
Force Transducer

Tips for Stronger Tenons

Make them bigger, reduce gaps, and don't spare the glue

BY DAN BOLLOCK

As part of my job as a technician in a wood research laboratory, I test joinery, materials, and glues to see how they withstand the rigors of use and abuse. But I'm also a woodworker and furniture maker, so I have a vested interest in my research. Recently, I spent time studying the strength of various mortise-and-tenon joints, an important study as the joint is typically used in high-stress and load-bearing situations in chairs, tables, and case pieces.

As part of the testing, we made and broke more than 150 mortise-and-tenons using a computerized hydraulic ram, called an Unaxial Load Frame, by MTS Systems. We discovered not only that bigger is better, but also that the final joint fit and glue-up procedure affect the joint's strength.

Make them wide and long

Most of the testing was done to determine how the size of the tenon affects its overall strength. For all three dimensions—width, length, and thickness—bigger directly equated to a stronger joint. For the width and length tests, we used ⅜-in.-thick tenons, a fairly common size.

Increasing the width of the tenon had the biggest effect

Testing the joints

To find out how different variables affect the overall strength of a mortise-and-tenon joint, we ran more than 150 different variations on the same joint through a computerized hydraulic press designed specifically to bring all manner of joints to their breaking points. To ensure accurate results, all the tested joints were made from kiln-dried yellow poplar with a consistent moisture content between 6% and 8%. Slip tenons were used for consistent sizing and for ease of manufacture. The tenons were sized with a drum sander and the mortises cut using a horizontal mortising machine. Finally, every joint was glued using the same bottle of Titebond I PVA.

The variables. *Bollock analyzed how tenon dimensions, fit, and glue-up procedures play a role in the strength of a joint.*

Photos: Dillon Ryan

Bigger is better

It isn't a surprise that the size of a tenon directly relates to its strength, but not every dimension plays an equal role.

WIDTH

When designing joinery that will see a lot of force, the widest possible tenon will give the best results. Jumping from a 1¼-in.-wide tenon to one that was 2¼ in. wide allowed the joint to take more than twice the force. Adding another inch to the width nearly doubled the force required to break the joint.

Tenon width	Failure load
1¼ in.	191 lb.
2¼ in.	464 lb.
3¼ in.	748 lb.

All tenons were ⅜ in. thick by 1¼ in. long.

LENGTH

Every ¼ in. added to the length of the tenon added 130 to 180 lb. of load-bearing capacity to the joint. When laying out mortise-and-tenons, make the tenon as long as possible to take advantage of this gain in strength.

Tenon length	Failure load
¾ in.	251 lb.
1 in.	383 lb.
1¼ in.	464 lb.

All tenons were ⅜ in. thick by 2¼ in. wide.

THICKNESS

While tenon thickness had the least effect on strength, it still can play a pivotal role in building a lasting joint. Where you don't have room for an extra wide or long tenon, increasing its thickness from ¼ in. to ⅜ in., or ⅜ in. to ½ in. will give you a joint that's about 40% stronger.

Tenon thickness	Failure load
¼ in.	341 lb.
⅜ in.	464 lb.
½ in.	511 lb.

All tenons were 2¼ in. wide by 1¼ in. long.

on the strength of the joint. As the width went from 1¼ in. to 2¼ in., the strength increased by 140%, and a 3¼-in.-wide tenon tested as 291% stronger than a 1¼-in.-wide tenon.

We also discovered that increasing the tenon length added strength. Going from ¾ in. to 1 in. resulted in a 53% gain, and increasing the length to 1¼ in. gave us an 85% increase in strength over the ¾-in.-long tenon.

As for tenon thickness, thicker is stronger. A ⅜-in.-thick tenon was 36% stronger and a ½-in.-thick tenon was 50% stronger than the ¼-in.-thick tenon. But increasing thickness has a smaller effect than increasing width and length.

Reduce gaps

Another crucial factor in the joint's strength was the fit of the tenon in the mortise. The tests proved that tight-fighting joinery is a must and that you can't rely on glue to bridge even small gaps. Ideally, the gap around the tenon should be no more than 0.005 in. When the gap is doubled in size, the strength of the joint decreases by 21%.

I know it's difficult to measure gaps precisely, so here's a tip to check the fit without math. A properly sized tenon can be inserted into the mortise with hand pressure to just short of the shoulder. A hammer or clamp should be needed only for the last fraction of an inch to fully seat the parts. The gap is too large if gravity is able to pull the parts apart when they are held vertically.

Don't skimp on the glue

Sizing the joint properly and fitting the tenon into the mortise are keys to a strong joint, but where you apply glue matters, too. We found that the best approach is to apply glue to both the mortise and the tenon. This method gave us a joint that was 103% stronger than the joint where glue was applied to the tenon only, and 34% stronger than when it was applied to the mortise only.

Designing the strongest tenon

All this testing gave me a description of a perfectly engineered, strong, durable mortise-and-tenon joint. Use

The fit counts

A loose fit can severely weaken a mortise-and-tenon joint. Using calipers to measure, keep the gap between the mortise and tenon to about 0.005 in. The joint should fit snugly by hand and hold itself together despite gravity.

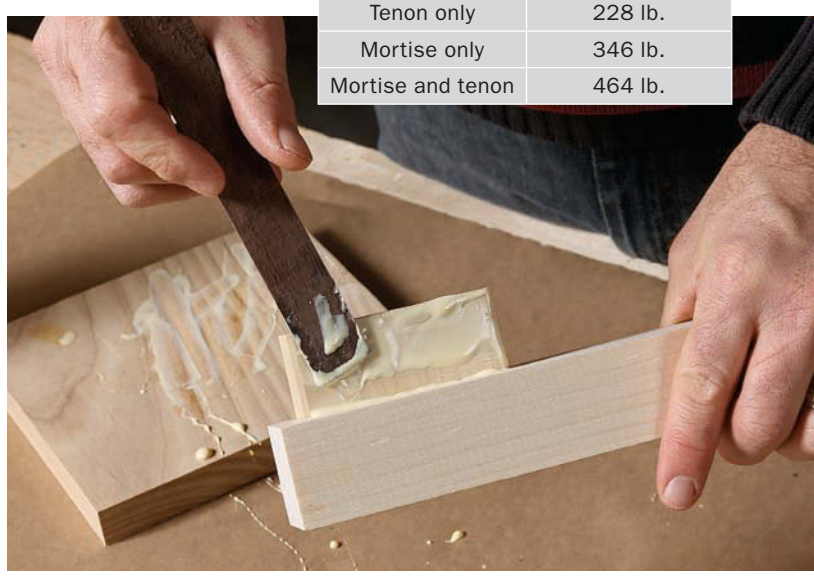
Gap	Failure load
0.005 in.	464 lb.
0.010 in.	368 lb.

All tenons were ⅜ in. thick by 2¼ in. wide by 1¼ in. long.

Proper glue-up

The joints with glue applied to both the mortise and the tenon were able to take twice the load of those with glue applied to the tenon only, and over 100 lb. more than those with glue applied solely to the mortise. Although it leads to more squeeze-out, gluing both parts of the joint will add strength.

Glue application	Failure load
Tenon only	228 lb.
Mortise only	346 lb.
Mortise and tenon	464 lb.



All tenons were ⅜ in. thick by 2¼ in. wide by 1¼ in. long.

the widest, longest, and thickest tenons you're able to fit into your design, keeping in mind the hierarchy talked about earlier—width first, length second, and thickness third.

After that, make sure your tenons and mortises fit together accurately. Last, apply glue to both the mortise and the tenon for the strongest glue bond and worry about the cleanup afterward.

Follow these tenon guidelines, and you'll build stronger, longer lasting furniture. □

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