus may be the cause of considerable loss in sales value.

Surface checking can be serious even in efficient kiln drying operations. A recent study at a ponderosa pine mill equipped with a modern battery of dry kilns showed that in 6/4 Select six percent of the volume dropped one or more grades because of surface checking, and the average loss in sales value at the mill amounted to $5.00 per thousand square feet for the entire production in this grade. Although an equal amount of surface checking might occur in common grades, appearance is of lesser importance in these grades and their value is little reduced by the presence of moderate surface checking.

What causes surface checking? Why is preventing it so difficult? What kiln drying techniques are available to the dry kiln operator for its control? Like many other seasoning defects, surface checking results from the unique shrinkage behavior of wood in drying. If wood structure did not shrink as it loses its moisture, drying lumber could be simple, rapid, easy, and probably inexpensive. If wood did not shrink in drying, we might well be making much more use of green lumber in construction and finish; but for many uses wood must be fully dried to its final "equilibrium moisture content." In commercial kiln drying, we do not evaporate all the moisture from wood, but reduce it to the amount it will reach when stabilized with the humidities prevailing under use conditions. The moisture content at which wood becomes stabilized with any given combination of temperature and relative humidity is called the "equilibrium moisture content."

In general, the shrinkage behavior of wood in drying has been described in the preceding talk.

The amount of shrinkage varies with the several species of softwoods. Redwood and western redcedar have low rates of shrinkage compared with Douglas-fir and western hemlock. The amount of shrinkage for several western species is shown in Table 1 for material dried from the green condition to a moisture content of 6 percent, a suitable moisture content for well dried interior trim and cabinet work.

From this table we can calculate that a flat grain western redcedar board 10 inches wide would be expected to shrink 4.0 percent, or 0.40 inches in width when dried to 6 percent moisture content while a vertical grain board would similarly shrink only 0.19 inches. A flat grain Douglas-fir would shrink 0.62 inches under the same conditions and a vertical grain board 0.40 inches.

Now let us return to the subject of the cause of surface checking. Since the surface of the green lumber is the first to begin drying, shrinkage is induced there as soon as that zone dries below the fiber saturation point, which is at about 28 percent moisture content. Conservative kiln drying schedules for western softwoods often begin with a drying humidity which maintains an equilibrium moisture content in wood of 14 to 17 percent. Seldom is the initial equilibrium moisture content drying condition as high as 20 percent and sometimes it has been as low as 12 percent. Consequently, the surface zones soon dry sufficiently to induce considerable surface shrinkage. The interior of the wood is still above fiber saturation point and has not started to shrink. A terrific tension stress develops at the surface and when it exceeds the strength of the wood, the wood fails and a crack or check results. If wood were not an elastic material, surface checking would develop immediately after tensile stresses are set up in the surface zones. Experience shows, however, that the elastic wood permits considerable surface drying and tendency to shrink before failure.

The only tool the operator has to avoid surface checking in kiln drying lumber is to maintain a high enough humidity to avoid such excessive surface drying. On the other hand, lower humidities, by lowering the moisture content at the lumber surface, result in a more rapid movement of moisture from the interior toward the surface and speed up the rate of drying. The operator must therefore balance the risk of surface checking against the advantage of a faster drying rate. Kiln drying schedules are developed with these two objectives in mind.

When drying progresses to the point where the interior of the lumber dries below the fiber saturation point, it, too, will begin to shrink. The surface zones then may be safely dried to lower moisture contents and the kiln operator accomplishes this purpose by making a change in his schedule—by reducing the equilibrium moisture content condition of the kiln atmosphere. This may be done by changing the temperature or relative humidity or both.

The risk of developing surface checking is greatest during the early stages of drying while the interior of the lumber is still wet (above fiber saturation point). The rate of drying and the condition of lumber dryness can best be followed by the use of sample boards which are weighed regularly to develop a drying curve for the kiln charge. If desired, a time schedule for temperature and humidity changes can be developed from the record of several runs including the use of sample boards.

End checking or splitting is another seasoning defect which often develops in kiln drying western softwoods. It results from rapid drying of end grain, causing the ends of the lumber to shrink considerably prior to the board proper.

It is minimized and controlled in the same way as surface checking—by maintaining high relative humidities, especially during the early stages of drying. End grain drying can also be retarded by applying moisture-resistant coatings to the ends of green lumber to reduce end checking, but such a process is not considered practical and economical for protecting lumber. It has, however, found some application to the drying of special items in larger cross-sectional sizes.

These forms of checking are directly the result of the shrinkage behavior of wood as it dries. We are not able to change the amount of shrinkage by modifying or altering the schedule under which it may be dried. European research has studied the drying of green softwood at temperatures beginning at about 220 degrees F. and going up to 240 degrees F. and has not found any evidence that wood shrinks differently than when using schedules conforming to those used in our commercial kilns. Shrinkage properties have been materially reduced in wood by impregnating it with synthetic resins followed by heat treatment, but no process has so far been found which would apply such benefits to the kiln drying of western softwoods.

Another major seasoning defect is cupping, which also is a direct effect of the shrinkage properties of wood structure. Cupping is related to the difference between tangential and radial shrinkage rates. If tangential and radial shrinkage rates were equal, lumber would not cup in drying provided drying took place equally from both faces. All of our western softwood species have a tangential shrinkage rate substantially higher than radial shrinkage (see table 1). Ponderosa pine, for exemple, has a tangential shrinkage of 5.0 percent compared to a radial shrinkage of 3.1 percent under the same conditions of drying.

All flat sawed lumber suffers a greater tangential shrinkage on the face toward the sap than on the face toward the pith of the tree—and therefore the board cups with its edges away from the pith. This differential in shrinkage increases as boards are cut nearer the pith of the tree. In truly vertical grain lumber both sides of the board have the same shrinkage rate and cupping does not develop. Intermediate grain boards develop intermediate amounts of cupping. Cupping is objectionable in dried lumber because many cupped boards split as they are flattened in passing through the planer. Planer splitting and roller splitting are terms often applied to this defect.

The amount of cupping developed in a board depends on its final dryness. Boards dried to a low moisture content cup more than boards in which drying is stopped at a higher moisture content. Consequently, a commercial practice has been developed to standardize commerical dryness for many items of the common grades of lumber at moisture contents ranging from 12 percent upward to minimize cupping and planer splitting.

Cupping can also be minimized by spacing stickers closely in stacking the green lumber for drying. The weight of the load serves to hold the lumber flat while drying. In the lower part of the lumber pile the weight of the lumber above is often sufficient to overcome the tendency to cup. The top courses in the pile have little weight on them and benefit less as far as being held flat is concerned. There is not much benefit from temperature-humidity combinations used in the drying schedule to prevent lumber from cupping except as it controls the final moisture content of the stock.

The position of the stickers as well as the spaces between them is important in loading lumber when maximum protection against cupping is desired. The lumber should be sorted for length and only one length used in a pile, with stickers placed at the ends of the boards to best hold lumber flat.

Cupping, resulting in planer splitting, is potentially one of the major seasoning defects encountered in the kiln drying of western softwoods. Kiln operators have made good progress in controlling it to minimum.

Warping is another major seasoning defect. Fortunately western softwoods suffer less warping than is found with the drying of many other species, especially hardwoods. However, lumber containing compression wood, irregular and distorted grain, and sometimes lumber cut from very young trees, suffers from warping in drying. Warping, like cupping, can be minimized by stacking the lumber to hold it flat during drying but the benefit seems to be of lesser effect. There is no evidence that the drying schedule temperature and humidities have much effect on the amount of warping, except as they control the final dryness of the stock. Warping seems to be increased by drying to lower final moisture contents.

A common defect in kiln drying lumber is honeycomb, or internal checking. This defect is quite common in some hardwoods but is sometimes found also in drying the thicker sizes of western softwoods. It develops when slow-drying lumber dries too rapidly in the surface zones and these zones reach a low moisture content and become set without normal shrinkage. Later when the interior dries and shrinks, it is restrained by the surface zones, and internal tensile stresses develop to the point where the wood fails and internal checks result. A more moderate drying schedule, restraining the surface zones from drying too far in advance of the interior, is the most practical method for minimizing honeycomb in softwoods.

The Douglas-fir door industry has experienced some development of honeycomb types of internal checks just back from the ends of 1-5/8 and thicker lumber, both in flat grain and vertical grain. Again, the use during initial stages of drying of more moderate drying schedules, including high relative humidities, is helpful in minimizing the development of this defect.

Collapse is a form of drying defect in which the wood cell structure is distorted and reduced in size as though by abnormal shrinkage. Only a few species of western softwood, having a very high green moisture content, give trouble with the development of this defect in kiln drying. Redwood and western redcedar are affected by collapse in lumber cut from sinker or very high moisture content logs. One explanation for the development of collapse is that under elevated kiln temperatures the wood becomes so soft and weak that surface shrinkage stresses exceed the strength of the cells in the interior zones and distort the structure. However, this does not seem to fully explain the "crimps" that develop in kiln drying redcedar shingles. The practical solution for minimizing collapse has been to use only relatively low drying temperatures—below 135 degrees F. in the initial drying stage until the moisture content of the wood has been reduced to 150 percent or less. Higher drying temperatures may then be used, increasing progressively as the wood dries to lower moisture contents.

A considerable portion of our softwood lumber contains pitch which is quite fluid in the green condition. As Douglas-fir and pines dry at atmospheric temperatures there is some drying of volatile turpentine from the pitch resulting in a partial hardening or setting. Later, under normal use conditions, the softer pitch within the board often oozes out through the surface of the dry board and spoils paint and other finish coatings. Kiln drying lumber at higher temperatures sets the pitch to a greater extent. Even well dried lumber, however, sometimes develops oozing of pitch in use. Some observations recently have shown that in order to thoroughly set all of the pitch in a thick board, not only are high temperatures, such as 160 degrees F. or higher, necessary but that the drying time must be extended beyond that needed to evaporate the water to the desired lumber dryness. Pitch pockets which are exposed on the face of lumber become dry and hard in a shorter drying time.

Stains and discolorations make up another group of defects which affect the appearance and grade of lumber but they are not generally a seasoning defect. Blue stain is a common development in many species of wood but is usually found only in green lumber held in a warm moist condition where drying is delayed or prohibited. Prompt logging, sawing, and seasoning can avoid blue stain. In a few species of wood, however, undesirable stains are sometimes developed during kiln drying. Sugar and ponderosa pine have a tendency to develop a brown stain during kiln drying, especially if the logs from which the lumber is cut have been lying in the woods for some time and if initial kiln drying conditions include high temperature and humidity. Just what happens in the wood to develop the brownish color is not thoroughly understood but it may be the result of a chemical reaction. The color is distributed within the wood as well as on its surface. Planing the lumber to finished size usually does not remove all of the discolored wood. The best practical method for avoiding the development of brown stain in the pines is to move logs promptly to the mill after felling the tree and dry the freshly cut lumber without delay. Even then some stain may develop unless special kiln drying schedules are used. Brown stain apparently will not develop to any serious degree if the drying temperatures are kept low until the lumber has dried to the fiber saturation point or below. There is very little brown stain reported in the air drying of western pine lumber. Kiln operators have been very successful in kiln drying these pines without brown stain when the initial drying temperatures do not exceed 120 to 130 degrees F. and a low relative humidity is maintained in the kiln, chiefly by using much ventilation. This drying condition is contrary to the high humidity required to avoid surface checking. In this case the dry kiln operator is torn between two desires. Fortunately the western pines are not as subject to surface checking as many other species of wood for the pines can tolerate considerable reduction in humidity before surface checking becomes serious. However, in the thicker sizes—such as 8/4 and thicker—the western pines are subject to checking and the operator must use considerable skill in choosing and maintaining intermediate humidities which will minimize both brown stain and surface checking. After the pine has been dried to the fiber saturation point and does not contain any free water, higher temperatures and relative humidities may safely be used for completion of the drying.

Some other western softwoods are also subject to the development of stain but to only a slight degree. Spruce and hemlock have been observed to develop a grayish color in streaks during kiln drying. The amount of stain has been small and no extensive research has been carried out to definitely determine the cause. In general, however, the use of lower drying temperatures during initial stages of drying here also appears to minimize the development of stain.

One of the defects in lumber which seriously affects the grade is the presence of broken knots and of knot holes in the surfaced lumber. In most western softwood lumber the knots can be planed without damage when the lumber is green. As the lumber dries the knots shrink in both directions of the face of the board; that is, across the width and along the length, whereas the board shrinks in width but not in length. Consequently the dimensions of the dry knot are smaller than that of the board containing the knot. The sound or solid knot usually cracks as the result of this differential in dimension while the unsound knot becomes loose and may even drop out. When such dry lumber is planed to finished size, the cracked sound knot often checks further and part or all of it may be broken out under the impact of the planing knives. The loose knot may be knocked out leaving a knot hole.

The amount of shrinage in knots increases as the board dries to a lower moisture content. When dried to less than 10 percent, such as is required for flooring, trim, cabinet work and furniture, the knots have shrunk and loosened to the point where excessive knot breakage develops in surfacing the dry lumber. When drying is stopped at higher moisture contents, the lumber can be surfaced without serious knot damage. It has become general commercial practice to segregate common lumber from finish grades and kiln dry them separately.

In pine a moisture content level of 12 to 15 percent in common grades appears to give satisfactory machining results, while in Douglas-fir a moisture content of 18 to 20 percent is required to achieve similar satisfaction.

Recent cooperative studies with the Oregon Forest Products Laboratory have shown that Douglas-fir joists containing only small tight knots can be kiln dried to 12 percent moisture content and then be surfaced with a satisfactory appearance.

While these moisture contents are not as low as those used in drying finish items of lumber, they provide the consumer with a product from which considerable shrinkage has been removed and in which a great deal of drying benefit is provided. The customer appears to prefer this better appearing product to one dried to a lower moisture content but accompanied by knot holes and serious knot breakage.

The dry kiln operator is able to control the drying of these common grades of lumber only by maintaining a relatively high humidity throughout the entire period of drying. It was this need for such a special drying schedule that generated the design and development of the internal fan dry kiln, in which a rapid movement of air through the stacked lumber could be maintained at any humidity level. The successful performance of the dry kiln has enabled the lumber industry to kiln dry a large portion of its knotty grades of lumber and find a ready consumer acceptance of the product.

These kiln drying defects which I have described and discussed are all readily discernible to the eye. The lumber grader and mill management can as readily spot them in observing the dry lumber as can the dry kiln operator. There are, however, two additional kiln drying defects which I should like to discuss which are not yet visible when inspecting the lumber but which cause further defects to develop in subsequent remanufacture and use.

The first of these defects is called casehardening. Casehardening has sometimes been used to describe a condition where the surface zones of lumber are dry and hard while the interior is still moist and relatively soft. But wood technologists and lumbermen use the term "casehardening" today to describe lumber in which there is considerable internal stress which makes the lumber distort and cup, bow, and pinch when it is resawn or worked to refined pattern. Casehardening causes the halves of a resawn board to cup away from the inner surface as they come off the saw. Cupping is highly objectionable in resawn box shock and bevel siding and becomes a serious source of loss. Cashardening causes distortion in machined furniture cuttings resulting in misfitted joints. Casehardening causes the lips of flooring to pinch in so that the tongue fits into the groove with considerable difficulty. Likewise, it sometimes becomes a problem in machining the edges of door stiles and rails where they receive the panels in assembling a door. Casehardening also causes increased splitting when boards are nailed in framed construction.

Casehardening is an unavoidable and natural development of the wood drying process because the surface zones must be drier than the interior to move moisture toward the surface to be evaporated. Due to this differential in dryness which is maintained during the initial and throughout most of the drying process, the surface zones are restrained from shrinking fully and they become dry and set in an expanded condition. During the early stages of drying these outer zones are in tension across the grain but in the final stages, as the interior becomes fully dry, they change and reverse to a compression stress. The interior zone is thrown into a state of compressive stress during the early stages of drying because of the tension stress in the outer zone. In the final stages of drying the interior changes to a condition of tension stress as it shrinks in reaching final dryness. This condition of compression stress across the grain in the outer zone and tension stress across the grain in the interior reaches its maximum condition as the lumber becomes fully dry in the interior. Such stress persists in the dry lumber and is not relieved with ordinary storage.

The development of such stresses in kiln drying lumber is inevitable but the amount of stress can be minimized by the use of high humidity drying schedules. Casehardening becomes most severe when using a low humidity schedule, which also cause surface and end checking. Schedules which are most favorable to minimizing checking, splitting, and honeycombing are also favorable toward minimizing casehardening.

While casehardening cannot be avoided entirely in kiln drying but can be held to a moderate amount, it can be fully removed at the completion of the drying by giving the dry lumber a special conditioning treatment. First the lumber must be thoroughly and uniformly dried so that the interior is as dry as the surface zones. Then the wood is heated to a temperature of 160 degrees F. or more and a relative humidity is maintained to cause the surface zones of the wood to pick up a slight amount of moisture, to a moisture content of one or two percent above that in the interior zone. This treatment applied for 12 to 24 hours on western softwoods will result in a readjustment of wood fibers, permitting the internal stresses to be dissipated. There is no additional shrinkage or over-all dimensional change in the lumber. The cooled lumber is then thoroughly dry and can be resawn or worked to shapes and patterns without distortion.

In the interest of high production and low drying cost, short cut treatments to relieve casehardening have been used in which excessive humidities up to saturation have been applied for just a few hours to relieve the casehardening. These periods are generally too short to develop relief entirely through the board but they can reduce the major portion of the stress in the wood. The minor unrelieved stresses still give some trouble where the lumber is used, but for many purposes the customer has been satisfied with the partial relief.

I want now to discuss another condition of dryness in kiln dried lumber which fits quite exactly the definition of the word **defect**—"a want of something necessary for completeness." Perhaps what I wish to discuss could more accurately be stated as—"a lack of adequate dryness." I am going to call this condition a kiln drying defect because we must depend on the dry kiln operator and his management to bring about improvement.

While the lumberman has several reasons for kiln drying lumber, some deal entirely with his production costs. The reduction in the weight of dry lumber as compared to green lumber results in a substantially lower freight cost. Lumber dried to a moisture content of 20 percent or less can be stored at mill, warehouse, or consuming plant without risk of deterioration by stain and decay. The principal benefit of dry lumber to the consumer, however, is that it is preshrunk when he receives it. The exact moisture content and uniformity needed depends on the purpose for which he uses it. Common grades of lumber are used for framing, construction, and similar purposes where there is considerable latitude for dryness. When used for the gluing of laminated timbers, moisture contents of the lumber should be quite exact and uniform. The primary objective here is that the laminations shall not be required to dry more after being glued together. If all laminations are not at the same moisture content at the time of gluing, the wetter ones will subsequently shrink and develop shearing stresses at the glue line, sometimes causing delamination. The glued member as a whole should be as dry as it will reach under service conditions. Otherwise further drying in use may develop surface checks for the same reason that we find surface checking develops in seasoning green lumber. One of the advantages of laminating structural members free of deep surface checks is that they will provide more strength. In order to glue such members we must have lumber uniformly dry at the correct moisture content before gluing.

In the production of furniture millwork, trim, cabinet work, doors, flooring and similar products, it is essential that the lumber from which it is made be thoroughly dry and preshrunk. Further shrinkage in these finished products resulting from the use of inadequately dried lumber would result in rejects.

It is particularly important that lumber be thoroughly and uniformly dry when conditioning treatments are given to relieve casehardening stresses in lumber. Successful relief requires that the interior of the lumber be fully as dry as the surface zones in order that all potential stresses be fully developed before the relief treatment is begun. The heated wood can adjust itself to the effect of stresses only after the stresses are acting fully on it. Applying a conditioning treatment to lumber which contains excess moisture in the interior zones does not accomplish casehardening relief. Quite frequently we hear of experiences where failure to recognize this moisture content variation has led to unsatisfactory results.

The impossibility of measuring the dryness of lumber by visual inspection and the limitations in using electrical moisture meters or other means to check these values often result in failure to complete the drying of lumber. Here we must depend on the skill of an able operator to adequately check the lumber with the facilities available to him to carry the responsibility of securing complete drying.

The losses to the lumber industry due to incomplete drying are to be measured not only in terms of complaints registered on specific sales but in the loss of consumer satisfaction—due to the drying defects he finds in the material he has received.

It should be encouraging to the lumberman to observe the progress that has been made in understanding the behavior of wood during drying, in developing better drying techniques, procedures and equipment to control the process. Modern dry kilns enable the informed management and operator to successfully kiln dry any of our western softwoods to the needs of the consumer without suffering excessive losses in wood quality or property in terms of the drying defects we have discussed. It might not be practical to dry the lumber so carefully and exactly that we avoid the development of any defect but we can expect to hold such defects to a minimum amount without incurring excessive drying costs.

Table 1.—Shrinkage of softwoods

Species	Green to 6% moisture content (percent)	
	Radial	Tangential
Western redcedar	1.9	4.0
Douglas-fir	4.0	6.2
Noble fir	3.6	6.6
Pacific silver fir	3.8	8.3
Western hemlock	3.4	6.3
Ponderosa pine	3.1	5.0
Sugar pine	2.3	4.5
Redwood	2.1	3.5
Sitka spruce	3.4	6.0
Engelmann spruce	2.7	5.3

(From mimeograph 1900-1 U. S. Forest Products Laboratory - Properties of Wood Related to Drying.)