Mokume Gane History and How-to: A Survey of Technique

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Introduction and History

Mokume gane is one of the most demanding techniques practiced by the modern metalsmith. Whether used for jewelry or other decorative metal objects, this specialty laminated material takes skill, patience, vision, and dedication to the craft. Many papers have been presented at the Santa Fe Symposium® on various parts of the manufacturing process. This paper is an overall view of the metal and the process used to create billets which can then be manufactured into jewelry items.

Invented in Feudal Japan by Denbei Shoami, its first uses were as Guri, or Guri Bori items, especially for use in ornamental sword furniture such as the tsuba, or hilt, of the samurai sword (Figure 1). Guri is representative of the popular Chinese lacquerware that was being imported into Japan at that time in history. By laminating a few layers of copper- and silver-based alloys together, the smith was able to create beautiful pieces by carefully chisel-carving and patinating the laminate. At some point, the resulting carved laminate was forged flat, creating what is accepted as the precursor to modern mokume gane. Its use was certainly not restricted to sword furniture, as there are early examples of other decorative objects including vessels (Figures 2 and 3) and *inro*, a type of Japanese "pocket book."

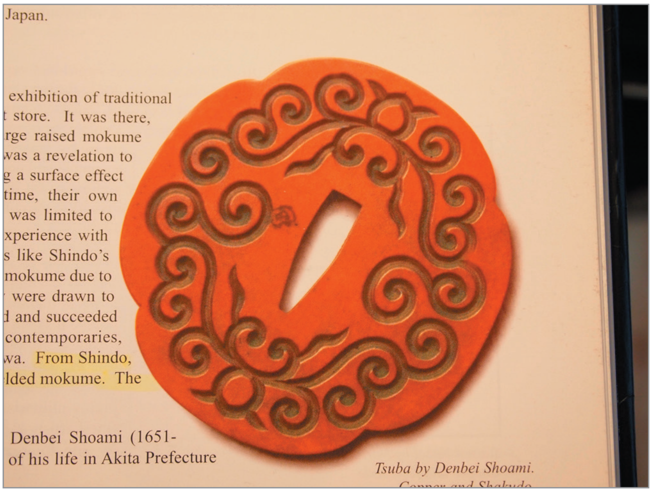

***Figure 1** Tsuba by Denbei Shoami (photo used with permission[1])*

***Figure 2** Sake cups*

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Figure 3 *Ice cream spoon, Tiffany & Co.*

In the early nineteen seventies, Eugene and Hiroko Pijanowski were traveling in Japan when they saw a vessel made from mokume gane. They were able to locate the maker, Gyokumei Shindo and two other contemporaries. One of the contemporaries, Norio Tomagawa (Figure 4), shared his method of making mokume gane laminates. This was brought back by them to the United States and taught to many students at the university level as well as in workshops. This method was the liquid-phase bonding technique, which was detailed at the 2010 Santa Fe Symposium® in a paper entitled "Mokume Gane Firing Methods and Their Effects on Appearances and Bond Strengths" by Stewart Grice and Chris Ploof.[2] From here, many individual makers started producing and teaching this method of making mokume gane.

Figure 4 *Norio Tomagawa, Living National Treasure of Japan, patterning a plate of mokume gane*

The method presented here is one based on solid-state diffusion in use by the authors in our shops. It's what we teach in our mokume gane classes.

It is best practice for a maker of mokume gane to take detailed notes—billet design, weights, firing cycles, yields—all of which will allow you to repeat processes that work. And, in the case of a failure, they will allow you to see what changes you made that may have contributed to the problem.

Material Selection

One of the most critical and sometimes overlooked parts of the mokume gane manufacturing process is the selection of alloys. Typically, with the right conditions we can laminate just about any two metals together. But it's the downstream processing that very quickly will tell you if your alloys are compatible with the amount of work required to produce quality mokume gane materials. Even the type of processing can affect the resulting materials, as evidenced in a paper given by Nyce, Grice and Ploof at the 2009 Santa Fe Symposium® entitled "Mokume Gane Billet Reductions and Their Effects on Bond Strength."[3]

Some key points to consider are:

- Alloy hardness
- Alloy color and thickness
- Layer count
- Quality of sheet goods from supplier
- Alloy karat

Alloy hardness is perhaps one of the most important considerations. We have found best results are obtained from using materials that have similar Vickers hardness to each other. Certainly, you can even bond stainless steel to silver (for example) but for ease of manipulation from the start of the process to finished jewelry, hardness variations of 25-50 Vickers seem to be ideal for the method detailed here. Some of the favorite combinations are listed in Table 1 below.

***Table 1** Favored metal combinations for mokume gane*

18K yellow gold	Sterling silver	
14K palladium white gold	Sterling silver	
14K red gold	Sterling silver	
Palladium 500	Sterling silver	
Palladium 950	Sterling silver	
18K yellow gold	14K palladium white gold	Sterling silver
14K red gold	14K palladium white gold	Sterling silver
Palladium 950	14K palladium white gold	Sterling silver

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Alloy color is fundamental to the design of the finished item. Just like other pieces made with multiple alloys of different colors, it's easy to overdo it or to end up with a combination that is unappealing. The thickness of the layers certainly contributes to this as well. If you use very thick layers of one color and very thin of another, you can almost make the pattern invisible. This may or may not be desirable. Carefully consider the final use of the material and the customer's needs. This helps in choosing the correct sheet thickness and color combination.

While you may want the rich yellow of 24K gold, it is so soft that it can be difficult to work with. The richest reds and grays are from 14K golds. If you desire to make a product that is all 18K golds, color differences can be difficult to see. I like what George Sawyer says: "Color trumps karat."[4]

Alloy color and sheet thickness are only half of the visual equation. The other very important factor is the number of layers. When mokume is patterned, typical methods call for carving and cutting through the top third of the layers. Cutting and carving farther than this can very easily lead to holes in the final sheet material. It is important to take this into consideration when determining a billet's layer count. A very tight pattern can expose as many as 15-20 layers of material, while a loose pattern may only expose 2-3 layers. These two kinds of materials each require a very different billet as a starting point.

And finally, in addition to all of this, you should be thinking about how much material you need to have at the end of your process. If you require 36 square inches (232 square centimeters) of 18-gauge mokume gane sheet, you need to calculate the volume of the billet to reach that goal. And here is the bad news: mokume is wasteful. This process generates large amounts of scrap. For beginners to the technique, it is not uncommon to have waste in the amount of 50-60% of the starting billet. The billet will also need at least 50% reduction prior to starting patterning. From the beginning of patterning to final sheet, depending on pattern density and final thickness, you can need up to a further 80% reduction. The final factor to consider is the tooling for firing billets. Bigger billets lead to bigger torque plates, which need bigger kilns to hold them. This leads to bigger presses to process the billets, and bigger rolling mills to convert the carved billet into sheet material. The final dimension of your mokume stock may be dictated by your tools as well as by your needs.

One of the most frustrating things to the maker of mokume gane is that not all alloys are created equally. The recipe used by one manufacturer may be completely different from another. Trace elements added to alloys to make them more workable for most typical jewelry uses may render them difficult to bond, if not completely unworkable. We've had great results purchasing precious materials from major suppliers. Major manufacturers have high-quality standards and produce materials that bond well. Flat, clean sheets without blemishes or imperfections are critical to the mokume gane process.

Billet Design

Let's apply all of these considerations to an example. Say we want to make a two-color piece of mokume gane that is gray and white, with a medium density pattern, a final thickness of 18 gauge and an overall sheet size of 6″ x 6″ (15.24 x 15.24 cm). Alloy choice would be 14K palladium-white gold for its gray color and sterling silver for its bright white appearance. We'd do this with a starting sheet size of 2″ x 2″ (5.08 x 5.08 cm). For a medium density pattern, begin with 23 sheets, 18 gauge in thickness; 11 sheets would be 14K palladium-white gold and 12 sheets would be sterling silver. Providing all goes well, this should leave us with about 36 square inches (232 cm^2) of material after processing. This combination makes a great bond; not only is it very durable, it is also easy to manipulate.

Cleaning

Cleanliness is very important to the bonding process and can't be stressed enough. Once you start cleaning, it's important to continue uninterrupted to make sure you don't contaminate the process. Start by washing your hands thoroughly, and from here on out be very clean. Nose itches and you scratch it? Chances are good you now have oils on your hands…wash 'em. Again. Clean, clean, clean!

First, all sheets are carefully inspected visually with 4X magnification. Any sheets that have blemishes, blistering or any other type of surface defect are either returned to the manufacturer or placed as an exterior layer on the billet. This way, if there is a failure, we'd not lose a whole billet (hopefully), just a few outer layers.

Once inspected (the 4X magnification Optivisor stays on throughout the whole process—if you can't see it, you can't clean it), the sheets are abraded with mounted Scotch-Brite™ on a polishing lathe turning at 3450 rpm (Figure 5). After cleaning both sides, the sheets are ready to be hand scrubbed. Three tubs are set up (small GladWare® containers work in a pinch; we use plastic shoebox-sized containers) and filled with distilled water. In the first tub, use a small amount (a capful) of Simple Green®. The second tub has nothing added, as it will be used for rinsing off the soapy water from the first tub. The last tub has a pinch of citric acid added to hopefully prevent oxidation as it is used as a holding tub for the pieces prior to drying them (Figure 6).

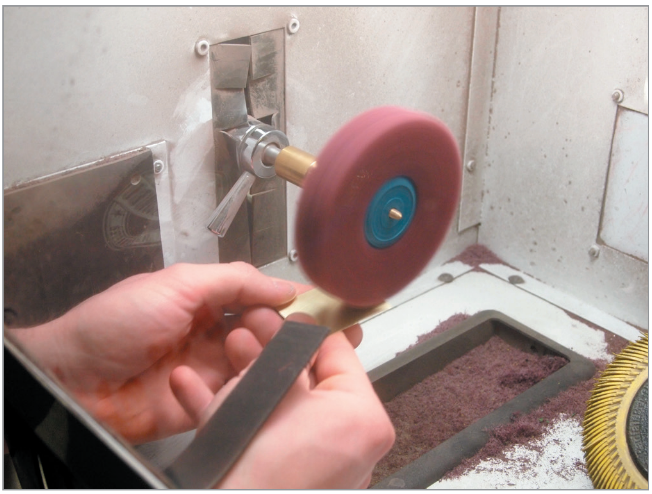

Figure 5 *Cleaning metal with a Scotch-Brite™ buff*

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Figure 6 *Cleaning metal in distilled water*

All of the sheets are placed in the first tub. One piece at a time is taken carefully through the following steps:

- Remove the piece from the water. On a clean surface, aggressively scrub both sides and all edges with a maroon Scotch Brite™ pad.
- Dip the piece back into the first tub of soapy water for a quick rinse and inspect the sheet. If it appears to be clean, free of any Scotch Brite™ particles, and water appears to be sheeting off of it evenly and not beading up, then…
- Dip the piece into the second tub of rinse water. Then, re-inspect once again. If the sheet looks clean, proceed…
- To the third tub. Place the sheet in the tub, and start the cycle all over again with a new sheet.

Once all of the sheets have been scrubbed clean, you can move on to the drying phase. The sheets need to be very dry because once you stack them, place them between the torque plates and put them in a foil bag containing charcoal, you don't want any residual moisture left to convert to steam. It's important to use a lint-free towel. Possible choices include well-laundered linen kitchen towels (the more they are washed, the less likely they seem to lint), laboratory wipes that are lint free, and (our favorite), blue shop towels from Home Depot. Available in a box or roll, they are easy to find, inexpensive, and pretty close to lint free. Take one of the towels and lay it flat; this is where the pieces will be stacked, in billet order, when dried. Remove the piece that will be the bottommost layer and dry it. Don't touch the face of the piece—handle by the edge only. Some people like to wear gloves, but we personally feel like they get in the way. Once the piece is completely dry, inspect it for any specks of lint and dust. If there are any small specks, GENTLY blow across it to remove them. Place the piece on the towel you laid out and proceed to the next layer in the billet. Continue this process until your billet is stacked up. Drop a piece? Start the cleaning process over from the first tub for that piece. Blowing lint off and accidentally spit on it? It's not the end of the world, but you do need to wash it again.

Once the billet is stacked up, it is time to place it between torque plates (Figure 7). At this point, it is critical to handle the stack by its outermost layers. Pick the stack up and place it between the torque plates.

Figure 7 *A-286 torque plates and 718 bolt studs*

These plates are made from A-286 stainless steel and have been painted with a thin layer of boron nitride (Figure 8) to keep the billet from bonding to the torque plate (Figure 9).

Figure 8 *Boron nitride paint*

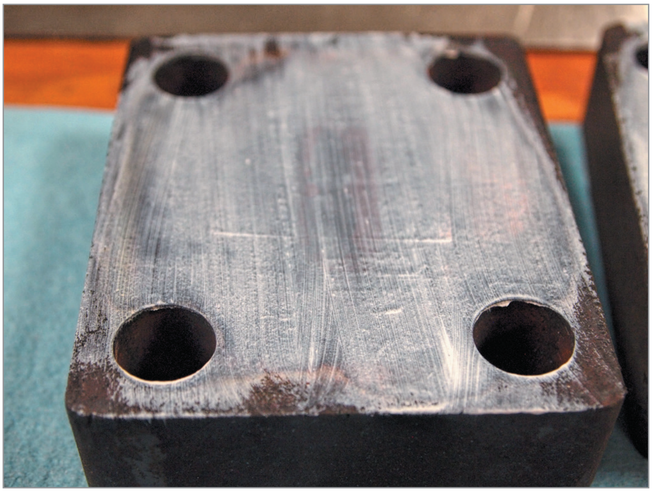

Figure 9 *Thin layer of boron nitride applied to torque plates*

316 stainless is also very good but after even one firing, 316 plates typically deform, even when cross sections of the plates are 1″ (2.54 cm) and must be finished smooth again. The A-286 is very hard, and even after a hundred uses typically does not need refinishing. These materials are ideal as they expand at the temperatures used to fire the billet. See the 2005 Santa Fe Symposium® paper, “Designing, Building and Testing a Thermal Expansion Mixmatch Torque Plate TEMTP) System for Diffusion-Bonding Mokume Gane Billets: 'The Poor Man’s Hot Press'" by Binnion, Grice, and Nyce,[5] about the way you can further capture these unique properties. Grade 8 hardware is used to hold the torque plates together and after each use for a firing cycle is retired. Another option is to use bolt studs made from 718 stainless. But if you aren’t making a lot of mokume, they can be cost prohibitive. When last purchased several years ago, the steel and machining were $100 per bolt because a large quantity of them was ordered. Once the plates are very loosely bolted together, use a series of different-sized shims to get between the torque plates and push the sheets into a “perfect” stack (Figure 10).

Ploof

Figure 10 *Aligning metal using a straight edge prior to tightening torque plates*

The closer you can get to a perfect stack, the better. All overhangs will have to be removed prior to further processing once the billet is bonded. Once the billet layers are as even as they can be, it's time to really compress the layers. We want intimate contact between the layers. This will make it much easier to effect a strong, solid-state diffusion bond. The easiest way to do this is with a hydraulic press. Using stand-offs, place the torque and bolt assembly into the press. Pressure is applied, paying close attention to the gauge. Once the gauge seems to pause or even fall off, stop applying pressure. This is the point when the metal is at its most plastic, and from here it will only begin to work harden. Tighten the bolts to at least 30 foot-pounds of torque.

Once this is done, it is time to make a 'bag' out of stainless steel foil. 304 stainless steel that is 0.002″ (0.05 mm) thick works well for this. Make a bag as close to the size of the torque plates as possible. Triple seams are used. Once the sides and bottom of the bag have been fashioned, the torque plate is inserted into the bag, covered with a generous scoop of activated filter carbon and then the top is sealed. This charcoal will help to create a reducing atmosphere inside of the bag and may aid with the bonding. Figures 11 through 15 illustrate this process.

Figure 11 *Using acrylic roller to make flat seams in stainless foil to create a bag*

Figure 12 *Rawhide mallet being used to seal bag end*

Figure 13 *Stainless foil bag ready for torque plate assembly*

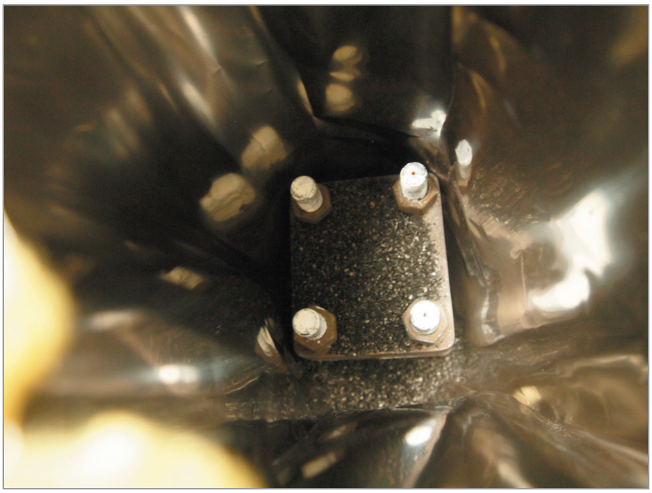

Figure 14 *Torque plate in bag*

Figure 15 *Sealed bag ready for kiln*

The bag is placed in the kiln and, in the case of this billet which contains sterling silver, will be heated for six hours at 1285°F (696°C). Once the time has been reached, the bag is removed from the kiln and allowed to cool to the point where it can be handled wearing high-heat gloves. The foil is cut open, the charcoal is poured off, and the whole assembly is placed back into the kiln long enough to come back up to temperature. Time depends on the size of the kiln. Once temperature is achieved, the billet is reinserted into the press and reduced by 25% (Figure 16).

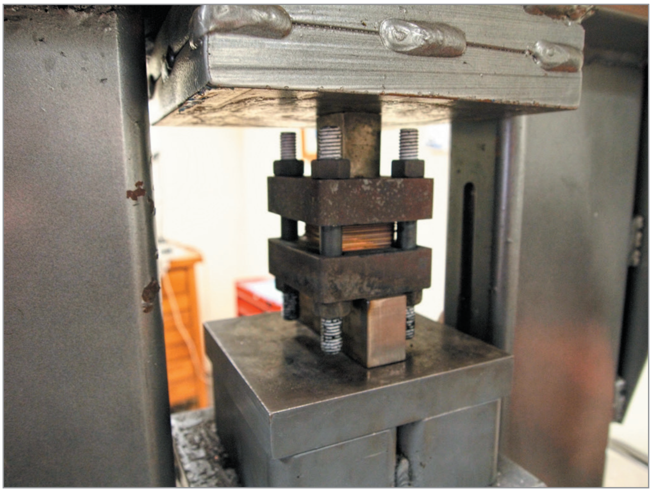

Figure 16 *25% hot press reduction*

By now, the bolts are very loose and typically the billet is easy to slide or 'shake' out of the assembly. Shake the billet out and let it air cool. Once you are comfortable with handling it, place it back into a torque plate and bolt assembly for further hot pressing. Don't press it; hand-tighten it, and here it is okay to use the Grade 8 bolts previously used in the bonding stage.

Depending on starting billet height and desired thickness (this billet started at 23 mm/0.91″ and patterning will begin at 6.5 mm/0.26″), you can repeat the process until you either have reduced the billet to 50% or your press can't compress it any further.

Now the billet needs to be trimmed. This stage can be done after the first press or at the 50% reduction. I've found that if the metals are very close in Vickers hardness, you can easily wait until 50% reduction. If the metals are more dissimilar, trimming sooner can be beneficial as the softer metal tends to extrude around the harder material. Imagine two crackers with lots of jelly between them, which you have pushed together. That jelly squirting out is how the softer metal reacts between the harder metal.

Trimming can be done with jeweler's saw blades (recommend #3), coarse files, grinding, machining—really, whatever method you are comfortable with. It is important, however, that you work parallel to the layers. Even at the 50% reduction stage, working against the layers can precipitate a failure in the lamination. Remove material until the layers look even with no overlaps, THEN remove 2 mm (0.08″) more. This is one of the most important steps in making quality material. It is also the step that is the most mind numbing, i.e., watch-paint-dry boring, other than maybe cleaning the sheets. By removing the edges, you are removing any possible contamination and thereby removing stress risers that can and probably will cause billet failures. It seems incredibly wasteful; you will want to know a good refiner. And did we mention it's our least favorite part?

Once the sheets are bonded, reduced to 50% and have been trimmed, it is time for more processing. We started at 23 mm tall. We are now at 11.5 mm (0.45″). We will need to further reduce this material regardless of use. This 23-layer material works well for patterned sheet and also for rings. Below, we'll detail the process for creating sheet as well as the process for making rod stock.

Sheet Stock

The 11.5 mm thick mokume billet will need to be reduced to plate in order for it to be patterned and turned into sheet. As mentioned earlier, the goal is to reach 6.5 mm before beginning to carve the material with a rotary tool. The rolling mill (Figure 17) is used to reduce the material to the desired thickness, keeping in mind that the rolling strategy controls the shape of the sheet. For example, the material elongates in the direction of rolling, so if square stock of a certain length is needed, roll in one direction until that length is obtained, then cross roll to gain width to the desired thickness. Always start rolling on annealed material and never exceed 10% reduction on the first pass before annealing again. Then, depending on metal hardness, 10 to 15% reductions can be made with annealing in between until the sheet is 6.5 mm thick.

At this point patterning. can begin We like to pattern in a glovebox-type arrangement, where the precious metal is easy to keep track of and collect for refining (Figures 18 and 19).

***Figure 17** Rolling mill (Don't put your hand in here; it hurts!)*

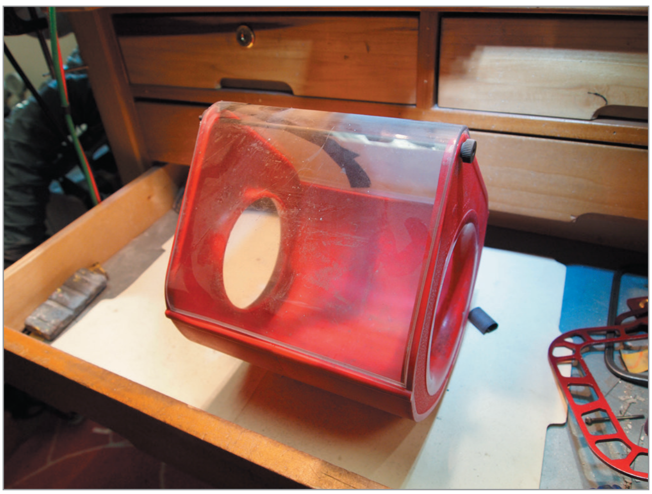

***Figure 18** Small, commercially available chamber which works for carving mokume patterns*

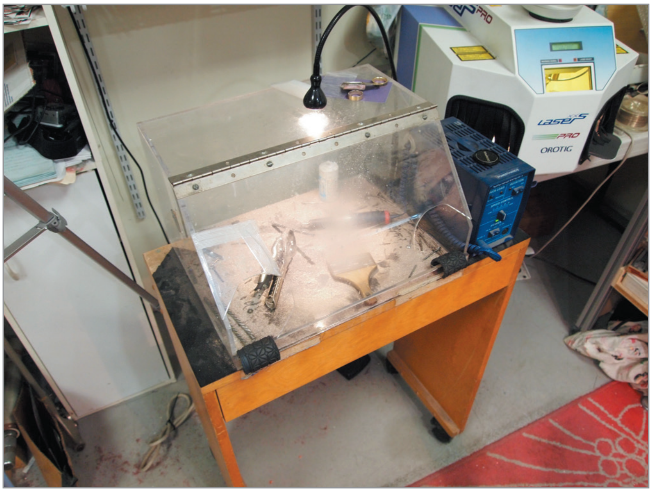

Figure 19 *Modified polishing hood used for carving into mokume*

Use round burs, round-edge wheel burs and even ball-end mills and drill bits for patterning. It's important to not cut below the top third of the layers. Any deeper and the metal will be too thin and may tear during further rolling. Also, at this stage it is important to think about the pattern. You will be rolling this further, so the size of the cut you make will enlarge in one or two directions, depending on how you roll it. Something 6.5 mm thick being carved and reduced to 1 mm (18 gauge) will see the pattern enlarge approximately four times. Plan carefully and select bur sizes that will take this into account. Cover the surface of the metal closely wherever you want it to have pattern. Figure 20 shows good coverage. Figure 21 is not enough for a tight pattern.

Figure 20 *Well-patterned mokume*

Figure 21 *Pattern that is too sparse*

Once the surface is covered tightly and you've cut through enough layers, it must be de-burred. Every bur and sharp peak must be removed. The easiest way to do this is with 3M Radial Bristle Discs, green or yellow. This same material can also be purchased as Roloc discs, which can help reach into deep recesses (Figure 22). Once the metal has been de-burred, it's time to anneal the material and continue to roll.

Figure 22 *3M Roloc bristle disc and Foredom angle-grinder attachment*

This next rolling step is really critical. It will give you your first glimpse of the pattern and also show you something else. With 23 layers, you should have cut through no more than seven of them during patterning. And even if you cut a very tight pattern, you will quickly see, after about a 5% reduction, just how much blank space is between your cuts. Remember, this space will also increase about four times. At this point, roll a few more times until about 7% reduction is achieved. Then, make new cuts between the old ones to increase the pattern density, following the one-third rule, i.e., don't cut below seven layers in a 21-layer billet. Once a sufficient number of fill-in cuts are made and the sheet is properly de-burred, the rolling can continue, being careful not to exceed the 10-15% total reduction between annealings. The pattern can be manipulated with additional cuts until the sheet thickness reaches 2 mm. After 2 mm you should be done cutting patterns and continue to roll and anneal until 1 mm (18 gauge) is reached.

Rod Stock

To make rod stock you can start with an 11.5 mm billet if your square rolls can handle that size. Otherwise, roll the sheet down to the largest size your square rolls can accommodate. If you do need to reduce it further, follow the steps in the sheet stock above until it is the proper thickness.

Once you have reached the proper thickness, cut a piece off that will result in a square cross section. Then, solder silver sheet on both ends and trim it to the size of the square rod so the ends are capped (Figure 23). After trimming the overhang on all four sides, trim the corners at 45° to match the grooves of your wire rolls.

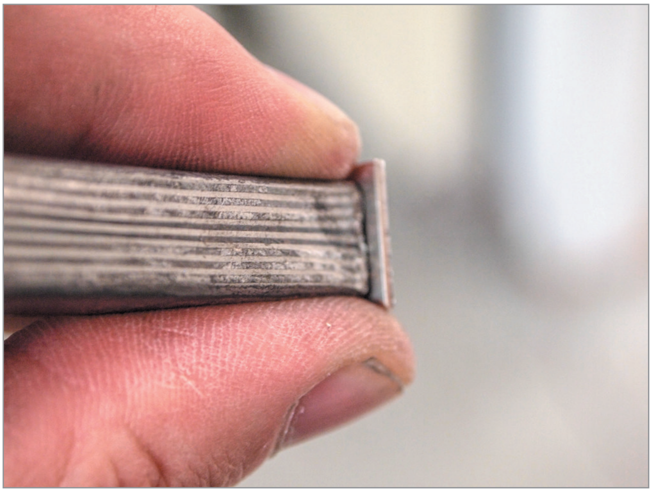

***Figure 23** Silver end cap ready for soldering*

On the first rolling pass, barely make contact with the surface of the rod. Each following pass should make a 0.1 mm reduction. Always lead with the same end of the mokume rod, and rotate it 90° with every pass. This first series of passes is not to reduce the size so much as to make it the shape of the wire rolls. The material is under tremendous shear, so aim for 5-10% reduction, never more. After annealing, continue to roll with 10-15% reductions until the desired size is reached. For the material detailed below, stop rolling at 4.8 mm square and anneal the material.

Rod stock allows for easy development of patterns that require twisting, such as those that resemble wood grain and the famous star pattern. Twisting the rod stock is simply done using a bench vise and vise grips. Clamp an end in each set of jaws (keeping layers in compression and faces parallel to the jaws) and twist. Depending on length of material, as well as the alloys, you will feel it work-hardening as you twist. As it starts to get more springy feeling, it is hardening and it's time to anneal again. After annealing, continue twisting until the twist is as tight as you'd like. DON'T twist backwards. If you started twisting clockwise, stick with it and likewise if you twisted counter-clockwise. Reversing the twist direction will almost always cause delamination. When making wood-grain stock, tight twists yield very dense patterns; loose twists have a very open look to them. For a star pattern, each twist yields a star so it is fairly easy to plan. However, the next step after twisting will be to anneal and roll to a square or nearly square cross section so that, much like the pattern on sheet material, it will elongate slightly. Bring the rod stock back to where you started twisting, in this case 4.8 mm in cross section. Figure 25 shows both a loose twist (top) and a tight twist that have been square-wire rolled after twisting.

Figure 25 *Loose- and tight-twisted square stock*

Once twisted and squared, if you cut through the center of it, you will expose the star pattern. Figure 26 illustrates both a loose-twist star pattern and a tight-twist start pattern. Every twist equates to one star, so the tighter you twist your material, the more stars you will have. The bottom star in Figure 26 was twisted about two times as many turns as the top one. If you carve one face of it and then roll or press, you will end up with a wood-grain style of pattern. Figure 27 shows two wood-grain patterns. The top wood-grain pattern has been twisted four times while the bottom pattern has been twisted five times. Don't forget to de-bur and remember when cutting, never cut deeper than a third of the thickness.

Figure 26 *Loose (top) and tight (bottom) star patterns*

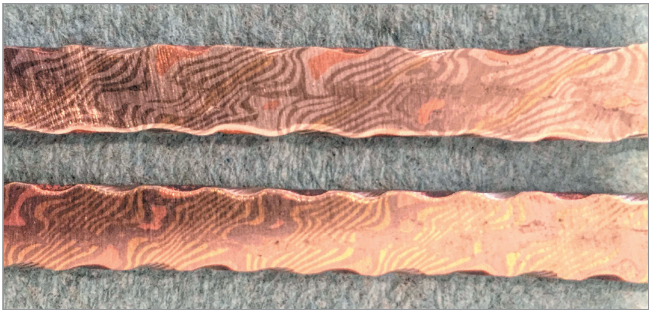

Figure 27 *Two wood-grain pattern samples*

From here, happy creating! These pieces of material can be further manipulated into whatever forms you wish, but take care not to overwork. When soldering mokume gane, use one temperature step lower (e.g., medium solder instead of hard) than you would typically use for the lowest melting material in the stock.

Conclusion

Although invented in Feudal Japan, mokume gane has really been advanced well beyond where the early practitioners took it in their time. This advancement has taken place over many years both in the United States and abroad. It is hoped that, with these instructions and a historical context of mokume gane, you will be able to better understand the material and start to see the many ways mokume gane can be incorporated into the world of jewelry design and manufacturing. With these instructions, we hope you can create your own mokume gane materials for your unique jewelry and other metal applications.

References

1. Steve Midgett, *Mokume Gane—A Comprehensive Study* (Earthshine Press, 2000).
2. C. Ploof and S. Grice, "Mokume Gane Firing Methods and Their Effects on Appearances and Bond Strengths, " *The Santa Fe Symposium on Jewelry Manufacturing Technology 2010,* ed. Eddie Bell (Albuquerque: Met-Chem Research, 2010).
3. C. Ploof et al., "Mokume Gane Billet Reductions and Their Effects on Bond Strength," *The Santa Fe Symposium on Jewelry Manufacturing Technology 2009*, ed. Eddie Bell (Albuquerque: Met-Chem Research, 2009).
4. www.georgesawyer.com.
5. James Binnion et al., "Designing, Building and Testing a Thermal Expansion Mixmatch Torque Plate (TEMTP) System for Diffusion-Bonding Mokume Gane Billets: 'The Poor Man's Hot Press,'" *The Santa Fe Symposium on Jewelry Manufacturing Technology 2005*, ed. Eddie Bell (Albuquerque: Met-Chem Research, 2005).