Chapter 8
Drying Defects

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The success of a company and the livelihood of the dry kiln operator may depend on knowing the causes of defects in lumber and methods to prevent their occurrence. Since some defects are not observed in green lumber and are first noted after the drying operation, they are often called drying defects even though the defects may have started in the tree, log, or green lumber. Defects that develop in dry wood products during machining, gluing, and finishing operations may also be blamed on poor drying practices. A drying defect is any characteristic or blemish in a wood product that occurs during the drying process and reduces the product's intended value. Drying degrade is a more specific term that implies a drying defect that lowers the grade of lumber. Every year, drying degrade and other drying defects cost the softwood and hardwood lumber industries millions of dollars in lost value and lost volume caused by poor product performance. When unexpected defects appear in dried wood products, their cause is often blamed on the drying operation. The purpose of this chapter is to describe the various types of defects that can occur in dried wood products and to show how these defects are related to the kiln-drying operation.

Many features of wood affect its utility when it is processed into lumber and special products. These includes knots, ring shake, bark, mineral streaks, pitch pockets, compression and tension wood, juvenile wood, and spiral or interlocked grain, all of which form in the tree and directly influence the grade and value of each individual board. Ordinary processing of lumber may remove some of these natural features through trimming and thus improve the quality and value of the remaining piece.

Defects that reduce the grade and value of lumber often develop during logging, sawmilling, drying, finishing, and mechanical handling. A principal objective is to dry the wood economically with as little development of defects as possible. The degree of care to exercise in controlling the development of defects depends on the final use of the lumbar. It is important for the kiln operator to be familiar with the various defects that reduce the grade and value of dry wood products, to know when the defects can be reduced or eliminated with proper drying practices, and to recognize when corrective measures other than drying are required. When drying is used to control defects, it should be done in a manner consistent with the economy of the overall manufacturing system. Before adopting a drying procedure to control specific drying defects, the kiln operator should determine whether the procedure will induce other defects that may lower the value of the lumber.

Effect of Drying Temperatures

High temperatures reduce the strength of wood in two ways. First, there is an immediate and reversible effect. For example, wood is weakened when heated from 75 to 240 °F but regains strength if immediately cooled to 75 °F. The second effect occurs over time and is permanent. When wood is heated for long times at high temperatures, 'it is permanently weakened; the loss of strength remains after the wood is cooled. Roth effects are greater at high moisture content than at low moisture content. The permanent effect is caused by a combination of time, temperature, and moisture content. Strength loss increases as any one of these factors increases.

The immediate,-reversible effect of high-temperature drying is important in the development of drying defects that result from breakage or crushing of wood cells. When the drying stresses described in chapter 1 become greater than the strength of the wood, this type of drying defect develops. This is why high temperatures early in drying are dangerous. The weakening effect of high temperatures coupled with high moisture content can cause the wood to fracture or be crushed.

High-temperature drying for long periods, particularly early in drying when the moisture content is high, may not result in breakage or crushing-type drying defects, but it can cause a permanent loss in strength or other mechanical properties that affect product performance in end use. Table 8-1 shows the effect of high-temperature drying (225 to 240 °F) compared to conventional-temperature drying (<180 °F) on stiffness (modulus of elasticity) and bending strength (modulus of rupture) of several species. In general, stiffness is not greatly reduced by high-temperature drying, hut bending strength may be reduced by as much as 20 percent.

For many uses of wood, some reduction in strength is not important. In some uses, it is quite important. For example, the 20 percent loss in bending strength noted in table 8-1 for Douglas-fir can be a concern in structural lumber. Wood for ladders, aircraft, and sporting goods requires high strength and toughness retention.

There is evidence that lumber treated with waterborne preservatives and fire retardants is particularly sensitive to strength reduction if drying temperatures are too high. Temperatures ranging from 140 to 160 °F have little effect on mechanical properties. The schedules in chapter 7 (tables 7-9 and 7-10) can be used where strength retention is a major concern.

Defect Categories

Most defects or problems that develop in wood products during and after drying can be classified under one of the following categories:

1. Rupture of wood tissue
2. warp
3. Uneven moisture content
4. Discoloration

Defects in any one of these categories are caused by an interaction of wood properties with processing factors. Wood shrinkage is mainly responsible for wood ruptures and distortion of shape. Cell structure and chemical extractives in wood contribute to defects associated with uneven moisture content, undesirable color, and undesirable surface texture. Drying temperature is the most important processing factor because it can be responsible for defects in each category.

Rupture of Wood Tissue

Many defects that occur during drying result. from the shrinkage of wood as it dries. In particular, the defects result from uneven shrinkage in the different directions of a board (radial, tangential, or longitudinal) or between different parts of a board, such as the shell and core. Rupture of wood tissue is one category of drying defects associated with shrinkage. Knowing where, when, and why ruptures occur will enable an operator to take action to keep these defects at a minimum. Kiln drying is frequently blamed for defects that have occurred during air drying, but most defects can occur during either process. In kiln drying, defects can be kept to a minimum by modifying drying conditions, and in air drying, by altering piling procedures.

Surface Checks

Surface checks are failures that usually occur in the wood rays on the flatsawn faces of boards (figs. 8-1 and 8-2). They occur because drying stresses exceed the tensile strength of the wood perpendicular to the grain, and they are caused by tension stresses that develop in the outer part, or shell, of boards as they dry (ch. 1). Surface checks can also occur in resin ducts and mineral streaks. They rarely appear on the edges of flatsawn boards 6/4 or lees in thickness but do appear on the edges of thicker flatsawn or quartersawn boards. Surface checks usually occur early in drying, but in some softwoods the danger persists beyond the initial stages of drying. They develop because the lum-

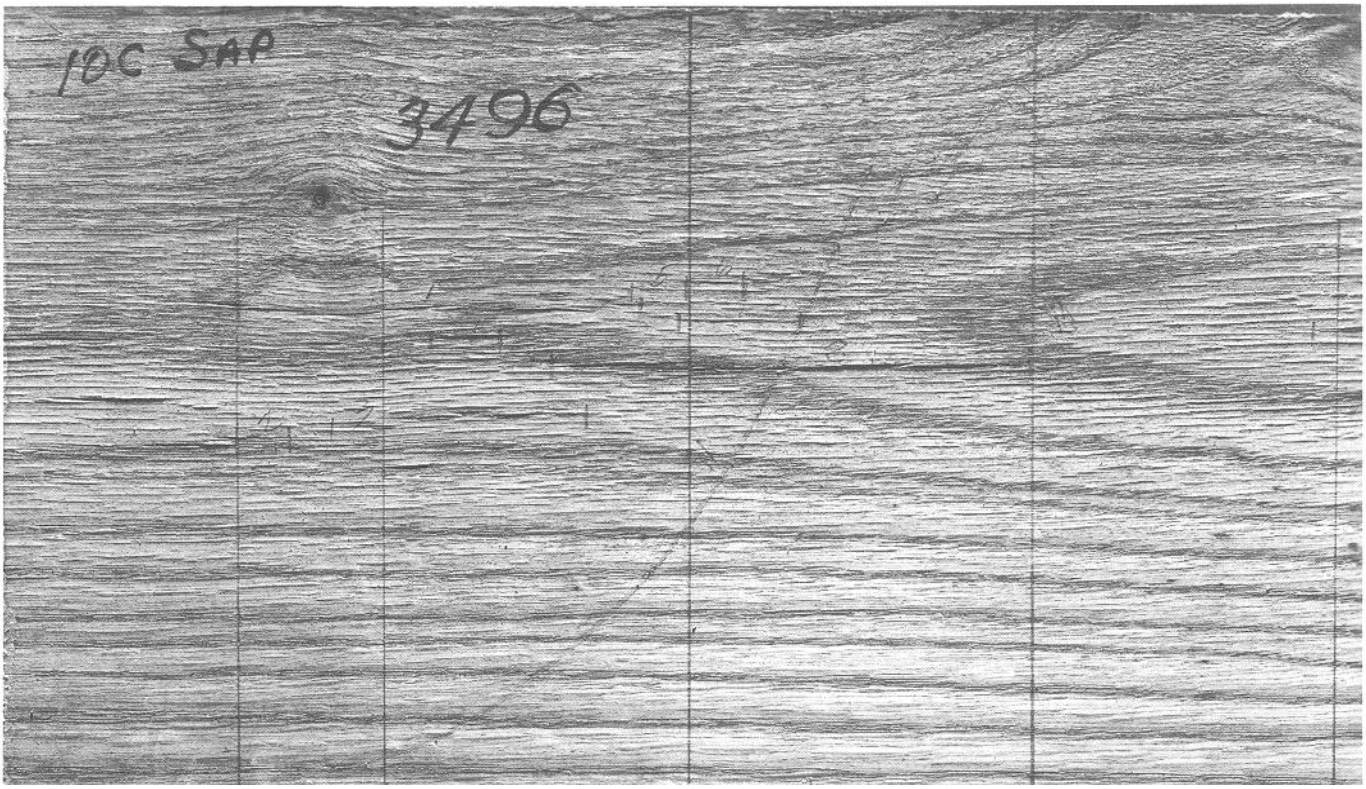

Figure 8-1—Surface checks in cherrybark oak. (M 137194)

Figure 8-2—Surface checks in Douglas-fir dimensional lumber. (M 22523)

ber surfaces get too dry too quickly as .a result of relative humidity that is too low. Surface checks can also develop during air drying. Thick, wide, flatsawn lumber is more susceptible to surface checking than thin, narrow lumber.

Many surface checks, particularly those in hardwoods, close in the later stages of drying This occurs when the stresses reverse and the shell changes from tension to compression (ch. 1). Closed surface checks are undesirable in products requiring high-quality finished surfaces, such as interior trim and molding, cabinets, and furniture. The checks will quite likely open to some extent during use because of fluctuations in relative humidity that alternately shrink and swell the surface. Superficial surface checks that will be removed during machining are not a problem. In products such as tool handles, athletic equipment, and some structural members, either closed or open surface checks can increase the tendency of the wood to split during use. In some products, such, as interior parts of furniture, wall studs, and some flooring applications, mild surface checking will not cause any problems in use.

Lumber that has surface checked during air drying should not be wetted or exposed to high relative humidity before or during kiln drying. Such treatments frequently lengthen, widen, and deepen surface checks. Lumber that has open surface checks after kiln drying should also not be wetted because subsequent exposure to plant conditions will dry out the wetted surface and enlarge the checks.

End Checks and Splits

End checks (fig. 8-3), like surface checks, usually occur in the wood rays, but on end-grain surfaces. They also occur in the early stages of drying and can be minimized by using high relative humidity or by end coat-

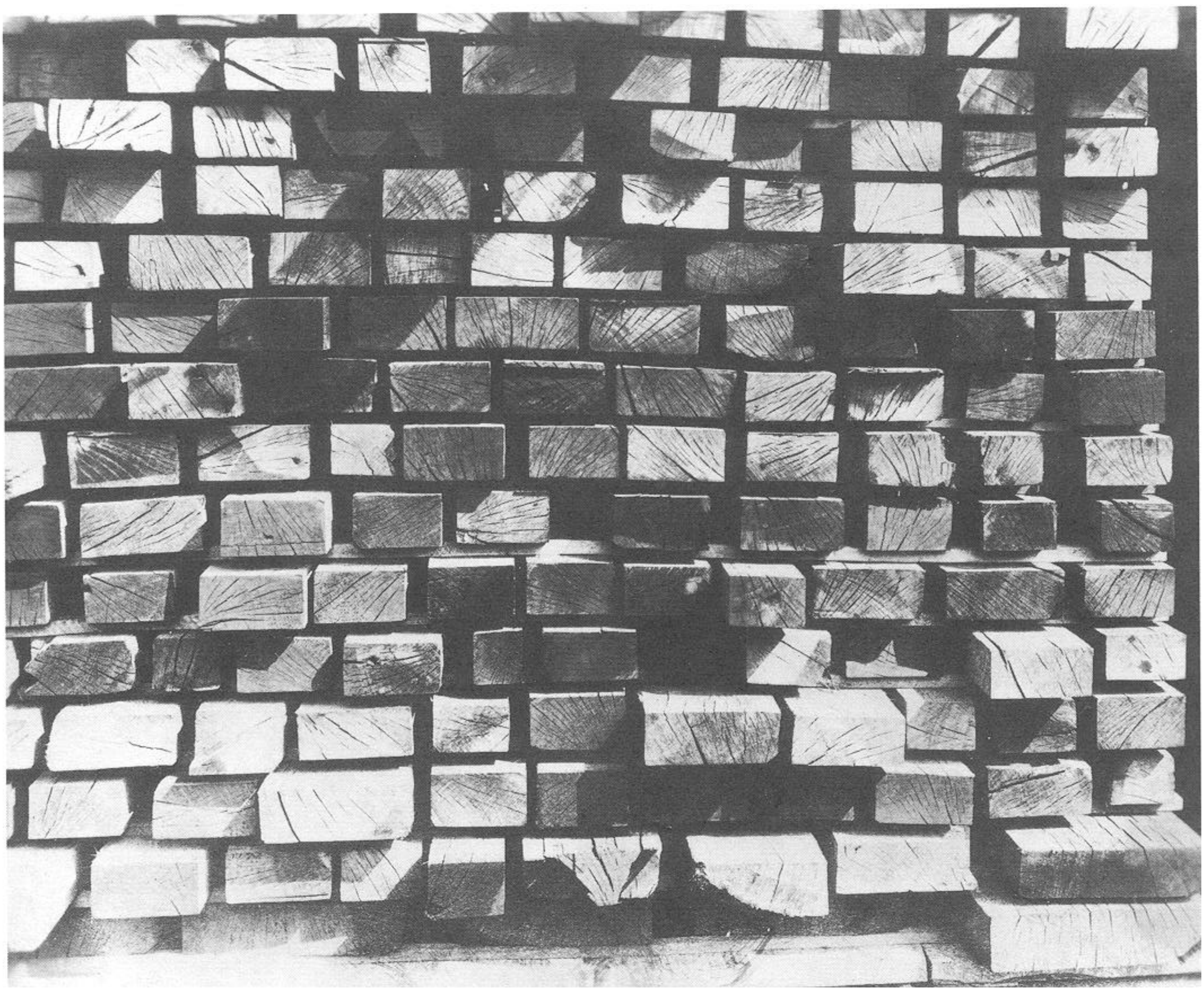

Figure 8-3—End checks in oak lumber. (M 3510)

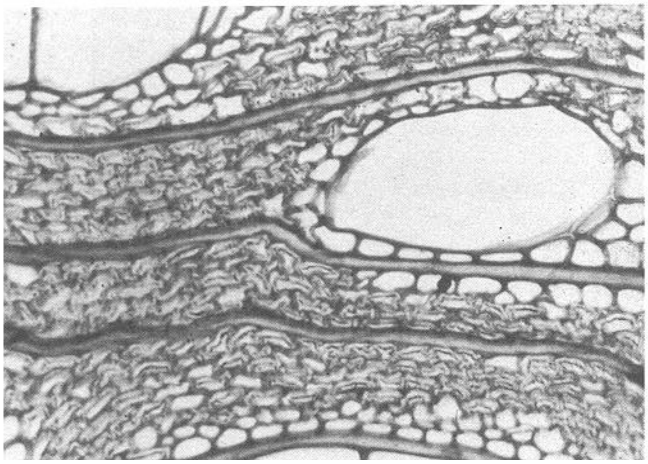

Figure 8-4—Photomicrograph showing collapsed wood cells. (M 69379)

ing. End checks occur because moisture moves much faster in the longitudinal direction than in either transverse direction. Therefore, the ends of boards dry faster than the middle and stresses develop at the ends. End-checked lumber should not be wetted or exposed to high relative humidity before any further drying, or the checks may be driven further into the board.

The tendency to end check becomes greater in all species as thickness and width increase. Therefore, the end-grain surfaces of thick and wide lumber squares, and gunstocks should be end coated with one of the end coatings available from kiln manufacturers and other sources. To be most effective, end coatings should be applied to freshly cut, unchecked ends of green wood.

End splits often result from the extension of end checks further into a board. One way to reduce the extension of end checks into longer splits is to place stickers at the extreme ends of the boards. End splits are also often caused by growth stresses and are therefore not a drying defect. End splits can be present in the log or sometimes develop in boards immediately after sawing from the log.

Collapse

Collapse is a distortion, flattening, or crushing of wood cells. Figure 8-4 shows collapse at the cell level, and figure 8-5 shows a severe case of collapse at the board level. In these severe cases, collapse usually shows up as grooves or corrugations, a washboarding effect, at thin places in the board. Slight amounts of collapse are usually difficult or impossible to detect at the board level and are not a particular problem. Sometimes collapse shows up as excessive shrinkage rather than distinct grooves or corrugations.

Collapse may be caused by (1) compressive drying stresses in the interior parts of boards that exceed the compressive strength of the wood or (2) liquid tension in cell cavities that are completely filled with water (ch. 1). Both of these conditions occur early in drying, but collapse is not usually visible on the wood surface until later in the process. Collapse is generally associated with excessively high dry-bulb temperatures early in kiln drying, and thus low initial dry-bulb temperatures should be used in species susceptible to collapse.

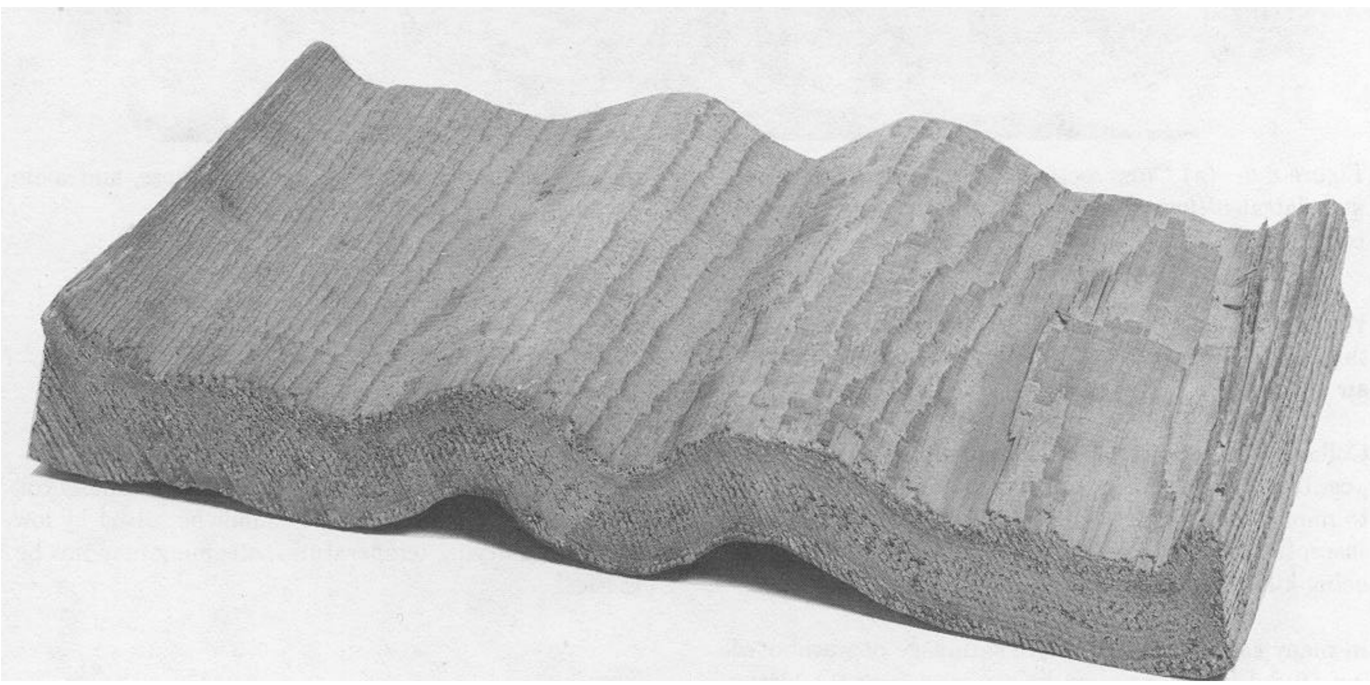

Figure 8-5—Severe collapse in western redcedar. (M 111997)

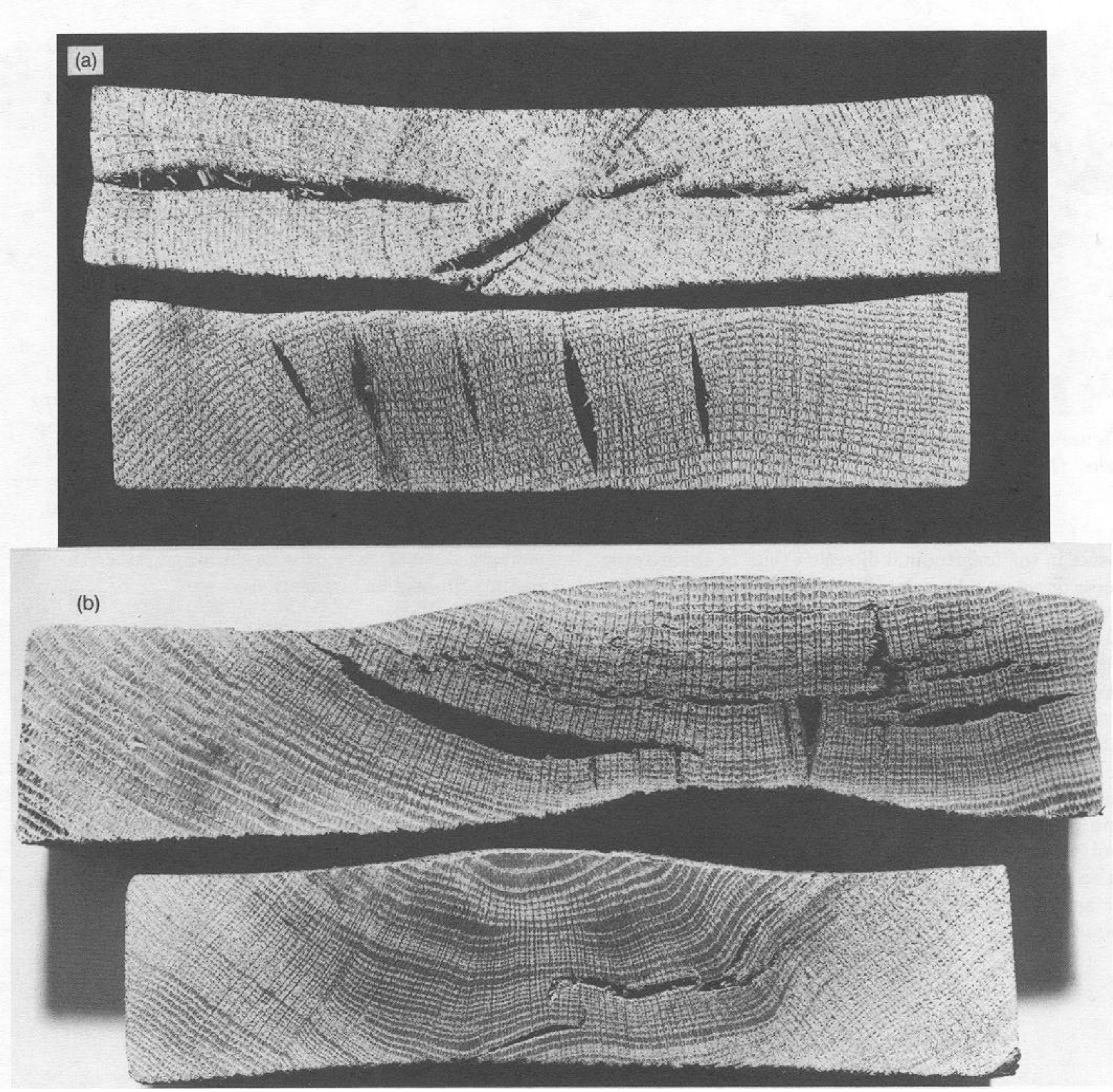

Figure 8-6—(a) Cross section of quartersawn (upper) and flatsawn (lower) red oak boards showing honeycomb and slight collapse; (b) cross section of flatsawn red oak boards showing ring failure, collapse, and some honeycomb. (MC88 9025)

Wetwood in particular is susceptible to collapse. Although rare, collapse has been known to occur during air drying.

Collapse is a serious defect and should be avoided if possible. The use of special drying schedules planned to minimize this defect is recommended. Some species susceptible to collapse are generally air dried before being kiln dried.

In many cases, much excessive shrinkage or washboarding caused by collapse can be removed from the lumber by reconditioning or steaming, a treatment first used commercially in Australia. This treatment basically consists of steaming the lumber as near as possible to 212 °F and 100 percent relative humidity. Reconditioning is most effective when the average moisture content is about 15 percent, and 4 to 8 h are usually required. Steaming is corrosive to kilns, and unless collapse is a serious problem that cannot be solved by lowering initial drying temperatures, steaming may not be practical.

Figure 8-7—Honeycomb that does not appear on the surface of a planed red oak board (lower) does appear when the board is machined into millwork (upper). (M 140291)

Honeycomb

Honeycomb is an internal crack caused by a tensile failure across the grain of the wood and usually occurs in the wood rays (fig. 8-6). This defect develops because of the internal tension stresses that develop in the core of boards during drying (ch. 1). It occurs when the core is still at a relatively high moisture content and when drying temperatures are too high for too long during this critical period. Therefore, honeycomb can be minimized by avoiding high temperatures until all the free water has been evaporated from the entire board. This means that the core moisture content of boards should be below the fiber saturation point before raising temperature because that is where honeycomb develops. When the average moisture content of entire sample boards is monitored for schedule control, there is no direct estimate of core moisture content. Depending on the steepness of the moisture gradient, which is often unknown in most kiln-control schemes, the core moisture content can be quite high even when the average moisture content of the whole sample is low. The danger is that schedule changes based on average moisture content that call for an increase in dry-bulb temperature can be made too soon while moisture content in the core is still high, thus predisposing the wood to honeycomb. Measurements of shell and core moisture content (ch. 6) should be taken before these dangerous schedule changes are made.

Deep surface and end checks that have closed tightly on the surface of lumber but remain open below the surface often called honeycomb, but they are also known as bottleneck checks.

Honeycomb can result in heavy volume losses of lumber. Unfortunately, in many cases the defect is not apparent on the surface, and it is not found until the lumber in is machined (fig. 8-7). Severely honeycombed lumber frequently has a corrugated appearance on the surface, and the defect is often associated with severe collapse.

Ring Failure

Ring failure occurs parallel to annual rings either within a growth ring or at the interface between two rings (fig. 8-6b). It is similar in appearance and often related to shake, which is the same kind of failure that takes place in the standing tree or when the tree is felled; wood weakened by shake fails because of drying stresses. In wood with ring failure, internal tension stesses, especially in high-temperature drying, develop after stress reversal. The failure frequently involves several growth rings, starting in one and breaking along wood rays to other rings. It can occur as a failure in the end grain in the initial stages of drying and extend in depth and length as drying progresses. Ring failure can be kept to a minimum by end coating and by using high initial relative humidity and low dry-bulb temperature schedules.

Boxed-Heart Splits

A boxed-heart split is shown in figure 8-8. These splits start in the initial stages of drying and become increasingly worse as the wood dries. The difference between tangential and radial shrinkage of the wood surrounding the pith causes such severe stresses in the faces of the piece that the wood is split. It is virtually impossible to prevent this defect.

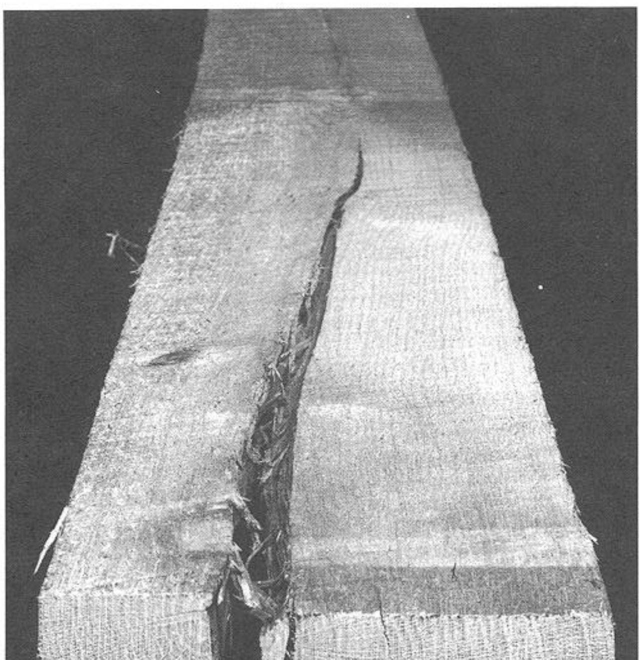

Figure 8-8—Boxed-heart split in red oak. (M 115582)

Checked Knots

Checked knots are often considered defects. The checks appear on the end grain of knots in the wood rays (fig. 8-9). They are the result of differences in shrinkage parallel to and across the annual rings within knots. Checked knots occur in the initial stages of drying and are aggravated by using too low a relative humidity. These defects can be controlled by using higher relative humidities and by drying to a higher final moisture content, but it is almost impossible to prevent them.

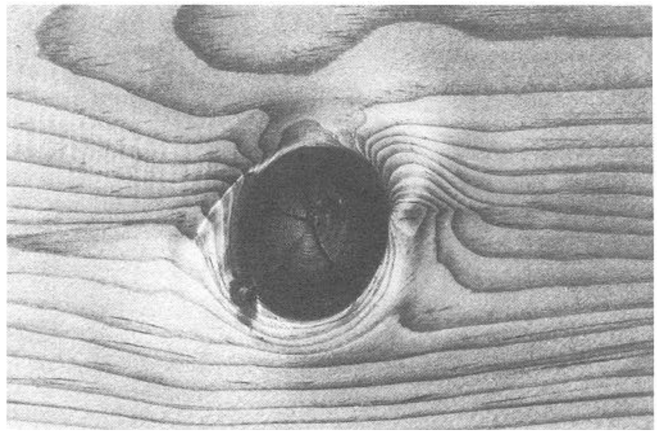

Figure 8-9—Checked knot in sugar pine. (M88 0157)

Loose Knots

Encased knots invariably loosen during drying (fig. 8-10) because they are not grown into the surrounding wood but are held in place by bark and pitch. These knots shrink considerably in both directions of the lumber face (across the width and along the length), whereas the board shrinks considerably in width but very little in length. Consequently, the

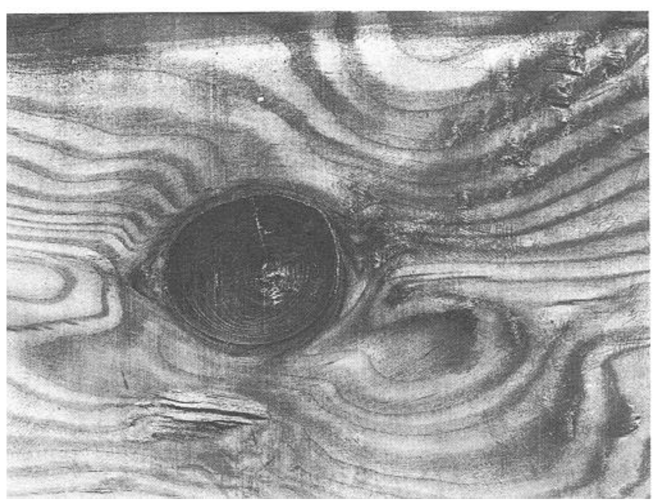

Figure 8-10—Loose knot in southern pine. (M 16268)

dried knot is smaller than the knothole and frequently falls out during handling or machining. Nothing can be done to prevent the loosening of dead knots during drying. Fewer dead knots will fall out during machining, however, if the final moisture content of the lumber can be kept as high as possible before machining.

Warp

Warp in lumber is any deviation of the face or edge of a board from flatness or any edge that is not at right angles to the adjacent face or edge (squares). It can cause significant volume and grade loss. All warp can be traced to two causes; differences between radial, tangential, and longitudinal shrinkage in the piece as it dries, or growth stresses. Warp is also aggravated by irregular or distorted grain and the presence of abnormal types of wood such as juvenile and reaction wood, Most warp that is caused by shrinkage difference can be minimized by proper stacking procedures (ch. 5). The effects of growth stresses are more difficult to control, but certain sawing techniques are effective and will be described later.

The five major types of warp are cup, bow, crook, twist, and diamonding (fig. 8-11). Cup is a distortion of a board in which there is a deviation flatwise from a straight line across the width of a board. It begins to appear fairly early in drying and becomes progressively worse as drying continues. Cup is caused by greater shrinkage parallel to than across the growth rings. In general, the greater the difference between tangential and radial shrinkage, the greater the degree of cup. Thinner boards cup less than thicker ones. Because tangential shrinkage is greater than radial shrinkage, flatsawn boards cup toward the face that was closest to the bark (ch. 1, fig. 1-10). A flatsawn board cut near the bark tends to cup less than a similar board cut near the pith because the growth ring curvature is less near the bark. Similarly, flatsawn boards from small-diameter trees are more likely to cup than those from large-diameter trees. Due quartersawn boards do not cup. Cup can cause excessive losses of lumber in machining. The pressure of planer rollers often splits cupped boards. Cup can be reduced by avoiding overdrying. Good stacking is the best way to minimize cup.

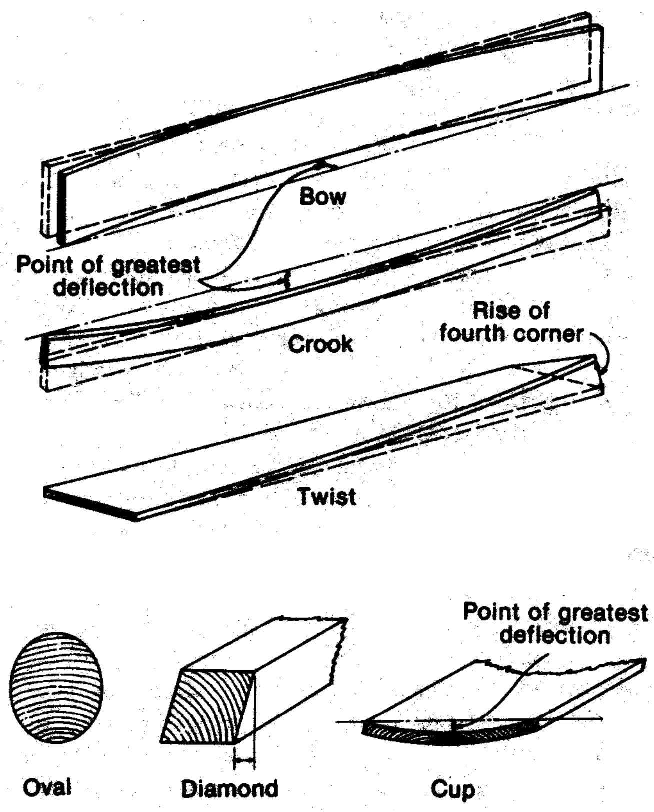

Figure 8-11—Various types of warp that develops in boards during drying. (ML88 5555)

Bow is a deviation flatwise from a straight line drawn from end to end of a board. It is associated with longitudinal shrinkage in juvenile wood near the pith of a tree, compression or tension wood that occurs in leaning trees, and crossgrain. The cause is the difference in longitudinal shrinkage on opposite faces of a board. Assuming that there are no major forms of grain distortion on board faces, bow will not occur if the longitudinal shrinkage is the same on opposite faces.

Crook is similar to bow except that the deviation is edgewise rather than flatwise. While good stacking practices also help reduce crook, they are not as effective against this type of warp as they are against cup and bow.

Twist is the turning of the four corners of any face of a board so that they are no longer in the same plane. It occurs in wood containing spiral, wavy, diagonal, distorted, or interlocked grain. Lumber containing these grain characteristics can sometimes be dried reasonably flat by wing proper stacking procedures. Twist, bow, and crook have definite allowable limits in the grading rules for softwood dimension lumber, so it is desirable to minimize these defects.

Diamonding is a form of warp found in squares or thick lumber. In a square, the cross section assumes a diamond shape during drying. Diamonding is caused by the difference between radial and tangential shrinkage in squares in which the growth rings run diagonally from corner to corner. It can be controlled somewhat by sawing patterns and by air drying or predrying before kiln drying.

Uneven Moisture Content

Wood is dried to an average moisture content that is compatible with subsequent processing operations and the use of the final product. Kiln operators in the United States generally aim towards a target moisture content of 15 percent for softwood dimension (construction) lumber and 6 to 8 percent for softwood and hardwood lumber to be manufactured into items such as furniture, flooring, or millwork. Uneven moisture content refers to a condition where individual boards in a kiln charge have a level of moisture content that deviates greatly from the target moisture content. These boards arc rejected for immediate processing and end we for two reasons: (1) the average board moisture content is either above or below an acceptable range for the intended moisture content or (2) the average moisture content of the entire board is within the acceptable moisture content range, but the core of the board has a water (wet) pocket that cannot be tolerated in the next processing step.

Board Rejects

Most boards are rejected because of moisture content that is too high, but boards with extremely low moisture content (overdried) can also be troublesome during later machining operations.-Softwood dimension lumber with an average moisture content of 19 percent or less is graded as "dry lumber," and boards 20 percent and over in moisture content are defined as unseasoned lumber. Softwood dimension lumber dried below 10 percent moisture content is usually considered overdried because it is subject to serious planer splits and breakage when surfaced. Overdried lumber is not rejected by lumber-grading associations, but the kiln operator might receive complaints from operators of m-house machining.

After drying, boards with excess moisture content will shrink more than boards within the desired moisture content range and may not yield an end product of acceptable size or shape. Satisfactory glue bonds are difficult to obtain between "wet" and "dry" elements in composite products. If the wood moisture content is too high for the equilibrium moisture content inside buildings, then furniture will develop loose joints, cabinet doors and shelves will warp, and moldings will have unsightly gaps.

Water Pockets

Some boards will have acceptable overall average moisture content and yet have internal water pockets or streaks with moisture contents of 10 percent or more higher than the average. Surfacing of boards containing water pockets can result in surface depressions when the core eventually dries. Resawing boards with water pockets results in bowing and twisting of the new pieces from additional drying of the exposed cores. Water pockets can be a problem with dried stock that is used for glued cores in the manufacture of doors and panels. Even though the water pockets may be pencil thin, they will build up enough steam pressure during electronic gluing operations to explode and shatter the surface of the pieces. Dielectric moisture meter measurements will be erroneous for wood containing water pockets.

Control Measures

Uneven moisture content causes drying problems in the kiln when (1). there are wide differences in moisture content in the initial kiln charge and (2) boards within the charge have greatly different permeability. Wide moisture content differences occur when the kiln is loaded with a mixture of green and partially dried boards. The problem can also develop when the charge contains species such as pine or hemlock where the green moisture content of the sapwood is much higher than the moisture content of the heartwood. Problems with uneven moisture content also occur when She charge contains boards with wetwood or boards of mined species with different permeability.

Initial moisture content differences.—When the kiln is loaded with a mixed charge of boards containing high and low moisture contents, the final drying conditions must be coincidental with the target moisture content. The charge will be dried according to the rate of moisture loss in the wettest boards and equalized to a final acceptable moisture content range that includes the driest boards. The drier boards will be in the kiln longer than necessary, which is the price paid for eliminating wet boards. This procedure is used when the target moisture content is 8 percent or lower. It is not practical for drying softwood dimension lumber where the target moisture content is 15 percent and green moisture content values range from 50 percent for heartwood boards to 170 percent for sapwood boards. By the time the sapwood reaches the target moisture content the. heartwood will be overdried, and it is not economical to increase the moisture content of the heartwood boards from 8-10 percent to 12-15 percent.

When mixed charges of high and low moisture content boards will not be dried to a target moisture content of 8 percent or lower, then the lumber should be segregated into different board sorts and each sort dried separately. In commercial practice, however, sorting for moisture content differences is usually done after kiln drying. The boards are identified for moisture content on the dry chain with dielectric inline moisture meters and the wet boards redried. Redrying can increase drying costs by 25 percent or more. It would be preferable to identify high and low moisture content boards on the green chain before drying. Presorting green wood cannot be accomplished with inline dielectric moisture meters when the wood moisture content is above 30 percent.

Although presorting on the green chain is possible through weighing individual boards when heavy and light board sorts are to be dried separately, this is not done commercially. Existing mills are not equipped to install inline weighing devices or to handle boards of different sizes and weights but similar moisture content values. Recently, a new technique has been developed by the Canadian Forintek Laboratory in Vancouver, BC, that has promise for commercial presorting of lumber by moisture content differences. This Method uses infrared surface measurements, and through computer-controlled equipment identifies each board by moisture content. Moisture content values ranging from below 15 percent to above 150 percent can be measured; and the equipment can be installed on existing green chain production lines.

Permeability differences.— Presorting boards on the green chain can solve the problem of permeability differences when the lumber charge contains a mixture of species. As a general guide to which species can be dried together and which cannot, the kiln operator can we the kiln schedules and tables of kiln-drying times in chapter 7. For example, 4/4 aspen and basswood are both dried under schedule T12-E7 from green to 6 percent moisture content in the same length of time. Two different species that have similar but not identical drying requirements, such as red and white oak, can still be dried together. However, the mixed oak charge must be dried under the milder white oak schedule using white oak kiln samples. This procedure can also be used for species with widely differing permeability although it may not be economically feasbile, For example, a mixed charge of soft maple and red oak must be dried under the milder red oak schedule with oak kiln samples. This will double the kiln residence time normally required for the maple.

When wetwood or sinker stock is responsible for uneven moisture content and water pockets, presorting on the green chain is the best solution, but this is not easily done with currently available techniques. For species such as hemlock, true fir, white pine, aspen, and cottonwood, the moisture content of wetwood will be higher than that of heartwood but equivalent to that of sapwood. Wetwood can be accurately presorted from normal lumber by hand, but this procedure has not been successfully applied to green chains in high-production mills. Research results from the Forest Products Laboratory indicate that electronic measurements could be employed to segregate green hem-fir lumber into three board sorts: sapwood, heartwood, and wetwood (Ward et al. 1985). To date, no method for commercial presorting of wetwood is available on the market.

Discoloration

The use of dried wood products can be impaired by discolorations, particularly when the end use requires a clear, natural finish. Unwanted discolorations can develop in the tree, during storage of logs and green lumber, or during drying. Discolorations may also develop when light, water, or chemicals react with exposed surfaces of dried wood. This section is mainly concerned with discolorations that develop in clear, sound wood before or during drying. Any discolorations beyond the control of the drying and related processing operations, such as mineral stain and decay in the tree, will be mentioned only when they might form the focal points for initiation of drying defects. Drying discolorations have been traditionally classified in association with fungal attack or chemicals in the wood. Current knowledge suggests that this dual classification needs to be broadened somewhat. Some discolorations once considered chemical in origin are caused by bacteria, which can only be detected underhigh-power microscopes, Also, the formation of unwanted color will vary with complex interactions of tree species, type of wood tissue, and drying conditions. Successful control of discolorations depends upon the ability of the dry kiln operator to recognize differences in the wood quality of the species being dried and environmental factors that will initiate discoloration.

To prevent discolorations, the dry kiln operator must know the wood species and determine the wood type (sapwood, heartwood, or wetwood). The third and sometimes hardest step is to determine if the causal factors are primarily chemical or microbial.

Sapwood Discolorations

When the tree is cut, sapwood contains living parenchyma cells, which are not present in fully formed heartwood. Sapwood parenchyma cells may still be alive when the logs are sawed into lumber; as these cells die, enzymes and chemical by products are produced that may darken the wood. This darkening is intensified by oxidative heating of, the moist wood or by attack by fungal molds or aerobic bacteria. Sapwood also contains starches and sugars that provide food for mold fungi and bacteria,

Chemical.— Chemical discolorations are the result of oxidative and ensymatic reactions with chemical constituents in the sapwood. They range in color from

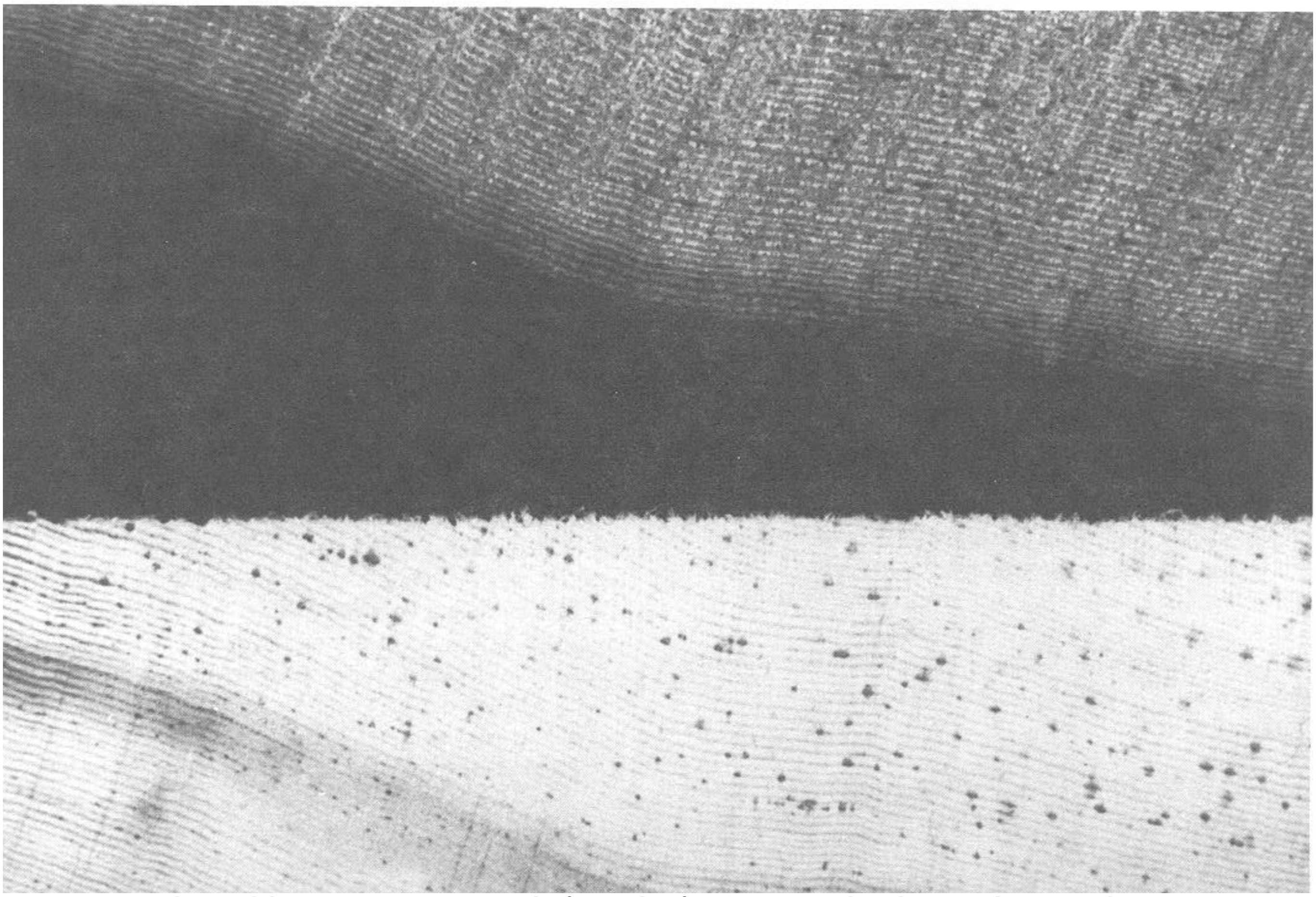

Figure 8-12—Chemical brown stain in sapwood of Douglas-fir. (Top) Board end exposed, to air; (bottom) internal wood. (M88 0162)

pinkish, bluish, and yellowish hues through gray and reddish-brown to dark brown shades. As a group, hardwoods are more subject to oxidative surface discolorations than softwoods. In some hardwood species such as alder and dogwood, intense discolorations will appear within an hour after the green wood surface is exposed to the air. Most oxidative discolorations are confined to within 1/16 in of the outer layer of the board and can be eliminated by planing.

A chemical brown stain that sometimes occurs in West Coast Douglas-fir penetrates deeper into the sapwood during kiln drying (fig. 8-12). Interior discolorations of this type cannot be satisfactorily prevented by treating the board surface with antistain chemicals. Miller et al. (1983) found that steaming the green wood to 212 °F inactivated the oxidative enzymes within the board and effectively eliminated the internal brown stain.

During drying, the degree of sapwood discoloration depends upon the chemical constituents of the sapwood and the drying temperature until the average moisture content of the board is well below the fiber saturation point. If drying temperatures are too high, chemical discolorations will penetrate deeply into the board. Above 140 °F, brown discolorations will become quite pronounced throughout sapwood boards of maple, beech, birch, and alder that is beiug dried from the green condition. Tan, yellowish, or pinkish hues may develop in the green sapwood of maple, hickory, and ash when dried under kiln schedules that are usually recommended for these species (fig. 8-13). Such seemingly mild discolorations are not acceptable for products requiring “white stock.” Drying schedules for produciug white stock (ch. 7) usually start with a dry-bulb temperature less than 110 °F and a 10 °F wetbulb depression. Drying temperatures are kept below 130 °F until the average moisture content reaches 15 percent.

Distinct brown discolorations will develop in the green sapwood of southern yellow pine at drying temperatures above 160 °F. When southern yellow pine is dried at high temperatures in excess of 212 °F, a dark brown discoloration develops that penetrates to at least 1/8 in below the surface (fig:8-14).

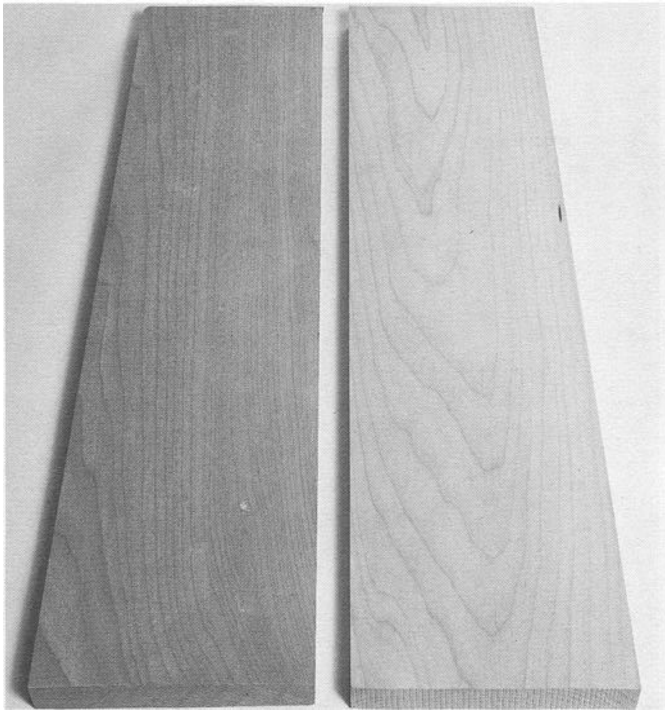

Figure 8-13—Kiln-dried and planed sugar maple with and without discoloration. (Left) General reddish-brown discoloration of sapwood from prolonged log storage and drying with conventional schedule T8-C3; (right) light sapwood board cut from fresh Jogs and dried with an anti-brown-stain schedule (ch. 7). (M 138652)

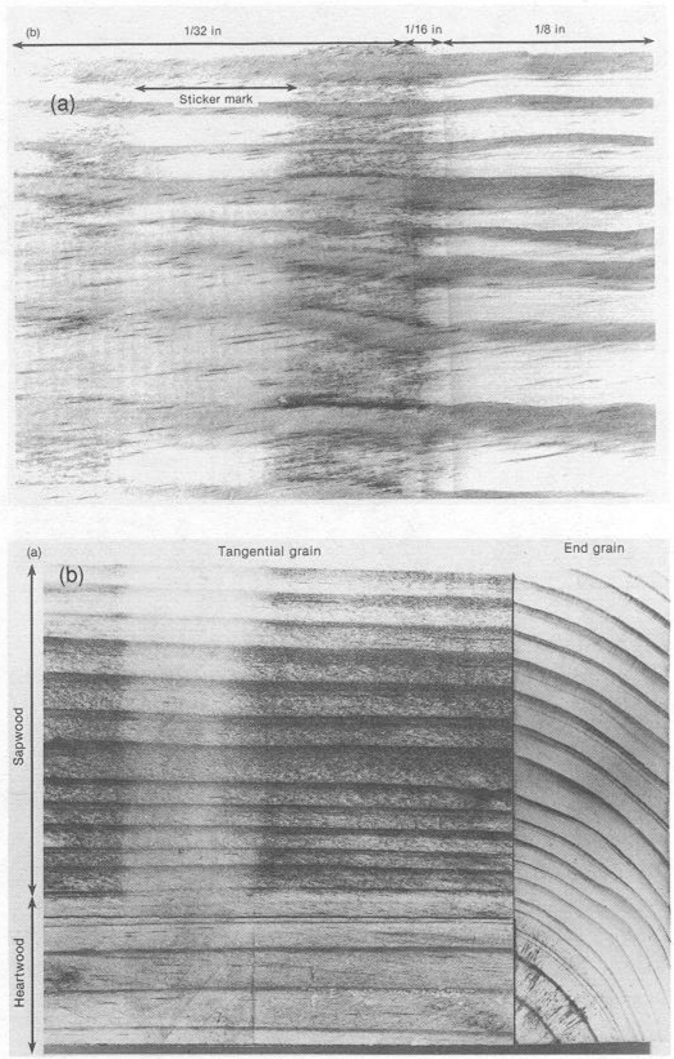

Figure 8-14—Brown sapwood stain in 8/4 southern pine kiln dried with a high-temperature schedule. (a) Rough, dry board showing surface darkening of sapwood but not of heartwood under sticker; (b) closeup of sapwood surfaced to 1/32 in, 1/16 in, and 1/8 in (left to right). (MC88 9041, MC88 9040)

Sometimes oxidative discolorations are not evident until the outer 1/32- to 1/16-in surface has been planed off. This is because the outer surface of the green board has dried to below the fiber saturation point before oxidative chemical reactions can be completed, but the major inner portion of the board is still green. This can happen with stacked lumber that begins to air dry before kiln drying is started.

Deep grayish-brown chemical discolorations may occur in the sapwood of lumber from air-drying yards and predryers. These low-temperature sapwood discolorations are an important problem in oak, hickory, ash, maple, tupelo gum, magnolia, persimmon, birch, basswood, and Douglas-fir (fig. 8-15). In contrast to chemical discolorations that occur with high drying temperatures, these discolorations develop during very slow drying or wet storage of the sapwood at relatively low temperatures. In this situation, enzymes are produced by slowly dying parenchyma cells, which darken when oxidized. To avoid this, the green lumber should be stickered immediately after sawing, and drying should be started at temperatures above 70 °F. Good air circulation is essential. Heating or steaming the green lumber at 212 °F has been tried, with limited success, to inactivate the enzymes that contribute to the darkening reactions.

Some kiln operators have observed that the tendency for sapwood to discolor varies in lumber from different areas and from trees growing on certain soils such as wet bottomlands.

Fungal.—Fungal stains, often referred to as blue stain, are caused by fungi that grow in the sapwood and use parts of it (such as sugars and starches) for food. Blue stain fungi do not cause decay of the sapwood, and they cannot grow in heartwood or wetwood that does not have the necessary food substances. However, poor drying conditions that favor the growth of blue-stain fungi can lead to infections by decay-producing fungi. With the exception of toughness, blue stain has little effect on the strength of the wood.

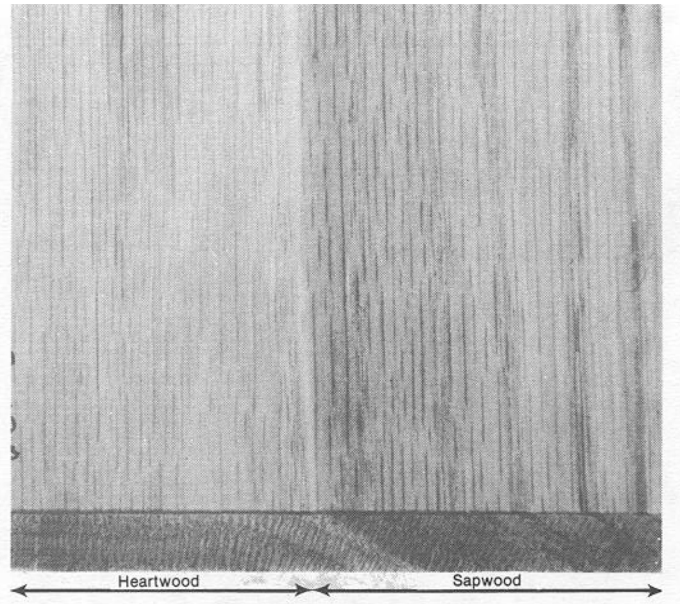

Figure 8-15—Gray sapwood stain in southern red oak dried green with humid, low-temperature conditions and with poor air circulation. (MC88 9037)

To prevent blue stain, it is necessary to produce unfavorable conditions for the fungi. Blue-stain fungi are disseminated by spores, which are produced in great abundance and are disseminated by wind and insects, or by direct growth from infected to uninfected wood. Blue-stain fungi will survive but cannot grow in wood with a moisture content of 20 percent or lower or a temperature of 110 °F. Temperatures higher than 150 °F are lethal to the fungi. This means the dry kiln operator may be able to employ drying schedules for control. In the summer months and in the tropics, the operator will need to chemically treat the wood with fungicides in addition to using proper kiln schedules.

Chemical fungicides, or biocides, make the sapwood unsuitable as food for blue-stain fungi (fig. 8-16). Sodium pentachlorophenol (PCP) has been one of the most effective and widely used fungicides for controlling sapwood stains in lumber, but its use has been recently curtailed by the U.S. Environmental Protection Agency (EPA) because of adverse effects on workers and the environment. New chemical formulations with lower mammalian toxicity appear promising for the control of sapwood stain (Cassens and Eslyn 1983, Tsunoda and Nishimoto 1985). For chemical control to be effective, the green lumber must be chemically treated soon after sawing fresh logs. Treating lumber from logs that have laid on the yard for a prolonged period and that are already infected with fungi will not be effective unless the lumber is kiln dried immediately under temperatures lethal to the fungi. However, under any conditions, chemically treated lumber should be stacked on stickers immediately after treatment.

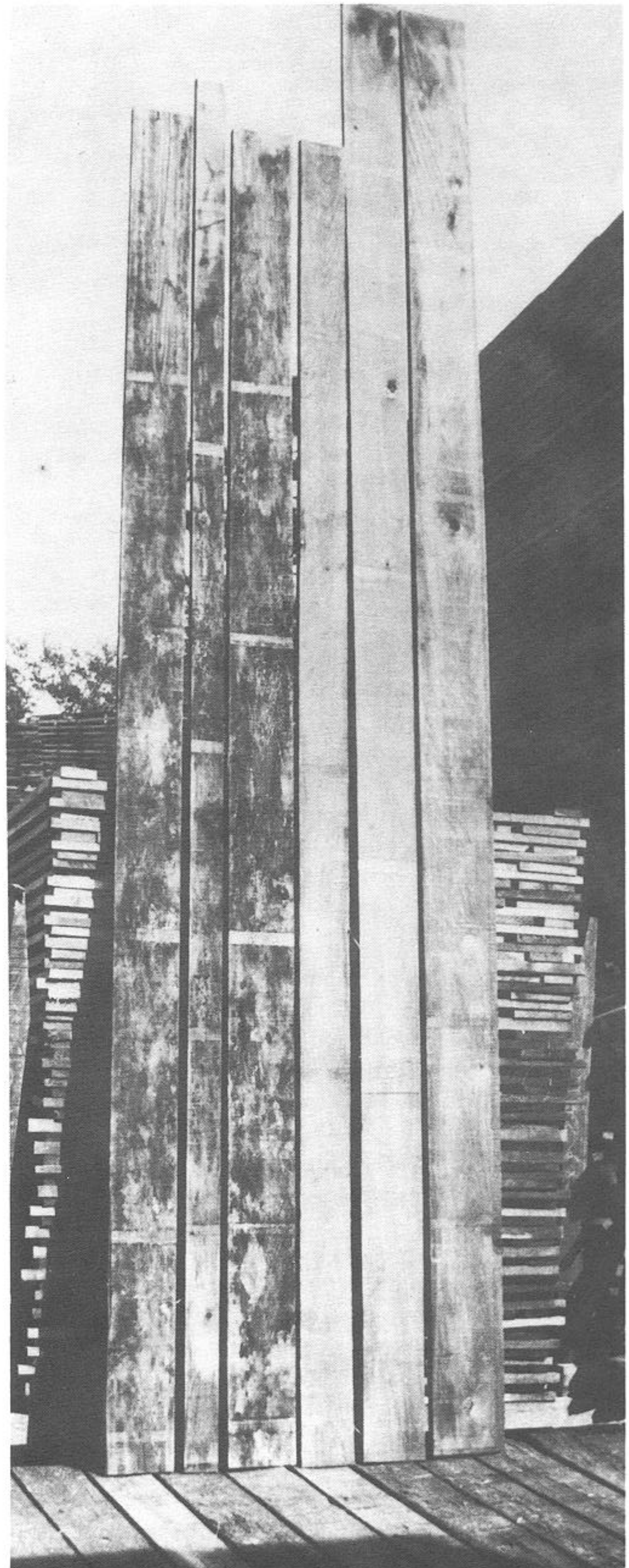

Figure 8-16—Untreated (left) and dip-treated (right) sweetgum lumber after 120 days in an air-drying yard. (M88 0158)

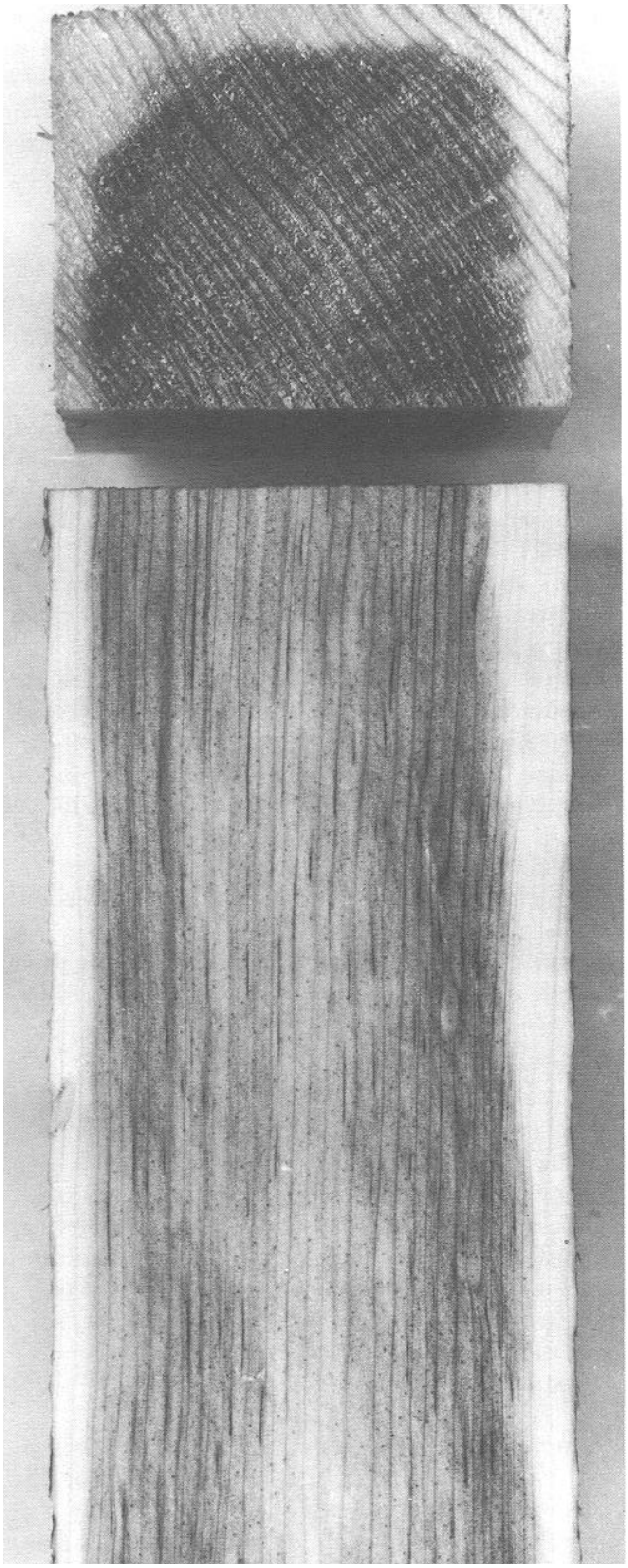

Figure 8-17—Interior sapwood stain in a section of 6/4 white pine lumber. Where lumber is bright on the surface but stained inside, conditions were initially suitable for infection. Later, chemical treatment or accelerated drying made the conditions unfavorable for further fungal growth in the outer portion of the piece. (M 39166)

Figure 8-18—Surfaced board of eastern white pine revealing blue stain that developed during the early stage of dehumidification drying. The lumber was from winter-cut Jogs and was not chemically treated. (M88 0160)

In warm, moist environments the airborne spores of sapwood-stain fungi seem to germinate very soon after landing on the surface of green, untreated sapwood. This means that the lumber must be chemically treated immediately after the logs are sawed or certainly no longer than 36 h afterward. Chemical fungicides will usually not soak into the board more than 1/32 in under commercial operating methods. Therefore, it is important to kiln dry the treated boards as soon as possible at initial dry-bulb temperatures above 130 °F to prevent the internal growth of fungi that have penetrated deep enough to escape the fungicide. Internal blue stain in the core of chemically treated sapwood is illustrated in figure 8-17.

Precautions must be taken with untreated lumber even when kiln dried within 1 day of sawing the logs. Sapwood-stain fungi will not grow at temperatures lower than 35 °F, and chemical treating is often curtailed, for economic reasons, during winter months in northern locations. Blue stain will develop on the surface of boards during drying at low temperatures and high humidities if the surface is not soon dried below 20 percent moisture content (fig. 8-18). This has occurred with dehumidification drying of untreated softwoods. Blue stain was found to develop under stickers in untreated southern pine sapwood that was kiln dried at 140 °F to avoid chemical brown stain.

Bacterial.— Bauch et al. (1984) in West Germany have associated the formation of dark discolorations in the sapwood of light-colored tropical woods with contamination of the logs and lumber by aerobic bacteria. They found that these bacteria grow on certain chemical components in the sapwood extractives, and the metabolic byproducts will discolor during kiln drying, especially on surface areas in contact with the stickers. These discolorations were controlled by spraying the green lumber with aqueous solutions of weak organic acids, such as propionic acid, before drying. The acid solution inactivates the discoloration reaction, which requires alkaline conditions.

Sticker stains and sticker marks.-Sticker stains and marks are both discolorations resulting from contact of the sticker with the wood surface. Sticker stains are imprints of the sticker that are darker than the wood between stickers (fig. 8-19). Sticker marks are lighter than the exposed surface of the board between stickers (fig. 8-14). Although these sticker discolorations can occur in heartwood, they are much more prevalent and troublesome in sapwood. The causes of these discolorations can be chemical, microbial, or a combination of these.

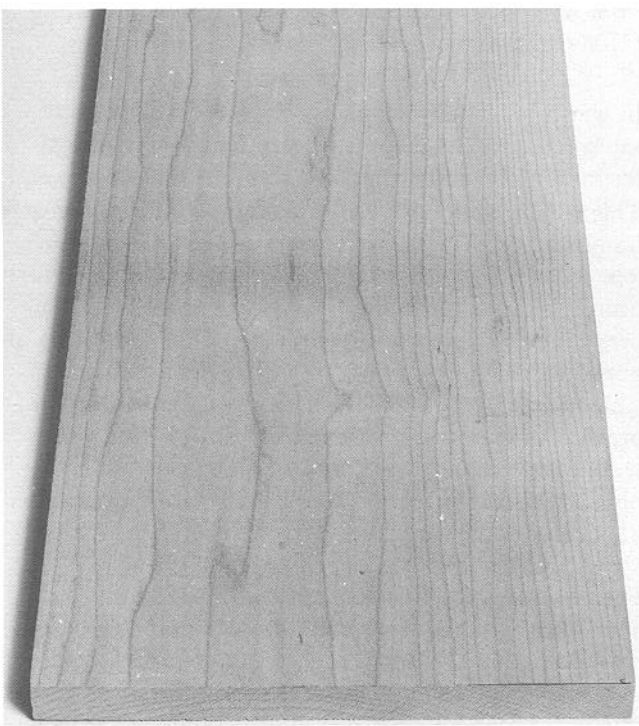

Figure 8-19—Residual sticker stain in sapwood of kiln-dried sugar maple after planing surface. (M 138660)

Sticker stains probably occur because the wood under the sticker remains moist longer or because it is rewetted. Sticker stains can be fungal sapwood stains that developed from stickers that were either too wet or contaminated with dirt and microoganisms. Even when using dry stickers, fungal sapwood stain can develop under stickers when drying conditions are poor and the wood is not chemically treated.

Sticker marks are chemical in nature-the exposed surface of a board oxidizes more readily than the surface under the sticker where oxidation is restricted. The intensity of oxidation staining is influenced by the chemical nature of the wood extractives and the presence of warm, moist drying conditions. High-temperature drying can also initiate sticker marking by degrading chemical extractives in the exposed surface of the board. Sapwood from a species such as red alder with highly oxidizable extractives is always subject to some degree of sticker marking depending on drying conditions.

Sticker discolorations are almost inevitable, but they can generally be eliminated with light surfacing of the dried wood. Control measures should be concentrated on drying procedures that will lessen the intensity and depth of the discolorations. These include using dry, narrow stickers or grooved stickers to reduce the contact area and starting the drying of green lumber as soon as possible. Dry-bulb temperatures should be moderate, and wet-bulb depressions should be sufficient for fast drying to avoid checking. There should be good air circulation of at least 200 ft/min across the load. Green boards should be chemically treated when sapwood-stain fungi or bacteria are contributing factors.

The photodegradation of extractives in green wood that is briefly exposed to bright sunlight can result in oxidative sticker stains and sticker marks during kiln drying (Booth 1964).

Heartwood Discolorations

Discoloration during the drying of heartwood will usually be chemical in nature and not as frequently encountered as when drying sapwood. Fungal discolorations will never develop under satisfactory drying conditions if the green heartwood is sound. Bacteria are not a problem when drying heartwood, but they do contribute to drying discolorations in wetwood, which is considered an abnormal type of heartwood and is discussed in the next section.

Chemical.— Heartwood of most species will darken uniformly during drying, and the intensity of the discoloration will depend upon the chemical nature of the extractives and the drying temperatures. In green heartwood, darkening intensifies with increasing drying temperatures. An example of unwanted, nonuniform darkening is the coffee-colored or oily-looking blotches that develop during the kiln drying of teak (fig. 8-20). These blotches develop just under the surface of the board and are chemically similar to the extractives that contribute to the normal warm, brown color of teak. Teak dried at kiln temperatures as low as 110 °F will

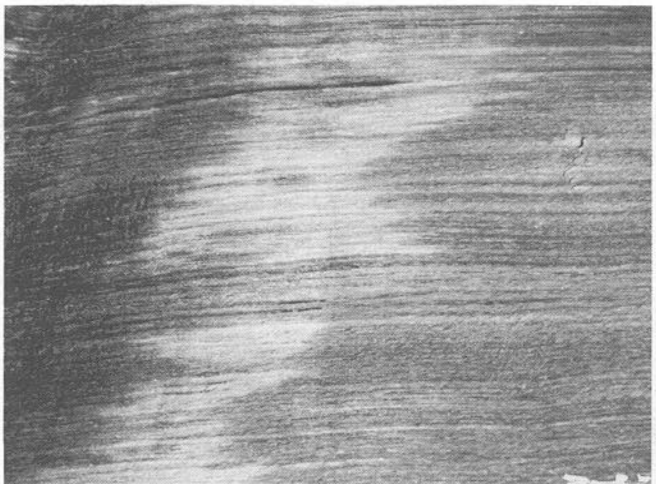

Figure 8-20—Chemical discoloration (coffee-colored blotches) that develop in heartwood of teak during kiln drying. (M88 0159)

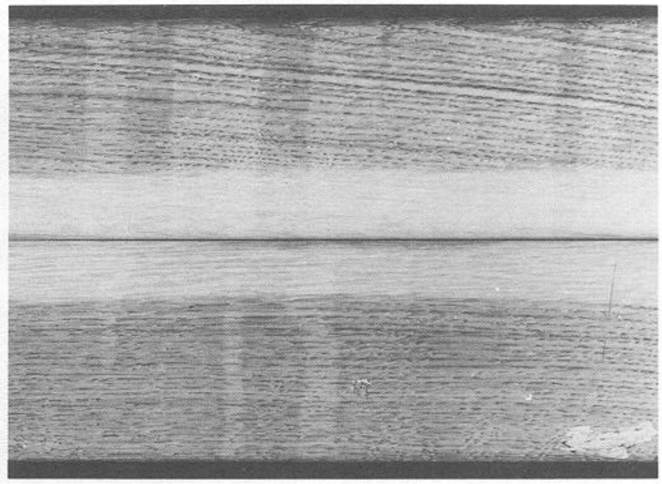

Figure 8-22—"Ghost" discolorations in white oak heartwood: middle zone, unfinished; outer zones, finished with stain. (M88 0163)

develop blotches, but they are much darker in wood dried at higher temperatures. The fundamental cause of teak blotching is not known; blotching occurs in lumber from trees grown in one region and not in another. The blotches can be lightened somewhat by exposing the dried wood to bright sunlight.

Fungal.—Most mold-type fungi, such as those causing sapwood blue stain, cannot grow on the chemical constituents in heartwood. There is one exception-the mold-type fungus *Paecilomyces varioti*. This fungus can feed on the tannins and organic acids found in the heartwood of species such as oak. It forms a tan mold on the surface of oak heartwood (not sapwood) under warm, humid conditions, particularly in predryers and dehumidification dryers with poor air circulation. The resulting discoloration is usually superficial and can be planed off, but it will penetrate more deeply into the board if the surface is not dried below 20 percent moisture content within the first week or two of drying (fig. 8-21). Control requires using the proper kiln schedule with adequate air circulation across the load.

Streaks of light-brown discoloration that run across the grain are sometimes found in white oak boards after drying and planing (fig. 8-22). These discolorations resemble sticker stains but they penetrate the entire thickness of the board and cannot be eliminated with

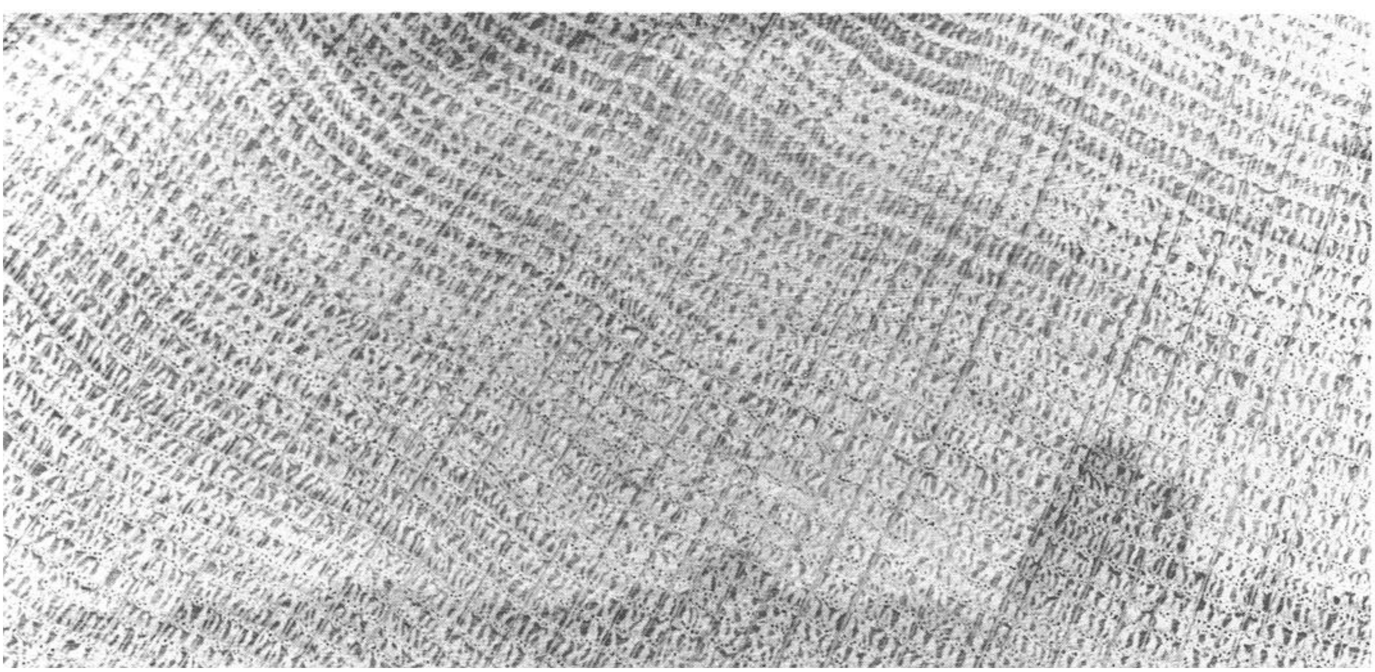

Figure 8-21—penetration of dark chemical discoloration into heartwood of white oak from surface growth of the mold-type fungus *Paecilomyces varioti*. (M86 0283)

Figure 8-23—Kiln-dried sugar pine shows chemical brown stain in center board that contained wetwood but not in boards with sapwood (left) or normal heartwood (right). End sections (top) were crosscut from rough, dry boards, and 1/16 in was planed from board surfaces (bottom). (MC88 9039)

planing. Clear finishes will intensify the streaks, and they may not be noticed until the last stages of production, which can be costly to the manufacturing operation. This discoloration is caused by a fungal infection in the heartwood of the living tree.

Discolorations in Wood Containing Wetwood

Wetwood is an abnormal, water-soaked type of heartwood; it is initiated by pathological rather than normal physiological changes in the living tree. Anaerobic bacteria are involved in the formation of wetwood, and they contribute to chemical changes in the extractives, which may later result in drying discolorations. Not all wetwood darkens during drying because of differences in tree species and bacteria associated with wetwood formation. For example, wetwood in white pine may or may not develop coffee-brown drying stains depending on the type of wetwood bacteria that infected the living tree.

Dark discolorations that develop in lumber with wetwood result from an oxidative or a metallic-tannate reaction. In both situations, wood extractives are chemically degraded by the bacteria (usually under anaerobic conditions in the tree), which results in the production of compounds that darken when heated under oxidative conditions or when placed in contact with metals such as iron.

The familiar coffee-brown stains that develop during the kiln drying of wetwood in white pine, sugar pine, and ponderosa pine, and to a lesser extent in aspen, cottonwood, and western hemlock, are the oxidative enzymatic type (fig. 8-23). Two methods have been used to control coffee-brown stains in softwood lumber: chemical treatment and special drying schedules. Treatment of the green wood with antioxidant chemicals such as sodium azide and sodium bisulfite is quite effective.. Untreated wetwood in high-risk species such as the white pines must be dried at low dry-bulb temperatures with large wet-bulb depressions (see anti-brown-stain schedules in ch. 7). Treated lumber can sometimes be kiln dried at higher temperatures with good results, but caution and pretesting are advised.

Organic acids are produced by bacterial growth in wetwood that catalyzes chemical reactions of tannins in the wetwood with iron, steel, and zinc, resulting in dark discolorations. Wetwood in oak, redwood, western redcedar, and western hemlock is very susceptible to these metallic stains when the outer shell of the board is green or wet. Galvanizing or coating steel straps will not always prevent these stains from forming in packages of green lumber with wetwood boards (fig. 8-24). Iron stains can generally be removed from wood by treatment with an aqueous solution of oxalic acid if surface penetration of the stain is not too deep.

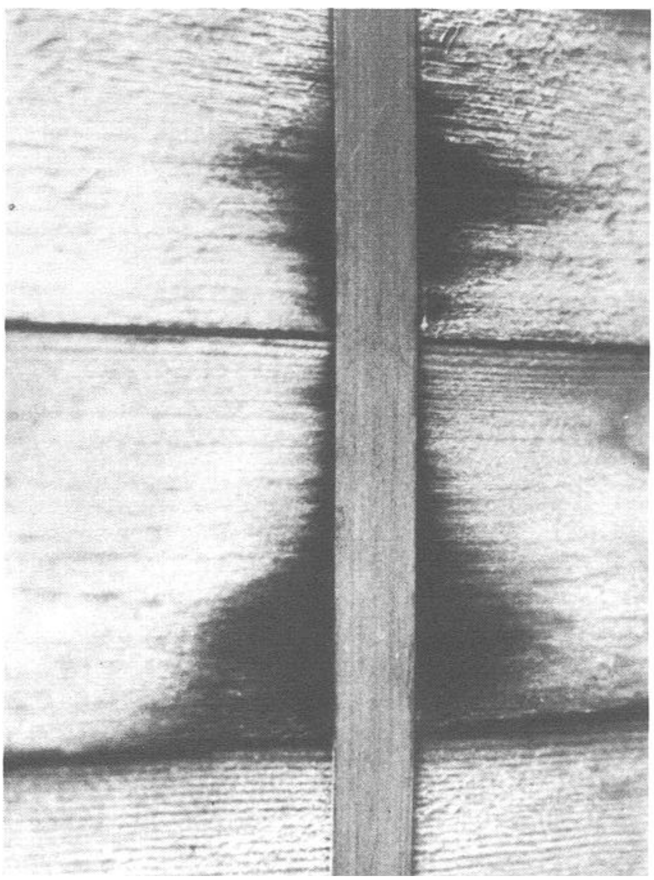

Figure 8-24—Dark discolorations in two green western hemlock boards (upper and middle boards) resulting from an acid chemical reaction of wetwood extractives with steel band that had an epoxy-powdered zinc coating. Lower green sapwood board did not react. (M88 0161)

Metallic and Alkaline Stains

Metallic discolorations can also develop in normal wood with high amounts of tannins and related compounds (polyphenols) but not as readily as in wetwood where higher amounts of organic acids are present to speed up the reaction. Metallic discolorations are mostly iron-tannate stains and are likely to develop in oak, chestnut, and walnut, and, to a lesser degree, in other species during kiln drying from steam condensates and water dripping from steel pipes, beams, and other kiln components.

Dark alkaline stains are caused by the chemical reaction of wood extractives with potassium and calcium hydroxides that leach out from concrete and mortar structures in contact with the wood. These stains might develop when lumber is dried in concrete or brick kilns that are not kept in good repair. They can also develop from contact of wood with solutions containing ammonia.

Removal of Discoloration From Dried Wood

Although preventative measures are advocated here, it may sometimes be economically necessary to remove discolorations that cannot be surfaced off on the planer. Some stains may be removed with a bleaching agent, but some trial and error method is often required to find the most effective agent for a particular stain. Bleaching operations can be costly in terms of handling and redrying the wood. To be effective, the bleaching treatment may have to be so severe that an objectionable amount of natural color is also eliminated. Of course, the bleached wood cannot be resurfaced without exposing interior discolorations.

If the stain is not too deep, it can often be removed or reduced in intensity with hydrogen peroxide. A concentrated aqueous solution of oxalic acid will bleach out chemical sapwood stains but not sapwood stains caused by mold fungi. **A** laundry bleach of 5 percent sodium hypochlorite solution can sometimes be used effectively (Forest Products Laboratory 1967, Downs 1956).

Drying Defects of Major Concern in Commercial Woods

All woods are subject to drying defects, but some species are more likely to develop certain defects than others. Refractory hardwoods such as oak and hickory will check more readily than basswood and yellow-poplar, which have less dense and more even-textured wood. Drying defects will develop more frequently in wetwood or sinker stock than in sapwood or normal heartwood. Wetwood occurs quite frequently in some tree species and rarely or not at all in other species. Common defects that occur during kiln drying are noted in tables 8-2 to 8-4 for U.S. softwood species, U.S. hardwood species, and imported species, respectively.

Relationships Between Drying Defects and Machining

Lumber can be damaged during machining if it contains certain drying defects. Planer splits, broken knots; knotholes, chipped and torn grain, raised grain, and warp can all occur as a result of improper drying. Precautions taken during drying can minimize or avoid these defects.

Planer Splits

A long split often develops when cupped lumber is flattened as it passes through the planer. End splits-already present aggravate planer splitting. This type of split, also called roller split, lowers the grade and value of lumber and causes waste. Not only does the amount of cupping increase as the moisture content of the wood is lowered but the wood becomes stiffer and is more likely to split when flattened.

Splitting on the planer can be reduced by taking steps to minimize cupping and end splitting through good stacking practices. Ensuring that lumber is not overdried will also reduce splitting. For example, softwood construction lumber is frequently dried to a target moisture content of about 15 percent. Drying below that target will increase the chance that planer splits will develop. The upper grades of both hardwood and softwood lumber are dried to 10 percent moisture content or less to meet end-use requirements. If the lumber becomes cupped in the process, splitting cannot be easily avoided during planing. Planer splitting can be reduced somewhat by relieving drying stresses and raising the moisture content of the surface of the lumber.

Broken Knots and Knotholes

In most grades of lumber, the knots in the surfaced boards should be smooth, intact, and unbroken. Knots check and loosen as drying proceeds, and they become more brittle as the moisture content of the wood decreases. While the lumber is in the planer, the knots are severely hammered as well as cut by the knives. The hammering breaks checked knots and knocks out loose ones, and it can thus lower the grade of the lumber.

In much of the softwood lumber industry, knotty grades of construction lumber are dried to a final moisture content of about 15 percent to permit better machining of the knots. At this moisture content the sound knots are not severely checked, and the encased knots are fairly tight: Therefore, common grades of softwood lumber are usually separated from upper grades and dried by different schedules; the upper grades are dried to 8 to 10 percent moisture content.

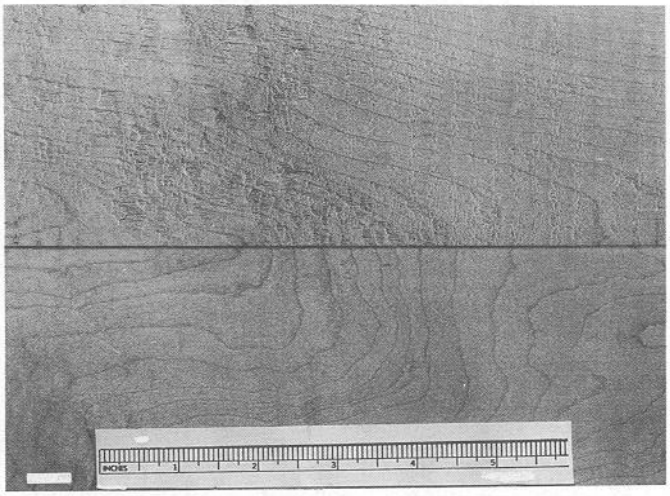

Figure 8-25—Chipped and torn grain in hard maple. (M 114737)

In some species, encased knots are held in place largely by pitch between the knot and the board. If the pitch is removed, the knots fall out of the board. Drying temperatures of 160 to 180 °F soften the pitch; it runs out from around the encased knot and the knot falls out. In these cases, knots can be prevented from dropping out by reducing the drying temperature.

Chipped and Torn Grain

When dry lumber is machined, wood may be chipped and torn from some areas on the surface (fig. 8-25). The occurrence of chipped and torn grain is influenced largely by the operating conditions of the machine, the sharpness and setting of the knives, the feed rate into the machine, and the slope of grain, including grain variations. To some extent, however, the susceptibility of lumber to chipping and tearing is affected by the moisture content of the wood layer being removed. Lumber of extremely low surface moisture content–5 percent and less-chips and tears more during machining than if the surface moisture content is 8 percent or higher. Consequently, kiln operators can prevent this problem to some extent by avoiding overdrying and by increasing surface moisture content with a conditioning treatment.

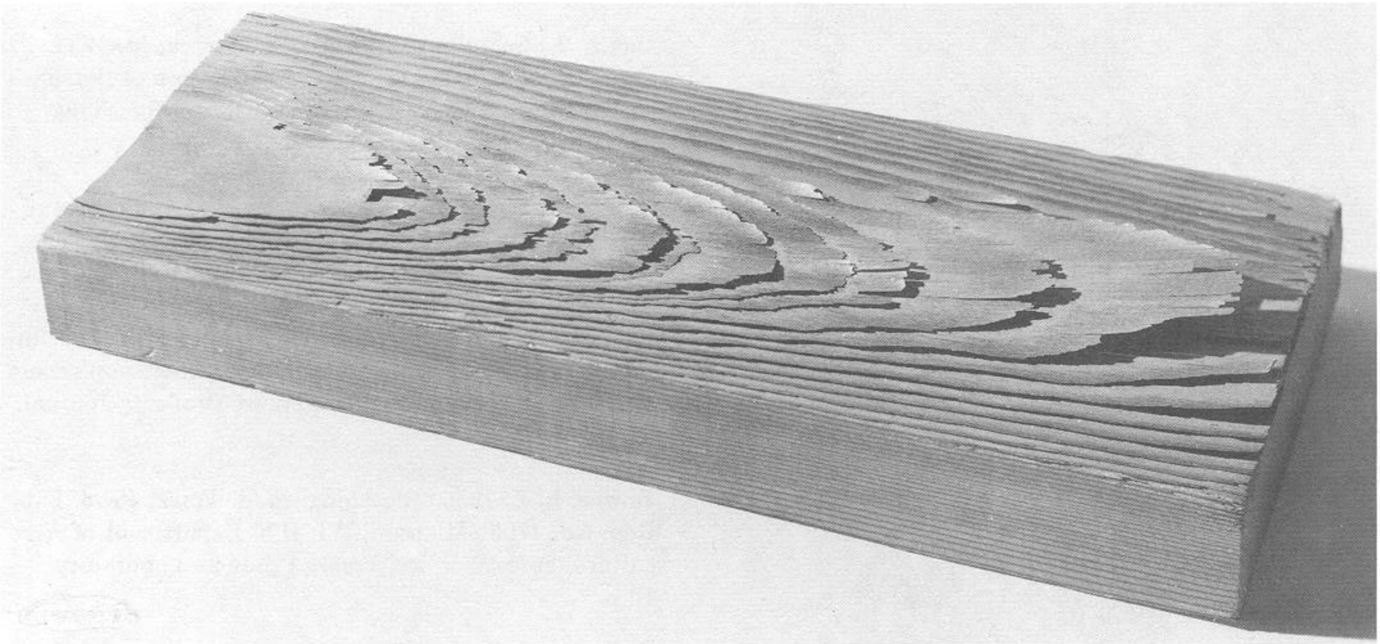

Figure 8-26—Raised grain in Douglas-fir. (M 97880)

Raised Grain

Raised grain (fig. 8-26) occurs primarily when lumber is not uniformly dried to a low enough moisture content at the time of machining. Generally, raised grain does not develop in wood that is machined while at 12 percent or leas moisture content. When wood is machined at a higher moisture content, the action of the knives forces the latewood bands into the softer earlywood bands on the flat grain surface. Subsequently, the compressed earlywood recovers and lifts the bands of latewood above the surface. The uneven surface usually reduces the grade and usefulness of the finished product.

Raised grain can occur in all species, but it is most pronounced in softwoods like Douglas-fir and southern pine that have distinct bands of earlywood and latewood that are different in density.

Residual Drying Stresses

Whether or not residual drying stresses (casehardening) are considered a defect depends on how the lumber is subsequently sawed or otherwise machined. The most common problems that occur in the use of casehardened lumber are end checking, planer splitting, and warping.

End Checks

End checks will frequently develop in the core of a freshly crosscut casehardened board that is exposed to low atmospheric relative humidity, even though the average moisture content of the board is fairly low. The tensile stresses present in the core, coupled with additional stresses brought on by end drying, exceed the strength of the wood. A check then develops, which can further extend into a split.

Planer Splits

Splits can occur in relatively flat casehardened boards that are being surfaced. The splits are caused by the internal drying stresses in the boards, coupled with the forces applied by the machine knives. A conditioning treatment will reduce planer splits from this cause.

Warp

If transverse or longitudinal stresses become unbalanced during sawing or any other machining operation on a casehardened board, the board will distort in an effort to rebalance the stresses. Resawing may cause cupping

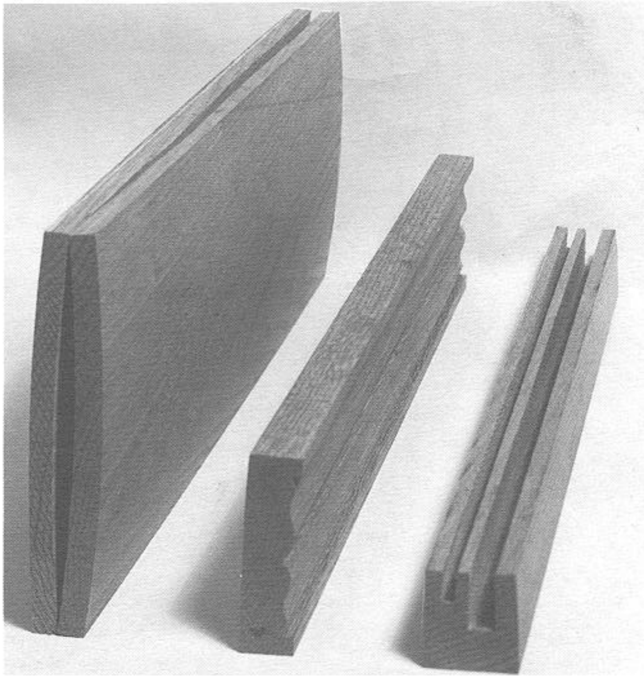

Figure 8-27—Distortion caused by unrelieved drying stresses: resawed board (left), lumber heavily machined on one face (center), and grooved lumber (right). (M 111992)

or bowing. The concave faces will be oriented towards the saw (fig. 8-27). Ripping may result in crook, in which the concave edges usually follow along the saw cut. In planing, the depth of cut is not likely to be the same on both faces; if the board is casehardened, it will cup with the concave face toward the most heavily cut surface. When casehardened lumber is edgegrooved, the lips of the groove may pinch inwards (fig. 8-27). A tongue or spline inserted into such a groove may break the lips. Cupping usually results when casehardened lumber is machined into patterns, as in the manufacture of molding and trim, or when unequal cuts are taken from the faces and edges of the lumber in routing and carving operations. Any warping of casehardened lumber that is due to sawing or machining is a source of trouble in further processing.

The relief of drying stresses by a conditioning treatment is strongly recommended for lumber that is to be used in furniture, architectural woodwork, sash and door stock, and other products that may require sawing or other machining that may unbalance residual drying stresses. It should also be used when the end use is unknown but could be one of the above-mentioned products.

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Table 8-1-Effect of high-temperature drying on modulus of elasticity and modulus of rupture of certain species[1]

Species	Reduction in property (percent) caused by high-temperature drying (225-240 °F) — Modulus of elasticity	Modulus of rupture
Douglas-fir	2	15-21
Western hemlock	0	10-14
Western white spruce	[3]4	0
Western redcedar	[4]0	0-3
Southern pine	4	4
Eastern spruce	0	11
Balsam fir	0	10
Jack pine	2	14
Trembling aspen	1	17
Balsam poplar	0	7

[1]Data derived from study by Gerhards and McMillen (1976). See Literature Cited.
[2]Compared to lumber dried by conventional temperatures below 180 °F.
[3]Conventional temperature in this study was 200 °F.
[4]Conventional temperature in these studies was 185 to 190 °F.

Table8-2—Common drying defects in U.S. softwood lumber species

Species	Drying defect	Contributing factor
Baldcypress		
Old growth	End checks, water pockets	Refractory wood, extractives
Young growth	Chemical brown stain	Wood extractives, poor air circulation
Cedar		
Alaskan yellow	Resin exudate	Extractives
Eastern redcedar	Knot checks, excessive loss of aromatic oils	Excessive drying temperatures
Incense cedar		
Heavy stock	Water pockets, collapse	Wetwood, excessive drying temperatures
Port-Orford	Resin exudate	Extractives
Western redcedar		
Heavy stock	Uneven moisture content, collapse, honeycomb, chemical stains, iron stains, resin exudate	Wetwood (sinker stock), extractives
Douglas-fir		
Coastal	Red-brown chemical stains	Wood extractives
	Gray sapwood stains	Sapwood extractive, slow drying
	Ring failure, honeycomb	Wetwood (infrequent occurrence)
Fir		
Balsam	Uneven moisture content	Wetwood
California red	Uneven moisture content, shake, splits, warp	Wetwood, compression wood
Grand	Uneven moisture content, shake, splits	Wetwood
Pacific silver	Uneven moisture content, shake, splits, chemical brown stains	Wetwood
White	Uneven moisture content, shake, splits, chemical brown stains	Wetwood
Subalpine	Uneven moisture content, shake, splits	Wetwood, compression wood
Noble	Warp, splits	Wetwood, compression wood
Hemlock		
Eastern	Uneven moisture content, warp, ring shake	Wetwood, compression wood
Western	Uneven moisture content, warp, chemical stains, shake, iron stains	Wetwood
Larch		
Western	Shake (ring failure, checks, resin exudate)	Wetwood
Pine		
Eastern white	Brown stain, ring failure	Wetwood
Western white	Brown stain	Wetwood
Sugar	Brown stain	Wetwood
Ponderosa	Brown stain	Wetwood (less common in ponderosa pine than in the soft pines)
Young growth	Warp	Juvenile wood, compression wood
Lodgepole	Warp	Compression wood
Loblolly	Brown sapwood stain, checks, splits	Excessive drying temperatures
Longleaf	Brown sapwood stain, checks, splits	Excessive drying temperatures
Shortleaf	Brown sapwood stain, checks, splits	Excessive drying temperatures
Slash	Brown sapwood stain, checks, splits	Excessive drying temperatures
Virginia	Brown sapwood stain, checks, splits	Excessive drying temperatures
Pond	Water pockets, dark chemical stains, honeycomb	Wetwood (infrequent occurrence)
Redwood		
Heavy stock	Uneven moisture content, collapse, honeycomb, chemical stains, iron stains	Wetwood (usually in old growth)
Spruce		
White	Water pockets, collapse, ring failure	Wetwood (rare occurrence in northern and southern limits of botanical range)
Sitka		
Young growth	Checks, splits, raised grain	Fast growth juvenile wood

Table 8-3—Common drying defects in U.S. hardwood lumbar species

Species	Drying defect	Contributing factor
Alder, red	Chemical oxidation stains (sticker marks)	Chemical wood extractives
Ash		
Black	Ring failure	Wetwood, drying temperatures
White	Gray-brown sapwood stain (sticker marks, stains)	Trees from wet sites, drying too slow, poor air circulation
	Surface checks	6/4 and thicker stock
Aspen	Water pockets, honeycomb, collapse	Wetwood, drying temperatures
Basswood, American	Brownish chemical stain	Sapwood from certain areas, drying too slow
Beech, American	End and surface checks	Normal wood is refractory
	Discoloration, honeycomb	Wetwood (occasional)
Birch		
Paper	Brownish chemical stain	Extractives in wood from certain sites
Yellow birch	End and surface checks	Refractory heartwood
	Collapse, honeycomb	Wetwood (heartwood), mineral streaks
Blackgum	Water pockets, collapse	Wetwood
Cherry, black	Ring shake, honeycomb	Wetwood (not common)
Chestnut	Iron stains	Extractives
Cottonwood	Water pockets, honeycomb, collapse	Wetwood
Cucumber tree	Sapwood discoloration	Poor air circulation
Dogwood		
Eastern and Pacific	Oxidative sapwood stains	Sapwood extractives, drying temperature
Elm		
American	Ring failure	Wetwood
	Warp	Grain orientation
Slippery	Ring failure	Wetwood
Rock	Boxed-heart splits	Growth stresses
Hackberry and Sugarberry	Sapwood discolorations	Slow drying with poor air circulation
Hickory	Chemical sapwood stains, ring failure, honeycomb	Slow drying with poor air circulation, wetwood
Holly	Sapwood stains	Extractives, poor air circulation
Laurel, California	End checks	Refractory wood from old-growth trees
Locust		
Black and Honey	End and surface checks	Refractory wood
Madrone	End and surface checks	Refractory wood
	Collapse	Wetwood

Table Common drying defects in U.S. hardwood lumber species—concluded

Species	Drying defect	Contributing factor
Maple		
soft		
Red and Silver	Sapwood discoloration, ring failure, honeycomb in heartwood	Wetwood, poor air circulation
Hard		
Sugar and black	Sapwood discoloration	Extractives, poor air circulation
	Collapse, honeycomb in heartwood	Mineral streaks, wetwood
Myrtle, Oregon (see California laurel)		
Oak, western		
California black	Honeycomb, collapse, ring shake	Wetwood
Oregon white	Honeycomb, collapse, ring shake	Wetwood
Oak		
Red upland	Ring failure	Severe wetwood
	Honeycomb	Severe drying of normal heartwood or wetwood with mild drying
	Iron stains	Extractives
Red lowland	Collapse, ring failure	Wetwood
	Honeycomb	Severe drying of normal heartwood or wetwood with mild drying
	Iron stains	Extractives
Southern red	Gray sapwood stains	Poor air circulation
White upland	End and surface checks	Severe drying
	Iron stains	Extractives
	Ring failure, collapse	Wetwood
	Gray sapwood stains	Poor air circulation
White lowland	End and surface checks	Severe drying
	Iron stains	Extractives
	Honeycomb, collapse, ring failure	Wetwood
	Gray sapwood stains	Poor air circulation
Pecan		
Water	Honeycomb, ring failure	Wetwood
Persimmon	End and surface checks	Severe drying
	Chemical sapwood stains	Slow drying at low temperature
Sapgum	Sapwood discoloration	Poor air circulation
Sweetgum	Surface and end checks	Severe drying
	Honeycomb, collapse, water pockets	Wetwood
Sycamore (heartwood)	Honeycomb, ring failure, water pockets	Wetwood
Tanoak	End and surface checks	Severe drying
	Honeycomb	Wetwood
Tupelo gum	End checks	Severe drying
	Honeycomb, collapse, water pockets	Wetwood
Walnut, black	End checks	Severe drying
	Iron stains	Extractives
	Honeycomb, collapse, ring failure	Wetwood
Willow, black	Honeycomb, collapse, water pockets, failure	Wetwood
Yellow-poplar	Mold, sapwocd stains	Slow and poor drying, moderate kiln schedule
	Honeycomb, water pockets (rare)	Wetwood

Table 8-4—Common drying defects of hard-to-dry Imported species[1]

Species	Drying defect
Albarco	Slight tendency to check
Andiroba	Slow drying with tendency to split, check, and collapse
Angelique	Moderate tendency to check, slight warp
Apitong	Slow drying with considerable tendency to check, collapse, and warp
Avodire	End checks
Balata	Severe checks and warp
Balsa (heavy)	Water pockets, collapse, splits, honeycomb
Banak	Strong tendency to check, collapse, honeycomb, and warp
Benge	Mild checks and warp
Bubinga	Slow drying with tendency to warp and check
Caribbean pine	End splits in thick lumber
Cativo	Occasional collapse in dark streaks in heartwood
Cuangare	Brownheart or wet streaks, collapse
Degame	Some tendency to warp, surface and end check
Determa	Some tendency to warp and check
Ebony, East Indian	Very prone to checks
Ebony, African	Slight tendency to check
Goncalo alves	Some tendency to warp and check
Greenheart	Slow drying and quite prone to check and end split
Hura	Warp
Ilomba	Fast drying, but prone to collapse, warp, and split
Imbuia	Thick lumber may honeycomb and collapse
Jarrah	Prone to checks and collapse
Kapur	Mild warp and shake
Karri	Pronounced tendency to check
Kempas	Mild tendency to warp and check
Keruing	Slow drying with considerable tendency to check, collapse, and warp
Mahogany, African	Severe warp if tension wood present
Manni	Moderate warp and checks
Mora	Some tendency to warp
Obeche	Slight tendency to warp
Opepe	Considerable checks and warp
Parana pine	Dark-colored material prone to split and warp
Peroba rosa	Slight tendency to warp
Ramin	Marked tendency to end split and surface check
Roble (Quercus)	Severe checks, warp, and collapse
Roble (Tabebuia)	Only minor checks and warp
Rosewood (Indian)	Dries readily with only minor defects
Rosewood (Brazilian)	Prone to check
Rubberwood	Severe warp, prone to blue stain and borer attack
Sande	Warp if tension wood present
Santa Maria	Tendency to warp and slight surface check
Sapele	Severe warp
Sepitur	End splits
Sucupira	Considerable checks and warp
Wallaba	Marked tendency to check, split, and warp: honeycomb in thick lumber

[1]Species listed in table 1-2 of chapter 1, but not listed in this table, tend to dry easily with few drying defects.