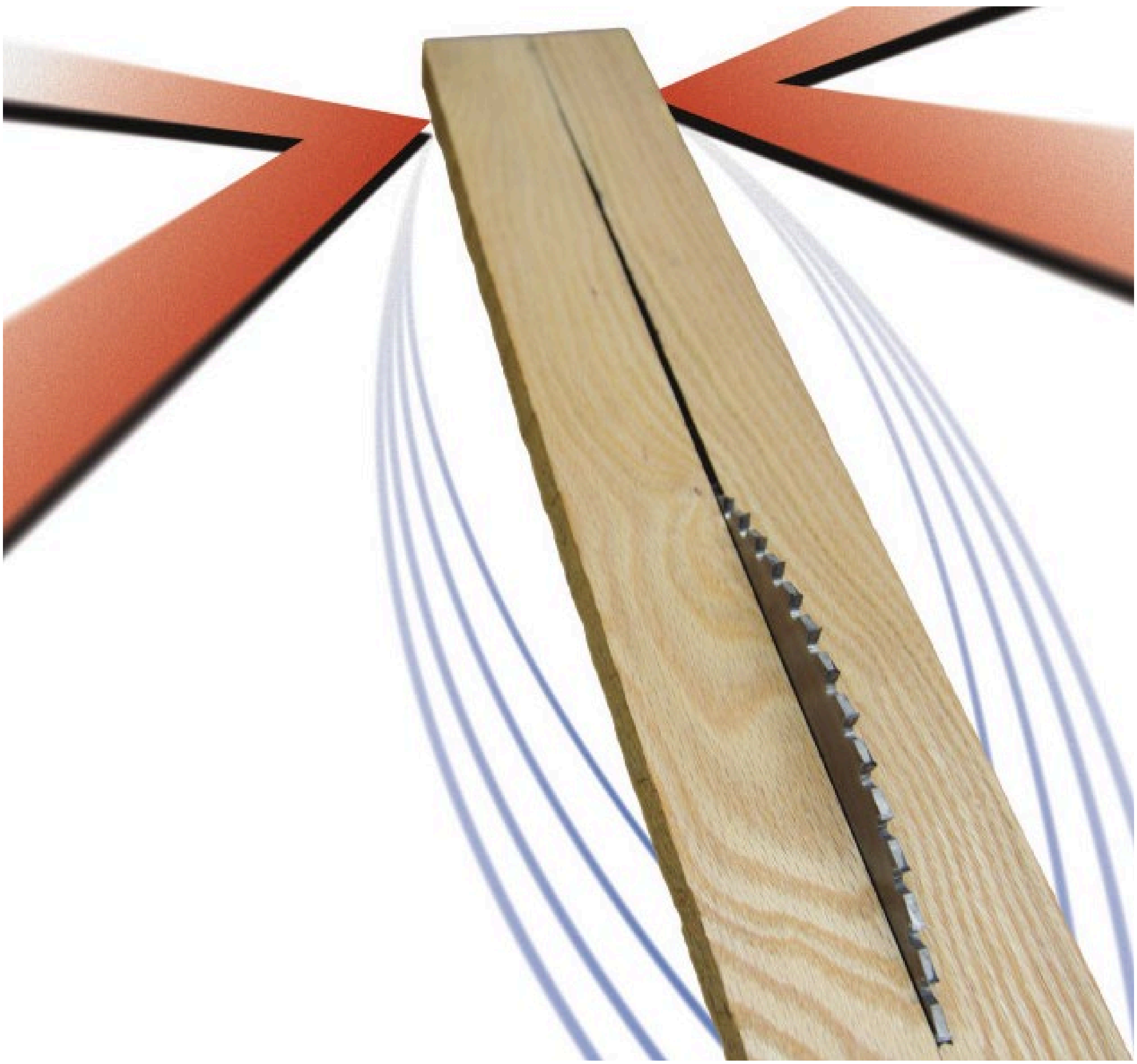
Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Forest Products Laboratory | General Technical Report FPL–GTR–298 | June 2023

Casehardening: A Misnomer

Understanding Heat and Moisture Effects in Air and Wood

Mark Knaebe



Abstract

Casehardening is commonly misunderstood. This report should improve understanding of wood moisture issues, especially for the woodcrafters and woodworker.

Keywords: bend; board; caseharden; compression; condition; dehumidification; drying; equilibrium moisture content (EMC); equalize; equilibrium; hardness; humidity; kiln; moisture; plastic; set; shrink; steam; stress; transition; warp

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June 2023

Knaebe, Mark. 2023. Casehardening: a misnomer—understanding heat and moisture effects in air and wood. General Technical Report FPL-GTR-298. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 9 p. https://doi.org/10.2737/FPL-GTR-298

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Casehardening: A Misnomer

Understanding Heat and Moisture Effects in Air and Wood

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Introduction

An early FPL report stated the following:

> Casehardening is a condition of stress and set in wood in which the outer fibers are under compressive stress and the inner fibers under tensile stress when the wood is uniformly dry.
>
> They therefore blamed "casehardening" for all their troubles. Early research workers found that the cause was stress, not hardness. They retained the name "case hardening," however. (McMillen 1958)

At the Forest Product Laboratory, we receive many questions regarding casehardening (see Appendix A for frequently asked questions) and this report is intended to help eliminate confusion on the issue of casehardening. Methods of assessing the problem include the prong test (Fig. 1) and another test in which a board is ripped lengthwise to create longitudinal stress sticks.

Casehardening becomes a problem when dried (usually kiln-dried) wood is remanufactured. A common example can be seen while ripping a board in which the pieces pinch the blade so badly that the operator must stop and insert wedges. The ripped boards will be warped, having significant sweep, with the newly cut side being concave.

A brief review of wood moisture content (MC) will help in understanding the problem. Typically, a living tree is about half water. People in the lumber industry call this 100% MC (dry basis) and the wood is referred to as green. People in the wood energy industry call this 50% MC (wet basis), because wet basis more closely predicts the energy available in firewood (Knaebe 2014).

On a dry basis,

$$\text{Moisture content (\%)} = \frac{\text{Weight of water in wood}}{\text{Weight of totally dry wood}} \times 100$$

On a wet basis,

$$\text{Moisture content (\%)} = \frac{\text{Weight of water in wood}}{\text{Weight of dry wood and water}} \times 100$$

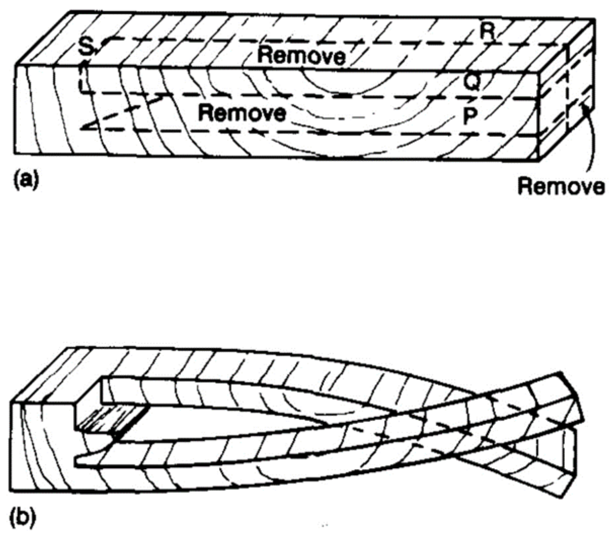

Figure 1—The two-prong test. (a) Method of cutting stress sections for severe casehardening tests. (b) Prongs are offset so that they can cross and indicate severity of casehardening. (Simpson 1991, p. 126)

If you attempt to dry a log before cutting it into boards, you will likely be disappointed because as wood loses moisture it shrinks. If the shrinkage were the same in all directions, a dried log (which is difficult to achieve and very time consuming) would just be smaller than a green one. However, if you cut a disk from a log and dry it, the result looks like a pie with one or more slices missing where the wood has split from the pith to the bark and the disk has opened up. The reason is that wood shrinks more in circumference (tangentially) than it does going from the center to the bark (radially). If you soak that dry disk in water, it will swell again, and the "missing" pie slices tend to close. Chapter 4 of the *Wood Handbook*, entitled "Moisture Relations and Physical Properties of Wood," provides additional details (Glass and Zelinka 2021).

Although you cannot prevent a log from splitting, you can force it to split where you want it to by cutting a slot along the length of the log from the bark to the center of the green log. This is done by precision log home manufacturers so that they can hide the split on the bottom of each course. Not cutting that slot may result in several smaller splits, creating many places for water to enter. If you were to cut a dry log into boards, the boards would end up with many deep cracks or may even separate into splinters. So if you want boards, the first step after felling a tree is to cut boards from the green log. Then the boards can be carefully dried.

Traditionally, boards were air dried under cover (to reduce rain wetting and direct exposure to sunlight), with the piles of boards separated by dry sticks (called stickers) to let air flow through the pile. Note that wet and large stickers can result in sticker stain because of the reduced drying rate of boards in those locations, resulting in undesirable visible chemical and biological processes. The final MC of a board, called the equilibrium MC or EMC (Glass and Zelinka 2021), depends primarily on the ambient relative humidity (RH). 50% RH corresponds to about 9% EMC; 65% RH corresponds to about 12% EMC. (See Appendix B for more on moisture in air.)

Depending on species (specific gravity is the most important characteristic of species), board size, and climate condition, covered boards outside can take a year or more to reach EMC. People commonly say that air is very dry in the winter, but outside the RH can be quite high. In cold climates, wood stored outdoors, including firewood, does not dry from November to April. There is not a lot of moisture in the air, but when it is cold, the air is holding close to as much moisture as it can possibly hold (that is, it has high RH). The RH dictates how fast water leaves the surface of a board. Therefore, in a cold climate in winter, wood dries very slowly because there is little driving force for water to evaporate from the wood surface and drying is further slowed because of the effects of the cold itself, which slows everything. (See Forest Products Laboratory (1999) for additional information.)

As water evaporates from the wood surface, water deep inside the wood migrates to the surface to also evaporate. About half the water in a green log is free (liquid) water. (There are a few atypical species, such as white ash, which has only about a quarter of the water as free, or cottonwood, which has 5/8 of the water as free.) The remaining water is bound to the wood. The free water leaves first, with no change in the shape of wood. There is a designation, called fiber saturation point (FSP), in which the free water is gone, and the bound water will begin to leave. For most species, this is about 30% MC. It is this bound water that keeps wood in the swollen condition, and when it leaves, the wood shrinks. The relationship of RH and the dimension of a piece of wood is not actually linear but is close enough to be assumed linear for our purposes.

To shorten the drying time, kilns were developed; table 1-6 in the *Dry Kiln Operator's Manual* (Simpson 1991) shows the EMC at various temperatures, wet-bulb depressions (described below), and RH to show the ultimate goal of each step of a dry kiln drying schedule.

During the kiln drying process, the surface is drier than the interior of a piece of wood. (See Appendix C for more on moisture in air in the kiln.) The warmer the temperature, the faster moisture moves throughout a board and can migrate from the center of the board to the surface to evaporate. Ideally, the range in MC throughout a board should be small to reduce degrade. For species that can handle high temperatures (primarily softwoods used mostly in construction), schedules go well above 220 °F, and the wood can be dried in a single day.

In short, the dryer the air, the faster a board surface dries, and the hotter the temperature, the faster moisture leaves the center of a board. For many species, even slightly elevated temperatures or air that is too dry, at least in the beginning of drying, will degrade the wood. This degradation is apparent by staining, enzymatic darkening, or other discoloration, but also by defects such as collapse, honeycomb, and immediately visible (by inspection) surface checks and end checks. Dry kiln schedules are designed to limit degrade and are based on temperature and humidity limits during the stages of drying. If you have time, you can use a milder schedule to reduce degrade.

Unlike softwoods, very dense hardwoods, such as live oak or weakened bacteria-infected wood, must be air dried (or a less expensive pre-drier can be used) until reaching the FSP; this will save valuable kiln time. This might take months or years. The kiln is started at about 100 °F with a high humidity of 90% (which corresponds to a wet-bulb depression of 3 °F), and it might take many weeks to dry.

A dry-bulb thermometer is just a normal thermometer that accurately indicates the ambient temperature. Adding a sock (a cloth sleeve) that wicks water from a container will create a wet-bulb thermometer that can be used to indicate RH when it is compared to the dry-bulb thermometer. To get representative temperatures, the bulbs should be positioned so that air flows by. It is even more important that the wet bulb be in a location where air flows across the sock to facilitate evaporation. The difference between the temperatures is called the wet-bulb depression. The wet-bulb depression is also affected by the speed of air over the wet sock. The drier the air, the faster water evaporates from the sock, and the more it cools its thermometer compared to the dry bulb. This phenomenon is similar to a person climbing out of the ocean in a dry climate (even if hot) and being cold until the water evaporates.

Casehardening

The Problem

To understand "casehardening," it is useful to discuss steam bending, a process that is likely more familiar to woodcrafters. It is well known that wood can be bent into different shapes using steam to make the wood more flexible. (See Appendix D for more on bending wood.) During steaming, both the MC and temperature of the wood are increased until the wood polymer lignin passes through its glass transition, which means the lignin transitions from a stiff glassy phase to a softer rubbery phase. In the softer rubbery phase, the lignin can flow. Once wood is properly steamed, the plasticized lignin flows as the woodcrafter bends the wood into a new shape. Then, if the shape is held while either the temperature, MC, or both are decreased, the lignin passes back through its glass transition into its stiffer phase, and the wood is "set" into its new shape. If the shape needs to be adjusted, the steaming process can be repeated. Ripping a steam-bent piece of wood will have unpredictable results. (See Appendix E for more on plastic flow.)

During kiln drying, the temperature and MC of wood are high enough that the lignin is above its glass transition phase and is in its softer rubbery state. The lignin can therefore plastically flow to relax any stresses that are in the wood. During drying, the center of a board is wetter because it is always playing catchup to the drier surface until the final steps of the schedule, when moisture is added in the hope of removing any moisture gradient. Casehardening occurs when a board has a moisture gradient and the temperature is decreased to the point at which the lignin passes back through its glass transition and becomes stiff again. The moisture-swollen core will form stresses with the drier outside of the board when the moisture equalizes. As the MC of the core decreases and the wood tries to shrink, it cannot because it is restrained by the drier outside, and stresses form inside the wood. This sets up a condition set in wood in which the outer fibers are under compressive stress and the inner fibers under tensile stress. Those tension stresses reveal themselves when the board is cut. Note that a hot board still in the drying process, having differential moisture but no stresses yet, can be cut and will not be distorted until the moisture equalizes in the next day or so. Casehardening can be avoided by preventing set while there are moisture gradients. In the absence of adding moisture at the end of a schedule, gradients can be minimized by drying the surface slowly, using high temperatures to increase the rate of moisture equalization in a board, or both. For many species, neither of these are possible, at least without the use of chemicals. Alternatively, if wood is kept above the glass transition temperature for long enough for any gradients to dissipate, such as conditions for an EMC of 16% to 20% MC, it is theoretically possible to produce stress-free wood, and this final step could be called a longer, milder conditioning step.

Softwoods that are used in construction are generally not remanufactured except for surfacing, cutting tongue-and-groove lumber, and sawing to length. Therefore, internal stresses are not revealed unless a carpenter rips a nominal 2×4 into two 2×2s, for example. The warped 2×2s can be straightened while attaching them to larger members, so casehardening is less of a problem. People who use softwoods for furniture or other products in which hardwoods are typically used should be aware that unless specifically dried for these purposes, users may have problems, and should realize that the softwood companies are not doing anything wrong. Hardwoods, on the other hand, are subject to a lot of rip-sawing, and stresses will become a problem if the wood is not properly conditioned to reduce or eliminate casehardening.

At the end of kiln drying (when RH in a kiln has been lowered to 20% to 30%), there is still a moisture gradient in the wood. To avoid casehardening, commercial kiln schedules recommend that the humidity be raised at this stage to 40% to 50% for 1 to 5 days to equalize the MC in the different boards. Then, to bring the outside of the boards to a similar MC as the inside (called conditioning), the RH is raised even more (80% to 85%) for 1 to 2 days.

The Solution

The goal is to eliminate MC gradients in every board by the end of drying. Assuming it is still above the glass transition temperature, because the boards are warm in the kiln, permitting plastic flow, there are no stresses. Once a board has no (or at least minimal) moisture gradient and it cools before moisture gradients can develop, no stresses develop during cooling.

Plastic flow relaxes tension stresses, but it requires a high temperature. Moisture lowers the temperature required for plastic flow (that is, it lowers the glass transition temperature) so that during cooling a drier part of a board will stiffen before a wetter part. Because the goal is to avoid a moisture gradient when cooling, the implications of this time difference between the set of different parts only adds confusion, so it will not be discussed further.

If weeks after drying a charge of lumber you discover that you have a pile of lumber that is full of internal stresses, you have a second chance to do the conditioning by going back to the kiln and warming the boards with steam. It may be worth aiming for 20% MC (using a wet-bulb depression between 2 and 3 °F) and bringing the temperature to at least 130 °F (140 °F or higher is probably better) for 2 or 3 days. When going back to a high MC is problematic (as in hardwoods), reaching the softening point at a high temperature at lower MC may be best. These are the moisture and temperature conditions necessary for the lignin to become softened and plastically flow so the stresses can be relieved. While warm, stresses are relieved, and then the moisture gradient can be decreased, followed by cooling.

Careful dry kiln recordkeeping will enable you to determine a precise cause and a precise solution to repair mistakes. By cutting samples into pieces (beyond preparing kiln boards), weighing immediately and again after equilibration or by experience, you can determine if the MC is equal throughout a board. You can then cool the charge. If the MC is uniform throughout the board, but still high (above 20%), it can take weeks for the wood to reach EMC at these cooler temperatures, but at least stresses will not develop. To speed up that last step, it would be simplest to extend conditioning while warm, with a wet-bulb depression of less than 10 °F. The hope is that as moisture leaves the surface, the center is not long behind. Now you can cool the charge. What determines the degree of set ("the problem") is the differential MC when you begin cooling. Be careful not to over-wet the surface or you will create reverse casehardening, which can be more complex to remove.

Hardness

Finally, the hardness of wood of different species is related to specific gravity (Wiemann and Green 2007), which can be related to growing conditions. However, when looking at one piece of wood, its hardness (as well as other properties such as strength and stiffness) is solely related to its MC and not "casehardening." As early as 1920, Wilson (1920) plotted compression crushing strength, which is related to hardness, versus MC. The plot is linear from 2% to 12% MC, then it begins to curve at higher MCs. Above the FSP, moisture only makes wood heavier without affecting strength.

Assuming that a piece of wood is not altered by chemicals or extreme heat, such as torrefaction, its hardness goes up and down dependent primarily on humidity. Therefore, after excluding the effect of specific gravity and its relationship to species, the hardness of a piece of wood is determined solely by its MC.

A moisture gradient at the end of drying can cause internal stresses that result in failures, such as warping or even collapse. These constitute reductions in properties and therefore reduced value. The conclusion by some woodworkers that improper drying causes excessive hardness is incorrect. Hardness is a function of current MC, not MC history. A board that seems excessively hard may be over dry, either on its surface or throughout the board. When properly dried, the process of equalization produces uniformity among all the boards, just as conditioning produces uniformity within each board. Excessive "hardness" is not the result of improper drying.

Appendix A—Frequently Asked Questions

I've overdried my wood, is it ruined?
Perhaps. What makes you think you did? How does it look? If the board is simply tension set (casehardening) and a cut board pinches the blade, there are potential solutions.

Why did my wood become so hard after drying?
If it is not over dry (which will change as it reaches EMC), that is just how hard it is.

When I cut my dried wood, I see honeycomb. Did I cause it to caseharden?
No, you dried it too aggressively. Some species require you to be gentle (see kiln schedules). There is no fix for this—any surfacing or cutting will expose damage. If you are gluing up a larger piece, such as a tabletop, it may be possible to hide the damage in the glue joints and only very lightly surface.

Why did my 1-by boards dry fine, but all the 2-by boards are warped?
That indicates tension set. With thinner boards, the interior MC can more easily keep up with the outside. This assumes that the boards came from the log randomly with random grain angles.

I can't rip the boards without pinching the blade and burning. Did I dry too fast?
Maybe, but you certainly did not have a low moisture gradient when you began the cooling. It's worth going back to the kiln.

The shaker boxes I made are very brittle. Did I caseharden somehow?
Maybe, but just as likely they are too dry (which will change in time) or you are not used to the species hardness at EMC.

My new floor squeaks and makes cracking sounds. Is it casehardened?
It's more likely that the humidity got too low over the winter. The moisture of flooring is set to 6% to 8% when it leaves the mill, which corresponds to a RH of 30% to 43%. The more the flooring gets out of that range, the more your wood will move. It can be more common in engineered flooring because sealer and varnish are not used after installation, which in typical installations may glue boards together. Neglecting to use rosin paper beneath may also contribute to sounds. Screwing tightly may be necessary. (See Appendix G for more on wood flooring.)

Why is my floor cupping?
That happens most often when the floor is installed over a vented crawl space, especially if you have air conditioning. You need to make sure that air in the crawl space has very similar temperature and RH to air in the living space. This means sealing the vents and exposed earth below and may involve connections to your ductwork or placing two small fans strategically in holes in the floor. Boards can also have a higher MC on the bottom (causing cupping) when the space below is cooler.

When I rip boards, why do they warp and pinch the blade, even with humidity control in my shop?
RH control in your shop is important, especially when shipping products to wetter climates, but you have tension set (casehardening).

Will heat sterilization of wood cause casehardening?
Only if you have a moisture gradient when you cool the load.

Why do my boards come out of the kiln flat, but then warp later?
They came out of the kiln with a moisture gradient that became a stress gradient when the moisture equalized.

Will kiln drying to below 15% prevent warp?
Only if there was not a moisture gradient when cooling began. There is also the issue of reaction wood (resulting from growing conditions), which can be problematic.

Appendix B—More on Moisture in Air

The amount of moisture in air is most easily described by its dew point. Dew point is the temperature at which water vapor in air condenses. Dew, or condensation, forms on the outside of a container of ice water (32 °F) (especially one made of aluminum because it conducts heat so well) when the dew point is above about 33 °F. On a day in Phoenix, Arizona, when the temperature is 80 °F and the RH is 16%, the dew point is only 31 °F, and no condensation will form on an ice-filled aluminum container. A different case would be a drink with alcohol, which depresses the freezing point, so the liquid could be below 31 °F and moisture from the air would condense on it. An online dew point calculator (such as the one available at http://www.dpcalc.org/) will clearly demonstrate the relationship.

This dew point relationship explains why we can have dry skin when the RH outside is very high. Like our skin, wood is most affected by RH, which is a function of dew point and temperature. The effect on our skin is a little more complex because we actively heat it and in a related way it is why wind chill has no effect when the air temperature is the same as that of our skin. (Note also that wind chill does not affect the difficulty of starting a car that has cooled to ambient frigid temperature, although it does affect how long it takes the car to reach ambient temperature.) Air having a dew point of 31 °F has an RH of 100% when the temperature is 31 °F; the humidity is as high as it can get. As the air warms, it gains the capacity to hold more water. That same air at 41 °F has an RH of 66%; at 51, 61, and 71 °F, it is 47%, 31%, and 22%, respectively. Twenty-two percent RH calls for skin lotion and a humidifier. The dew point is always as low as, or lower than, the outside temperature. When you bring 0 °F air inside and warm it to 71 °F, the RH is at most 6%, and the EMC of wood is only 1.5 %. It should be noted that for a healthy environment, you should have 35% exchange of air every hour (less than 3 h to replace all the air) (EPA 2023), so a lot of dry air comes into a healthy home in winter. With the newer tighter construction methods, homes are too tight and require heat recovery ventilation (HRV) to provide enough fresh air. For a 1,500-ft^2 home, one fan pumps out about 70 ft^3/min (CFM) of dirty air from areas such as bathrooms to the outside while a second equivalent fan pumps in fresh air. The two streams of air pass each other by a variety of methods to recover up to 95% of the heat. Many use material barriers that permit moisture passage, so less re-humidification is required. They also work in reverse in air-conditioning climates, keeping most of the heat and humidity outside.

In humid locations, even when there has been no rain, grass is often wet in the early morning because it is cooled below the dew point. On cloudless nights, heat from the grass (and any location without trees, clouds, or other barriers above) radiates into outer space (called black body radiation). When the temperature of the grass is below the dew point, we get dew. Similarly, the ceilings of open porches and pavilions in humid climates are frequently covered with mildew due to condensation because of this phenomenon. The solution to the problem of mildew is to insulate between the ceiling and the roof to keep the ceiling warmer. Most builders would consider this a waste of time and money because the structure has no walls.

Appendix C—More on Moisture in Air in the Kiln

During kiln drying, air flows though the stack and collects moisture. By the time the air exits the stack it has a higher RH. The forces for water to leave the surface of wood reduce as the moisture in the air increases. That means the boards at the far end of the stack will not get as dry. It could be described as increasing moisture back pressure as the air travels through the stack. The primary solution to this problem is to use reversing fans so periodically the air flow changes direction, and the wetter boards (now at the beginning) get to catch up or even surpass the dryness of wood at the other side of the stack, at which time the fans are again reversed.

Increasing the air flow also helps even out the rate of drying because the air has less time to absorb moisture. Wood at the end of a stack is exposed to air that is similar to air at the beginning, and drying is more even. The energy required to operate fans results in significant expense, so unless high fan speed gives a significant cost savings, higher fan speed may be an unnecessary expense. Furthermore, many species require slower drying; this is controlled by temperature and humidity, so a high fan speed helps little.

When experimenting with a new kiln, especially a dehumidification kiln, increasing fan speed may seem the only solution to even out drying between boards at the top of a stack and those at the bottom. In the beginning of drying with limited overhead fans a temperature stratification can develop. The air at the bottom is cooler, so it is denser. Most air coming down from the fans follow the easier path, primarily traveling through the top of the stack, so the flow rate through the top of the stack can be many times the rate at the bottom. This is a problem. Adding fans or increasing fan speed overrides the density difference, preventing stratification by mixing the air, but there are more economical solutions if a high fan speed is not necessary for other reasons, such as the need to quickly dry structural lumber. When fans are located on a side or beneath the load, cooler air at the bottom is just as likely to travel to the fan, resulting in mixing of all the air and no stratification develops. This alternate location of fans can permit taller stacks of wood when you have height restrictions. When fans are located on a side, some directional baffling may be necessary to direct air traveling to and from the far end of the load. With slow airspeed, back pressure from the sticker space tends to even out flow. Of

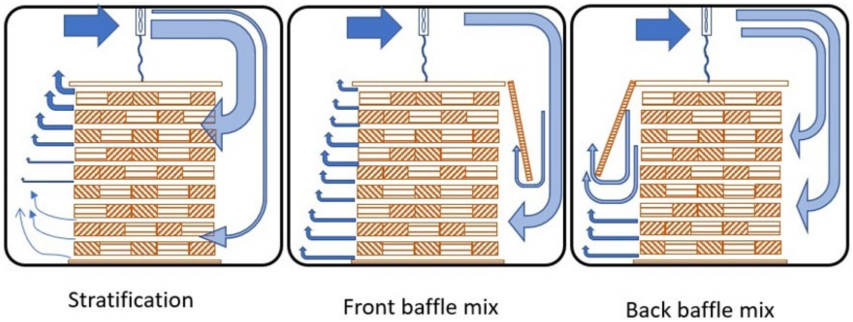

Figure 2—Baffles to promote mixing when fan speed is slow.

course, you still need the baffle from the top of the kiln to the top of the stack to prevent air from short circuiting.

With fans located above, an alternative to higher velocity air is to add a baffle extension from the top of the stack to the front, back or both sides of the stack. Figure 2 shows

uneven flow in the first panel followed with two baffle options. Any arrangement that forces air towards the floor or draws if from the floor will force mixing. If drying at a high rate, reversing air flow direction may be helpful.

With steam or hot water kilns, radiators near the floor will force mixing and reduce any temperature gradient (stratification). An additional small fan near the floor would also force mixing.

Appendix D—More on Bending Wood

Although requiring a pressure vessel, there is a way to bend wood into extreme shapes, mostly for the novelty of doing it. An example is to carve an arrow (with a large head and tail) out of wood and insert it through a hole that is barely large enough for the shaft in any stiff material (including wood). The arrow is placed in a vessel with anhydrous (meaning without water) ammonia and brought to a pressure to liquify it (about 110 lb/in^2 or 750 kPa). When soft, the arrowhead is forced through the hole and permitted to re-expand. If all of this cannot be done while under pressure, which requires remote fixtures, it can be done quickly after removing it from the vessel. If the ammonia has evaporated before the arrowhead has re-expanded, it may be necessary to return it to the vessel to repeat the last step.

Appendix E—More on Plastic Flow

A trick carpenters have used for years involves wetting wood to remove dents. A small dent in wood from a misplaced hammer blow or other impact can be removed with water alone, but larger dents may additionally need heat. The dented wood is under extreme stress, which can be relaxed. Filling the dent with water and covering it with a wet cloth followed with a hot iron to steam the dent removes it in seconds. The warmth and moisture allow the wood to move to relax and relieve the stress. Because the wood cools before moisture equalizes, there may be some residual stress in the area of the dent, but that stress is unlikely to be revealed later.

Appendix F—More Reasons Why Wood Warps

Growing Conditions

In general, shrinkage in the longitudinal direction, which usually corresponds to the length of a wooden piece, has low shrinkage (0.1% to 0.2% from green to ovendry). Radial shrinkage, which is perpendicular to the direction of the growth rings, ranges from 2% to 6%. Tangential shrinkage, which is in the direction of the growth rings, ranges from 7% to 12%. The values for individual species are available in chapter 4 of the *Wood Handbook* (Glass and Zelinka 2021).

Juvenile Wood Longitudinal Shrinkage

Unlike mature wood, the longitudinal shrinkage of juvenile wood can be several percent. Juvenile wood includes up to the first 15 growth rings, with the highest shrinkage in the first few rings. The pith, located in the tree center, begins the juvenile wood zone. A board with pith on one side is almost guaranteed to have severe end-to-end warp, concave on the pith side. Juvenile wood is also prone to cross-grain checking, in which the rings separate, because it is surrounded by mature wood that has very little shrinkage. To avoid this problem and still use the pith, nominal 4 by 4 posts are generally sawn so that the pith is in the center (boxed heart)—these posts can remain straight and have maximized strength by concentrating the stronger mature wood farthest from the neutral axis. If such posts are used in contact with the ground, decay is likely. If the posts are cut from small pine stems, the corners may be sapwood and will be durable if treated, which can be discerned by the green color of common water-borne pressure treatments. The green color may not be visible in some “premium” treated wood because pigment or a dye hides it. Because heartwood is difficult to pressure treat, a species such as Douglas-fir, which has little sapwood, is said to be refractory. When

Douglas-fir is pressure treated, it must be incised (many knife cuts), which makes at least the surface treatable.

Oil-based preservatives such as creosote and pentachlorophenol are used for power poles and railroad ties. Oil-based copper naphthenate is an excellent field-applied preservative and is worth considering for dry (a few weeks kept off the ground) nominal 4 by 4 treated posts from a few inches above ground to at least a foot below. Other preservatives found in siding and deck coatings cannot protect areas in ground contact, but their water repellency above ground slows liquid water absorption, reducing cracks and checks, which extends life.

Reaction Wood

Reaction wood also has abnormal shrinkage, especially in the longitudinal direction. In hardwoods it is called tension wood and forms on the upper side of leaning stems or branches, or on the windward side of a tree in constant strong wind. In softwoods it is called compression wood and forms on the lower side of leaning stems or branches or on the leeward side of stems exposed to prevailing wind. Reaction wood has axial movement due to moisture changes that are similar to those in juvenile wood and can be just as much of a problem. When limbs are large, (for example, when they are from trees grown in a park setting), you may be tempted to use them for lumber. You may have some success after throwing away the top half (in a hardwood) or the bottom half (in a softwood) because the remaining "opposite wood" has normal properties.

Spiral Grain

Some trees have a tendency to produce spiral grain (Fig. 3), which is usually visible in the bark. A log or large timber with spiral grain will twist with fluctuations in MC. Planing a board flat at one MC and moving it to a different MC will result in a twisted board. Cutting boards oversized makes it possible to plane them flat after reaching final MC—the wood must be machined after it has reached its service MC. A simple device called the swivel-handled scribe is similar to a phonograph needle attached to the end of a bar that can swivel in the handle (Fig. 4). As you drag the scribe down the wood, the point will follow the grain, leaving a small indentation showing the direction of grain.

Figure 3—Example of spiral grain in a utility pole.

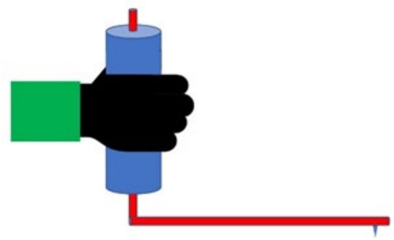

Figure 4—Scribe for determining grain angle.

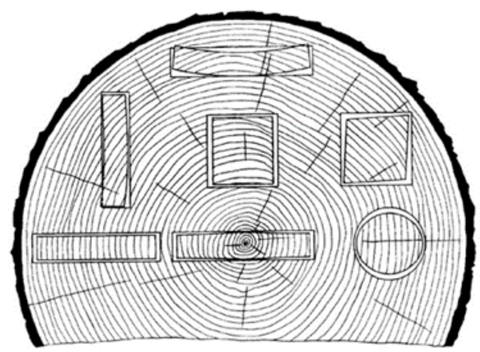

Figure 5—Characteristic shrinkage and distortion of flat, square, and round pieces as affected by direction of growth rings. Tangential shrinkage is about twice as great as radial.

Radial–Tangential

The introductory section of this report discussed the shrinking and swelling of "pie slices" when drying and rehydrating. A similar problem, in which a flat-grained board will cup to the bark side as it dries, is shown in Figure 5. If the moisture of that board is then increased, the cup will revert towards its original shape and look more like it did before drying. Its shape will change as moisture changes. If that dry board is planed flat and then its moisture is increased, it will cup to the pith side. To prevent an obvious warp of a glued-up tabletop, woodworkers alternate boards bark side up and bark side down so that if moisture changes, the resulting wavy pattern is less visible. This is another reason to make products under the conditions they will see in service. It should be noted that an edge-grained (also called quarter-sawn) board maintains its shape better; it just gets a little smaller as predicted by shrinkage rates. For laminated timbers or other objects glued up to increase thickness, all pieces should be close to their EMC, especially if there is a mixing of grain angles; this way fewer stresses will develop if a radial surface is glued to a tangential surface. Mixing grain angles of finger-jointed wood (a way to make straight boards by removing knots) also creates stresses if MC changes after assembly. Rustic furniture with dowels fitted into drilled holes has many combinations of grain angles—movement will vary with MC swings, and the joints will require close attention. If you manufacture wooden items to be shipped to a destination with a different climate, it would be worthwhile to create a conditioning space matching the destination, then make and carefully wrap the item, and ship promptly. A surprising practice of flooring manufacturers is to bring the MC to 6% to 8% (corresponding to the EMC of a RH range of 30% to 43% at 75 °F) regardless of where that wood will go. It is always a good idea to sticker flooring boards (for at least a week, with fans) in the location where they will be installed. If you cut, dry, manufacture, and use what you made under museum conditions (that is, under very tightly controlled temperature and humidity), you should not have problems.

Tabletop Cleats

A tabletop made by laminating boards, even alternating bark and pith sides, and then attached to cleats at the underside to attach legs and to increase stiffness could present a problem. The width of the table will swell and shrink with increase and decrease in MC as dictated by RH. Because the length of a board changes very little (except for juvenile or reaction wood), a cleat will not move as the top moves. As humidity increases the top expands and will crown because it is being held in place by the cleats. If the tabletop shrinks as conditions dry, it will form a large cup. The solution is to tightly fasten the center of a cleat to the center of the table and then use slots in the ends of the cleats so that screws can slide and not restrict movement in the long direction of the cleat.

MC Differential Top and Bottom in Deck Boards

Deck boards almost always become cupped. One explanation is that with drier conditions on the top (due to sun and wind) and wetter conditions on the bottom (due to proximity to wet soil), temperature and humidity differences produce a moisture gradient of 1% to 3%. Dark-colored wood in full sunlight, where the top is dry and the soil beneath is wet, show the greatest effect. Cupping can be reduced with a lighter color wood if exposed to sunlight and by covering the soil, providing drainage, and increasing below-deck ventilation. This cup is reversible, such as after a period of dry weather, for a raised, ventilated deck that is out of sunlight, if the MC equalizes from top to bottom. Unfortunately, this is not the primary cause of cupping, as discussed in the next section.

Fiber Crush in Top of Decking from Liquid Water

Without a water-repellent coating, deck boards will continue to cup for another reason. Liquid water rushes into wood exposed to rain, but it can only leave slowly as a vapor. The difference between these rates can be two orders of magnitude (100 times). After a dry period of a week or more, the wood will have a MC close to its EMC. For much of the United States, this is about 12%. When it rains, the top of a board can quickly reach fiber saturation (30% MC), but it will take time for the bottom to catch up. The bottom of a deck after a rain may have wet spots from water that ran around the edge, but it will not be nearly as wet, nor will it stay wet for as long, as the puddles of water on the top. Soon the top has forces that would cause it to expand, but it is being restrained by the majority of the board. The result is that the surface fibers experience transverse buckling, causing an irrecoverable plastic deformation. Now when the board dries, tension stresses are formed on the top, causing the board to cup. Cracks also develop on the surface as a result of these stresses; this allows water from the next rain event to penetrate faster and deeper. A premium deck can become unsightly and dangerous (although not decayed) in well under 10 years due to lack of water repellency. A cheap coating of wax or paraffin oil applied yearly, or a good coating with wax and pigments applied every 5 to 8 years, could greatly extend the life by slowing the rate of liquid water entering to match the rate of moisture exiting. Look for water to bead up on your deck. Some expensive tropical woods that are naturally oily have a natural water repellency, at least initially.

Deck owners who used screws or another reversible attachment method have had remedial success by removing and flipping the boards over. When they become less crowned, a water repellent should still be considered. Regularly flipping boards will crush the fibers on both sides and cause the boards to narrow over time.

Other Causes

Other causes of warp in flooring boards included crawl space under air-conditioned rooms and in-floor heat.

Appendix G—More on Wood Flooring

Wood flooring can have moisture issues unrelated to precipitation, usually cupping or crowning. Most common problems are related to ventilated crawl spaces in humid climates, especially if the living space has air conditioning. Moisture from humid air (which comes through the vents) migrates into the floor from below. A small air conditioner, which accentuates moisture removal in the living space, can dry the top of boards and causes cupping, similar to decking in the sun. Oversized air-conditioning units run intermittently and maintain the set temperature while removing less water, which can actually create a more clammy environment. In this case, the major issue is that the top of the board is cooler in an environment with more moisture in the air, which leads to a higher MC and boards that may crown. A confounding issue may be the moisture-excluding effectiveness of a thick varnish, but other than saying that moisture flows may be decreased by 25% to 75% (so time to equilibrate is a little longer), the issue is beyond the scope of this report. In almost every case, the solution is to seal the crawl space vents, cover the earth with a plastic barrier, and match the crawl space conditions to those of the space above the wood floor. With the space sealed, one method to match conditions is to connect small ducts (in and out from opposite corners of the space) to and from the ventilation system. Alternatively, a small fan (such as a 5- to 10-W cooling fan of the type found on computers) used with similarly placed holes in the floor will work well. One fan is good, but two fans (one blowing down and one up) decrease the pressure difference between spaces, which helps when the space is not perfectly sealed.

Using EMC charts and knowing that the dewpoint of air does not change with heat alone, you can calculate a substantial lowering of MC from small increases in temperature. When in-floor heating is used, a room at 70 °F with a RH of 50% will have a dew point of 50 °F and EMC of 9.2%. By raising the temperature of the heating elements to 80 °F, the EMC drops to 6.6%; the dew point remains at 50 °F, but the microclimate on the bottom of the boards is at a RH of 35%. If you go to 100 °F, the EMC drops to 3.8%. Considering that some hydrothermal boilers are set to 180 °F (where EMC is close to oven dry), it becomes clear that hydronic heating underneath wood flooring cannot come from the same system. A separately controlled loop is required (consisting of a sensor, valves, and pump) if the boiler will be producing higher temperature water for other purposes, such as radiators or towel driers. In well-insulated homes, with very large floor surface area, 80 °F can be warm enough to heat a home. If not, a few ordinary radiators, strategically placed, may be necessary. Dropping the MC much below 6% will cause cupping on the bark side (Fig. 4). Because floorboards are installed randomly, some will be bark side up and some bark side down—some will cup while others will crown. There will also be separations between boards that are drier than when they were installed. The yearly increase in MC when the heating season ends causes stresses to form in boards. Moisture swings from highest in the summer to lowest in the winter, so set your under-floor temperature to as low as acceptable. Because of thermal conductivity, tile and other masonry products feel cooler than wood at room temperature. They are a better surface to warm from below where 100 °F is acceptable.

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