GLUING WOOD: A STICKY BUSINESS

Gene Wengert, The Wood Doctor

Nature spends decades putting wood together into a tree. Then we take the tree from the woods, saw it into smaller pieces, dry it, and saw it into even smaller pieces. Finally, we begin to glue these smaller pieces back into larger pieces, trying to obtain the shape, size, and other properties that we want rather than the properties that the wood had when it was in the tree. Actually, this process of putting wood back together usually works out fairly well, but there are times when things do not go right. This article discusses the basics of gluing wood—requirements, good practices, and problems to watch out for.

The key point that needs to be mentioned at the beginning and that needs to be stressed is that all adhesives used for woodworking and gluing wood are about 50% stronger than the wood itself. Exceptions are the mastic adhesives and some hot melts. What this means is that a glue joint in a wood product should never fail, as the joint itself should not be the weak link—the wood is the weakest link. Stated another way, when a wood product develops a crack or similar failure, we should potentially see 100% wood failures and never glue failures. Yet in practice, we often see failures in the glue joint itself. How can this be? The answer is that something was done incorrectly when making the glue joint.

As a corollary of this discussion, it is probably incorrect to change adhesives (usually change to a more expensive adhesive) when there is a gluing failure. The problem is not the adhesive, as it is stronger than the wood, but rather the problem is in the preparation of the joint. We need to fix this manufacturing problem. On the other hand, you may need to change adhesives to get different properties, such as color, curing time, water resistance, lack of heat sensitivity, air pollution and so on.

With the properly made glue joint being substantially stronger than the wood, we can actually be a little sloppy and still have a joint that is as strong as we need it. But, if we are sloppy and have little excess strength, a little change in conditions can easily drop our joint strength below the required value. So, it is prudent to make the strongest joint possible at all times JIC (just in case) an “oops” happens, and you safely lose a small amount of the excess strength.

So, let’s look at the basics of gluing so we can identify the practices that make glue joint perform at less than its potential. Then we will look at examples of common problems and discuss what it takes to fix things.

PART I. HOW DO ADHESIVES STICK TOGETHER?
When gluing wood, there are several mechanisms that develop the adhesive-wood strength. Here are four important concepts.

A. First there is the geometry factor. A wood surface to be glued is, at a microscopic level, a series of nooks and crannies. During the gluing process, the glue flows or is squeezed into these nooks and crannies. The glue then hardens. The end result is that it is very difficult to pull the joint apart. It is similar to the pieces in a puzzle; the pieces interlock with each other due to their shape. This interlocking with a glue joint provides mechanical strength (especially shear strength).

B. Second, some adhesives are chemically active. That is, they have hydrogen bonding sites on the glue molecules or other chemically active sites. When the water or other vehicle that carries the glue evaporates or disperses, then these hydrogen bonding sites attach to similar sites within the wood. Hydrogen bonding is what holds water vapor molecules together to form a liquid and also gives ice its strength. Note that with some adhesives, when their glued joints are exposed to water, the water moves in and replaces the glue's hydrogen bonding to the wood. When this happens, the joint essentially loses its strength and begins to fall apart. The familiar white glue is in this category.

A few species of wood have oils naturally in the wood. Teak is one example. Such species need to be cleaned with a solvent to remove the oils. Such cleaning is done less than a minute before gluing.

Note that heat makes the joint cure faster.

C. Third, some adhesives undergo a chemical reaction when they cure and form chemical bonds with the wood molecules. Oftentimes a catalyst (a catalyst is merely a chemical facilitator) or heat is used to encourage this reaction to occur. Once the chemical change happens, it is not possible to reverse the reaction with water or heat. Oftentimes, this reaction is called an aliphatic reaction, meaning that the carbon atoms are involved in this chemical reaction and bonding. Two commonly used adhesives that develop these bonds would be urea and epoxy.

This chemical reaction of the loss of water or solvent takes time. Therefore, the maximum strength of a joint may take 24 hours or longer to develop.

Most chemical reactions of this sort will go twice as fast when the temperature goes up by 20 degrees; so ambient temperature (temperature of the wood and the glue) are very important.

D. Fourth, it is important to also understand that many adhesives loose strength as their glue lines (the distance between the two pieces of wood that is filled with glue) become thicker. Most commonly used wood adhesives require the two wood surfaces to be within 0.002 to 0.006 inches apart. Adhesives that can tolerate wider distances (thicker glue lines) are called "gap filling" and include epoxy and some hot melts, such as PUR.

So, let's use these four basic concepts as a basis for understanding some practical aspects about gluing.

A. First, the wood surface to be glued must be freshly prepared so that there are plenty of hydrogen bonding sites. An old surface will often have these bonding sites occupied with moisture, dust or other debris; old surfaces, hours to weeks to months old, do not develop strong joints. It takes just one light swipe with a piece of sandpaper to reactivate an old surface. (It would not be uncommon to find that gluing within 15 minutes after the surface has been prepared will enhance the joint strength significantly, partly due to aging and also due to moisture movement discussed in the next paragraphs.)

How do you know if you have a surface that is active and attractive for gluing? Here is an easy, effective test. Put a drop of water on the surface to be glued. If the surface is active, that drop

should disperse and get soaked into the wood within a minute or two. If the surface is inactive and will not be well attached to the glue, the water droplet will standup on the surface just like water droplets will appear on the hood of a freshly waxed car.

B. Second, the surface prepared with a sharp knife (planer, for example or even a sharp saw) will have more nooks and crannies and therefore have better mechanical strength joints than a surface that was sanded with dull sandpaper or a dull saw, which pushed the wood fibers into the nooks and crannies. Old sandpaper or a dull saw can also leave a multitude of loosely attached fibers on the surface; these fibers are easy to glue to each other, but they are not well attached to the underlying piece of wood, so the joint does not have high strength.

Likewise, dusty surface may have many of the spaces already filled before gluing.

C. Third, the adhesive, at the time the pressure is applied, must be able to flow into the nooks and crannies and must be able to make intimate contact with the wood. Any excess adhesive must also be fluid enough to flow out of the joint initially before it cures. We do not want a thick, stiff adhesive applied initially—thick because it is old or cold or been spread out too long before pressing.

Note that an adhesive that has the correct flow properties in the warm summertime may become too thick in the winter when the manufacturing facility is cooler. In some cases, cold wood can cool the adhesive quickly making the adhesive too thick to flow properly. Both the adhesive and the wood need to be warm—the exact temperature depends on the adhesive requirements, but oftentimes 70 to 80 degrees Fahrenheit is appropriate. Many operations store the adhesive before use at a constant temperature

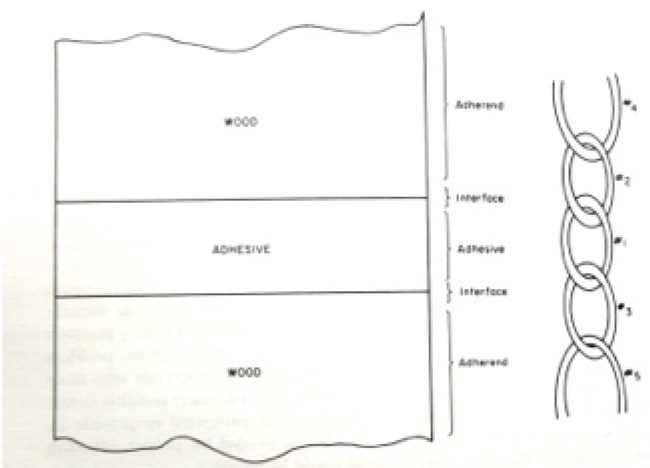
D. Fourth, note that pressure does not squeeze glue into the wood's cell structure. Pressure pushes the wood together so that the two pieces are within 0.002 to 0.006 inches, squeezes the glue and forms a uniformly thick layer of glue, squeezes the glues into the nooks and crannies, and squeezes out any excess glue. Too little pressure results in a thick glue line and lower strength. Too much pressure squeezes out all the glue, again giving a weaker joint. Stated another way, a little squeeze out is good in that it shows that there was sufficient adhesive; no squeeze out means that the glue was insufficient or was pre-cured. Too much squeeze out means that the pressure was too high or there was too much adhesive.

It should be obvious that the pressure applied needs to be uniform along the entire joint; uneven pressure will mean too much or too little pressure, both which lead to poor joints. So, this means that the two surfaces to be joined must be of the same shape (usually this means flat) along the entire joint. The big factor that changes the joint shape (or flatness) is moisture. So, to achieve correct pressures, we need to avoid moisture changes in the wood pieces that are being glued, as moisture changes mean size and shape changes and will lead to uneven pressure and a poor joint. I believe more than 75% of the gluing failures are due to moisture changes in the wood prior to gluing.

Another pressure issue results when the pressure is initially applied, which squeezes out the excess glue, but then is slightly reduced. With the reduced pressure, the joint will open up slightly (probably not even enough to measure), but there is no longer excess glue to fill in the voids. One very subtle way to open a joint after the pressure is applied is to apply additional pressure to the unglued faces, causing the wood to move. (A specific example would be in a panel gluer where top pressure is applied after the side pressure is applied. Another would be when the face of a panel is pounded or has a ram on the unglued face after the edge pressure is applied.)

A special note about epoxy adhesives is the adhesive develops heat, and this heat helps the chemical reaction occur. To get enough heat, the joint needs to be fairly thick – thicker than with the PVA adhesives that are popular within our wood working industry. Excessive pressure with epoxy is a common problem for the casual user of epoxy and is also the reason that “horror stories” about epoxy being weak are heard.

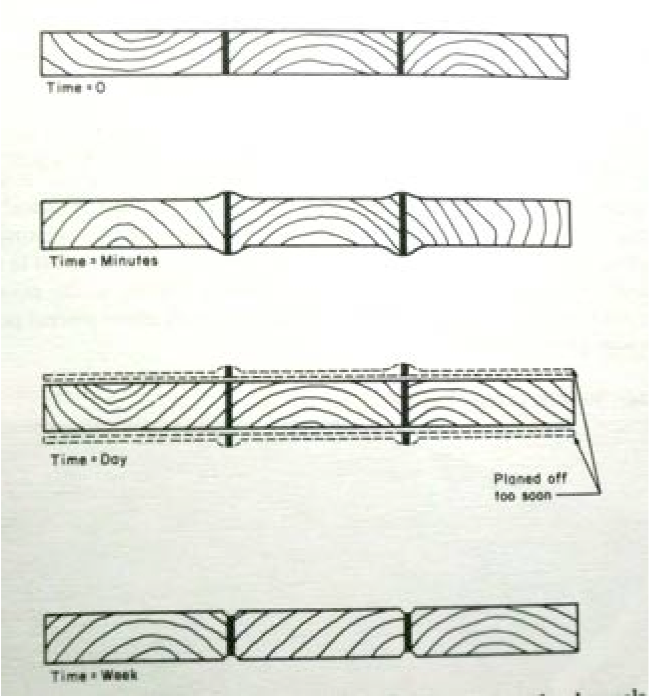
E. To assist in analyzing a gluing failure or problem, consider the implied analogy between the joint and the links of a chain. Try to figure out which “link” has broken and then figure out why it broke. Note that in 50 years of work in this area, only twice I have seen the weak link being the



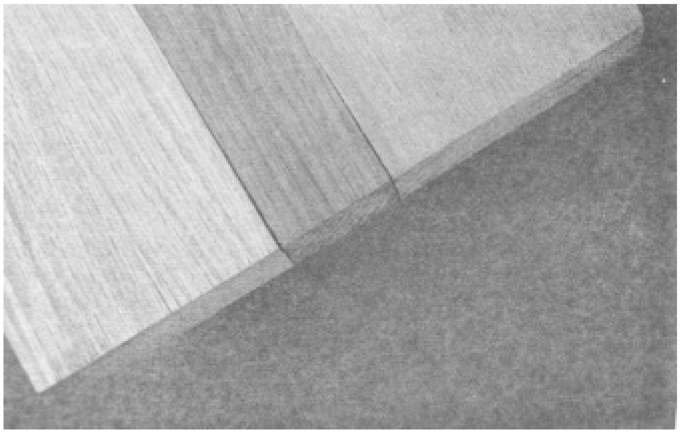
adhesive, and such weakness was caused by poor handling of the adhesive by the purchaser.

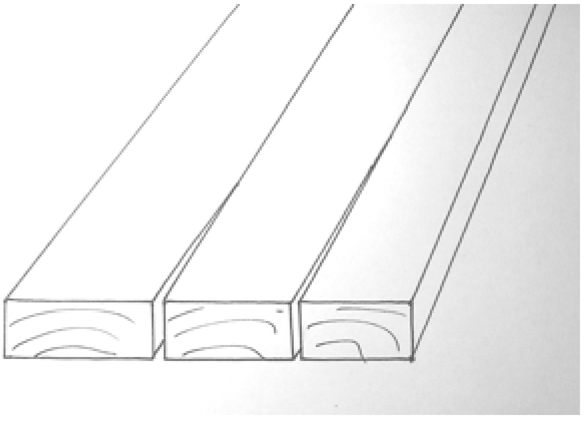
PART II. PRACTICAL EXAMPLES
So, now, with this technical background, let's apply our knowledge to every-day, practical problems.

A. Sunken joints. Consider an edge glued panel made of several strips of wood and glued together with an adhesive that has some water in it. When the panel is first glued together, within an hour or two, the wood right around the joint (within 1/8" nominally) will swell in thickness due to the water in the glue that moves into the wood fibers right near the glue line. So, right after gluing, there is actually a small bump at the glue line. As soon as this water evaporates, the swelling will go down and the wood is back to "normal." The problem arises when we machine this panel BEFORE the water has left and the swelling has gone down. Right after sanding or planning, the panel will be perfectly flat, but then as the rest of the excess water leaves, there will be a slight amount of shrinkage right at the glue joint. You will find it nearly impossible to see this slight depression with your eye UNTIL you put a smooth finish on the wood. In fact, the glossier the finish, the more that this small imperfection, called a sunken joint, will show up.

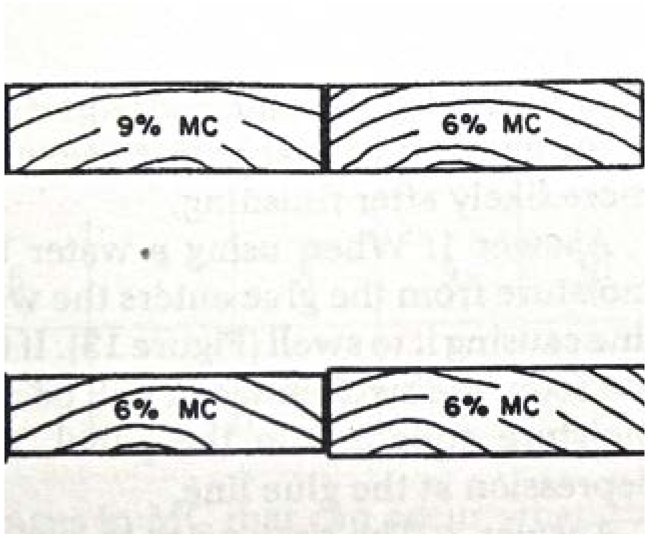


B. End Splits. End splits in glued-up panels (left figure) seem to occur every winter in some shops. The basic reason is that the wood is a bit too wet for the shop’s environment. So, what happens is that the ends of the individual pieces will dry out a bit (end grain dries faster than side grain) before the adhesive is applied to the joints. This small shrinkage means that the distance between the pieces at the ends is several 1/1000” to far apart (right figure), so the joint is weak. Any stress on this joint after gluing will result in a failure.

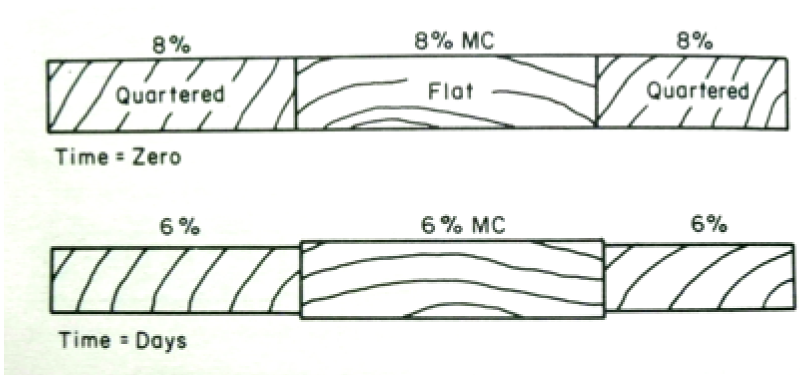




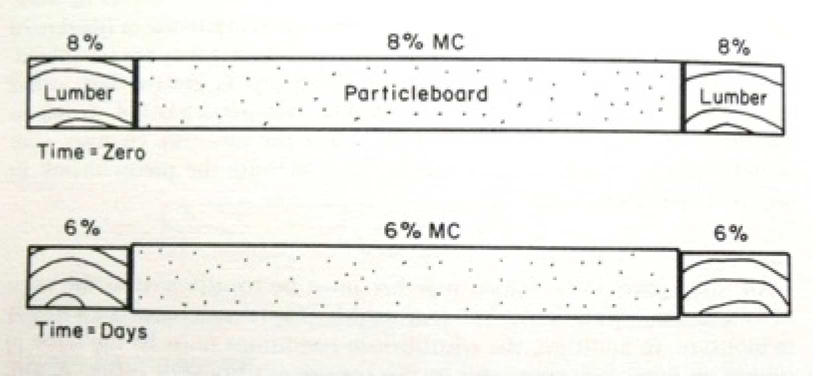
C. Planking. The third defect, which is often seen with a glossy finish, occurs when the individual pieces are at different MCs when assembled and then shrink or swell slightly as they adjust to their environment.



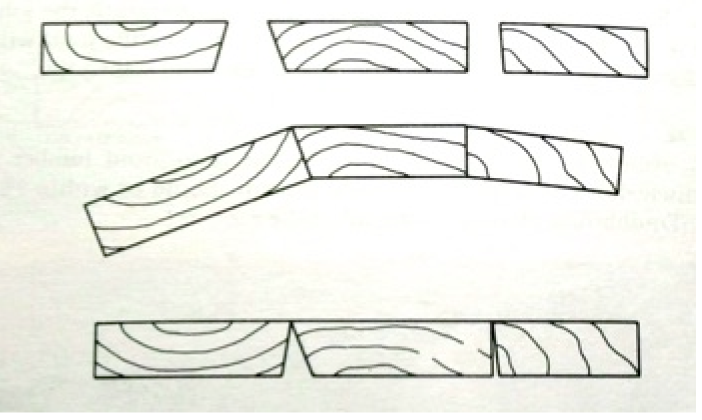
Planking can also occur when flat-sawn and quarter-sawn grain pieces are joined, as quarter-sawn piece shrink and swell twice as much as flat-sawn.



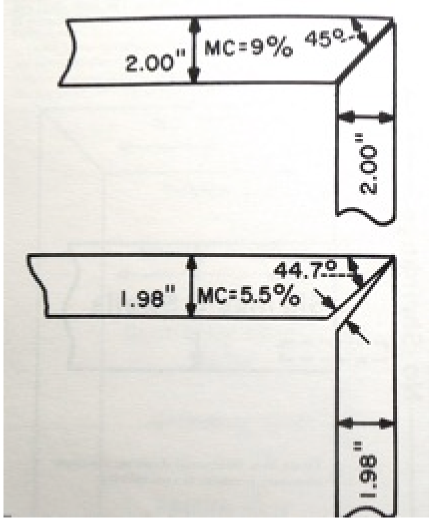
Planking can also occur when two dissimilar wood pieces are joined, as different wood products shrink differently than solid wood.



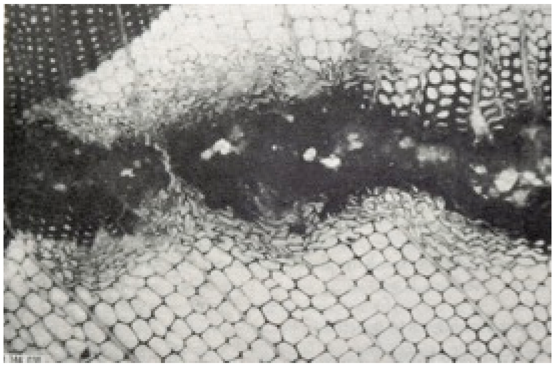
D. Open Joints immediately after gluing. This defect can occur because the edges are not square to the faces. When face pressure is used to flatten the panel during the gluing process, the joints are opened and are without adequate glue.

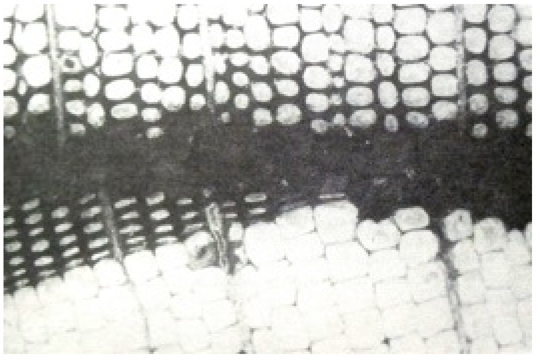


E. Opening of a miter joint. Miter joints are very sensitive to moisture content change. As a piece with a miter dries, it becomes more pointed, because it shrinks more in width than in length. Miter joints also have a lot of end grain; joints with a lot of end grain are not very strong unless splines or other techniques are used.

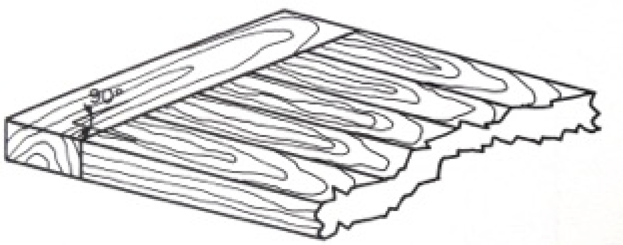


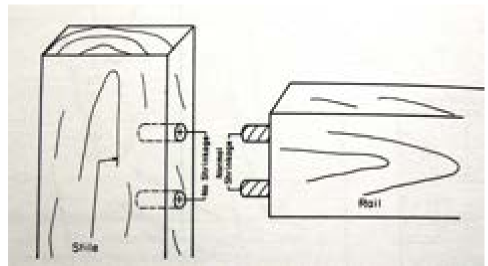
F. Low strength joint. One reason for a poor joint is that the wood right at the joint is not well fastened to the solid wood below. As an analogy, the joint formed is like trying to glue to peaches with a lot of peach fuzz together. You can easily glue the fuzz, but the fuzz is not well attached to the skin itself. The dissected glue joint (glue is the dark region in the middle running horizontally) shows a joint prepared by sanding the surfaces (left) and all the debris and squished wood cells; the joint prepared with a sharp knife or saw (right) is cleaner and will be much stronger (as mentioned earlier, note how the glue does not penetrate deeply into the wood).

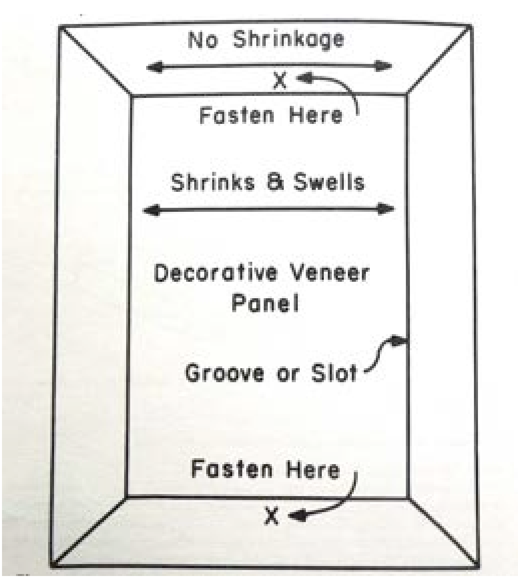


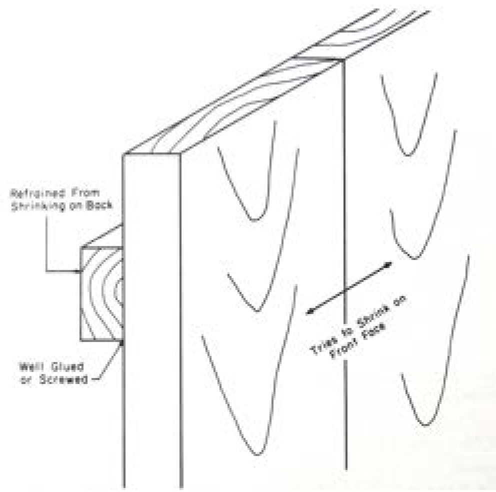


G. Grain at 90 degrees causes warp and joint failure. Wood does not shrink or swell lengthwise when its moisture content changes, in most situations. But, wood does move across the grain as much as 1% when the moisture changes by 3% MC. For this reason, it is advisable to avoid construction where the grain of two pieces glued together is at 90 degrees; four situations to avoid are illustrated (note that wood moves due to moisture changes and not due to temperature changes).









PART III. STICK IT TO ME

Here is a quiz that will test your stick-to-it-ness and what you learned in this article. Anyone scoring 18 or more correct is super-duper sticky person. Signed: Professor Gene, THE WOOD DOCTOR.

1. Basically, all glues are the same in that they all stick to wood in the same way. TRUE or FALSE
2. Yellow PVA glues are stronger than white PVA glues. TRUE or FALSE
3. The term “aliphatic” on the label indicates a better adhesive. TRUE or FALSE
4. Formaldehyde glues are heat curing. - TRUE or FALSE
5. A thick glue-line is almost always better than a thin one as it will fills gaps and voids. - TRUE or FALSE
6. Higher pressure is better, as it squeezes the glue deep into the wood. - TRUE or FALSE
7. Some glues will stain or finish just as good as wood. TRUE or FALSE
8. Moderate changes in moisture content affects the rate that a PVA glue joint cures. TRUE or FALSE
9. The temperature of the wood affects the rate that a PVA glue joint cures. TRUE or FALSE
10. The temperature of the glue affects the rate that a PVA glue joint cures. TRUE or FALSE
11. When edge-gluing, the pieces should be assembled and pressure applied ASAP (10 seconds or less) after spreading the adhesive for maximum strength. TRUE or FALSE
12. After edge-gluing, the panels can be machined as soon as they leave the clamps (about 60 minutes). TRUE or FALSE
13. The term “water resistant” means that the adhesive is waterproof and is not affected by submersion in water. TRUE or FALSE
14. A few adhesives have toxic chemicals and they should not be used. TRUE or FALSE
15. Water-based glue that has been frozen should not be used. TRUE or FALSE
16. Low humidity in the area around the gluing operation can likely cause open end joints if the wood is a little bit high in moisture. TRUE or FALSE
17. When edge-gluing, if a warped piece can be pushed straight in the press or clamps, it is OK to use. TRUE or FALSE
18. If unopened or tightly sealed, adhesives will last for decades. TRUE or FALSE
19. Wood surfaces, once prepared properly for gluing, can be stored and used months later and still be just as good. TRUE or FALSE
20. PUR adhesives only are applied with a heat gun. TRUE or FALSE

ANSWERS:

1. FALSE. There are at least 100 different wood glues, some similar to each other and some quite a bit different in properties.
2. FALSE. The color has no relationship to strength of the adhesive.
3. FALSE. The term refers to the type of chemicals in the adhesive, but not the strength of a bond necessarily.

4. FALSE. Formaldehyde is merely a catalyst and is not the adhesive itself.
5. FALSE. Any adhesive will lose its strength when it is too thick (over 0.006").
6. FALSE. Pressure spreads the adhesive, moves the two pieces of wood close to each other squeezing out any excess adhesive, and fills any small nooks and crannies, but does not squeeze glue into wood.
7. FALSE. Wood adhesives do not absorb stain like wood.
8. TRUE; wetter is slower.
9. TRUE; hotter is faster.
10. TRUE.; hotter is faster.
11. FALSE. Indeed, some urgency is required, but not this fast, except for hot melts.
12. FALSE (most of the time). Greater strength and mitigation of some moisture issues require waiting a bit longer…usually 24 to 48 hours.
13. FALSE. This term only means that the adhesive can tolerate intermittent wetting.
14. FALSE. Probably all adhesives have some degree of toxicity, but all can be used if label directions are followed.
15. TRUE.
16. TRUE. This is perhaps the leading cause of poor joints.
17. FALSE. The warp piece will be trying to straighten and put stress on the joint, lowering the stress it can take until it breaks. Also, where the warped piece meets an adjacent piece, the pressure can be so high it squeezes out all of the adhesive.
18. FALSE. Adhesives have a shelf life.
19. FALSE. Time makes wood surfaces untrue and not as active for gluing (= weak joints).
20. FALSE. Some PURs do not need heat.

PART IV. FINAL THOUGHTS

It is extremely rare that the adhesive itself is the problem with a weak or failed glue joint. Therefore, changing adhesives when there is a problem will not solve the problem. Instead, look for the basic cause of the failure (such as shrinkage of the wood between the time or preparation and the time of gluing, which can often lead to a gap over 0.006 inches). Then change the process to cure the problem. Example: I was consulting with a small cabinet shop that would experience as many as 8 failures out of 50 when gluing panels in the wintertime. Before I visited with them, I had them rip the strips to be glued and then glue the strips within 5 minutes after cutting. The results were only one bad joint out of 50. Time delays in the wintertime, when the wood is often wetter than the atmosphere in a shop, are almost always a serious problem).

Do not count on the clamps or the press to straighten warped pieces. Although this equipment may straighten the pieces, when the pressure is removed, the joint will have a great deal of stress initially. It may take only a little extra stress, such as from a MC change, for the panel to split or crack.

The wood to be glued should be at 7.0% MC in the wintertime; the shop RH must be at 30% to 37% RH. Small plastic walled rooms with humidity control are very effective when the entire shop area cannot be controlled well. Store lumber in these rooms as well as any work-in-process that is moisture sensitive.

Letting the adhesive cure in a warm (not hot) location will often help the adhesive cure rapidly. Avoid low relative humidity when heating the air, however.

Some adhesives allow the joint to be moved and repositioned before the final pressure is applied. The best example of this property is the “old fashioned” PVA white glues. Although old, this class of adhesives is still excellent. On the other hand, some adhesives do not allow the joint to repositioned without a loss of strength; contact adhesives are one example, but many common woodworking adhesives are also intolerant of much joint movement prior to pressing. As a general rule, those adhesives that have high instant tack (adhere somewhat almost instantly) will be intolerant of movement.

PART V. POST GLUING

After wood is glued together, be aware that finishes can have solvents that dissolve or otherwise affect the adhesive. Water-based finishes can affect some adhesives and the wood around them, creating joint weakness and appearance issues, especially a sunken joint. Heating in finish-curing ovens can affect some adhesives, creating joint weakness and appearance issues, especially a raised joint. Heat, which will be accompanied by very dry air, can also cause wood movement (shrinkage) opening weak joints and preexisting cracks, checks, or joints.

About Gene Wengart

Gene Wengert is President of The Wood Doctor's Rx, LLC, based in Madison, WI 53711-6502 and Professor Emeritus at the University of Wisconsin-Madison. As a former professor and extension specialist at Virginia Tech and researcher at the U.S. Forest Products Lab, Gene teaches over 30 practical wood processing classes and seminars a year for the wood products industry, including sawing, edging, grading, drying, machining and gluing. He is the author of eight practical books and has published over 400 articles relating to the wood products industry.