

Laminating Curves

A bundle of square-sectioned plies bends easily around almost any curve

by Rob Hare



A couple I know wanted a special table, something low with a top that tilted up to hold sheet music. The table would go in a formal room. They looked at possible designs and settled on one with delicately tapered legs of wenge that curved outward at the corners. The legs needed to be strong and graceful, with grain lines that emphasized their curved shape.

I worked through my options for making the legs and chose a technique I call bundle laminating. The legs are made from a bundle of square-sectioned plies all cut from the same blank, each ply limber enough to bend around the compound curve of the leg. To get the best grain matching possible, I number the plies before resawing the leg blanks and glue them back together in the same order. The result—a strong curve with grain so well matched it's hard to see the gluelines (see the photo at right).

Bundle laminating is not as difficult as it may look, but it does require more time and care than many other methods of lamination. I use a jig similar to the type boatbuilders call a strongback (see the photo at left). It has a strong outer frame that holds a series of upright molds notched to contain the bundles as they bend around the curve. The method is well-suited for any compound curve, like stair railings or the backs of Windsor chairs.

Drawing the curve to design the jig

To build the jig, I start by drawing the leg's critical curve—its outer corner—which goes face-down in the jig. I scale a few points from my design sketch and then transfer them to a piece of plywood (see drawing 1 on p. 72). Next I bend a clear oak batten about 1/4 in. by 3/4 in. by 4 ft. through the marked points just to see how the curve will look. Rarely is the first curve quite right to my eye, so I move the batten around until I find just the curve I want and then trace that on the plywood. The line represents the outside corner of the leg.

The leg measures 2 1/4 in. diagonally, so I use the batten to draw a second line parallel to the first and 2 1/4 in. away from it. This line represents the inner corner of the leg. Finally, I draw a line midway between the first two lines to represent the remaining corners (see drawing 2 on p. 72).

I can now draw parts for the jig, full size, around the leg. I begin by drawing a baseline about 6 in. below the lowest part of the curve to represent the benchtop. Then I draw vertical lines every 3 in. to represent the plywood molds (see drawing 3 on p. 72). The spacing of the molds isn't critical; my rule is to space the



molds evenly, use as many molds as I can and leave at least 2 1/2 in. between them to operate the clamps.

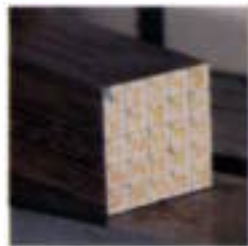
At this point, I have all the information I need to build the jig except for the shape of the notches that hold the plies. The notches are square where the leg is not curved. But as the curve increases, the notches become more diamond-shaped because the molds are no longer perpendicular to the axis of the leg. Figuring out the exact shapes of the notches may sound complicated, but they easily can be taken from the full-sized drawing. The bottom drawing on p. 72 explains how to do it.

Build a strong and accurate jig

The jig is a ladder frame made from 3/4-in. plywood. The molds are the rungs of the ladder, and they are set in 1/4-in. dadoes and glued and screwed to the sides of the frame. It's essential that the molds be located in the frame in exactly the same location as in the drawing. A discrepancy of only a fraction of an inch means the jig won't produce a smooth curve.

Before I fasten the jig together permanently, I set it up and bend a square-sectioned test ply over it. The test piece should nestle into the bottom of every notch. Any major gaps between the strip and the bottom of a notch are usually the result of an error in measurement in the mold location or the notch. I remove the mold (and sometimes those on either side) to check it against the drawing. I'm more likely to find small gaps between the test ply and the notches in a few molds.

To improve the fit, I have to determine if the gap is the result of a notch being cut too deep or if the notch in one of the molds on either side is too high. I glue shims in the notch or use a rasp as

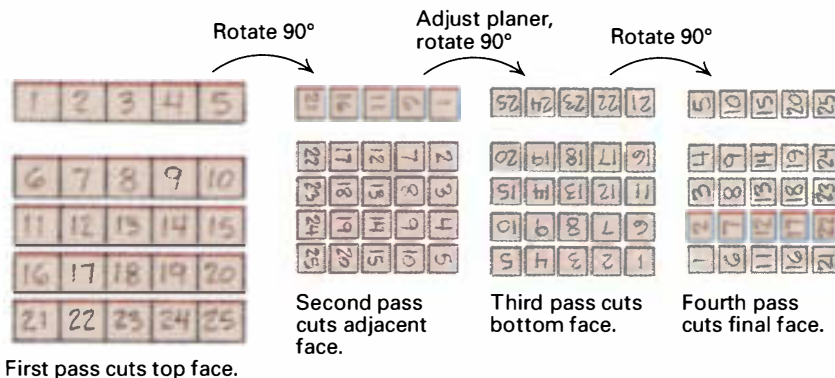


Mark stock before cutting plies. Plies are numbered (above) so they won't get mixed-up as they are band-sawn and then run through a thickness planer (right).



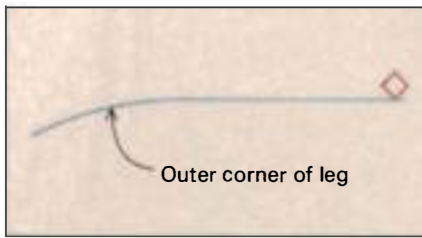
Thickness the plies one row at a time

To remove bandsaw marks, lightly plane the plies in the sequence shown below. The planer is reset only once, after the second pass, to the correct finished thickness.

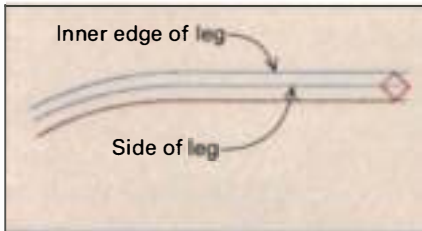


An accurate jig starts with a full-sized drawing

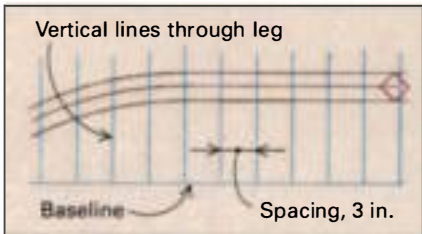
For bending smooth curves, the jig must be accurate. This is easy to do by drawing the leg full size and designing the jig around it. Build the jig exactly as drawn; fine-tune the notches with shims or a rasp.



1. Use batten to establish curve of outer edge of leg.



2. Use batten to draw inner edge of leg parallel to first line and $2\frac{1}{4}$ in. above it. A third line midway between the first two defines the side corner of the leg.



3. Once the leg is drawn full size, draw the parts of the jig under it. Draw a baseline about 6 in. below the lowest part of the curve to represent the bottom of the jig. For the molds, draw evenly spaced vertical lines about 3 in. apart.

necessary, frequently checking with the test strip. Changing one mold affects those on either side. Only when the test piece fits into all the notches do I glue and screw the molds into the frame.

Size the plies for strength and beauty

By using a straight-grained wood and a little care, I can assemble a bundle lamination so the grain is matched and the gluelines are almost invisible. I do that by cutting all the plies for each bundle from one blank and then planing all four sides of each ply. Some material is lost in the process, so before I do any cutting, I have to figure out three things: the thickest ply that will bend over my jig, the number of plies that will make up a bundle with specific finished dimensions, and the size blank that I will need to yield that bundle.

To find the thickest ply that would bend around the coffee table leg jig, I cut a $\frac{1}{2}$ -in.-sq. piece of wenge. When I tried to bend it around the jig, it broke. Working down in increments of $\frac{1}{32}$ in., I found that a $\frac{11}{32}$ -in.-sq. blank was the largest section that would bend over the jig without breaking.

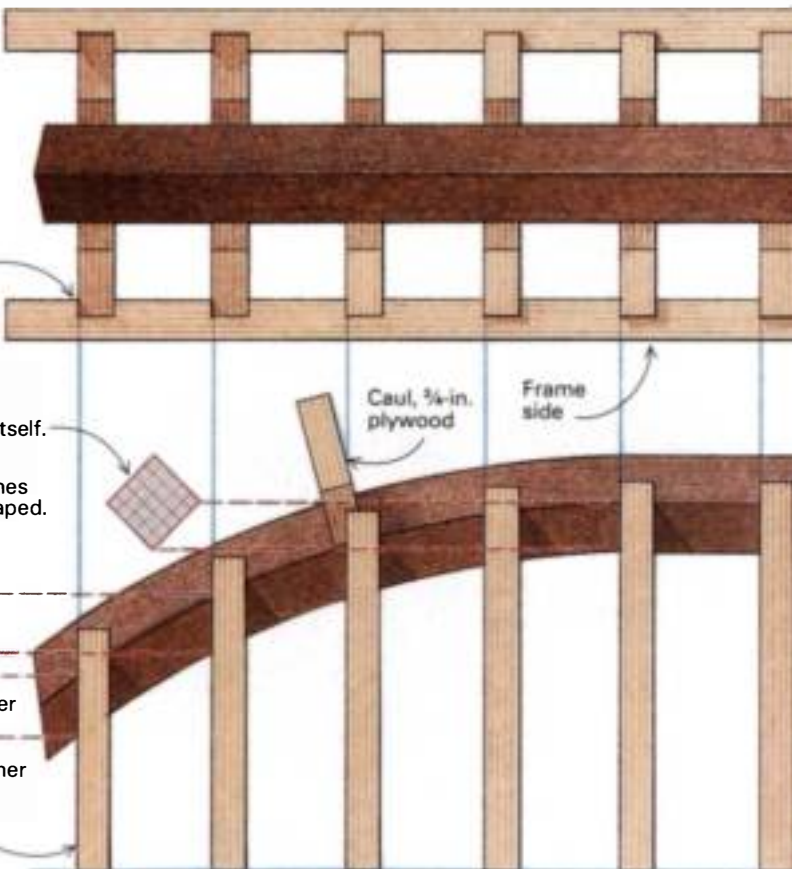
Simple division told me that if a $1\frac{5}{8}$ -in. leg were made of 16 plies (four on each side), they would be too thick to bend around the curve. So I divided the finished dimension into 25 plies (five on a side) and found that each ply would be very close to $\frac{21}{64}$ in., only slightly smaller than the maximum section that bent around the jig.

I wanted to use 2-in.-sq. material for the leg blanks, but I wasn't sure that I could resaw it into 25 plies, plane the sawmarks out of all four sides of each ply and still be able to reassemble them into a bundle $1\frac{5}{8}$ in. sq. To find out if this would work, I ran a few tests on my bandsaw and planer.

I started by setting my bandsaw fence to rip a 2-in. blank into five

Finding the shapes of mold notches

Mold notches are square where the leg is straight, but they become more diamond-shaped as the leg curves. To find the shape of any notch, use the full-scale drawing of the jig. Start by projecting perpendicular lines from points where the side corner and outer corner layout lines intersect the mold. Along the side corner line, mark the length of the leg diagonal (in this case, $2\frac{1}{4}$ in.). Make a tick mark at the center of the diagonal, and at that point, draw a perpendicular line. The point where this new line intersects the outer corner layout line is the bottom point of the notch.



Molds glued and screwed into $\frac{1}{4}$ -in. dadoes in frame sides

Where the leg is straight, the notches have the same dimensions as the bundle itself.

As the leg curves, the notches become more diamond-shaped.

Caul, $\frac{1}{4}$ -in. plywood

Frame side

Shape of caul notches remains constant

90°

$2\frac{1}{4}$ in.

Plywood mold, $\frac{3}{4}$ in.

Hole for clamp, $1\frac{1}{4}$ in.

Projected from side corner

Projected from outer corner

Plywood mold, $\frac{3}{4}$ in.

strips of wood. Without changing the fence setting, I took one of those strips and resawed it into five square plies. Each ply ended up $\frac{3}{8}$ in. on a side, which was larger than the section that would bend around my jig, but not by much. I ran a test ply through the planer set to make a very light cut. It was possible to plane away the sawmarks without losing too much material. Armed with this knowledge, I could lay out and cut my plies from a 2-in.-sq. blank.

Lay out and machine the blanks for grain matching

To match the grain in my bundle laminations, I glued up the pieces as they came out of the plank. Keeping track of all the pieces during the many steps of matching can be difficult. I cut the wenge into 2-in.-sq. blanks (I always make at least one extra blank). I selected the end of each blank with the straightest grain and painted it white. When the paint was dry, I used a different color pencil for each leg, drew a 5x5 grid and numbered each box. Then I looked at the grain in each blank and decided which corner I wanted facing outward. I put a tick mark in that corner of each box. I used the bandsaw to cut the wenge blanks into plies, stacking them in a holder while ordering them by the numbers on the end.

Planing all four sides of each ply is not as hard as it sounds (see the drawings on p. 71). I set the planer to remove one-half of the material required to reach the finished dimension and run the bundle through, row by row planing the top face. As each row comes out of the planer, I rotate it 90° and place it in another holder. Then I run the top face of each row through the planer, rotate it 90° and stack it in a holder. At that point, I reset the planer to the final dimension and plane the third and fourth sides.

Throughout the process, I inspect the stacks for proper number orientation and squareness. Sometimes one piece is out of place,

usually the result of feeding an entire row through the planer in the wrong order. If this happens, you might be able to reduce the final dimension of the bundle and rework the stack. But it's usually easier to start over with the spare blank.

Prepare for the glue-up with a dry run

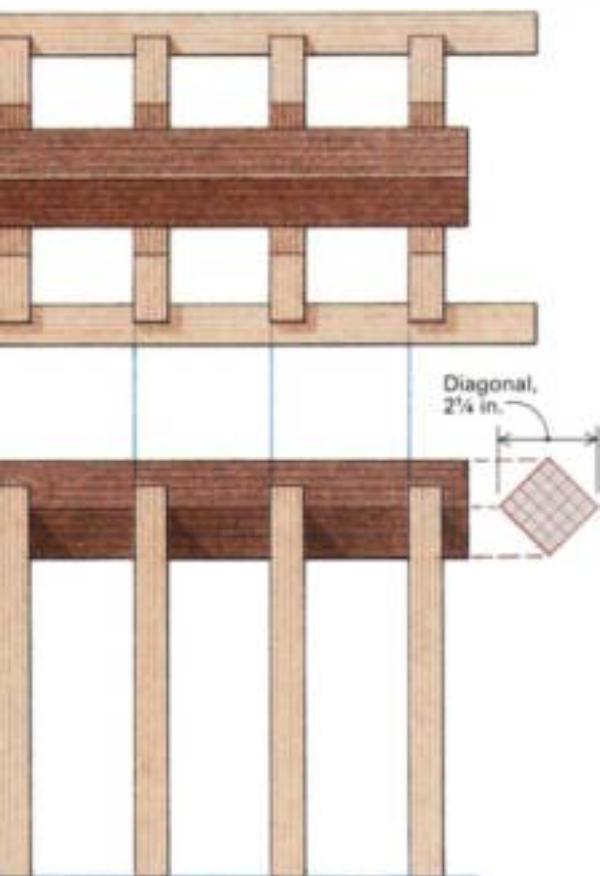
Given the number of pieces involved and the tendency toward confusion, I always make a dry run of the glue-up. This allows me to find and solve any problems with the jig and clamps. When I know that everything works, I put two coats of varnish and a coat of wax on the mold notches and cauls so the bundles won't stick to them.

To keep the glue-up as hassle-free as possible, I use West System epoxy with a slow hardener. When mixed up and left in the pot, the epoxy has a gel time of about 20 minutes, but once it's spread on the plies, I have at least an hour to get the bundles arranged. I mix small batches as needed; rarely does a batch of epoxy sit in the pot long enough to kick.

Before I start gluing, I arrange the bundles so I can easily lift a ply, spread the glue over all four sides with a bristle brush and lay it in the jig in the proper order. When all the plies are glued, I check the numbers one last time to make sure every piece is in its place. Then I clamp the bundle just as I did in the dry run. Before the glue is dry, I clean up as much of the excess glue as I can using scrapers, sticks and paper towels dampened with alcohol.

When the blank comes out of the mold, it's mostly clean and smoothly bent. All it needs is to be tapered to its final shape. □

Rob Hare designs and builds furnishings and sculpture in both wood and metal. His home and studio is in Kingston, N.Y.



EVOLUTION OF A LEG

1. Popped out of the mold, the laminated leg still bears the imprints of the notched molds and some glue squeeze-out.

2. Cleaned up, the leg can be marked for final shaping.

3. The final result is a graceful shape in which grain lines follow the leg's curves and gluelines are virtually invisible.