Steam Bending

Heat and moisture plasticine wood

by William A. Keyser, Jr.

Ever wonder how old bentwood furniture parts were made or how ribs for boats are formed? Probably by steam bending. This process uses steam or boiling water to plasticize the wood so that it can be bent, usually over a form or mold. Upon cooling and drying, the bent piece retains its shape. The distinct advantage of steaming is that the grain of the wood follows the curve, thus eliminating the short-grain problems associated with bandsawn curves.

Of course a lamination, i.e., several thin pieces glued together in the curved position, will also do the job. But there is something nice about one integral piece of wood making the bend, with the grain following the curve. The time required to resaw and surface all the laminations is saved, no wood is lost to saw kerfs and ugly glue lines don't surface if the bent piece is subsequently carved or shaped. Also, a lot fewer clamps are required.

Steam bending has shortcomings. The most troublesome is accurately predicting springback. A laminated member will conform very closely to a mold; the greater the number of laminations, the less it will spring back. In steam bending the results depend upon the grain structure of each piece of wood. Local eccentricities—knots, checks and cross grain—will affect the final curve much more than in lamination, where the process itself tends to homogenize the structure of the member. This disadvantage becomes critical when exact duplicates must be made. Also, some breakage or rejects can be expected in steam bending. If ten pieces are required, bend twelve or thirteen.

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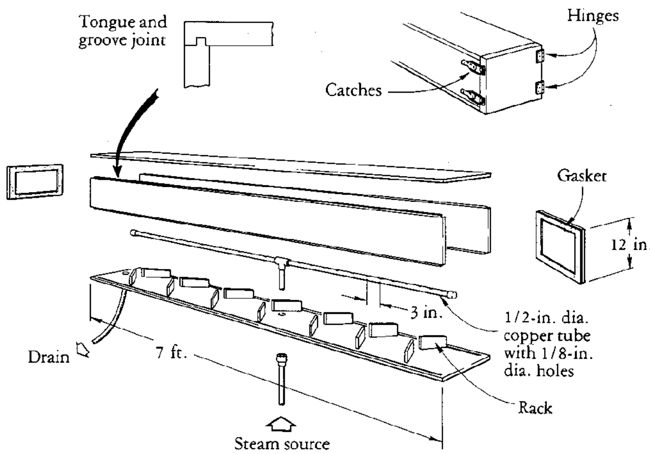
When deciding whether to steam-bend or laminate, reason it out this way: If the member must start precisely at some point *A,* negotiate a specific curve and end up exactly at point *B,* and do so repeatedly, the odds are better if you laminate. If the relative positions of *A* and *B* are not critical, or if their relationship is maintained by the rest of the structure and if there is some tolerance in the path taken from *A* to *B,* then the integrity of a single piece would justify steam bending. Where either process is appropriate, the material and time saved in steam bending by not resawing settle the question.

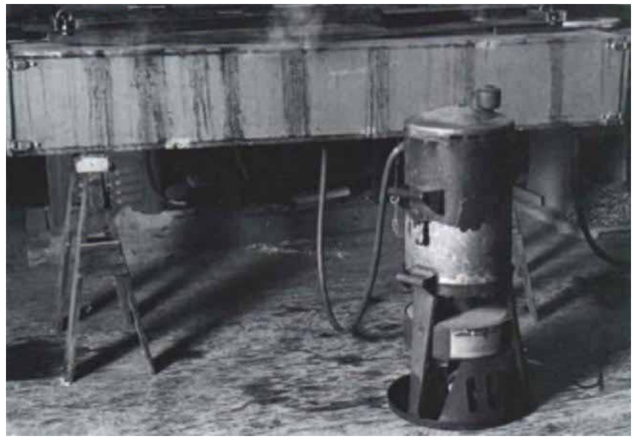
The piece of wood to be bent is placed in a closed container or steam box and bathed in steam generated by boiling water. The steam gradually softens the structure of the wood and makes it flexible. The wood is then forced around a mold and clamped in position. The outside circumference of the wood must usually be reinforced with a metal strap. The shape of the mold is determined by the curve desired, with due allowance for springback. The bent piece is either left clamped on this mold to cool and dry, or it is immediately placed on a separate jig to hold it in position during drying.

When the piece has cured and is removed from the mold or drying jig, it usually springs back slightly. With luck, it now

Ark at Interfaith Chapel, University of Rochester, is 8 ft. high and made of steam-bent teak angled and then joined edge-to-edge to create the shell's compound curve. Pieces bent off-the-corner become legs of small table in chapel at Geneseo, N. Y.; plain bends joined edge-to-edge support altar and lectern.



Keyser's steam box is made from one sheet of ordinary 3/4-in. plywood and is supported on sawhorses.



Wet steam for bending can be generated in a variety of ways. Keyser uses a kerosene-fired wallpaper steamer.

coincides with the desired curve. Machining, cutting of joints and shaping can then be done on the bent piece of wood.

When wood is steamed, the heat and moisture soften its fibers and allow them to distort with respect to one another, thus permitting the piece to bend. Steam at 212 ° F warms the wood and whatever moisture is already in the fibers; the moisture in the steam supplements the initial moisture content of the wood, especially in those fibers near the surface. Apparently, pressurized steam doesn't help much; in fact, there is some evidence that it makes the wood brittle and is detrimental to successful bending.

It's important to make sure the steam is saturated with moisture. Bubbling the steam through a trough of water or leaving some free water lying in the bottom of the steam box will ensure this. Generally, the wood should remain in the steam for about one hour per inch of thickness. Steaming for longer periods of time doesn't increase the bendability much.

Generating steam

Steam can be generated in a variety of ways; I use a kerosene-fired wallpaper steamer. Electrically heated versions are available from Warner Manufacturing Co., 13435 Industrial Park Blvd., Minneapolis, Minn. 55541. Local paint and wallpaper stores often rent them. The steam-generating units from home sauna baths can also be used. One unit, the Hot Shot Model MB4L, is available from Automatic Steam Products Corp., 43-20 34th St., Long Island City, N.Y. 11101. A lidded 5-gal, can with a filling cap and a hose fitting brazed or soldered into the lid also works well. It can be heated on a large camp stove, plumber's furnace or open fire.

The steam box can be made from one sheet of 3/4-in. exterior fir plywood, either C-C, B-C or A-C grade, depending on how much you want to spend, with the best face toward the inside of the box. You could use marine exterior grade, but it's not necessary. Tongue and groove the corners, or butt and screw them. A manifold can be made from 1/2-in. dia. copper tubing drilled with 1/8-in. dia. holes every 3 in. Introduce the steam through a hose adapter and tee midway along the length of the manifold, to equalize distribution. A drain hole for the condensation should be provided at one end, with a hose adapter to carry the water to a floor drain or outside the shop. A rack or some other method of supporting the wood above the manifold should be provided so the wood doesn't lie in the condensate. I use blocks of wood screwed to the bottom and angled toward the drain end of the box. A coat or two of porch and deck enamel or marine paint, inside and out, will preserve the steam box for years. Assemble the bottom and two sides, install the manifold, drain and rack, and paint the interior surfaces before putting on the top. Use a good waterproof glue and brass screws at the corners. Both ends should have hinges, gaskets and catches. Thus, the box can be loaded from either end if short pieces are being steamed, or very long pieces can be run right through the open-ended box and the gaps stuffed with burlap or rags to contain the steam. When the box is supported on sawhorses or on a permanent stand, slant it slightly so the condensate runs toward the drain.

Selecting wood

Some species of wood steam-bend better than others. I've found that white and red oak, walnut, ash, hickory, pecan and beech bend well. Cherry is not quite as good, and it's just barely possible to bend teak and mahogany. Softwoods do not bend well. The tables below show the relative bendability of various species, expressed as a percentage of unbroken pieces, and the limiting radii of supported and unsupported bends in 1-in. stock. Such tables have been compiled to guide industrial users and are only approximations—the craftsman's best guide is experience.

Bendability of Domestic Hardwoods	% Unbroken Pieces
Ash	.67
Beech	.75
Birch	.72
Elm, soft	.74
Hackberry	.94
Hickory	.76
Magnolia	.85
Maple, hard	.57
Oak, red	.86
Oak, white	.91
Pecan	.78
Sweetgum	.67
Sycamore	.29
Tupelo	.42
Walnut, black	.78

U.S. Forest Produces Laboratory, *Wood Handbook: Wood as an Engineering Material,* 1974.

Limiting Radii of Curvature (in inches for 1-in. stock)	Supported By Strap	Unsupported
Afrormosia	14.0	29.0
Alder	14.0	18.0
Ash	4.5	13.0
Beech	1.5	13.0
Birch, yellow	3.0	17.0
Douglas fir	18.0	33.0
Ebony	10.0	15.0
Elm, white	1.7	13.5
Hemlock	19.0	36.0
Hickory	1.8	15.0
Mahogany	36.0	32.0
Oak, white	0.5	13.0
Oak, red	1.0	11.5
Spruce, Sitka	36.0	32.0
Teak	18.0	35.0

W.C. Stevens and N. Turner, *Wood Bending Handbook* (Princes Risborough, England: Forest Products Research Laboratory, 1970).

Industrial research has also found that air-dried wood at a moisture content of 15% to 20% is best for steaming. But I have bent some species of kiln-dried wood at 8% to 12% MC with good success. If difficulties arise and the wood seems too dry, try soaking it in water for a day before steaming. The added moisture is absorbed mainly by the fibers near the surface and will evaporate quickly when the heated wood cools.

Stock for bending should be selected for straight grain and must be free of cross grain, knots, checks and other defects. I have found that flatsawn stock bends better than quartersawn; that is, the annual rings of the board should run parallel to the mold, as closely as possible.

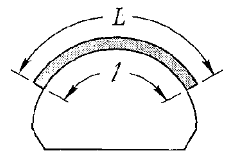
Preparing the stock

It is best to place the heartwood side of the board on the inside of the bend. The board should be jointed and thicknessed, but usually not to finished dimension, particularly if the stock is thick. With cross sections 1-1/2 in. x 4 in. and larger, it is best to leave a little extra stock so the final profile can be sawn or otherwise worked to final form after bending. But having the stock smooth on four sides before bending prevents cracks and splits from propagating from a surface irregularity such as sawmill or circular-saw marks. A small chamfer, perhaps 1/16 in., on all four edges of the stock also helps prevent splits from starting at points where the grain might be slightly crossed. On thin stock or where curvature is not great, I sometimes presand the parts before bending. Although steam raises and sometimes discolors the grain, at least the mill marks are gone and all that is required after bending is light scraping and final sanding.

The piece of wood to be bent should always be several inches longer than the desired finished length. During bending the ends frequently are distorted and these defects can be cut off later. An end coating (such as that used around kilns, or ordinary oil-base paint or roofing cement) spread on the end grain before presoaking or steam bending prevents excessive absorption of moisture and subsequent end-checking during drying.

It is usually better to cut joints after the piece is bent; however, I have cut mortises and tenons before bending where they occurred on the straight portion of a member.

In any bend, the distance *L* around the outer convex side of a curve is longer than the distance *l* around the inner concave side. Ordinarily, when stock of length *l* is bent around a curve the outer fibers stretch (or go into tension) to attain the addidional required length *(L-l)*. Wood plasticized by steam will stretch only very slightly before fracturing (failing in tension), but it can be compressed to a much greater degree. The fibers in compression slip, compress, bend and distort without failing. Therefore, the objective is to begin with the plasticized stock at length *L*, prevent the outer convex fibers from stretching (going into tension), and force the inner concave fibers to compress (and therefore shorten to length *l*). This is done by fitting the outer surface of the stock with a heavy steel strap securely welded or bolted to steel end blocks. Assuming the strap does not stretch as the wood is bent, the end blocks push against the inner fibers, compressing them to length *l*.



Wood fits tightly against strap between solid steel end blocks, which extend outward from small clamps to provide leverage. Then assembly is clamped to center of mold to prevent initial buckling and quickly pulled around. After setting for 15 minutes, wood is clumped overnight to drying jig, left.

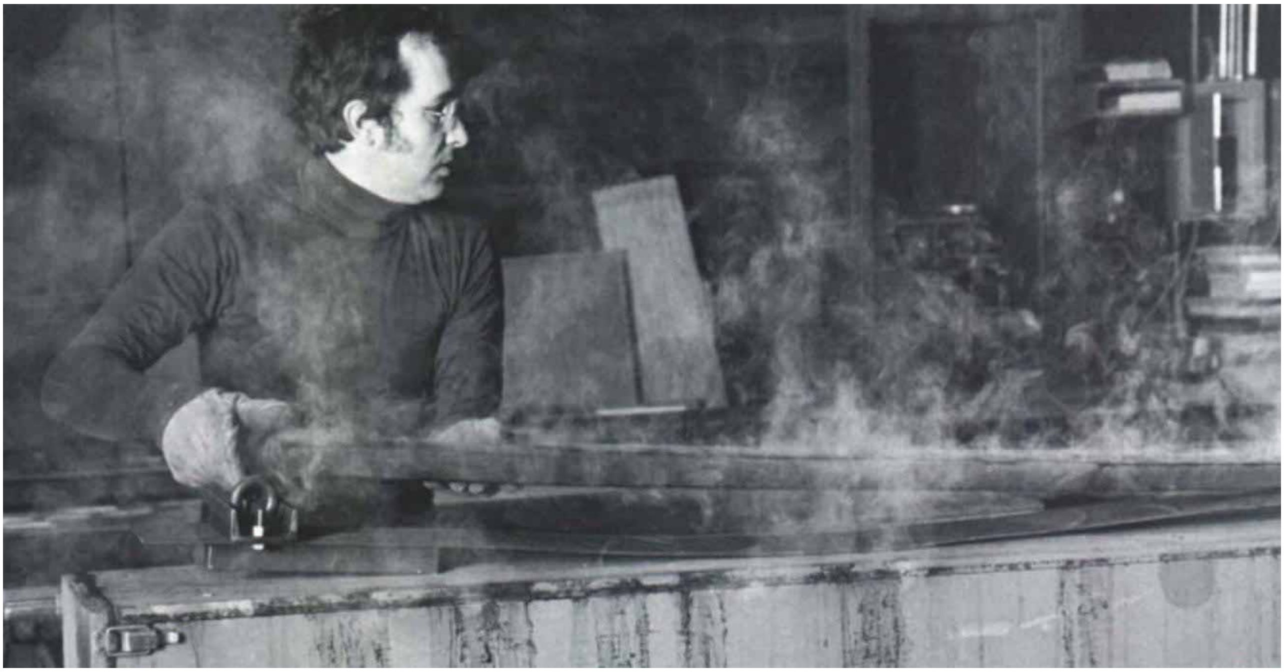
Straps and molds

I use 16-gauge cold rolled steel for straps on stock up to 1/2 in. thick, 1/16-in. hot rolled steel for stock 1/2 in. to 1 in. thick and 1/8-in. hot rolled steel for stock 1 in. to 2 in. thick. I make end blocks from angle iron or channel iron at least 1/4 in. thick, or solid steel bar stock when available. Don't underestimate the amount offeree the end blocks must withstand when bending heavy stock. Frequently the force is great enough to bend the angle iron. Welding corner blocks behind the angle iron helps prevent this.

The strap must be wide enough to cover the full width of the stock being bent, and end blocks must be large enough to cover the entire end of the piece. When bending stock thicker than 1 in., I fasten each end block to the bending strap with at least three 1/2-in. dia. bolts. When I buy the strap material, I get it long enough to accommodate quite long stock. Then I can redrill the holes and rebolt the end blocks to reuse the strap for other bends. Chemical reaction with the steel strap will discolor the surface of most woods. Discoloration is usually removed in subsequent shaping and finishing, but if it is objectionable, use stainless steel straps or cover them with polyethylene sheeting.

The plasticized wood member must be bent around a mold. This mold must be very strong, must support the full width of the bent piece and must accommodate some clamping arrangement for drawing the wood around the curve. A male mold is always used, so that it will support the inner fibers of the bent wood. I make many of my molds from discarded telephone-pole crossarms (about 4 in. x 5 in.) glued into a blank and bandsawn to shape. Stacked 3/4-in. thick fir plywood or laminated 2-in. construction lumber also works well. Regardless of construction method, strength is the key word, because incredible forces can be generated in bending a piece of wood around the mold.

It is important to allow for springback when shaping the mold, so that after the bent part is released it assumes the intended shape. Only experience will teach how much to overbend in compensation for springback. Among the variables are the nature of the curve, thickness of the wood and species. Usually the more gentle the curve, the more one must compensate. It seems that the more the fibers on the concave side of the member are displaced, the less they spring back.



Keyser puts the hot wood into the strap, which has been warming atop the steam box. A clamp at each end secures it to the heavy channel-iron reverse levers, tight against the end blocks. Speed is essential; do a dry run to make sure mold, clamps, tools are handy.

When making molds, I work from the full-size drawing of the piece and guess at the amount of springback. I cut the mold, bend a trial piece and then revise the mold if necessary.

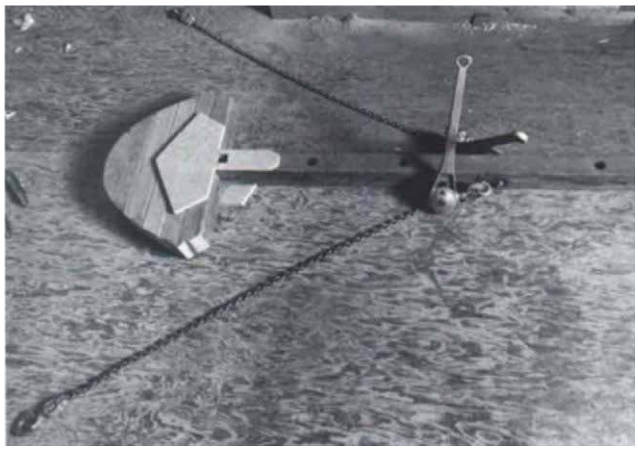
If only one piece is to be bent, the strap and wood can be left clamped to the mold for a day until the piece cools and dries thoroughly. If several pieces must be bent, it saves time to construct a drying jig. This allows you to bend, remove the clamp and strap after about 15 minutes, and clamp the wood onto the drying jig. This frees the bending strap and mold for the next piece to be bent.

I usually allow one day per inch of thickness (or fraction thereof) for the bent piece to cool, dry and set before removing it from the mold or drying jig.

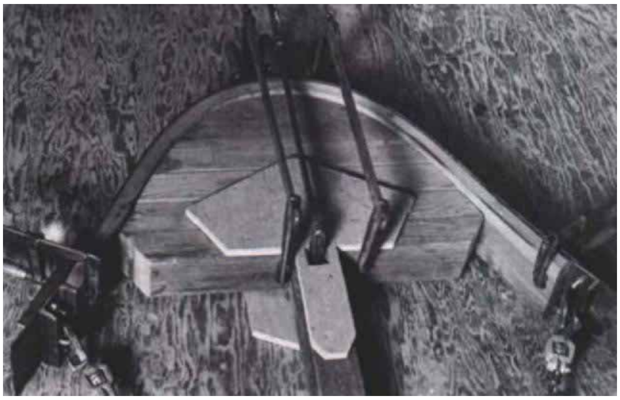
Bending in one plane

The simplest bend is a single curve in one plane. In bending a 1-1/2-in. x 5-in. x 56-in. piece of walnut around a 10-in. radius mold, I've used a giant cross-bow arrangement. Be careful with this method; don't take a chance on lightweight equipment failing and recoiling. I use two 1-ton heavy-duty chain hoists for the job. The wood is removed from the steamer and placed between the end blocks of the bending strap, which has been warming on top of the steam box. The strap is secured to the wood by a clamp at each end, then the strap and wood piece are aligned and clamped to the center of the mold. This is important because as bending progresses, the wood will try to pull away from the mold at the tangent point and will immediately crack if not clamped tightly there. Continue to wind the chain hoists and pull the piece around the mold as quickly and smoothly as possible, until the bend is complete. You have only a few minutes to work, for the longer the bending operation takes, the more the piece cools and dries, and the greater the risk of failure.

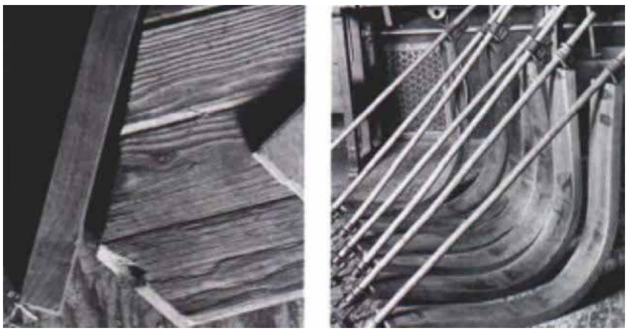
When the curve is this severe, the compressive forces against the end blocks become great enough to overturn the



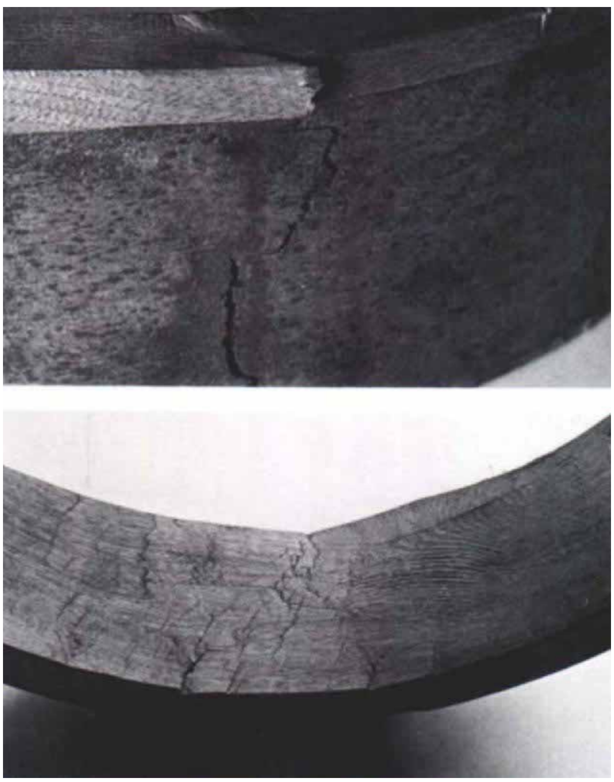
Cross-bow mold is made from telephone-pole crossarms and fitted with one-ton chain hoists. Center clamp at base of mold and two more clamps hold wood firmly in place as hoists pull it around.



Bend is complete. Enormous compressive forces are apparent in slight curve away from mold's ends, despite heavy reverse levers.



After two days on mold, wood still springs back, left. Bar clamps, right, shackle bent pieces to minimize further springback.



Catastrophes: Tension failure, top, indicates loose or overturned end blocks and too-narrow strap (discoloration); compression failure, bottom, occurs when bend is too tight or wood is too plastic.

steel blocks and allow the strap and wood to recurve away from the mold. To counteract this tendency, a reverse lever made from heavy channel iron is bolted through the strap to the end block. This lever, pushing against the back of the strap, prevents the end block from overturning.

In good weather and when a helper is available, the mold may be staked to the ground and a car or truck used to pull the bent piece around the mold. The steamed piece with the strap in place is clamped to the mold on one end of the curve, and the other end of the strap is fastened to a tow chain. The advantage is that the piece can be pulled around very quickly; the danger is that lightweight chains can snap and recoil.

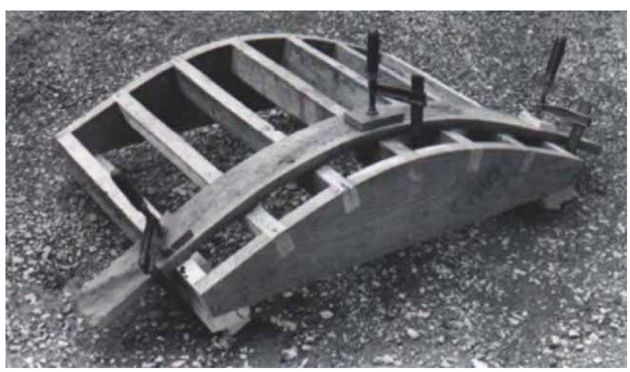
A few cautions are in order; live steam is dangerous stuff. The steam box and steam generator should not seal tightly, to avoid building up pressure inside. You must be sure the generator doesn't run dry and burn up. Wear heavy gloves when handling the steamed wood, and when opening the box, beware of scalding your face in the blast of steam. If you wear glasses, the steam will fog them.

Failures

Much can be learned from pieces which have failed during bending. In tension failure, the fibers on the outside surface of the bend simply pull apart. It is the result of reduced end pressure caused by the end blocks not fitting tightly against the ends of the wood or distorting during bending. The outer fibers go into tension instead of the inner fibers being compressed. If the bending strap is not wide enough to cover the entire piece of wood, a crack is liable to start at the unsupported edge. Wrinkling, or compression failure, occurs on the inner surface because of over-plasticization, too tight a bend or a bad choice of species for the particular bend.

Bends without a strap

Bending without a strap and end blocks is possible only when the curve is slight or the stock is very thin. I have found that the difference between the lengths of the outer and inner faces of the bent piece should be less than 3%, although this varies from species to species. For 1-in. stock, the minimum radius I would bend without straps and end blocks is about 33 in. Bends made without straps are less stable and more springback can be expected. The bends are not as predictable for duplication because complete distortion of the fibers has not taken place and the "memory" of the wood cells will straighten it out. I seldom bend without a strap.



For shallow bends, or when stock is very thin, bending can be done without a strap. The steamed wood is clamped directly to a combination mold and drying jig such as the one shown above.

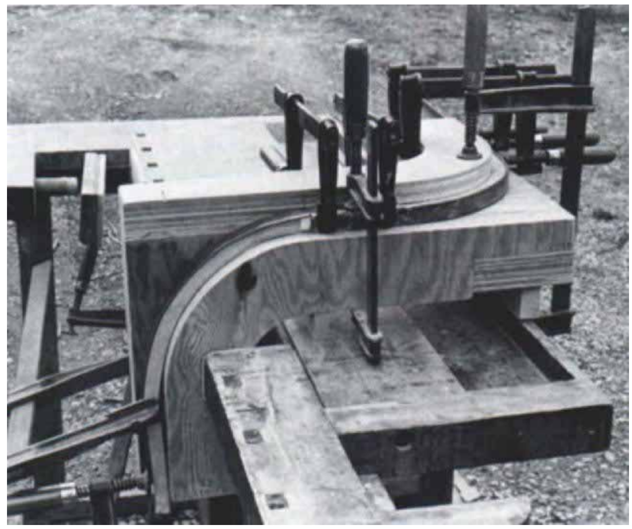
Complex curves

Bending a single piece of wood in a reverse, or S, curve or bending in two planes requires only a more complicated mold and strap. The principles remain the same: the strap must follow the convex side, or outside, of each portion of the curve, and end blocks must force the wood fibers on the inside of the curve to compress. Extensions of the end blocks, welded or bolted to the strap, provide handles to help in pulling the wood around the mold. Then it is clamped in place and left to set.

For a reverse curve in one plane, strap iron is fastened to each portion of mold where curve changes direction. Steamed wood is clamped at end blocks, then to mold, and quickly pulled around. End blocks are angle iron, backed up with hardwood fastened by bolts.

Bending off the corner

Table or stool legs can be bent off the corner by using a 1/2-in. x 1/2-in. x 1/8-in. angle iron as the bending strap. It fits over the outside corner of the steamed piece. Near the ends, the strap is fortified by welding on short lengths of a larger-size angle iron, to which is welded the solid steel end blocks. The small angle iron is flexible enough to bend around a gentle curve. The bending mold is made of two pieces of solid wood bandsawn to the desired curve, with the bandsaw table tilted 45°. The steamed stock is placed in the bending strap, the strap and stock are inserted under a shackle at the end of the bending mold and then the piece is simply forced around the mold and clamped.



For a bend in two planes, ends of two pieces of strap iron are overlapped at right angles and welded edge-to-edge—in effect, forming a few inches of angle iron at point where curve changes direction. Three clamps hold overlapping iron and hot wood to mold; end blocks and handles are lengths of tee iron welded to straps.

Further Reading

Forest Products Laboratory, *Wood Handbook: Wood as an Engineering Material.* Agricultural Handbook No. 72, Washington, D.C.: U.S. Government Printing Office, 1974.

Forest Products Laboratory, *Wood Handbook. Basic Information on Wood as a Material of Construction with Data for Its Use in Design and Specification.* Agriculture Handbook No. 72, Washington, D.C.: U.S. Government Printing Office, 1955.

Peck, Edward C., *Bending Solid Wood to form.* Agriculture Handbook No. 125, Washington, D.C.: U.S. Government Printing Office, 1968.

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Wangaard, Frederick J., *The Steam-Bending of Beech.* Beech Utilization Series No. 3, Northeastern Forest Experiment Sta., 1952.

Off-the-corner strap, left, is welded from two sixes of angle iron. Steamed wood fits tightly between end blocks, is tucked under shackle on mold, and forced into place, above. After 15 minutes it is removed, placed in drying jig, and clamped with the aid of blocks notched at 45°.