Create Curves with Bent Lamination

A virtuoso of this powerful technique explains the basics and far beyond

BY BRIAN BOGGS

Photos: Jonathan Binzen; drawings: Dan Thornton

Bent lamination—gluing up thin layers of wood to create a curve—allows you to generate curved parts that wouldn't be possible by sawing or steaming. It lets you make sharp curves and reverse curves, enables you to make wide parts, and delivers uniform results for multiple parts. Lamination produces a workpiece whose grain follows the curve completely, which, combined with all the face-grain glue joints, gives a bent-laminated part great strength. Achieving a successful bend requires accurately machined laminates, careful attention to glue, and uniform clamping pressure throughout the bend. I'll discuss all of these in detail.

Make solid stock into laminates

Let's start with sawing. Slicing laminates is the work of a well-tuned bandsaw. Tablesaws can be used, but you lose lots of material in the kerf. This is expensive, and it reduces grain continuity on the edge of the glued-up part.

Bent lamination works with virtually any species of wood, even tropical ones that typically don't respond well to steam-bending. Air-dried stock is best, if you can get it. Kiln-dried wood can contain a significant amount of stress, and if it does it won't resaw well. If the stock is bowing and twisting as you saw it, use a different board.

How thin the laminates need to be depends on the wood choice and the degree of the curve. The brittler the wood and the tighter the curve, the thinner you'll need to make the laminates. For each new curve, cut a test laminate, guessing how thick it might need to be (⅛ in. to 3⁄16 in. is a good place to start). Bend it over the form. If it's too stiff to make the curve, make thinner ones until you have a laminate that bends to shape easily. Keep in mind that you'll be bending a stack of laminates, so any resistance to taking the bend will be multiplied.

I always make the laminates at least 6 in. longer than the part I'll be creating. It's hard to pull the stack of laminates tightly against the bending form without these few inches of extra leverage, and while you might get there with great force, great force is not good for glue bonding. If the end of your part has a really tight radius, add even more extra length. Make your laminates long enough that you can trim off any planer snipe and still have those extra inches. I make laminates ½ in. wider than the finished part to allow for slippage during glue-up and for jointing and trimming the part afterward.

While it's possible to cut laminates with glue-ready surfaces right off the bandsaw, don't plan on it. I almost always smooth my laminates after sawing. If you don't have a thickness sander, find a local shop that will sand the laminates for you. Alternatively, you could build a vacuum box for your planer. I made one that allows me to plane laminates down to 1⁄16 in. It's a hollow box with a hole underneath for a vacuum hose and slots through the top to exert suction and hold the stock down. If your laminates come off the saw with much twist or cup, the

MAKING THE LAMINATES

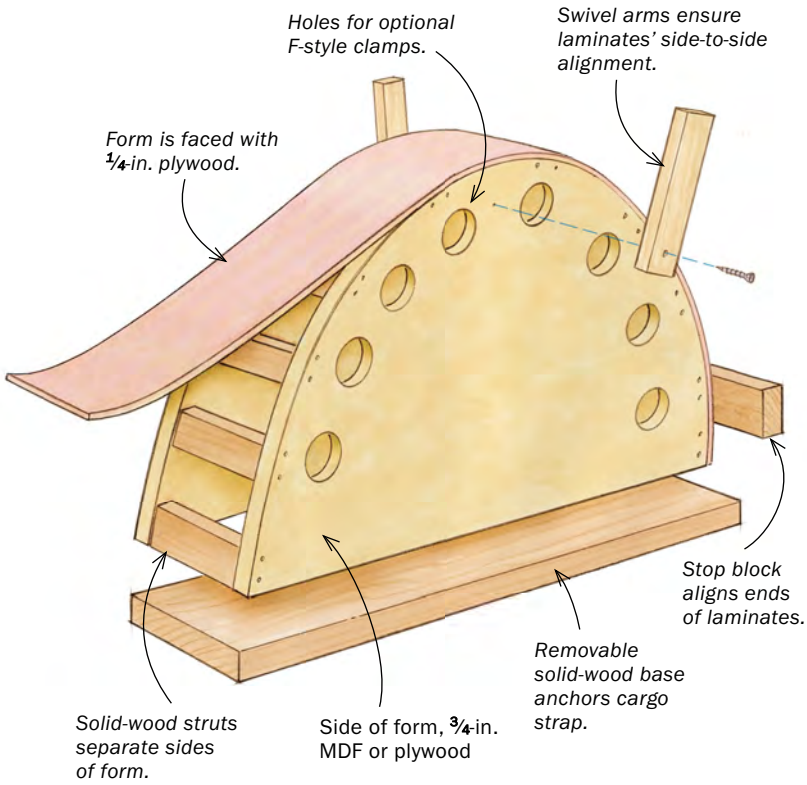
Bent lamination involves slicing up solid stock and then gluing it back together against a bending form. Boggs does the slicing on a bandsaw, then smooths the sawn surfaces with a planer or thickness sander.

First build a fence. *Boggs uses a high fence on the bandsaw when slicing laminates for bending.*

Suction table for the planer ensures smooth results. *With a port on the bottom for the shop vacuum and slots on the top to suck down the laminates, Boggs's hollow suction table lets him plane very thin laminates.*

BUILD A BENDING FORM

To make the first side of the bending form, Boggs trims a piece of sheet material to shape, using a curved stick as a guide. Then he saws out the second side of the form and flush-trims it to the shape of the first side.



Bend a stick to determine the curve. *Having drawn his curve on a sheet of MDF, Boggs bends a thin stick to match it. To fix the bend he clamps the stick to blocks at the ends and middle of the curve; each block has just one screw at this point, so they swivel.*

Screw and glue. *When he has the curve he wants, Boggs drives the second screws through the blocks, adheres the stick to the MDF with hot glue, and screws through the stick into the end blocks. If the stick won't conform to the drawn curve, Boggs revises the design, deferring to the curve of the stick.*

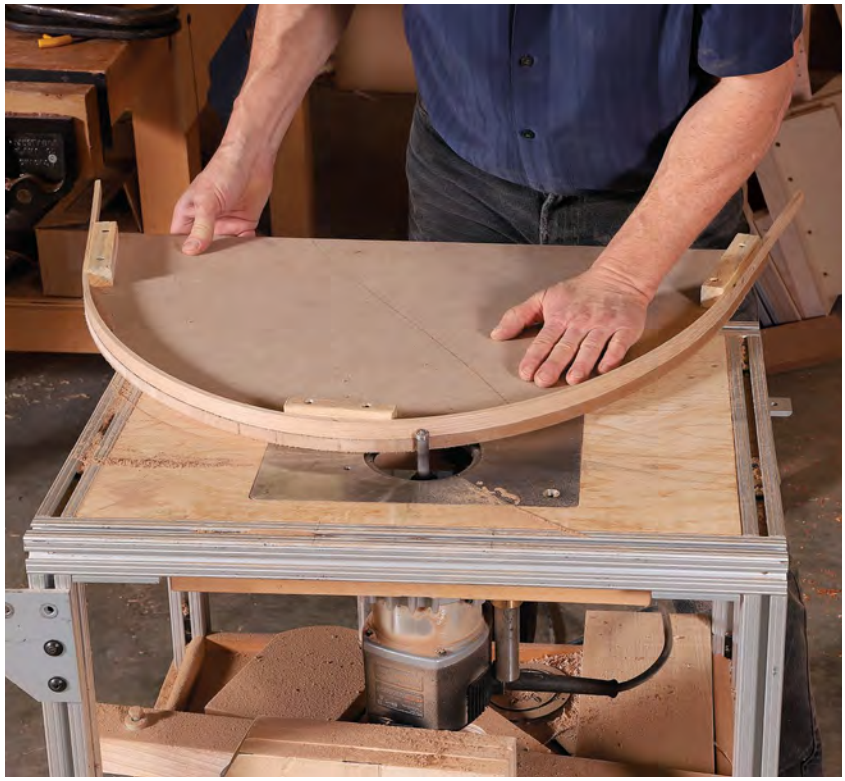
planer might not be the tool for thicknessing them even with a vacuum box. Don't sweat it, just find a mill shop to sand them, ideally one with a vacuum table on their sander.

Get the glue right

Bent lamination depends entirely on glue bonds for its structural integrity, so choosing the right glue is vital. There are various factors, but the rigidity of the glue is key. With so many laminates being glued up, you'll get springback if the glue is not rigid. Depending on the application, I use either Unibond 800 or epoxy.

Epoxy is strongest and penetrates the wood rather than simply bonding to the surface, which is particularly beneficial in those cases where the laminates are used straight off the saw. Epoxy is also great in outdoor applications. I have long used All Wood Epoxy Glue from Rot Doctor, but it is no longer available. They recommend substituting System 3 T-88; West Systems Epoxy is also very good.

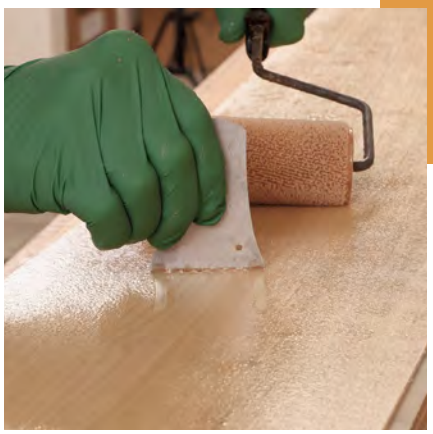
As much as I like epoxy, in my shop we use Unibond 800 for most bent lamination. It has less open time than epoxy, but it still allows plenty of time to get most bends pulled together. It rolls out more easily, cleans up more easily, and is a lot less expensive, so we use it for everything that does not require epoxy. Be sure



Flush to the stick. *After bandsawing the MDF close to the curve, Boggs trims it flush to the stick on the router table.*

USE A STRAP FOR THE BENDING

A heavy-duty cargo strap is an excellent clamping tool to bend a thick stack of laminates. It applies pressure evenly to produce excellent glue joints.



Just enough glue. *With a stack of laminates it's important not to overglue or the package will be gushy and the laminates will slide around. A painter's wet film gauge helps ascertain how much glue is just enough.*

Preparing the package. *After applying the glue, stack flexible cauls on top of the laminates. Here a kerfed plank of solid wood spreads pressure evenly across the laminates. The glue used for this leg of an indoor table was Unibond 800.*

Strap time. *Using a cargo strap, Jay Hallinan (left) and Brandon Light bend a hefty stack of laminates to the form. A stop at one end of the form keeps the laminates aligned end to end, and the swivel arms at the top of the form keep them from sliding side to side.*

to wear a mask when mixing the Unibond 800 powder with the liquid resin.

It's important to apply the perfect amount of glue. This gets you minimal squeeze-out, making it easier to see what is going on at the gluelines. More importantly, you get less squish than with excessively glued laminates. Thick gluelines make it harder to get even clamping pressure and to avoid clamp impressions. They also allow the laminates to slip all over the place. Worst of all, if you apply more glue than needed you risk weakening the part (unless you are using epoxy). Evenness of application is important, too; when you have multiple glue joints stacked up, no clamping system will even out irregular glue application.

So get a painter's wet film gauge and measure the glue thickness until your eye gets good enough to judge the right amount. For Unibond 800 we aim for a 0.006-in.-thick glueline (6 mil). The gauge and a roller make it fairly easy. It's a little trickier to judge the thickness of epoxy. Epoxy absorbs into the wood unevenly, much like an oil finish. After applying a generous thickness

CLEAN UP THE CURVE

After glue-up, Boggs saws the stack of laminates to width, joints the sawn edges, cuts the curve to length, and applies edging.

Clever overlap. *The lamination includes one laminate, on the inside face, that is ½ in. wider than the others. After glue-up it rides the fence so the opposite edge can be bandsawn cleanly. Boggs then perfects the first bandsawn edge at the jointer.*

Sawing side two. *The jointed edge then goes against the bandsaw fence so a parallel edge can be ripped.*

Coming to the end. *To crosscut the ends of the lamination, Boggs uses a simple sled on the bandsaw that holds the curved part in place and runs against an auxiliary fence.*

Cover the lines with a curved lip. *Solid-wood edging gets glued to both curved edges, creating the illusion of a solid curved piece. PVA glue works fine here. Curved cauls distribute the clamping pressure.*

(about 1⁄64 in.), wait 15 minutes to give it time to absorb. Then roll it out again to get an even 0.012 in. as measured with your gauge and stack your laminates right away. While the manufacturer recommends a thicker epoxy layer, more epoxy just seems to make a mess, and the strength of these thinner bonds tests very well.

A good roller with an adhesive cover works well for applying either glue, and using a paint tray helps get an even load on the cover, making it easier and faster to get the right amount of glue on the wood. Don't underestimate the skill required for good glue application. Draw upon your inner painter and really focus on applying a perfect layer. It won't slow you down much, if at all.

The array of bending forms

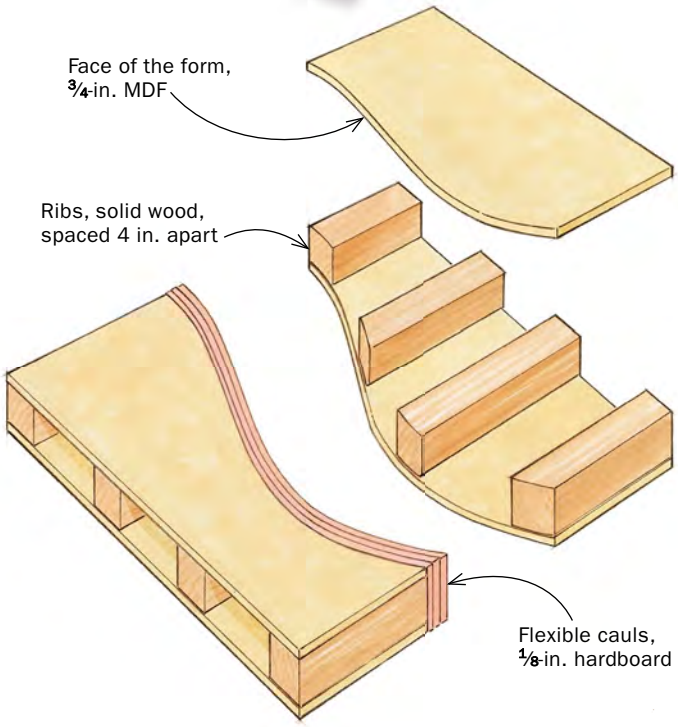
With the laminates and glue worked out, you just need a form to get bending. There are many kinds of bending forms and clamping systems; I'll describe the ones I find most useful.

Bending over a male form with straps—One of the most widely used techniques—a male form with an array of clamps—is workable, and I sometimes use it, but it doesn't make my list of favorites. When you use a single form and a lot of clamps it's difficult to get even pressure across and along the part. Instead you get areas of higher and lower pressure. Of all the processes I've used, this is the most cumbersome and time-consuming. I tend to avoid it.

Instead, when the curve calls for a single form, in my shop we typically use a vacuum bag or, if the part is too big for the bag, we bring out cargo straps. A cargo strap is a great way to distribute pressure evenly onto laminates on a male form. A heavy cargo strap can press a hefty stack of laminates to a fairly tight curve.

HOW TO MAKE A TWO-PART FORM

The halves of a curved, two-part bending form are designed to mate exactly only after the laminates and cauls are in place; if they match with nothing between them, the fit will be imperfect once the laminates and cauls are loaded. Boggs starts by gluing up a large rectangular blank made with two sheets of ¾-in. MDF that sandwich solid-wood ribs. Next he makes a two-part template by drawing the centerline of the curved part he wants on a piece of MDF and sawing down the line. Then, to draw the lines along which he'll cut the form apart, he uses both halves of the template, one after the other—along with a washer that creates an offset. You can see an alternative two-part form for smaller bends in Skills Spotlight on p. 23.



Washer wizardry. *Boggs first traces one half of the template, using a shopmade washer to create an offset equal to half the thickness of the bending package: the stack of laminates plus the flexible cauls. Then he pushes the second half of the template right up against the first and removes the first one. Again using the washer, he traces the second template. Then he saws carefully along the two curved lines.*

Cauls perfect the curves. *With the laminates in place but unglued, Boggs epoxies bendable cauls to each other and to both halves of the form. The epoxy allows the cauls to bridge minor irregularities in the forms. Once the cauls have been glued to the form and cured, you can apply glue to the laminates and begin producing parts.*

LAMINATION WITH A VACUUM BAG

Vacuum bags are an ideal match for bent lamination. They provide perfectly even clamping pressure along a curve and across a wide surface. Typically, the bending form goes inside the bag with the laminates; but in some cases the form stays outside the bag.

BEND WITH THE FORM IN THE BAG...

Gentle bend. *Creating a mild curve with a male form is a snap in the vacuum bag. Boggs applies Unibond 800 to the laminates and wraps them in polyethylene sheet for bending.*

The laminates and form go into the bag. *A modest bend like this requires no cauls; the vacuum bag easily pulls the laminates tight to the form.*

A clamp might be needed to tighten the laminates to the end of the curve, but the strap does the bulk of the bending very nicely. Do a dry run to see how the strap and the laminates behave. If the laminates get pulled toward one end, add an end block to the form to solve the problem. It's important to note that cargo straps work for continuous curves, but not for S-curved parts or parts that have flat sections.

Vacuum pressing with the form inside the bag— A vacuum bag is a powerful tool for bent lamination, and a versatile one. When you want to bend a part with a shallow curve, just slide the male form and the laminates into a vacuum bag and presto—perfect clamping. You don't even need cauls; just tape the laminates in position and add a sheet of cardboard on top to protect the bag from tears. A thin layer of packing foam between the cardboard and the wood keeps the cardboard from sticking to the laminates.

The vacuum bag has no problem with wide parts; it exerts even pressure right across the surface. Since wide curving parts are so easy to laminate in the bag, I often bend multiple narrow parts as one wide blank, then rip them to width after they've been laminated.

Two-part molds—If you're after a more complicated curve—say an S-curve or one with straight sections—a two-part mold is a great way to go. But it will require more time to make the mold halves as they need to mate accurately in order to apply pressure evenly.

To make a two-part form, I start by building one big form blank and cut it in two along the lines of the curve. The trick to making mating forms is accounting for the thickness of the laminates and the cauls that you'll be squeezing between the halves of the form. If you don't account for that space, the two halves

Dual-purpose form. *The bending form serves as a sled while Boggs rips one overhanging edge of the laminated workpiece. Because the vacuum bag works so well for pressing wide workpieces, Boggs often makes narrow parts by bending a wide workpiece and ripping it into strips afterward (right).*

...OR BEND WITH THE FORM OUTSIDE THE BAG

Three points of contact make a form. *For one-of-a-kind curves, Boggs will sometimes bend laminates over a plank with a riser block on top. The angled ends of the plank and the top of the block represent three points on the curve he's after. He glues the angled cutoffs underneath the ends of the plank for clamp purchase.*

won't mate properly. I create a two-part template of the curve I want and use it as a guide.

Simple bending over a block—When we are making a one-of-a-kind bend and have some leeway as to its exact shape, we'll sometimes use a technique I call bag and block. Instead of going to the trouble of building a form for a single bend, we'll use a plank and small blocks of wood to represent points along the desired curve; then we clamp the laminates to them. To make this work, we first wrap the laminates in the vacuum bag and start the pump. The vacuum pulls the laminates together in a stack and holds them tight while the whole thing, bag and all, is clamped to the blocks. There is hardly a faster or more freeing approach to bent lamination than bag and block.

Stop-cut lamination—In making outdoor chairs with curved back slats, I ran into an issue: The end grain of the slats faced straight up, exposing the most vulnerable part of the slat to the weather. I didn't want to subject gluelines to these extremes, so I developed what I call stop-cut lamination, which creates a component that is part solid and part bent-laminated. You might use the same technique for legs that bend only at the bottom, or for other parts that are part straight and part curved.

To create the part, we start with a blank just a bit longer and wider than finished size. Instead of cutting the blank all the way from end to end to generate laminates as with other bends, we stop the cuts, staggering the end points of the kerfs so they don't create a weakness in the part. Once the kerfs are cut we fill them with veneers we've milled to just the right thickness. A measured amount of epoxy on both sides of a veneer makes for a good bond.

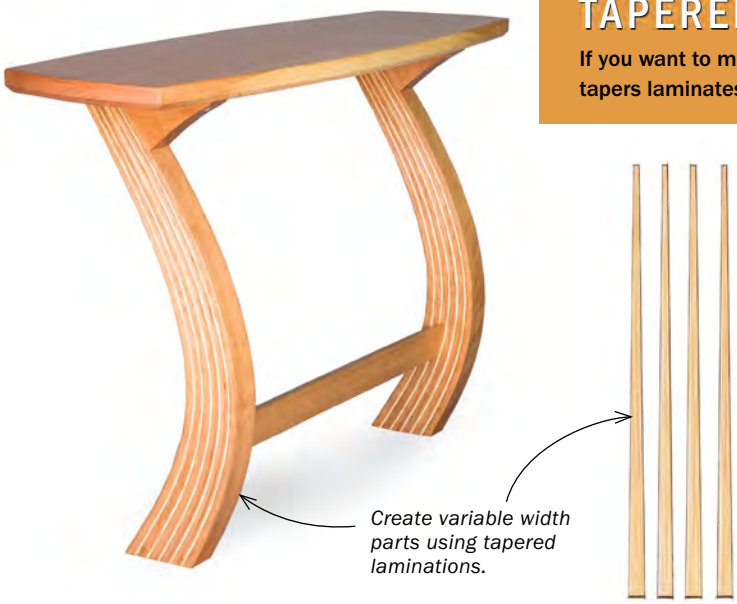
We bend these slats in a two-part form, but depending on what you are building, you could use a different approach. When using stop-cut lamination, be sure

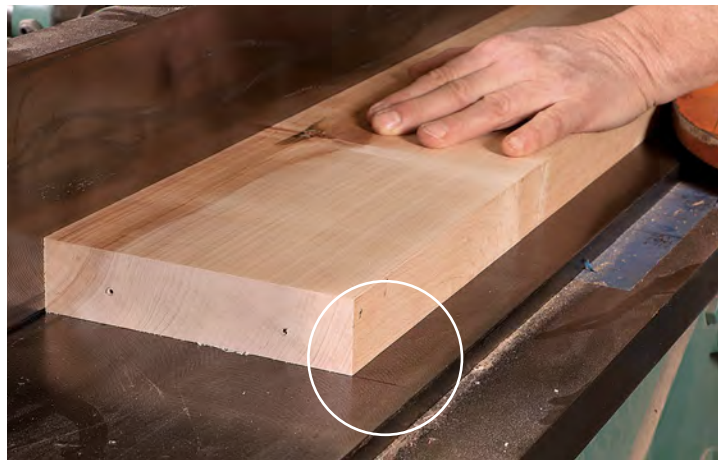
Wrap the laminates. *Putting the laminates into a vacuum bag with moderate suction pulls them together but leaves them somewhat flexible.*

Clamps create the curve. *A couple of C-clamps at each end bend the bagged laminate package to the desired curve.*

TAPERED BENT LAMINATION

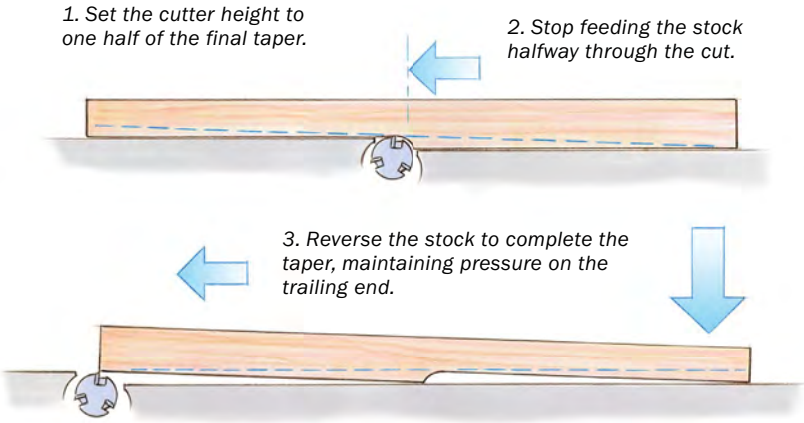
If you want to make a curved part that's also tapered, simply taper the laminates. Boggs tapers laminates with a tapering jig that works both on the bandsaw and in the planer.





Jointer makes the sloped sled. *To create a sled that's tapered in thickness from end to end, Boggs first joints to halfway along the board and stops (above). Then he lifts the board and makes a full pass (below).*

MAKE A TAPERING JIG ON THE JOINTER



Taper jig on the bandsaw. *After a stop block is added at the end, the taper jig is ready for use. Push it and the laminate blank through together, with the jig riding against the bandsaw's fence.*

Taper jig becomes a taper sled. *The same tapered plank can be used as a sled to smooth the laminates in the planer or drum sander.*

STOP-CUT LAMINATION

When he wanted to make workpieces that were partially bent laminated and partially straight and solid, Boggs devised a system of stopped kerfs filled with veneer.

Incomplete kerfs. *Boggs makes the stopped cuts on the bandsaw, locating the kerfs by inserting a series of shims between the workpiece and a short fence. He stops the cuts in a staggered pattern to avoid creating a weak spot in the workpiece.*

Veneers slide in to fill the kerfs. *Having produced veneers just thick enough to fit the bandsaw kerfs, Boggs glues them up and slides them home. He uses epoxy here since the sawcuts can't be smoothed. For bent-laminated workpieces with a reverse curve, a two-part mold is best, ensuring pressure all along the piece.*

the kerfs go past the end of the curved section of the workpiece. Otherwise the solid section will cause a kink in the curve, and the form won't press the veneers evenly.

Tapered curves—With bent lamination you can make a curved part that is also tapered: just taper the individual laminates before bending them. A simple taper sled can serve for both bandsawing and smoothing. At the bandsaw you hold the laminate blank against the sled and slide the sled against the fence. Then use the same sled in a planer or sander. If need be, use double-sided tape to hold the laminates to the sled. □

Brian Boggs makes furniture in Asheville, N.C.