The author sights along the side-panel rungs of a stool to make sure they're aligned. By beginning with green wood and monitoring the moisture content of the parts, you can capitalize on wood movement as the pieces dry to make stronger post-and-rung joints.

Green-Wood Joinery

Dry tenons, wet mortises for long-lasting joints

by Drew Langsner

Most contemporary woodworkers depend on commercially sawn, kiln-dried lumber. Green wood, high in moisture content (MC), is generally avoided: We hear that it warps, twists and shrinks unpredictably. However, in past centuries, wood was commonly worked green, often with outstanding results. All successful joinery is dependent on attention to and control of the moisture content of the wood being used. Even with kiln-dried wood, it's necessary to take into account the potential for expansion or contraction of parts being joined. The techniques used in working green wood not only allow for wood movement, but actually use it to advantage to make post-and-rung mortises and tenons that are often superior to comparable joints in kiln-dried wood.

"Green woodworking" is a term coined by ladderback chairmaker John Alexander. The techniques begin with riving (splitting) your material directly from a log and rough-shaping the green (wet) wood with hand tools, such as drawknives and spokeshaves. Riven wood has very high tensile, shear and bending strength, because each rived "billet" follows the natural, long fiber direction of the wood. "Green-wood joinery" does not mean joints are assembled wet; Final joint dimensioning and assembly are not undertaken until each of the parts has dried to a specific moisture content. A more accurate term is dry/wet joinery—dry tenons into moist mortises. Most dry/wet joints utilize cylindrical tenons and bored mortises. I'll briefly discuss the principles involved in dry/wet joinery, then I'll describe my techniques for applying these principles in the construction of the post-and-rung stool in the bottom photo on p. 63.

Moisture content and differential shrinkage—In green woodworking, the most important principle to remember is that wood is hygroscopic, which simply means the wood will absorb and release moisture with variations in environmental humidity. Freshly cut wood contains moisture within the cell cavities, called "free water"; and moisture in the cell walls, called "bound water." As wood dries, it first loses free water, down to about 30% MC. This is the "fiber saturation point." The cell cavities are empty, but the cell walls are still saturated. As wood dries, its dimensions remain stable until it reaches the fiber saturation point. Then it begins to shrink, check and warp as it loses bound water. Tangent to the growth rings, most woods can shrink from 10% to 15%, while on the ray plane (perpendicular to the growth rings), maximum shrinkage is only half as much, 5% to 7%. This is "differential shrinkage." Because of differential shrinkage, a cylinder shaped from green wood will eventually dry into an oval cross section, with the oval's long axis on the ray plane (see figure 1 on the facing page). Oak and other ring-porous hardwoods, commonly used by "green woodworkers," are among the species that shrink the most. For a success-

fill dry/wet joint, you must take into account both of these principles: the fluctuations in the moisture content of the joint components, and the differential shrinkage that occurs during these fluctuations.

In a heated house during the winter, the moisture content of the wood in your furniture can drop to between 5% and 10%. You don't want the tenons that join this furniture to shrink under these dry conditions and come loose. When the tenons are fitted to the mortises, they should be at 5% MC to 8% MC, to ensure that they're as dry and as small in diameter as they will ever get. In contrast, the ideal moisture content of mortise components at time of assembly is about 15% to 20%. This allows for slight swelling of the dry tenon as it absorbs moisture from the shrinking mortise.

In the Eastern United States, air-drying wood in a drafty shed will lower moisture content to between 15% and 20%, ideal for "wet" mortise components. A homemade kiln, like the one described in the sidebar on p. 63, can be used to dry the tenon stock to the desired 5% MC to 8% MC. In the arid West, wood air-dries to below 10% MC, which should be within allowable tolerances for mortise wood, as long as the tenon stock is thoroughly kiln-dried. As a rule of thumb: Air-dry mortise wood; kiln-dry tenon wood.

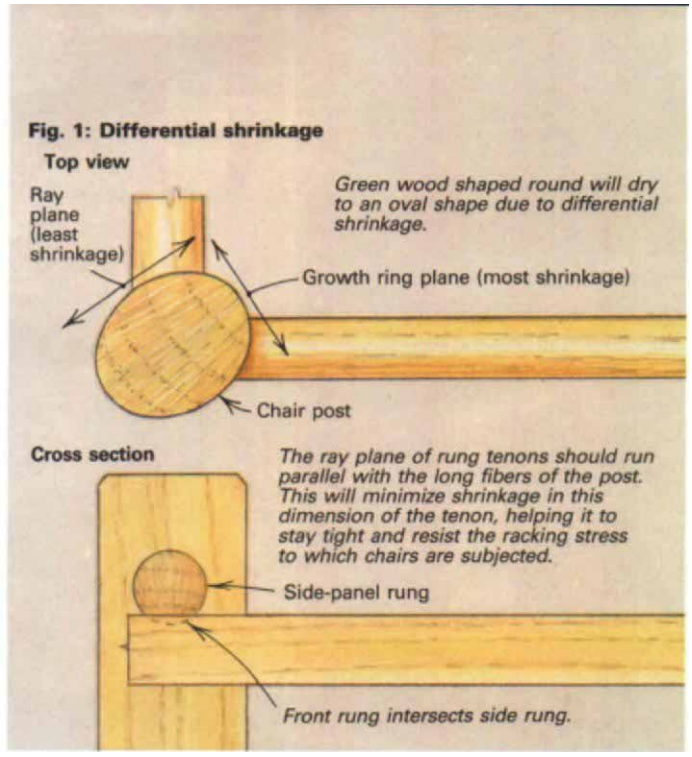
You can account for the second principle—differential shrinkage—by paying attention to growth-ring orientation of the mortise-and-tenon components (see figure 1). Chairs tend to fall apart during winter when the dry interior environment causes the tenons to shrink. However, much of the structural damage occurs as the tenon swells during the humid summer, causing the fibers of both mortise and tenon to crumple from overcompression. With a subsequent change to low humidity, moisture content drops and the tenon shrinks; but because of the crumpled fibers, it dries to a size smaller than its original diameter, thus creating a loose joint.

When a dry/wet joint is assembled, you can compensate for this potential compression. Orient the tenon's ray plane, which is subject to the lesser amount of shrinkage and swelling, parallel to the long fibers of the mortise wood, which also will shrink less (see figure 1). This orientation is partly dependent on the purpose and the anticipated stresses that the joint will be subjected to. For instance, a chair or stool rung is stressed mostly by racking, which puts the load on the top and bottom of the tenons. There is very little force on the sides of the joint; therefore, rung tenons are positioned with the ray plane parallel with the long fibers of the chair posts. This ensures that the joint will stay tight in the racking plane. If there is any compression of the tenon from expansion during a humid cycle, it will occur in the less critical sides of the tenon. In fact, I usually slightly undersize my tenons on the sides to allow for the additional shrinkage of the mortise and the expansion of the tenon.

Differential shrinkage is also considered when locating mortises. If mortises are on one plane only, they should be bored tangent to the growth rings (into the surface perpendicular to the ray plane). Because this is the plane of minimum shrinkage, the mortised wood is less likely to split as it dries around the tenon. However, in many cases, such as on the legs of the stool in the bottom photo on p. 63, multiple mortises in one member are located perpendicular to one another. Then, a compromise position is selected so shrinkage is about equal for mortises bored in either location (see figure 1).

A moisture-resistant finish on completed furniture helps minimize swelling and shrinkage from moisture cycling. I've used tung oil thinned with turpentine on my ladderback chairs, but recent studies show that tung oil is not an effective moisture barrier. I'm now experimenting with a mixture of tung oil and polyurethane varnish.

Building a post-and-rung stool—To show how the above principles are applied, I'll describe the joinery involved in building the stool. If you begin with green wood in log form and intend to rive



billets for your stool parts, you should use strong, straight-grained, ring-porous hardwoods, such as white and red oak, hickory or ash. Avoid defects; rot, bug holes and knots, or a combination of heartwood and sapwood in one piece, can all cause the wood to dry and shrink unpredictably. You can also use diffuse-porous hardwoods, such as birch, cherry and maple, but they don't split as well and must be machined or turned on a lathe.

Wet wood splits, shaves, whittles, bends and turns much easier than dry stock. So after riving, I immediately rough the parts out with a drawknife or spokeshave. I shave the parts square; then octagonal; then round, leaving them about 10% oversize in diameter to allow for shrinkage and final sizing. This translates to about 3/32 in. per 1 in. of thickness, or 1/16 in. for a 5/8-in.-dia. rung tenon. You'll note in figure 2 on the next page that the top rungs in the front and rear have an "airfoil" shape to make the seat more comfortable on the backs of legs. Then, I crosscut the parts to length, making sure that the tenons have a diameter/length ratio of about 1:1½. Shorter tenons have too little surface area to resist racking and may pull loose. The 5/8-in.-dia. tenons for the stool should be 1 in. long. The posts are roughed down to a green diameter of about 1⅜ in. To prevent the top mortise from splitting during assembly, I let the post length run long about 1 in.

If I'm not in a hurry to use the parts, I begin by air-drying them slowly, leaving them in a shed or a corner of my shop. If you air-dry the wood in a heated room, away from the heat source, it will take about two weeks for very wet green wood to dry to 15% MC to 20% MC. A couple of days before I plan to assemble the stool, I dry the rungs on a rack located above a wood stove or in a drying kiln.

Sizing the tenons—Final shaping and sizing of the tenons is done when the rungs are thoroughly dried (5% MC to 8% MC). I size tenons with a spokeshave, then use a wood file to remove the small facets left by the spokeshave. If it's humid, I keep all rungs on the drying rack or in a plastic bag, except the one I'm working on; in humid conditions I've seen swelling occur within 30 minutes.

To test-fit the tenons as you work them to size with the spokeshave, make a gauge from a piece of dry hardwood about ½ in. thick (see the top photo on the next page). Bore three holes, using the same bit that will be used to drill the mortises, and number the holes. With a rat-tail file, enlarge the entry to hole #1, and use

Drawings: Kathleen Creston

Langsner uses a shaving horse to hold a rung as he shapes and sizes it with a spokeshave. The small block with the three holes is his fitting gauge. The sides of the first hole are colored, so when a tenon is rotated in the hole, the color shows where the tenon needs to be shaved more.

The notched blocks hold the post so all the mortises in one side can be bored without having to loosen the vise to move the post. A builder's line-level taped to the bit extension aligns the bit and a depth-stop clamped to the bit controls depth.

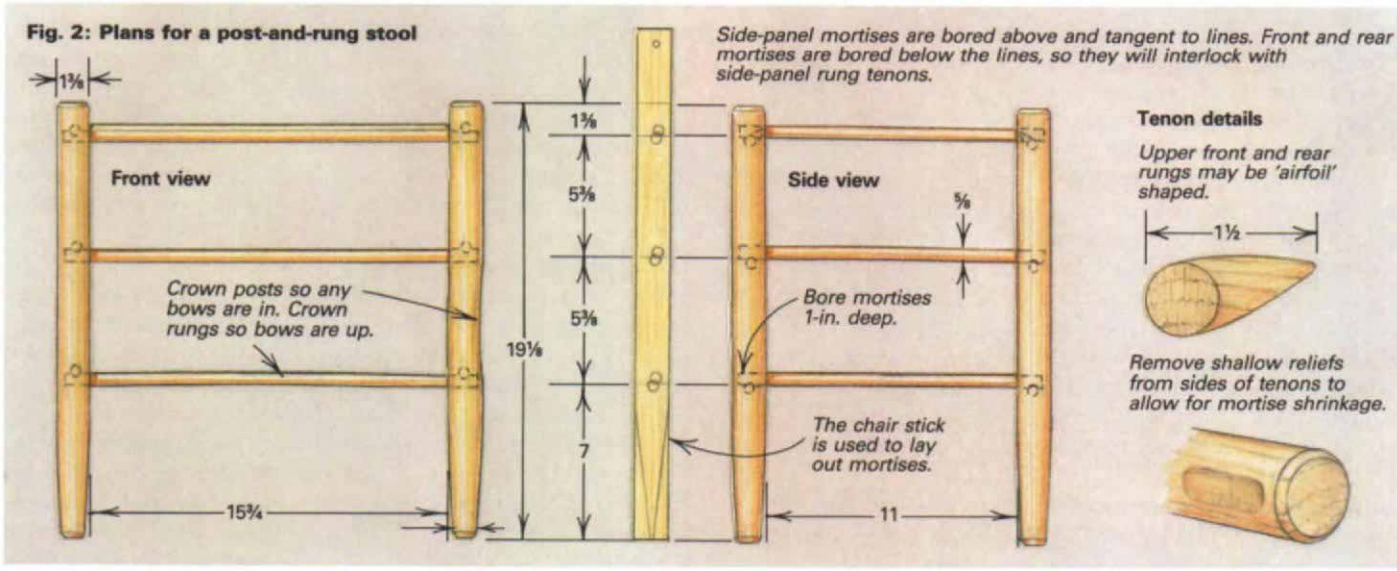
a water-soluble drawing pencil (available from art-supply stores) to coat the inside of the hole. Slightly chamfer the tenon ends with a file, to ease their fit into the gauge holes. As you insert the tenon into hole #1 to gauge your progress, the pencil marks will rub off on the tenon, showing where to shave more. When the tenon is close to size, use hole #2 for the final test fits. You'll be fitting 24 tenons for the stool, so when hole #2 gets enlarged from repeated reaming, use hole #3 to check the final fit.

You want a squeaky-tight fit on the top and bottom of the tenon. The side-to-side dimension, tangent to the growth rings, can be slightly undersize. Remove wood in small increments and test often. Final sizing is done with the file. After fitting the tenon to the mortise, I often relieve the tenon sides with a half-round file, reducing the chance of mortise split-out during assembly or later drying cycles. The shallow relief begins about ⅛ in. from the end of the tenon and ends ⅛ in. from the tenon's "shoulder" (see detail in figure 2).

On stools and ladderback chairs, the side-panel rung tenons, which bear the brunt of the fore-and-aft racking stress, can be further strengthened by interlocking with the tenons of the front and rear rungs. To accomplish this, bore and assemble the side panels first. Then bore the mortises for the front and back rungs so they slightly overlap and cut through the tenons of the side-panel rungs inside the chair post, like a log-cabin notch. To lay out the mortises on the posts, make a chair stick as shown in figure 2. The lines are not the centers of mortises. The side-panel mortises are drilled above the line, with their bottoms tangent to the line; the mortises for the front and rear rungs are drilled below the line so they overlap the line by 1/16 in.

Boring the mortises—Mortises should be bored after the wood has been air-dried to about 15% MC to 20% MC. Determine this by testing with a moisture meter or by kiln-drying a spare post along with the rungs and using it to compare relative weights to air-dried posts, as described in the sidebar. If mortises are bored in saturated green wood, they are often rough or fuzzy and as the wood dries, they take on an oval shape. In addition, mortise wood that's too wet can cause bone-dry tenons to absorb excessive moisture, leading to overcompression of the joint fibers as the tenons expand.

When mortise wood is thick enough that there's no danger of running a leadscrew out the back end, I use ordinary auger bits; in close situations, I switch to Forstner or Stanley Powerbore bits. I prefer the Powerbore bit because it's easy to sharpen, but I file the



lead point to about half the factory length. A Stanley #47 auger-bit depth-stop ensures that the mortises are consistently 1 in. deep. To bore at the proper angles, I use a variety of sighting aids, including try squares and sliding bevel gauges. A drill extension makes it easier to align the bit, and a builder's line level, taped to the extension, provides a constant horizontal reference. The post, or assembled side panel, is clamped in a bench vise, as shown in the lower photo on the facing page. The simple clamping device holds the post so all the mortises on a side can be bored without having to unclamp the vise.

I bore the side-panel mortises above the layout lines with a brace or hand-held, variable-speed electric drill, and then assemble both side panels. Check each panel by eye for flatness, as shown in the photo on p. 60. You may have to twist it to eliminate any wind in the panel. Then, bore the front and rear rung mortises below the line so they will intersect the side rungs.

Although green woodworkers often assemble chairs without glue, I use it. Even though stressed surfaces in the joint mate endgrain to long grain, modern glues do provide some bonding strength. Perhaps more importantly, glue seals the endgrain of the tenon, slowing down moisture exchange within the joint. 1 use common white glue instead of yellow wood glue, because it sets up slower and is slipperier, thus serving as a lubricant during assembly. After the front and back rungs are glued into the side panels, you may have to "wrassel" the frame to eliminate any unevenness. With one of the legs braced on the floor, use your strength and body weight to force the frame into alignment. Check this by lining up the top rungs by eye until you have a flat seat plane. Then if necessary, scribe and saw off appropriate post bottoms so the stool stands flat.

For seating, you can use the inner, bark of hickory, as shown in the photo below, or ash or white-oak splits. Woven cotton "Shaker tape" is also an option and is available, along with weaving instructions, from Shaker Workshops, Box 1028-FW17, Concord, Mass. 01742. Wrap the warp from front to rear in a continuous strip-not tight and not loose, rather slightly snug. Then, weave the weft in a checkerboard or herringbone twill pattern. □

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This oak post-and-rung stool is an example of finely crafted furniture built with green-wood joinery techniques.

A piece of sheet metal on the bottom rack of this kiln deflects the direct heat from the electric baseboard heater below.

Drying green wood

Small drying kilns: During summer, when we're teaching week-long classes at Country Workshops, we often need to speed up the drying process for our chair parts. Over the past 10 years, I've built several small wood kilns. The first was built with cinder blocks and used a wood fire. Later, we used a 500-watt radiant heat lamp set in the bottom of a horizontal 55-gal. drum. Last summer, I built a more sophisticated kiln, shown in the photo above, with a 3-ft.-long heater in the bottom. The walls are two pieces of ¼in. plywood that sandwich ¾-in. styrofoam insulation, assembled into a box 4 ft. by 4 ft. and 18 in. wide. Because the maximum setting on a standard thermostat is too low, the temperature is controlled by a heat-limit device mounted near the top of the box (stock #2E372 from W.W. Grainger Inc., 5959 W Howard St., Chicago, Ill. 60648; 312-647-8900). A relay, appropriate for the amperage of the heater and the temperature control, is wired between the two. A small exhaust fan in the top of the kiln is used at the beginning of drying, when a great deal of moisture is being released. Doors at both ends of the cabinet double as adjustable dampers. Don't let the temperature rise above 160°. Charring or internal honeycombing can occur if the interior fibers dry too quickly.

With Windsor chairs, legs and stretchers present a unique drying requirement; their ends are tenons, which should be bone-dry, but they also have mortises, which should be left slightly damp. The solution is to dry the end tenons in a pot of heated sand. For heat, I use an electric hot plate, again limiting the temperature to 160°. Tenons are dry when they develop an oval cross section.

Checking moisture content: A piece of wood with 75% MC weighs 75% more than the same sample if it were completely dry (5% MC is the attainable minimum). To determine moisture content by percent, weigh a wet sample piece of wood and then dry it in an oven (under 200°) and weigh it again. Wood is "kiln-dry" when it stops losing weight. Percent moisture content equals green weight minus dry weight, times 100, divided by the dry weight.

Moisture meters measure electrical resistance between two probes inserted in the wood, but they're expensive, and most green woodworkers find them unnecessary. With experience, you can judge approximate moisture content by knowing the history of the wood after it was cut, and by sensory tests. When two pieces of dry wood are knocked together, they "plink"; wet wood "thunks." And, a piece of dry wood held to your cheek feels warm; wet wood feels cool. Try these tests with samples you know to be wet, air-dried and kiln-dried —*D.L*