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# Delamination of Edge-Glued Wood Panels

## Moisture Effects

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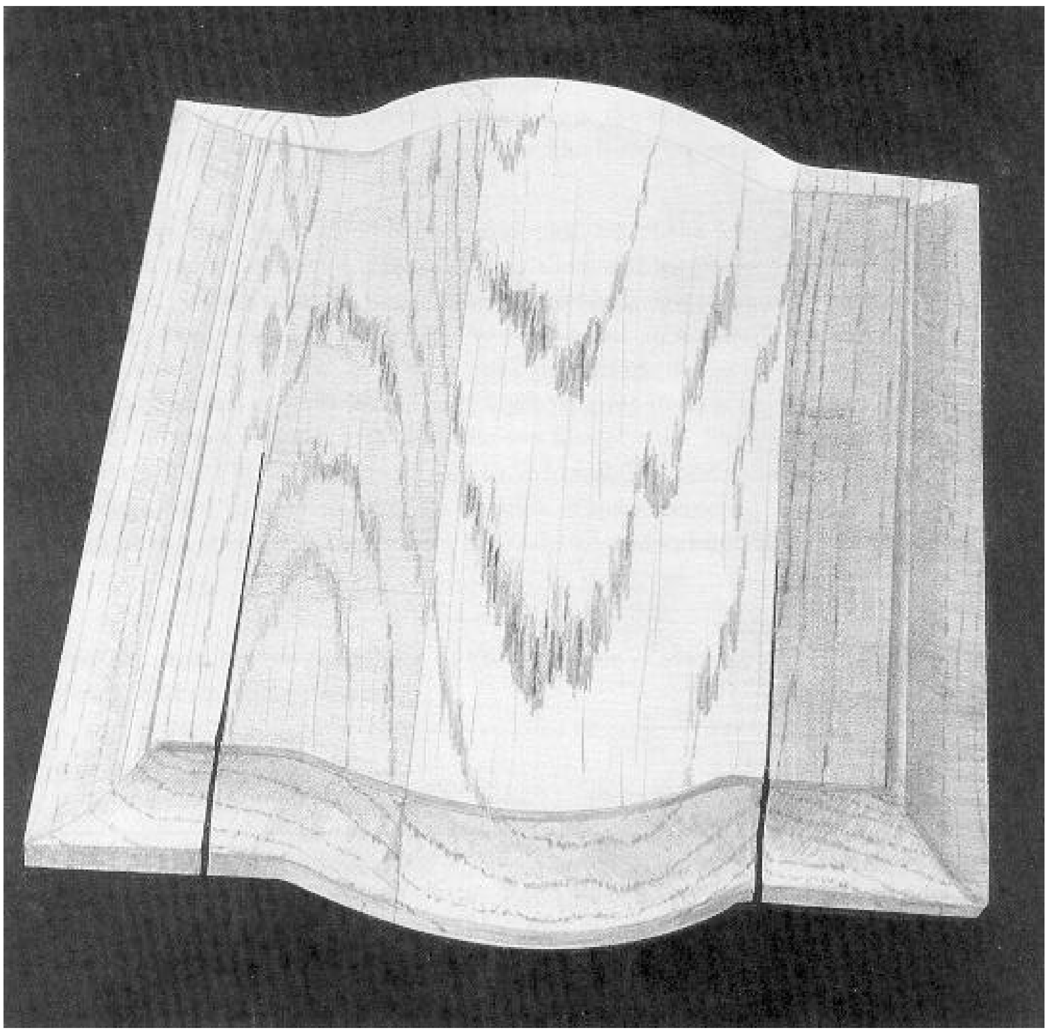

## Abstract

Delamination of edge-glued furniture and cabinet panels or narrow face-laminated turning squares is a fairly common problem, particularly during the heating season. The problem is not restricted to any particular glue or species. Why these failures occur and how they can be prevented is the subject of this report. We discuss the relationship of species, glue consistency, and clamping pressure, with emphasis on the role of moisture content in delamination.



Keywords: Edge-glued panels, starved joints, delamination, gluing pressure

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# Delamination of Edge-Glued Wood Panels: Moisture Effects

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## Characteristics of Defective Joints

Typically, defective joints are delaminated at one or both ends. In severe cases, the entire length of the glueline may be delaminated. Inspection of failed surfaces reveals certain characteristics. On a fine-texture softwood like white pine or diffuse-porous hardwood like maple, the failed surface feels relatively smooth; inspection with the unaided eye reveals little or no glue on the failed surface. On a ring-porous hardwood like oak, the failed surface may not be smooth because of glue castings of the large vessels or pullout of weaker earlywood tissue. Inspection with a microscope or a 10- to 15-power hand lens may reveal no visible glue film or a glueline consisting of bubbles or foam (Figs. 1 and 2). If the panel has already been finished, stain may be evident. If an unfailed portion of such joints is viewed from the edge under a microscope or hand lens, no glue will be visible (Fig. 3). Joints like these are called “starved” joints.

In a starved joint, most glue has been squeezed out of the joint so that not enough remains to form a continuous film between the wood members. The glueline is discontinuous, and its strength depends upon relatively few strands of glue extending from one wood surface to the other. As can be seen in Figure 2, the strands between the two wood surfaces can be a very small percentage of the total bond area. The strength of a starved joint (that has not yet delaminated) is only a fraction of the strength of a proper joint with a continuous film of glue. Shear strength specimens cut from the joint (Fig. 3) averaged 1,005 lb/in$^2$, and no wood failure had occurred. (See Appendix A for conversion table for SI units of measurement.) A well-made joint should have a strength of more than 2,500 lb/in$^2$ and exhibit 50 percent or more wood failure.

Three principal factors contribute to the formation of starved joints: species, glue consistency, and clamping pressure.

### Species

Species, of course, is relatively uncontrollable. However, the higher the density of the wood or the more porous the wood, the more critical the determination of optimum gluing conditions and the control of these conditions in production. The problem of starved joints seems especially prevalent in the gluing of oak, a high density and quite porous species. However, the prevalence of oak in today’s market in comparison to other species may also explain the high incidence of starved joints in oak.

The main factors that can be controlled to avoid starved joints are glue consistency and clamping pressure (Fig. 4).

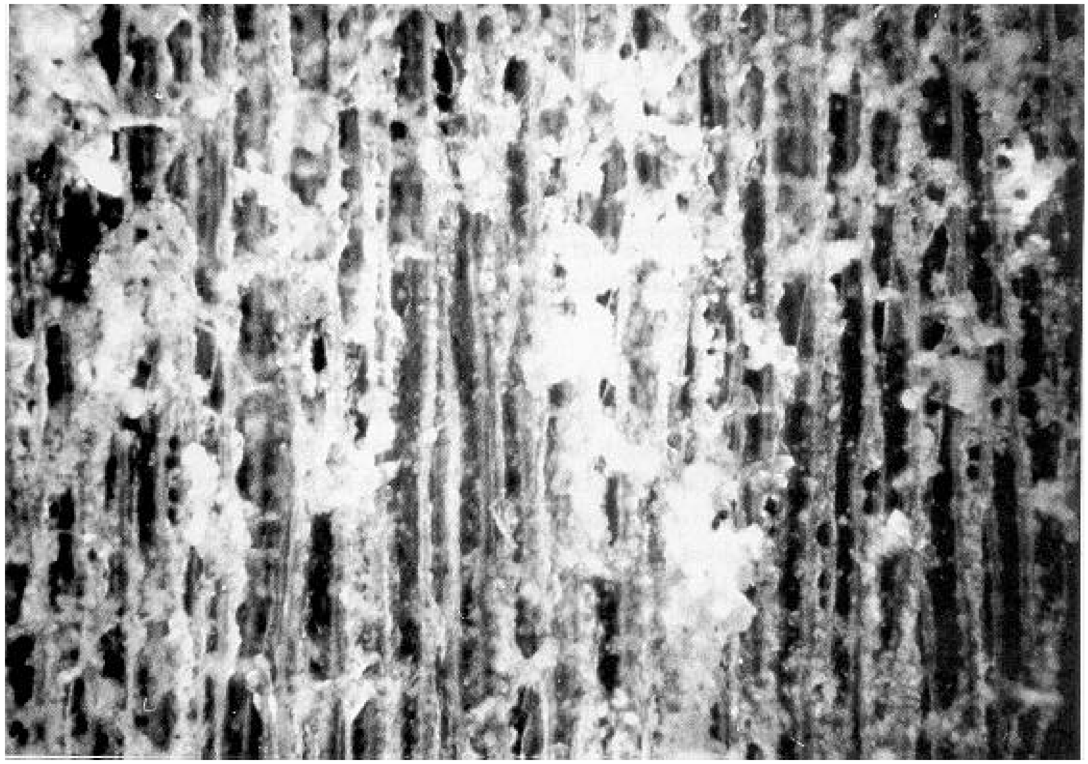

*Figure 1–Surface view of a broken joint with no visible glue film; only the filler is visible. (M90 0037-19)*

## Glue Consistency

Consistency is the resistance of the glue to flow, and it is related to the viscosity and plasticity of the glue. Consistency is critical when the glue first makes contact with the wood surfaces and again when the joint is clamped. When the glue contacts the wood surface, its consistency must be low enough for the glue to flow into the irregularities of the wood surface and establish good adhesion. If the glue is only applied to one surface, the consistency must remain low until the second surface is brought into contact with the glue. After adhesion has been established with both surfaces, low consistency becomes less desirable. Some flow is still desired as pressure is applied so that the glue penetrates the surface and flows out into a thin continuous film. However, excessive flow leads to a starved glueline. During these critical stages, consistency is affected by

- glue formulation (molecular weight, solids content, type and amount of filler, type and amount of liquid dispersant, and catalyst),
- storage time, time on the spreader, or age of mix,
- spread rate,
- humidity of air in the plant,
- wood moisture content (MC),
- temperature of both wood and air, and
- assembly time.

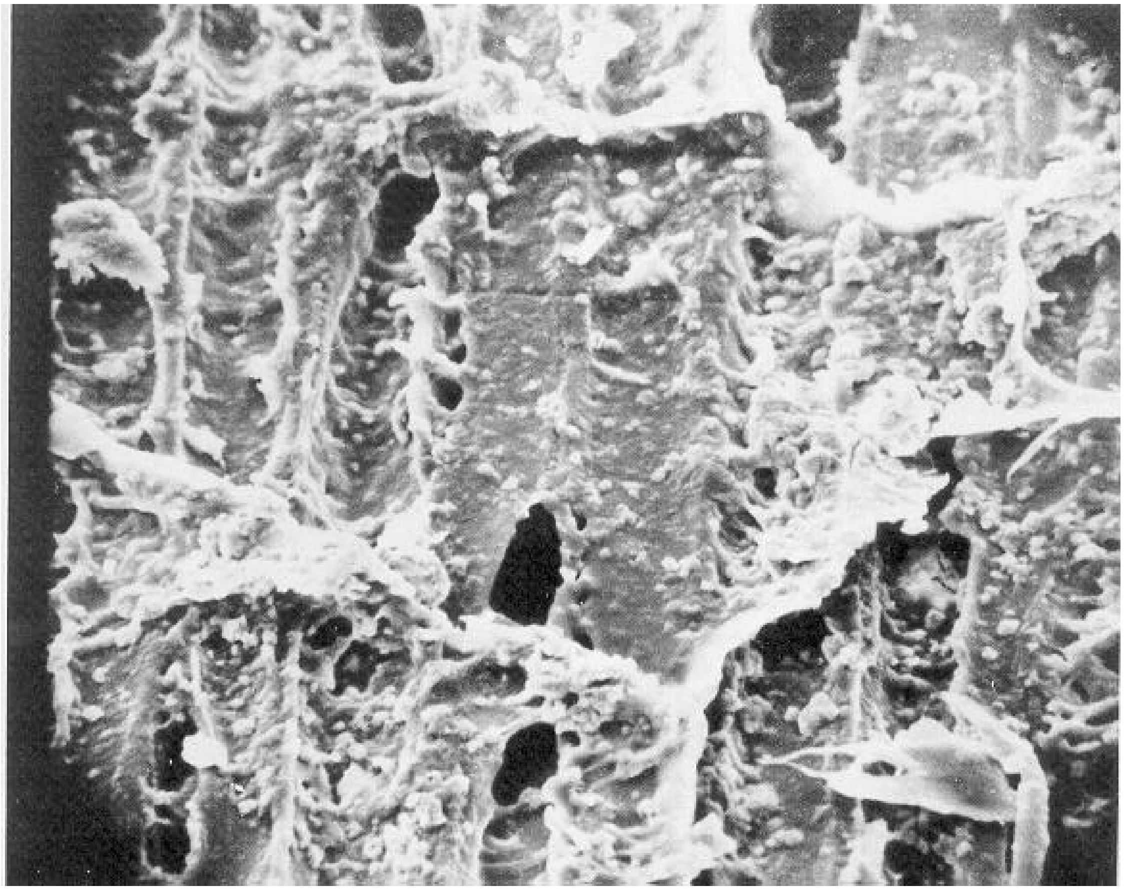

*Figure 2–Surface view of a broken joint with only thin webs or strands of glue extending from one surface to the other. The actual glueline is only 20 percent of the total area. (M90 0038-34)*

### Effects of Glue and Plant Conditions on Glue Consistency

Generally, the consistency of glue increases with storage time, time on the spreader, and age of the mix. Increased consistency reduces the possibility of starved joints, but it also increases the possibility of poor adhesion and thick joints. The glue spread rate affects how fast the consistency increases. A light spread may lead directly to starved joints because there simply is not enough glue to form a continuous layer. Conversely, a heavy spread may lead to starved joints because the consistency increases too slowly before clamping. A heavy spread has the same surface area but more volume, and thus more liquid must be removed to increase the consistency. Hot weather lowers consistency. High humidity, high wood MC, and, to a lesser extent, low wood and air temperatures all slow down the rate of increase in consistency.

The glue manufacturer can and often does modify the glue formulation to compensate for seasonal and other effects on consistency. But the glue user can also compensate for changes in the variables that affect consistency by changing the assembly time (Fig. 5).

### Effects of Assembly Time on Glue Consistency

Assembly time is the time between glue application and clamping of the joint. Assembly time is divided into two periods, open and closed. Open assembly is the time after

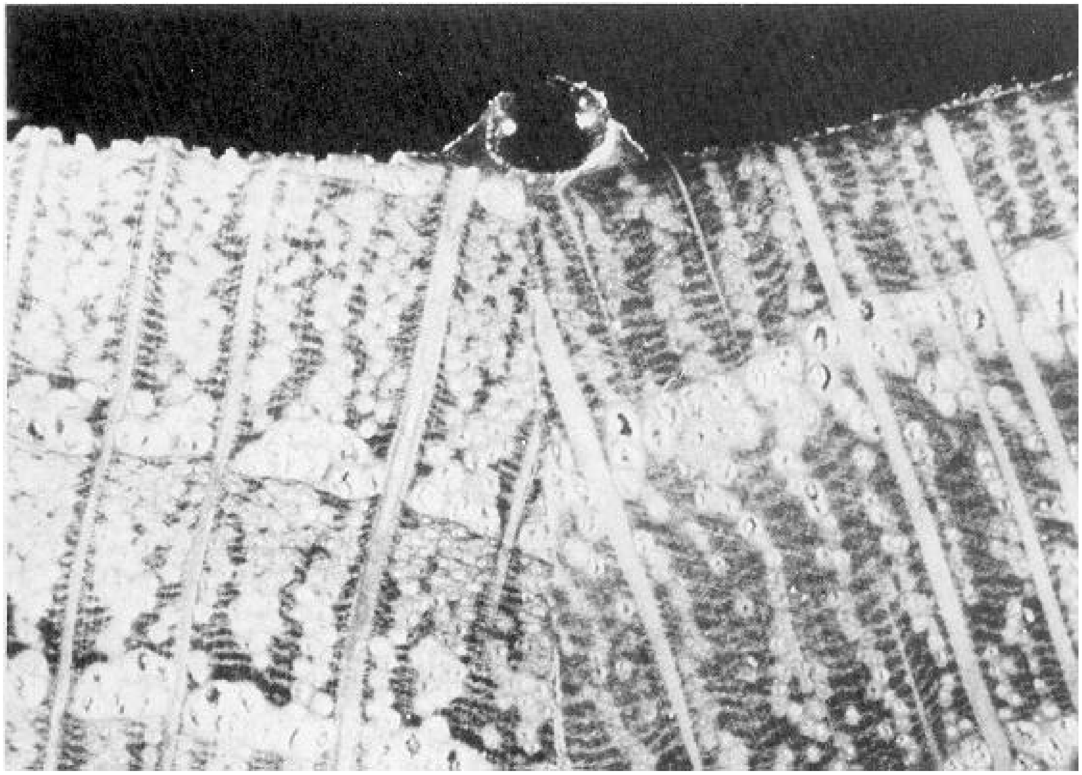

*Figure 3–End view of an intact joint with no visible glueline. (M90 0037-1)*

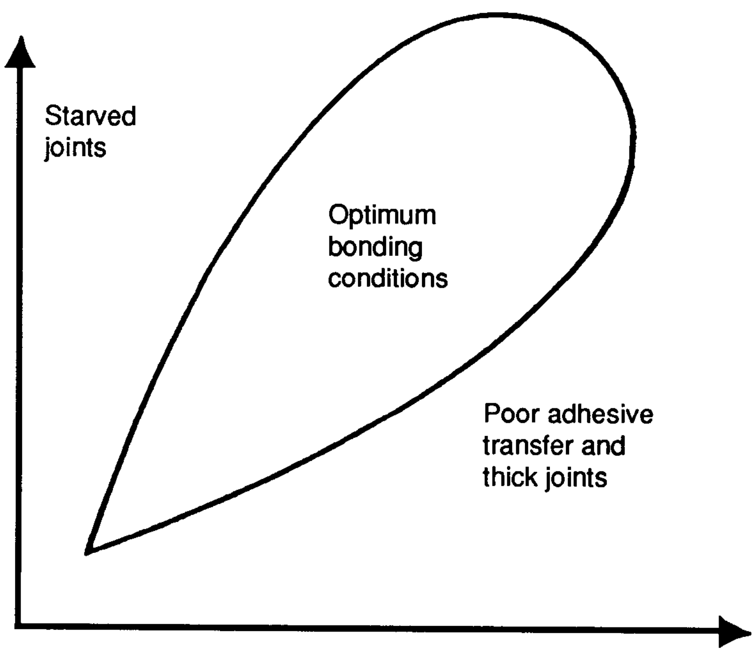


*Figure 4–Schematic relationship between gluing pressure and glue consistency, (ML84 5348)*

the glue is applied and before the joint is closed. Closed assembly is the time between closing the joint and placing it under pressure. During the assembly time, the glue consistency increases as moisture in the glue evaporates or is absorbed by the wood, or chemical curing begins. Usually, open assembly time is more effective in increasing

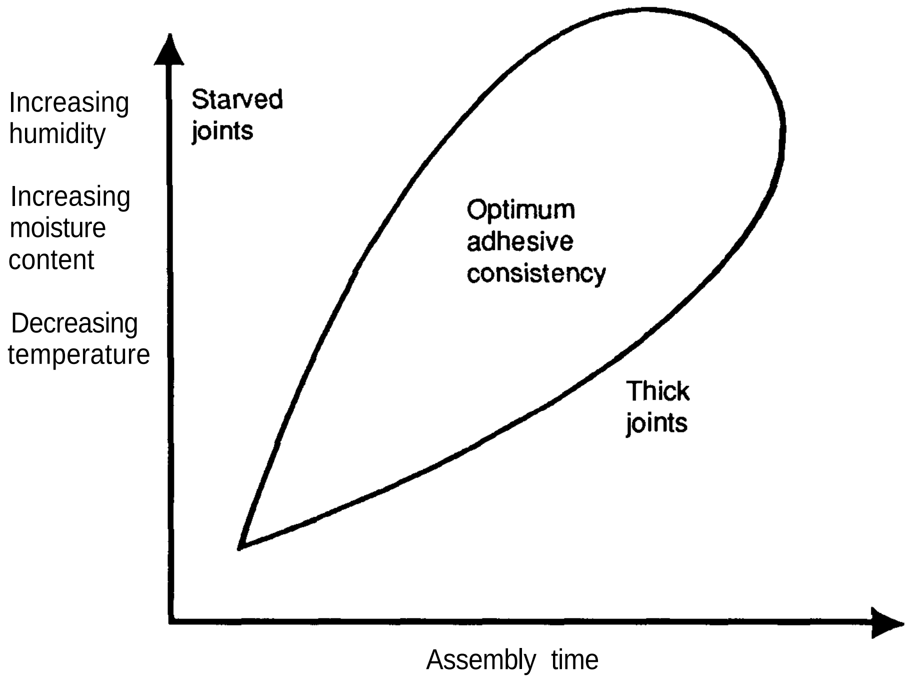


*Figure 5–Schematic relationship between assembly time and the humidity and wood moisture content at the time of gluing.*

glue consistency with dense woods. In dense wood, the water in the glue will evaporate into the air faster than it can be absorbed by the wood. Starved joints caused by low glue consistency can be prevented by close attention to the wood and manufacturing conditions and by adjustments in the assembly time to compensate for changes in these conditions. Care must be taken in adjusting assembly time because excessive time will lead to predrying and poor transfer of the glue to the mating surface.

Careful control of the assembly time following the manufacturer's guidelines for plant conditions and seasonal changes in the weather is probably the most effective method for ensuring that the glue consistency is correct for the pressure that must be applied to the joint.

## Clamping Pressure

Clamping pressure is required to achieve intimate contact between the two surfaces being glued. The correct pressure depends on the density of the wood. For example, high density species like red oak require 200 to 250 lb/in$^2$ clamping pressure; intermediate density species like cherry, elm, walnut, soft maple, and yellow poplar require 150 to 200 lb/in$^2$; and low density species like basswood, fir, spruce, cedar, and white pine require only 100 to 150 lb/in$^2$.

Starved joints are most likely to occur in the high density group, in particular with an open-grained or porous species such as red oak. High density woods require high pressure to overcome slight irregularities in the wood and to force the wood surfaces into uniform contact over their entire length. In addition, the large pores in ring-porous woods such as red oak and ash provide easy escape routes for the liquid glue.

Assume that the correct glue consistency has been achieved and the proper pressure has been selected for the species to be glued. The next task is to apply the correct pressure uniformly along the glueline.

### Correct Pressure

The clamping pressure is the force applied by the clamps divided by the area of the glueline. The correct force and consequently the correct pressure is calculated by multiplying the desired pressure by the glueline area and dividing this number by the number of clamps. The correct force is then achieved by calibrating the clamping system with a compressometer and adjusting the air pressure that actuates an air-operated torque wrench or pneumatic cylinder. The clamping system should be calibrated and adjusted for each joint length and board thickness. If either length or board thickness is changed during a day of production, then the force applied by the clamping system should also be reset for that joint. Slight variations in board thickness or clamp spacing can be accommodated without changing the air pressure. However, if the change in glueline area causes more than about a 50-lb/in$^2$ change in the clamping pressure, the clamping force should definitely be reset. Often, a needed change is not made under the false impression that saving time is saving money.

The amount of pressure that will cause a starved joint also varies with the width of the joint. Excessive pressure is less likely to cause starved joints in wide joints because of the greater distance to the edge of the joint and because resistance to flow of the glue increases as this distance increases.

Even if all these factors are under control, pressure variation within a glueline can lead to localized starved areas and delamination within a given joint.

### Pressure Variation

Correct clamping pressure and a properly calibrated clamping system merely ensure the correct average pressure on the joint. The actual pressure at any given point in the glueline may vary for several reasons. Lumber often comes into a plant at a moisture content (MC) different from the equilibrium moisture content (EMC) conditions of the plant. Generally, the lumber MC should be within 2 percent of the plant EMC conditions. The plant EMCs for different relative humidities are as follows:

| Relative humidity (percent) | EMC (percent) |
|---|---|
| 15 | 4 |
| 30 | 6 |
| 50 | 9 |
| 80 | 16 |

A difference of more than 2 percent between lumber MC and plant EMC may be caused by the following:

1. lumber was not dried to a MC within the recommended range (6 to 8 percent in summer, 5 to 7 percent in winter),

Table l-Change in width of 3-in.-wide boards with change in moisture content

| Change in moisture content (percent) | Change in width for different species (in.) | | |
|---|---|---|---|
| | Red oak | Hard maple | White pine |
| 1 | 0.005 to 0.011 | 0.003 to 0.008 | 0.002 to 0.006 |
| 2 | 0.009 to 0.022 | 0.006 to 0.015 | 0.004 to 0.012 |
| 3 | 0.014 to 0.033 | 0.009 to 0.022 | 0.006 to 0.019 |
| 4 | 0.019 to 0.044 | 0.012 to 0.030 | 0.008 to 0.025 |

2. dried lumber was stored improperly (wrong EMC condition) for too long and its MC was therefore altered, or
3. plant EMC condition was outside the recommended range (6 to 8 percent in summer and 5 to 7 percent in winter).

If the lumber is cut to exact dimensions for gluing when its MC and the plant EMC conditions are not aligned, the wood MC begins to change immediately. For example, a change of 1 percent in red oak will change the width of a 3-in.-wide board by 0.005 to 0.011 in. (Table 1). This change in width affects the pressure variation along the joint. The most common causes of pressure variation are end swelling or shrinking and generalized warping. Improper machining is another cause of pressure variation, but that subject is beyond the scope of this article.

**End Swelling or Shrinking** –Boards gain or lose moisture 10 to 15 times faster from the ends than from the faces and sides. Furthermore, most faces and sides within a stack of boards are not directly exposed to the plant atmosphere. The more rapid change of MC from the ends than from the sides of the pieces causes the width of the ends to change relative to the width of the board center. The change may be great enough to cause glueline problems even within a few hours after the pieces are cut to width. This is a major cause of weak gluelines at the ends of the joints.

A difference of a few thousandths of an inch in width at the ends causes a significant difference in pressure. The denser the wood, the smaller the difference in width required to cause a problem in pressure. In a dense wood like oak or maple, as little as a 1- or 2-percent change in MC can result in a width change of 0.005 to 0.011 in. in a 3-in. board. Here is an example of what can happen when moisture causes a change in board width.

Flat-sawn red oak lumber is brought into the plant. The wood has been carefully kiln-dried and then stored at 42 percent relative humidity to maintain 8 percent MC. It is summertime and the EMC in the plant is 10 percent (Fig. 6, top). The lumber is carefully cut to 3-in. width and 30-in. lengths, and it is then stacked on a skid along with other boards waiting to be glued. The board edges are perfectly straight after cutting. However, the board ends immediately begin to pick up moisture because the EMC condition in the plant is above the MC of the boards. Within 6 h after cutting, when the boards are actually glued, the first 2 in. at each end have picked up between 1 and 1.5 percent moisture and have swollen in width by about 0.010 in. compared to the center of the boards. The edges to be glued are no longer straight (Fig. 6, middle). Although the width difference of 0.010 in. may seem insignificant, it is not, especially if the wood is dense and has a high resistance to compression (modulus), like oak.

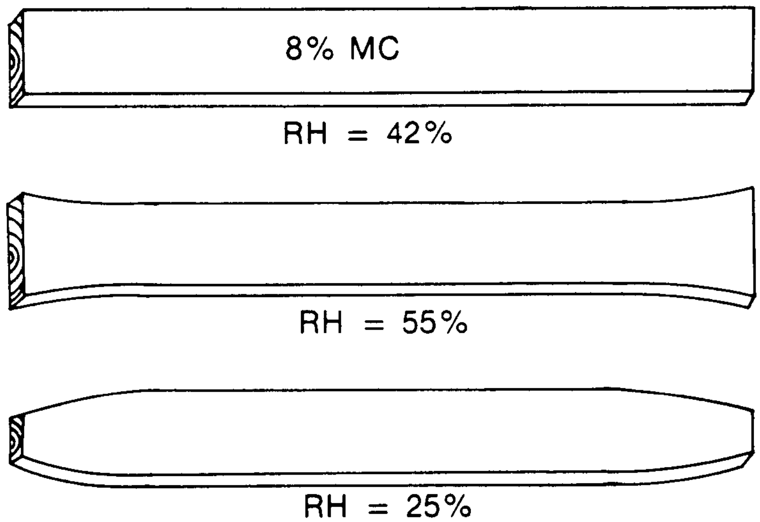


*Figure 6–Schematic drawing of end swelling and shrinking caused by change in lumber MC when gluing is delayed 1 day after sawing. Top. status of lumber when brought into the plant at 8 percent MC and immediately after sawn to width. Middle, swollen lumber, 1 day after sawing, when plant EMC is 10 percent. Bottom, shrinkage of board ends, 1 day after sawing, when plant EMC is 6 percent. (ML89 5773)*

The preferred clamping pressure for oak is 200 $lb/in^2$; with a glueline area of 30 $in^2$, the total clamping force required is 6,000 lb (200 $lb/in^2 \times 30\ in^2$). When pressure is applied, the pieces will first make contact at the swollen ends; therefore, the clamping force will be concentrated at the ends and not distributed evenly along the length of the joint. This concentration of force compresses the wood at the ends by 0.010 in. until the surface is again in the same plane as the unswollen center portion of the piece. Since oak has a modulus of 90,000 $lb/in^2$ in compression perpendicular to the grain, the pressure at the ends is 900 $lb/in^2$ (pressure = modulus × compression = 90,000 $lb/in^2 \times 0.010 = 900\ lb/in^2$). Compressing the swollen ends uses only 3,600 lb of the total clamping force (900 $lb/in^2 \times 4\ in^2$). The remaining 2,400 lb (6,000 - 3,600 = 2,400) will be exerted over the entire 30 $in^2$ of glueline for an average clamping pressure of 80 $lb/in^2$. Thus, the ends of the joint will be subjected to a total of 980 $lb/in^2$, while the center will receive only 80 $lb/in^2$. All the glue will be squeezed from the glueline at the ends of the joint, whereas in the center, the low pressure may actually cause the glueline to exceed the desired 0.002 to 0.006 in. of thickness.

Admittedly, this is a simplistic example. The stress variation along the glueline in actual boards is far more complex because the board edges are never perfectly straight. But the example shows how a very small local change in MC between sawing and gluing can have a very large effect on the gluing pressure along the joint and consequently on the quality of the joint.

A somewhat different but equally disastrous scenario develops when the boards shrink a little at the ends before they are glued (Fig. 6, bottom). In this case, the pressure at the ends will be lower than average, and consequently the gluelines at the ends will be thicker than desired. Such joints will be weak because of the formation of large voids (Fig. 7) or internal stress arising from shrinkage as liquid leaves the glue. Clamp operators may try to compensate for shrinkage at the board ends by placing the clamps at the very ends of the panels and increasing the clamping force. This applies

*Figure 7—Surface-view micrograph of a broken joint showing a thick glueline with large voids. This glueline was formed without adequate pressure.* ***(M90 0037-7)***

sufficient force at the ends to close the gaps. However, when the clamping force is released, the glue at the end of the joint is still not fully hardened. In this condition, the still soft glue is subjected to high tensile stress as the gap attempts to reopen. This may lead to a type of starved joint that has a very fine, thin-walled, foamy appearance.

End swelling and shrinking can be isolated by measuring (with a micrometer accurate to 0.001 in.) and recording the width of the pieces as they come out of the straight-line ripsaw and then remeasuring the pieces at the same location immediately before they are spread with glue. Note that variation in width may also be caused by problems with the straight-line ripsaw. Regardless of the source, pieces that vary in width more than 0.005 in. should not be glued to avoid problems with localized pressure variation. If the measurements show that the variation is due to MC change after sawing, then the pieces should be redried and resawn before gluing.

**Generalized Warp** —Loss of moisture from the faces and edges of pieces is slower than from the ends. However, enough moisture may be lost, especially from pieces on the top of a stack, so that some warping may occur. The edges to be glued may then no longer mate properly. Contact and thus gluing pressure are no longer uniform along the glueline. Note that this problem, like end swelling and shrinking, can also be caused by sawing if the board is slightly cupped or twisted as it passes through the straight-line ripsaw. A few thousandths of an inch may be enough to cause significant irregularities in the board edges. Clamping pressure helps flatten out such irregularities; however, the wider the pieces to be glued and the higher their density, the less likely that uniform pressure can be achieved, and the more likely that part of the joint will be weakened by localized pressure variations.

Warp may be more difficult to recognize because cup, bow, or twist of only a few thousandths of an inch is difficult to see or even measure without a special gauge. Measures must be taken to identify and segregate lumber with out-of-bounds MC, or to adjust the plant EMC conditions if warp after sawing is identified as the cause of pressure variation.

## Conclusions

Moisture, or rather, lack of moisture control in several stages of panel production can lead to weak joints that easily delaminate. Understanding the effects of moisture and minimizing moisture content variation are probably the most cost-effective measures for minimizing expensive failures in most types of glued wood assemblies.

## Appendix A

Conversion Table for SI Units

| Type of measurement | Unit of measurement |
|---|---|
| Force | 1 lb = 4.45 N |
| Length | 1 in. = 25.4 mm |
| Pressure | 1 $lb/in^2$ = 6.89 kPa |



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