

THE EFFECT OF DRYING ON GLUING AND MACHINING

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Understanding the needs of the customer is essential for effective marketing; however, it is equally important for proper manufacturing of a product. The lumber produced in Western North American is much more likely to be processed further today than 10 years ago. This means that the lumber we produce is more likely to be machined and glued. The result might be a nonstructural product for which appearance and durability are important. Or, it might be an engineered wood product where strength and durability are important to product performance and appearance is important to the confidence of the consumer. The objective of this paper is to make the kiln operator aware of how drying lumber affects gluing and machining,

Gluing

By gluing, we mean applying an adhesive between two pieces of wood, bringing the surfaces of the pieces into close contact, and holding them in that position until the adhesive has cured enough to prevent the pieces from separating. After the adhesive is fully cured, it should be stronger than the wood. That is, if we try to pull the bond apart using a testing machine, most of the failure should be in the wood rather than the glue line.

For a good bond to form, the adhesive must demonstrate both cohesion and adhesion. Cohesion means that the adhesive must bond well to itself. Adhesion means it must adhere well to the wood. A good portion of the adhesion between glue and the wood is simply due to mechanical fastening. This means that the glue has penetrated into the wood cells and hardened so that the surface of the glue and the surface of the wood are intertwined. Secondly there are electronic forces of attraction between the molecules of the wood and the adhesive that provide some holding power. Chemical bonding also provides holding power.

Three things must happen as the wood and adhesive are brought into contact: the adhesive must wet the surface of the wood, there must be good contact between the wood surfaces, and the adhesive must penetrate into the wood.

On a wettable surface, the adhesive will spread out. On a nonwetable surface, the adhesive will have a greater affinity for itself than for the wood, and a drop of the adhesive will not spread out on the surface of the wood. A familiar example of this of this is the hood of your car before and after you apply wax. Before waxing, water spreads out and forms a layer on the wettable surface. After waxing, the water beads up because the water and wax repel each other. An observation of the angle formed between a water droplet and wood is used as an indicator of the how well and adhesive is going to wet wood. This is called the contact angle and is shown in Figure 1.

Most of the adhesives used in manufacturing are not formulated to fill gaps between the two pieces of wood. Thus, the wood surfaces must be brought into close contact so that the adhesive forms a thin, continuous layer. To accomplish this the wood must be machined, usually flat, so the surfaces mate.

For an good bond the adhesive should penetrate 2 to 3 cells deep into the wood. If penetration is greater than this, the manufacturer is wasting adhesive. If the penetration is less than this, the bond will not be very strong and will fail between the glueline and the wood.

How Drying Affects Gluing

Effect of Drying Temperature

High drying temperatures can inactivate the surface of the wood so that it is difficult for the adhesive to wet the surface. This is a surface phenomenon and is usually not a problem for kiln dried lumber because the wood is planed prior to gluing. Planing uncovers a fresh surface that has not been deactivated. Higher drying temperatures also lead to surface inactivation more readily than the temperatures used in a kiln. Thus, surface activation problems most often occur with veneer.

Effect of Moisture Content

Adhesives are formulated to work with wood of a particular moisture content. When the moisture content is too high, the adhesive loses viscosity and penetrates into the wood too much. That is, too much adhesive moves from the glueline into the wood and there is not enough adhesive left in the glueline to form a continuous layer. This is known as a starved joint. Wet wood will also cause problems if radiofrequency energy is used to cure the glueline. High moisture content wood will absorb more energy from the radiofrequency field resulting in long cure times.

When the moisture content is too low, the adhesive will be too viscous and will not penetrate two to three cells into the wood. This results in insufficient adhesion between the glue and the wood and poor joint strength. Additionally, the adhesive may have trouble wetting the surface of the wood in the same way that water will bead up on a dry sponge.

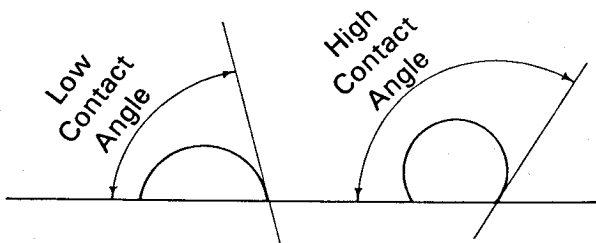


FIGURE 1. Contact angle. The adhesive beading up on the surface of the wood is an indication that the surface is not wettable. A good bond will not be formed.

Effect of Moisture Content on Layup, Assembly, and the Product

In addition to interfering with the adhesive wetting and penetration, wood at the wrong moisture content will gain or lose moisture and cause problems due to shrinking and swelling. These can occur before layup and cause pieces not to fit or after assembly causing irregular surfaces in the product.

Two examples of the effect of a moisture content change after assembly can be seen in Figure 2. Each product has gained moisture and swelled. In Figure 2a, the difference between the longitudinal and cross grain shrinkage that has caused the corners of the picture frame to open. In Figure 2b the difference between tangential and radial swelling has caused the quarter sawn boards in the panel to become thicker than the flat sawn boards.

Wood should be kiln dried to a moisture content equal to the in-service product moisture content. Factories in which wood parts are assembled should be humidity controlled or precautions should be taken so that the wood does not gain or lose moisture during cutting and assembly. Otherwise, the pieces may not fit together well. Like drying, moisture pickup is a transient process where the outside of the piece gains moisture first, then the moisture moves to the inside. The entire piece will reach a uniform moisture content if left long enough, with exposed end grain reaching the new moisture content faster.

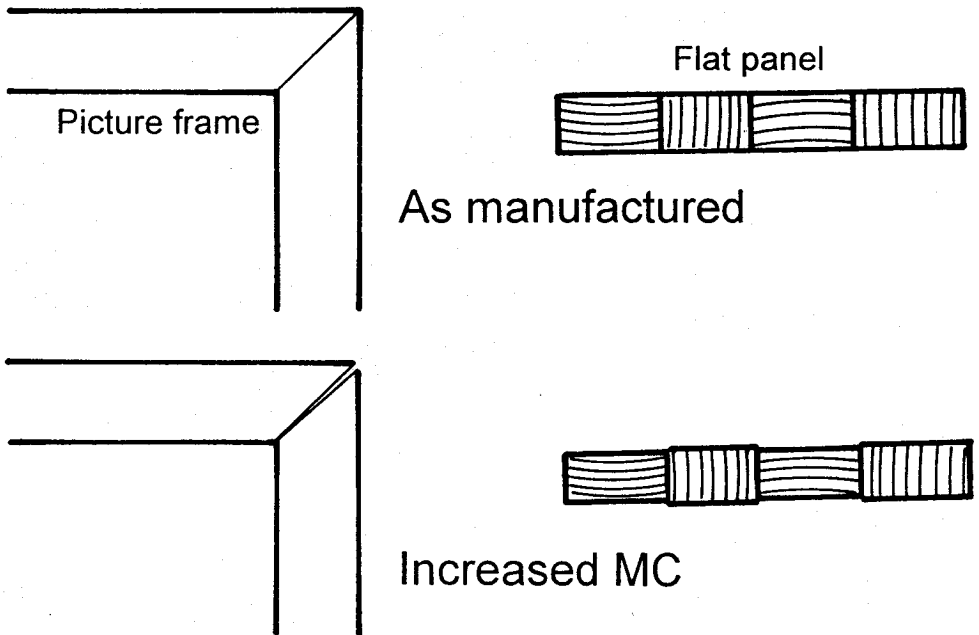


FIGURE 2. Differences in shrinkage in the three grain directions of wood cause products to change shape and not fit together well.

Figure 3 shows two pieces of wood that have gained moisture just prior to cutting. Most of this gain is through the end grain, firstly, because the permeability is much greater along the grain and, secondly, because the end grain is exposed in a bundle. Thus, swelling at the ends of the piece occurs prior to further machining. The piece is surfaced smooth and planed on the edges (the edges are made parallel but the MC is not uniform along the length), then glued, all in a relatively short period of time. Glued wood eventually comes to a uniform moisture content. This results in stress and possible splits at the ends of the panel. Fortunately, machining of the edges and cross cutting are often in one line, so this situation is often avoided.

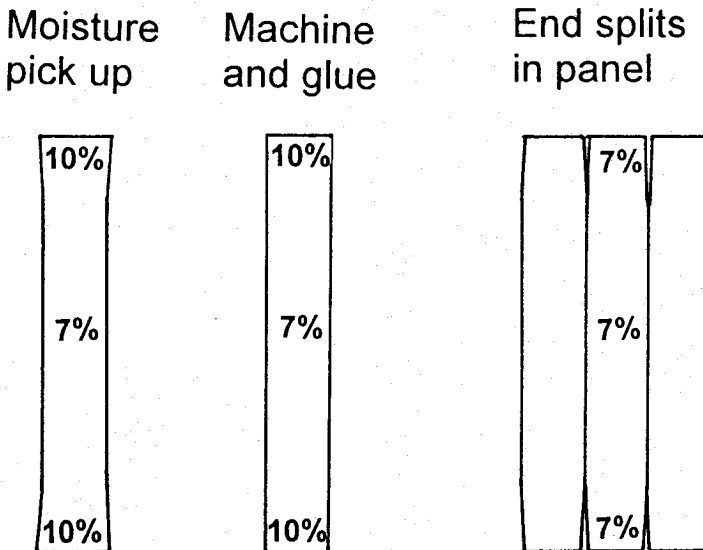


FIGURE 3. If the ends of pieces gain moisture prior to processing, then end splits can result when the entire piece reaches the equilibrium moisture content.

A similar situation can arise, however, when the wood is machined on one day while at a uniform moisture content and glued on the next work day, especially over a weekend. The ends of pieces can pick up or lose moisture and either swell or shrink. This can result in the situations shown in Figure 4. If the ends gain moisture, the middle of pieces have poor contact during gluing. If ends lose moisture, ends of piece have poor contact during gluing.

Adding a water-based adhesive to the wood causes a local increase in moisture content near the glueline. This initially causes the wood near the glueline to swell (Figure 5) and it is necessary to wait long enough between gluing and machining for this moisture content to even out. Planing too soon after gluing can result in a slight depression at the glueline after the wood reaches the equilibrium MC throughout the piece.

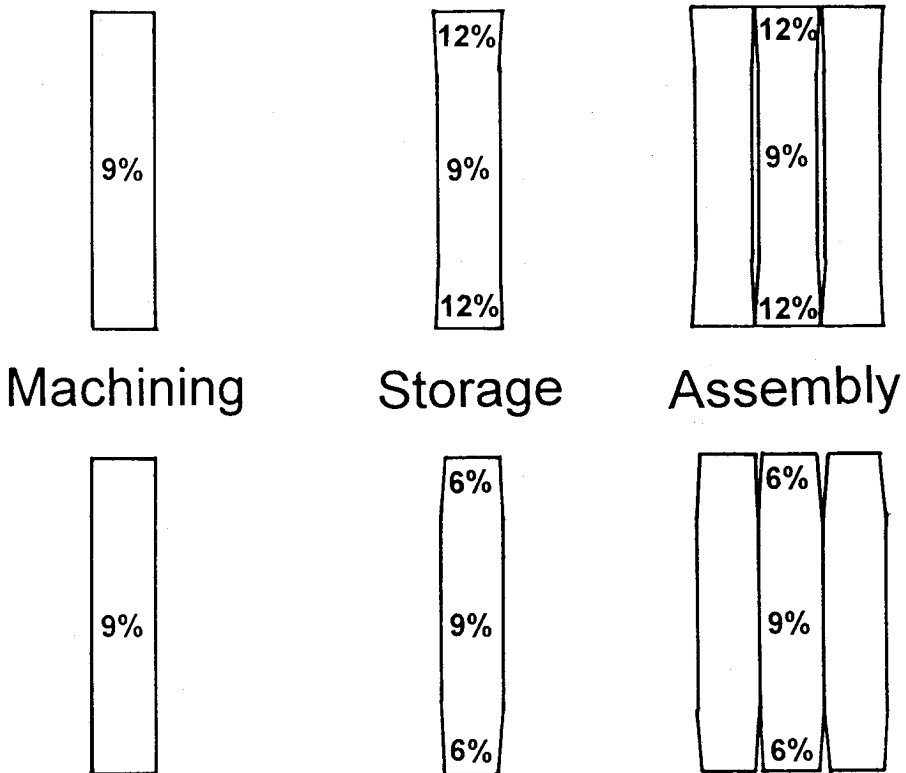


FIGURE 4. If the ends of pieces gain or lose moisture during processing, then splits can result when the entire piece reaches the equilibrium moisture content.

Stress

Drying results in stresses in the wood - compression in the shell of the piece and tension in the core. See the Dry Kiln Operator's Manual (Available from Government Printing Office, USDA Ag. Handbook #188) for more information on stress formation and relief. If lumber to be remanufactured contains stress, then it will warp when resawn or ripped. Edge glued panels can cup. Molded contours can deform so that the parts will not fit together. Conditioning at the end of the kiln drying is done to put moisture back into the wood and relieve the drying stresses. The EMC in the kiln during conditioning must be greater than the MC of the wood meaning that the kiln must be capable of a 6 to 8°F wet-bulb depression (Figure 5). To achieve this, a kiln must be well-insulated to prevent condensation on the walls, and free of leaks in the kiln structure. Any steam added to the kiln that does not remain as vapor and eventually get adsorbed by the wood adds heat to the kiln but does not help to maintain the high humidity. Conditioning can be improved by using desuperheated steam, water baths, or water sprays to humidify the kiln. Reducing the fan speed to the minimum during conditioning minimizes the side-to-side pressure differential and reduces leaks. Less mechanical energy (which eventually gets converted to heat) is added to the air when the fan speed is slow.

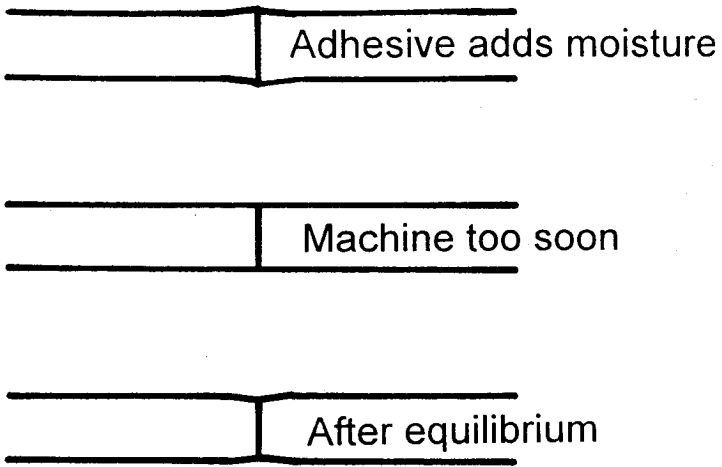


FIGURE 5. Localized moisture content change at the glue line.

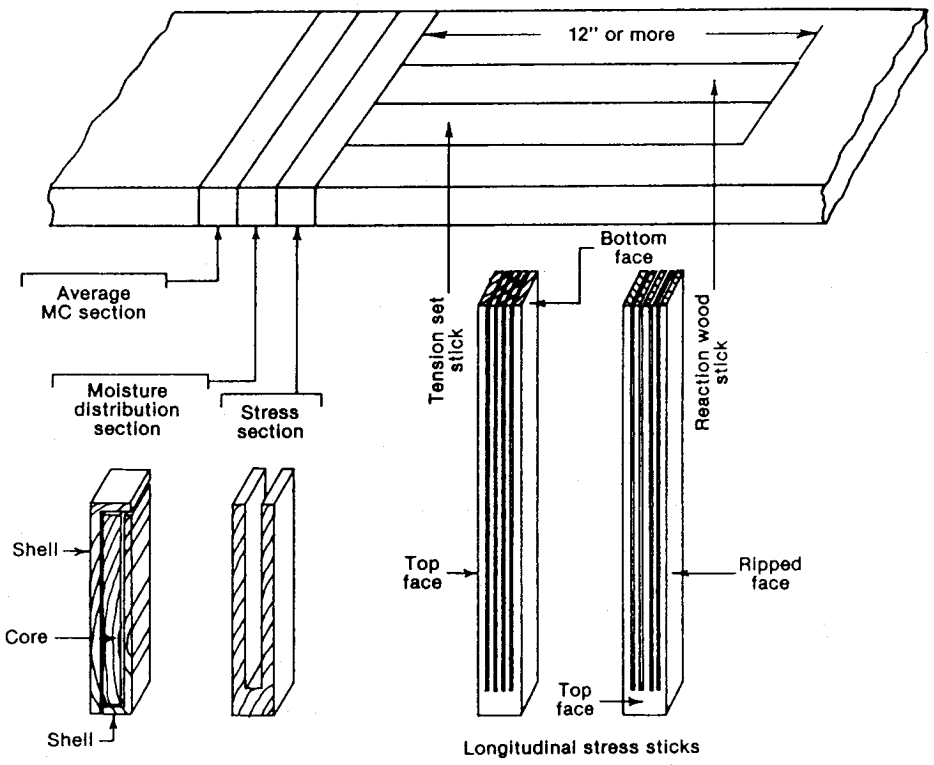


FIGURE 6. Stress and final MC checks on lumber.

The prong test (Figure 6) is done to determine if stresses have been relieved. It is necessary to wait 24 hours to interpret the results of the prong test. If the prongs bend inward, ripped or resawn lumber will crook or bow, respectively. If the prongs pinch the bandsaw when cutting, you can bet that the prongs will deflect inward significantly after 24 hours. If the prongs bend outward slightly as they are cut, they will probably deflect slightly with time and be straight after 24 hours. The Europeans do this test by simply making one saw cut down the middle of the piece, simulating ripped lumber.

The prong test can be misleading if the lumber has been conditioned at a very narrow (2-3°F) wet-bulb depression for a short period (1 to 4 hours) of time. This situation makes it possible to balance the stresses by starting to reverse the stress state in the wood in the outer layers but not relieving stress in the inner layers. Cooling the lumber excessively and then humidifying to promote condensation and rapid water pick up can also lead to this problem.

Conditioning at too small a wet-bulb depression long enough will cause the stress state to reverse and cause the prongs to bend outward. This condition is uncommon, but as we go to more efficient conditioning systems it is more likely to occur. To avoid this problem, control the dry-bulb and wet-bulb temperatures to maintain an EMC that is 4% moisture content greater than the moisture content of the wood. Under this condition it is not possible to cause the prongs to bend outward when conditioning, no matter how long the wood is conditioned.

Machining

If wood is kiln dried to too low a moisture content, skip can result when the wood is planed. This will downgrade lamstock (where a good surface for gluing is necessary) and be undesirable in most other products. As wood gets drier, cup will increase, leading to an increase in roller split at the planer.



Flat sawn face
latewood is pushed into
earlywood, then springs back
with moisture changes

Quarter sawn face
dense latewood swells more

FIGURE 7. Raised grain due to planing of moisture change.

Raised grain (Figure 7) is a condition in which the latewood is raised above the early wood. In quarter sawn lumber this may result from the entire piece gaining moisture after planing. The higher density latewood swell more and raises. In flat sawn lumber the planer knives push the latewood into the early wood, crushing the early wood. When the earlywood cells regain moisture they regain their shape and the latewood is raised. Crushing will also occur at a high moisture content and subsequent moisture cycling will result in raised grain. The best condition is when the wood is planed at its final MC. MC change is only one of many factors, such as planer knife sharpness and clearance angle, that can contribute to raised grain.

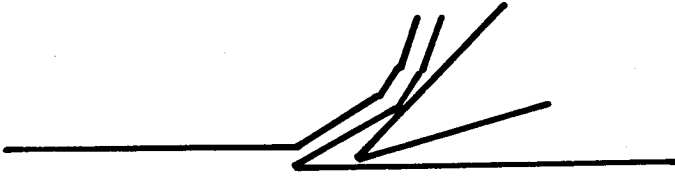
Loosened grain, or shelling, is a condition in which the latewood bands have separated from the earlywood. This results from a combination of mechanical stress and differential shrinkage at the growth ring boundary. Too much pressure in a sander or dull planer knives can cause this condition. Late wood shrinks more tangentially and less longitudinally than early wood resulting in additional stresses if moisture changes are allowed to occur. Years of moisture cycling and wear on a hardwood floor can result in loosened grain, especially in abrupt-transition woods.

Chipped, torn, or fuzzy grain can result from wood at the wrong moisture content. When the wood is too dry, splits occur ahead of the planer knife rather than the knife cutting the fibers. This situation is shown in the top part of Figure 8 on the following page. Fuzzy grain can result when the moisture content is too high during planing. In this case (bottom of Figure 8) there is compression failure ahead of the knife, the fibers are cut unevenly and can later swell to form a fuzzy surface. Ideally, a curly chip will be produced (middle of Figure 8) when the knife cuts the fibers without compression at the surface. Moisture content cannot be blamed for all machining problems. Dull planer knives, excessive roll pressures, reaction wood, feed speeds, and tool angles can also cause similar surface defects. These factors are all interactive, for example, a certain feed speed and knife angle may work well at one moisture content but require adjustment at another moisture content.

Conclusion

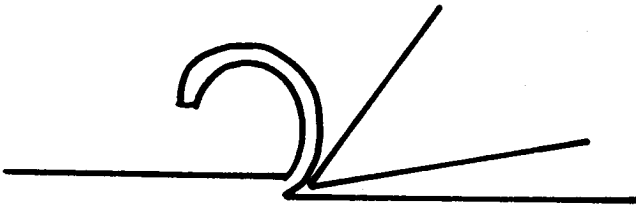
Wood should be kiln dried to the final moisture content at which it will be used, then kept at this moisture content throughout manufacturing. Drying stresses should be relieved by conditioning. It is important for producers of lumber to fully understand the implications of these two statements on secondary manufacturing to remain competitive with other producers in the market place.

Type I - MC too low



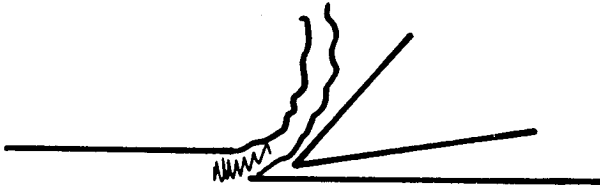
Splitting ahead of knife
Torn grain, Chipped grain

Type II - MC correct



Knife cuts, Curly chip

Type III - MC too high



Compression ahead of knife
Higher energy, Fuzzy grain

FIGURE 8. Effect of MC on chip formation and surface quality.