Designing the Wedged Mortise and Tenon

Attention to detail yields exceptionally strong joints

by Carl Swensson

The author taps in wedges that won't come out. Careful design will yield a joint that is nearly impossible to pull apart.

A door can be slammed only so many times before the tenons pull out of their mortises. Even the sturdiest chair will not survive an overweight, hyperactive teen who tilts back on the chair's rear legs. These are extremes. Most furniture that falls apart has not been abused. When a chair squeaks or a table wobbles, it's usually just bad joinery design.

Good design buys time against the use and abuse that all furniture will bear. Unless you plan to make all your furniture exclusively for your grandmother, you must choose and design furniture joints to withstand years of stress. Many antique stores offer living proof that well-made furniture can outlive its maker. Look closely at an old chair or door, and you may find the distinctive bands of wedges still holding through tenons in place.

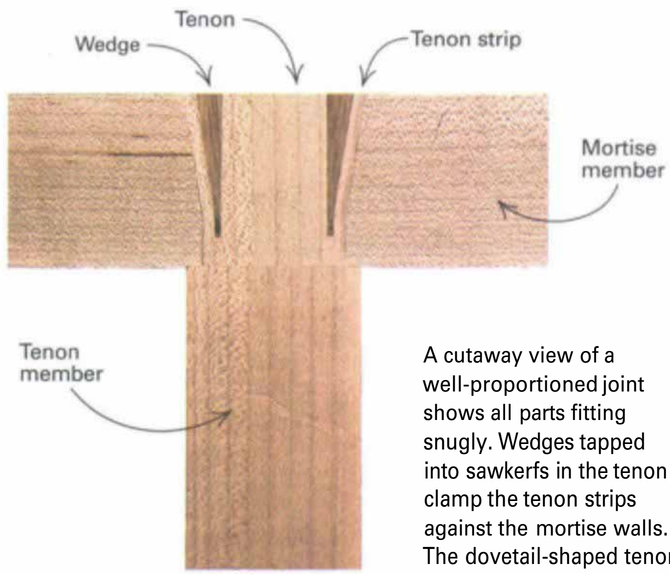
The wedged mortise and tenon is a simply made and very effective woodworking joint (see the photos at right). Two kerfs cut in the tenon accept wedges to make the tenon dovetail-shaped. To accommodate the wedged tenon, most of the mortise wall is relieved (or cut) at the same angle as the tenon wedge. This joint is particularly good at resisting racking, a common stress on table and chair legs. And as a visible and beautiful joint, it will add value beyond its structural contribution.

There are no simple guidelines to cutting a successful wedged mortise and tenon. There are no best angles or right lengths for the wedges nor any proper thicknesses for the tenon strips. Designing the wedged mortise and tenon must take into account not only the many stresses the finished piece must withstand but also the particular characteristics of the wood, even of the particular boards you use. The design process must leave the drawing table and become part of the construction process.

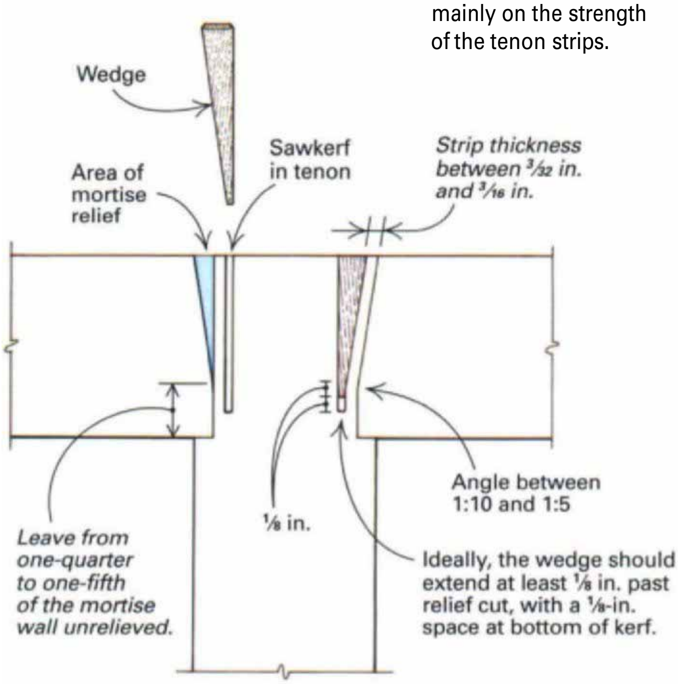
The stresses that break joints

There are two types of forces that work joints loose: internal, from the seasonal expansion and contraction of the wood, and

The wedged mortise and tenon



A cutaway view of a well-proportioned joint shows all parts fitting snugly. Wedges tapped into sawkerfs in the tenon clamp the tenon strips against the mortise walls. The dovetail-shaped tenon will not withdraw from the mortise under tension, but joint integrity depends mainly on the strength of the tenon strips.



external, from human use. Unless you live in an environment with perfectly controlled humidity, variations in the wood's moisture content are inevitable. Because of the cross-grain construction in joints like a mortise and tenon, these seasonal changes are a long-term threat to the joint's integrity. Quartersawn lumber is more stable than flatsawn and should be used for all joints. This grain orientation ensures that the wood will move the least along its greatest width. It also minimizes the wood's movement against itself.

Normal use will put several forces on a joint: compression and tension, shearing, racking and twisting. The connection between the internal faces of the mortise and tenon does most of the work in keeping the joint together, though the tenon's

Photo above right: Scott Phillips; drawing: Vince Babak shoulders help to prevent compression.

Twisting forces are often overlooked in joint design. Kicking a table leg or leaning back on the rear legs of a chair can create very strong twisting forces on a joint. A mortise near the end of a board is particularly vulnerable to this stress because of the short grain. It is better to keep the mortise at least twice the width of the tenon away from the end of the board. These forces will be less likely to cause joint failure.

Wedging the tenon against tension

A simple glued mortise-and-tenon joint with shoulders will resist compression, shearing, racking and twisting forces quite well. But this joint does not respond well to tension. In time, when the glue crumbles away, the tenon will come out almost as easily as it went in.

Wedging the tenon creates an internal dovetail shape that is extremely resistant to tension and does not compromise the joint's strength in any other way (see the drawing on p. 67). Under tension, the mortise walls exert an even clamping pressure along the side of the tenon. This pressure holds the wedges firmly inside the tenon and does not squeeze them out of their kerfs. As long as the tenon keeps its dovetail shape, it will not withdraw under either tension pressure.

The key to the strength of this joint is the integrity of the thin strip of tenon between the wedge and the mortise wall. The joint is nearly impossible to break under tension if the strip remains intact. However, if both strips break, the tenon will not resist withdrawal any more than a plain tenon would. The variables affecting the soundness of the tenon strip are its thickness, the mortise-relief angle, the length of the mortise-relief angle and the length of the kerf in the tenon. Each of these must be determined in turn. As the examples on this and the facing page show, it's easy to misjudge one of these factors.

Templates to test thicknesses and angles

Determining the tenon-strip thickness and mortise-relief angle as a working unit depends largely on the properties of the wood you are using. Hard maple will often work in a wide range of thicknesses and angles. More brittle woods, such as cherry, may require a very low angle ratio and a thin strip to work. Even variations from board to board make it necessary to test the angle and strip for each project.

Make a series of templates with slope ratios from 1:10 to 1:5 to simulate the mortise-relief angles in the actual joint (see the top photo at left). File or chisel a slight round at the angle, both on the test jig and in the actual joint. This slightly reduces the chances that the tenon strip will kink, crack or break when it bends around the angle. Next make five to six strips of various thicknesses from the same wood as the tenon, preferably from

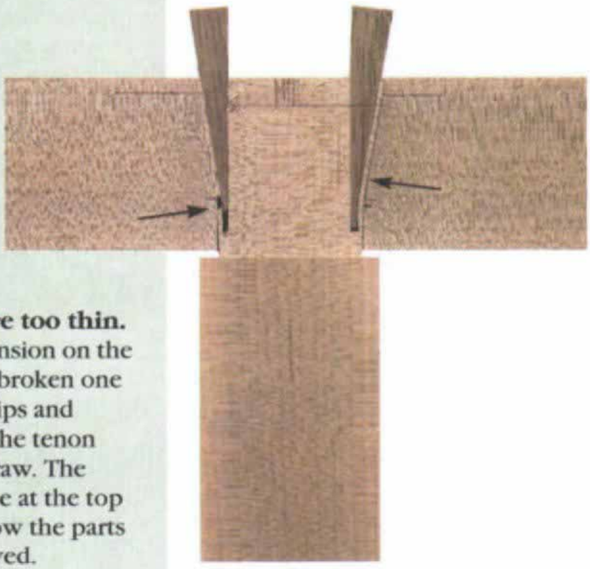
3⁄32

and not more than 3⁄16 in.

Clamp the strips to the different templates until you find the combination of greatest thickness and highest angle that will not break the strip. A higher angle gives better withdrawal resistance, but requires a thinner and more vulnerable strip (see the center photo at left). A lower angle can accommodate a thicker strip, which is less likely to break, but will not offer as much resistance to tension. However, really thick strips do not bend as easily and may crack if bent too far (see the bottom photo at left). As a rule, I start testing with a strip 3⁄32 in. thick

Strip thickness

Test tenon strip material with a template. A few outside fibers have failed on this test strip, but it is basically sound.

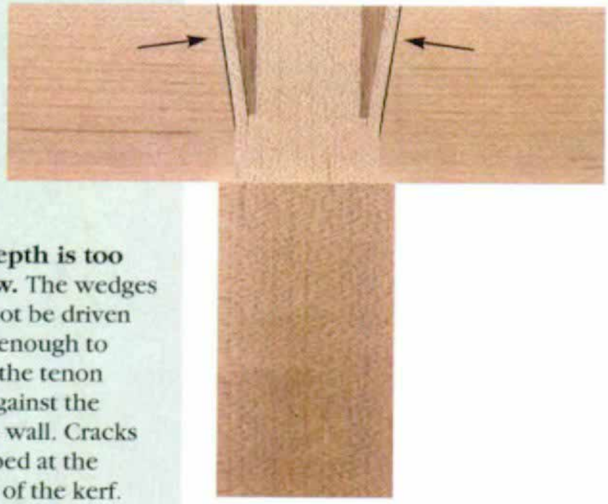


Strips are too thin. A little tension on the joint has broken one of the strips and allowed the tenon to withdraw. The layout line at the top shows how the parts have moved.

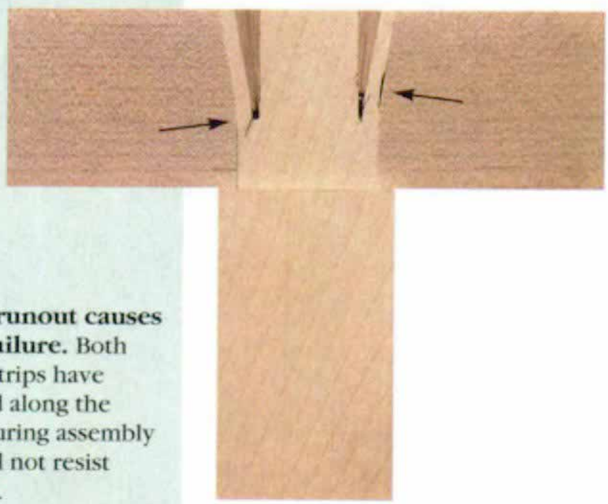
Strips are too thick. Even though they were tough, the tenon strips were asked to deflect too much and have cracked substantially at the base. Note how the layout lines at the bottom have moved.

Photos except where noted: Strother Purdy

Problem joints



Kerf depth is too shallow. The wedges could not be driven deeply enough to deflect the tenon strips against the mortise wall. Cracks developed at the bottom of the kerf.



Grain runout causes strip failure. Both tenon strips have cracked along the grain during assembly and will not resist tension.

Close, but no cigar. The proportions of this joint are promising, but uneven insertion of the wedges caused permanent racking during assembly.

and a slope ratio of 1:7 and increase either the ratio or the thickness or both from there to find the best balance.

Proportions for mortise wall relief and tenon kerf

You now know the angle to relieve the mortise wall and to cut the wedges. The next step is to determine how much of the mortise wall you should relieve. This will, in turn, determine the length of the wedge and the depth of the kerf in the tenon.

The deeper the mortise-relief cut is, the more surface area you create on the mortise wall to resist tension. However, you must leave some room at the base of the tenon so the wedge can be driven past the end of the mortise relief. Leaving from one-quarter to one-fifth of the mortise wall unrelieved works well.

The sawkerf in the tenon should extend beyond the mortise-relief cut, but not by much. This allows the wedge to be driven farther than the end of the mortise relief without bottoming out in the kerf. That ensures the tenon strip will be pressed snugly against the entire relieved mortise wall Driving the wedge beyond the relief cut also allows the wedge to support the weakest side of the strip where it bends. If the kerf is too shallow, the wedge will bottom out, and the strip cannot be compressed against the mortise wall (see the top photo at left). Trying to insert the wedges farther during assembly may cause a split in the tenon.

If the tenon has grain runout, splits that develop during assembly may follow the grain out of the wood, causing complete joint failure (see the center photo at left). The first defense against such splits is selecting straight-grained wood for the tenon member. Deep sawkerfs and the snug fit of all the parts in the joint also will help prevent this problem.

Another way to keep a strip from splitting is to drill a ⅛-in.-dia. relief hole at the bottom of the kerf. It will distribute the stress at this point. The hole also thins the strip where it bends, helping it to take the bend without cracking. This step should not be necessary if the grain is straight and the relief angle and strip thickness are well-balanced.

The wedges for final assembly

Perhaps, without realizing it, you have already designed the wedges. The angle of the wedges is the same as the slope ratio of the mortise relief. The thickness of the wedges at their tip should be a little less than the tenon kerf. The wedges should be at least in. longer than the kerf is deep to make it easier to tap in during assembly.

Final assembly, however, is not the time to relax. Much of the joint's integrity depends on how well the parts come together. If you hammer the wedges in unevenly, the joint will rack to one side (see the bottom photo at left). Keep the joint square and the tenon firmly in the mortise as you tap in the wedges.

Yellow wood glue, because it sets fast, can make this joint even trickier to assemble. It sets so fast you won't have much time to make sure all the parts are aligned properly. For this joint, I use a glue with a slower set up time. If you have avoided design mistakes, the result should be a very tight, strong joint and an ornament to your work.

Carl Swensson is a professional woodworker and furniture designer. He has built tracker organs, doors for a Buddhist temple in Japan and countless Appalachian-style chairs. He lives in Baltimore, Md.