

# Diffusion Bonding of Platinum

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Over the past several years much has been written about the processes of fusion welding, laser welding and brazing for bonding platinum to itself and other metals. In this paper I would like to talk about a different method for bonding platinum: diffusion welding.

## Diffusion Welding

The Merriam-Webster Dictionary defines diffusion as: “the process whereby particles of liquids, gases, or solids intermingle as the result of their spontaneous movement caused by thermal agitation and in dissolved substances move from a region of higher to one of lower concentration”. In diffusion welding two or more surfaces are joined by the diffusion process. To describe how this works, it is probably best to think of an often-used simple model for the crystal structure of a metal.

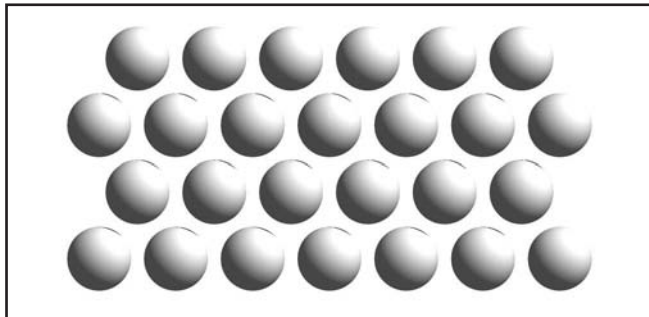


Figure 1: The Crystal Lattice

In Figure 1 the spheres represent metal atoms in the idealized crystal lattice, however real world metal structures are not so neat. Impurities, the way the

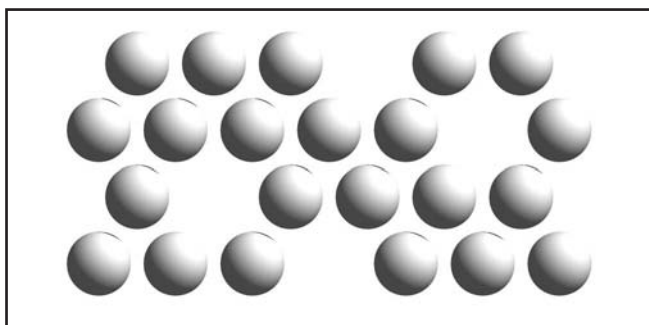


Figure 2: Vacancies in the crystal lattice

metal solidified, working stresses and many other factors make the lattice a much more unruly structure.

In Figure 2, there are holes in the crystal lattice called vacancies. The number and location of these openings is affected by many of the same factors that distort the lattice. Atoms at temperatures above absolute zero are in constant vibration. This motion increases as the temperature (amount of energy) in the atom is increased. If an atom has sufficient energy it can jump from its current place in the lattice into one of the vacancies or even swap places with one of its neighbors. Due to this motion, a certain number of the atoms in a piece of metal are constantly moving around. As temperature increases, the number of atoms changing position in the lattice and the frequency of this motion increases until the melting point of the metal is reached. At this point all of the atoms are now moving about and the crystal structure ceases to exist.

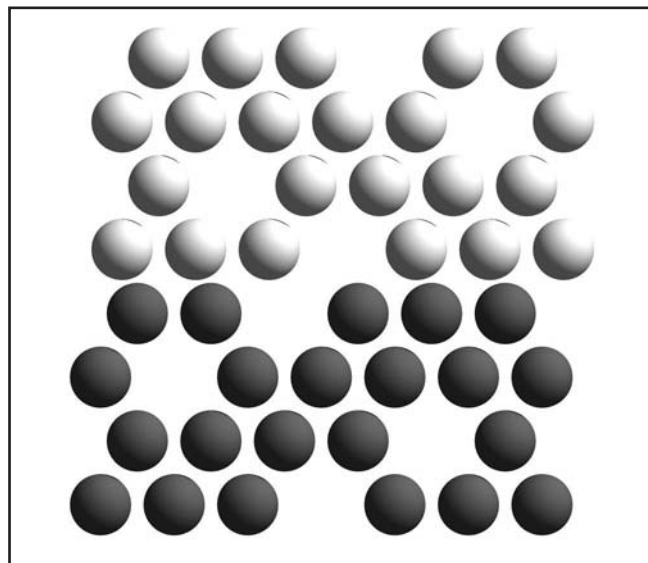


Figure 3: Two surfaces in intimate contact

However, well before the melting point is reached, if two metal surfaces are placed in intimate contact with each other the atoms from one surface will diffuse into the other, and new crystal structures will grow across the surfaces creating a molecular level bond.

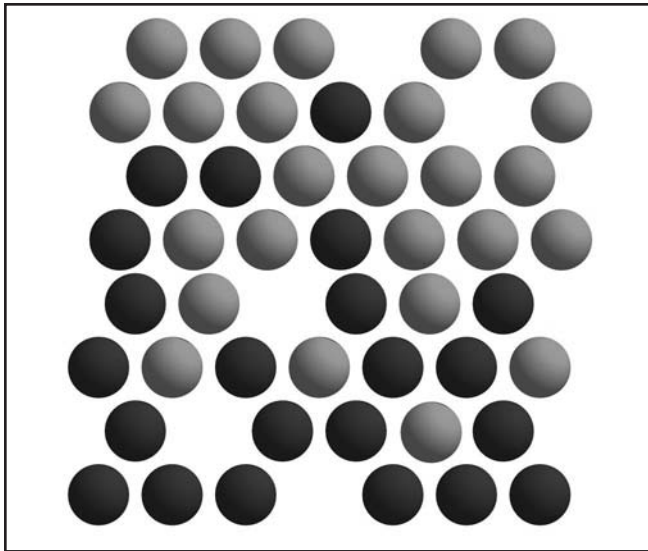


Figure 4: Heating promotes diffusion across surfaces

The quality of this bond depends on a number of variables including how good a solvent one metal is for another, how intimate the contact between surfaces is, and how clean/free of oxides the surfaces are. With care and attention to detail, it is possible to make very strong bonds between most of the metals used in jewelry work by diffusion.

### Mokume Gane: an Example of Diffusion Welding

The diffusion welding process is central to the work that we do in my studio. All of our work is made of patterned laminated metal. This technique dates back to the 17th century when the Japanese swordsmiths developed a means of laminating and patterning non-ferrous metals that were similar to the patterns they achieved in forge welded iron and steels. They called this technique of patterning, mokume gane, which translates to wood eye metal in English.

In the style of mokume gane, (we work in sheets of metal)z are thoroughly cleaned) with detergent and abrasives and then rinsed in water to remove oxides and other foreign elements. These cleaned sheets are clamped between a pair of thick metal plates and bolted tightly together. This provides for intimate contact between the layers during lamination. This stack is then placed in an oxygen free environment, a kiln. In the kiln, the stack is raised to a temperature that is between 50 and 80 percent of the solidus of the metal alloys that are being laminated and allowed to soak at this temperature while the diffusion process is occurring. After soaking long enough for significant diffu-

sion to occur, the stack is removed from the kiln and allowed to cool. Once cool, the laminated stack is removed from the laminating fixture, and it is then processed by one or more standard metalworking techniques to develop patterns in the laminate. For more detailed information on patterning and other aspects of the mokume gane technique, Steve Midgett's "Mokume Gane A Comprehensive Study" is a good reference. There also is a paper co-written by myself and Bryan Chaix, "Old Process, New Technology: Modern Mokume Gane", that provides more background.

We work with a variety of alloys in both precious and base metals that we have learned to laminate. One of the combinations that we work with is platinum and gold as seen in the star pattern ring shown in Figure 5; another is sterling, copper and brass as seen in the teapot in Figure 6. Both were formed from diffusion welded billets that were further processed by forging, rolling, drawing and raising. These examples give a good indication of the bond strength achievable by diffusion welding.



Figure 5: 950 Pt-Ir and 18K yellow gold ring



Figure 6: Teapot in sterling, copper and brass

For this article I decided to try something different from our typical laminates. For several years I have thought it would be interesting to laminate platinum to iron, because of the color and textural differences that can be achieved between the two. I thought it would be a beautiful laminate. This seemed to be a good chance to experiment with it.

## The Faraday Connection

The inspiration for this particular laminate comes from a book brought to my attention by my assistant Bryan Chaix. The book is about the metallurgical work performed by the famous British scientist Michael Faraday (1791-1867) who is best known for his pioneering work in electromagnetism. However, he made many discoveries in a variety of fields. What is not as well known is that his first research when he was in his early twenties was in the field of metallurgy. This research focused on improving steel by alloying it with other metals. In the process, he developed some of the first deliberate alloy steels. He was seeking to find alloys that would be harder, tougher or more corrosion resistant than plain carbon steel.

The platinum group metals were very much a curiosity at this time and there was not much use of them. This was partly because many of the processes needed to work them did not yet exist. Dr. William H. Wollaston, early investigator of platinum group metals, discovered palladium and rhodium in platinum ore. He also made his fortune from developing a process to make platinum malleable and used this to produce metal stock and platinum vessels for the chemical industry. Faraday developed a friendship with Wollaston. Due to this, he had access to osmium, palladium, platinum, and rhodium. All of which he used in his steel alloys. In regards to platinum, he produced alloys ranging from 1-81% platinum and steel with these results:

“From 1 to 3% of platinum improves steel for edge instruments; probably 1.5% of platinum forms the best possible alloy of these metals. Equal parts by weight form a beautiful alloy which takes a fine polish and does not tarnish; the colour is the finest imaginable for a mirror; 90 of platinum and 20 of steel also gives a perfect alloy with no disposition to tarnish; 10 of platinum to 80 of steel forms an excellent alloy, but one that is quite unfit for mirrors owing to a fine damask. However, this alloy, after laying many months had not a spot of rust on its surface.”

Faraday's co-researcher in these alloys was James Stodart. As a cutler, his main business was the fabrica-

tion of fine surgical instruments. One of the areas of research they pursued was the duplication of two fine steels of a type not produced or readily available in Europe at the time. One of these steels called wootz came from India, and the method of its production was a secret. Cutlers used wootz to produce the finest of surgical instruments and cutting edges. One of the characteristics of wootz was a very fine pattern of light and dark areas distributed throughout the steel. The second steel was called damascus steel which was a pattern welded laminated steel produced in the Middle East. It received its name from the city in Syria from where it was shipped to the west. No steel then available in Europe had the same quality of cutting edge as that exhibited by these imports. Both types of steel had very distinctive patterning present in the finished material which was directly related to their methods of manufacturing. While Faraday and Stodart performed many experiments on trying to make steels similar to the imports, the one of particular interest to me was in attempting a type of damascus steel. This particular attempt was by forge welding platinum and steel. In one of their papers they state,

...wires of platinum and steel of about equal diameter, were packed together and, by an expert workman, were perfectly united by welding. This was effected with the same facility as could have been done with steel and iron. On being forged, the surface polished, and the steel slightly acted on by an acid. A very novel and beautiful surface appeared. The steel and platinum forming dark and white clouds

This sounded like an interesting challenge: to diffuse laminate platinum to iron. While forge welding and diffusion welding are similar, forge welding is a much higher energy welding process. Because of this, I was not totally sure we could successfully laminate the two.

## Diffusion Welding Platinum to Iron

The steps listed below for this laminate are basically the same as would be used for any of the typical jewelry metals and alloys. The main difference is that the time and temperature must be adjusted for whatever combination is being bonded.

An early decision was to use very low carbon steel for the laminate since modern steels have a number of alloying elements in them that were probably not present in Faraday's steel. It seemed as close to pure iron as we could get and would be the least likely to cause problems. We found a commercial grade of iron sheet

with negligible amounts of carbon and other impurities. For the platinum portion of the laminate, the 950-platinum 50-palladium alloy was chosen because it closely matched the iron in Brinell hardness. If there is too great a difference in hardness exhibited during the rolling of a laminated stack, the softer layer will end up extruding out of the laminate and result in a much thinner layer of the soft material in the billet.

## The Process

The initial stack consisted of 8 layers of platinum and 7 layers of iron. Each sheet was 1.5" x .5" x 16 gage. The metal sheet must be free from surface defects, dings, heavy scratches or other gross imperfections. The edges of the sheet need to be de-burred so that the sheets will stack evenly.

## Cleaning

Thorough cleaning of the surfaces to be bonded is extremely important. If this step is improperly done, the diffusion process will then be impaired and will most likely result in the failure of the bond. The surfaces to be laminated must be free of all dirt, oils and oxides. The intention is to bring the surfaces into full metal-to-metal contact with nothing else in between. While it is not possible in a real world situation to achieve a totally clean metal surface, it is important to come as close as possible. While not the only way to achieve a surface clean enough for diffusion welding, the steps described below have worked well for this particular application.

The sheets are cleansed by wet scrubbing with ScotchBrite abrasive pads in a series of three baths (Figure 7). The first bath contained water and a very small amount of detergent to help remove the oils and oxides present on the surfaces of the sheets. The second bath is clean water and the sheets are again scrubbed to remove the last of any dirt/oxides and to remove the detergent. The final bath is a clean water rinse.

After the final bath, each sheet is dried with a cool, high velocity, low-pressure air stream and set aside. This is probably the most difficult part of cleaning the sheets. The sheet must be completely dried to prevent rapid oxidation and/or corrosion of the surface by the remaining water, yet held firmly against the pressure of the air stream. If it is not handled carefully, the sheet will go flying off across the shop and will need to be re-cleaned.



Figure 7: Cleaning the plates

Once all the sheets are cleaned and dried, the sheets are stacked in a clamping fixture also known as a torque plate (Figure 8). A hydraulic press is used to compress the fixture and stack. This insures that the sheets are in full face-to-face contact and overcomes any minor variations in thickness of the sheets. The bolts are then torqued down to hold the stack in compression so that the layers remain in intimate contact during the diffusion process. The faces of the torque plate shown have been coated with a ceramic paint to act as a release agent. This prevents the bonding of the stack to the torque plates, which will occur, if there is no release agent between them.

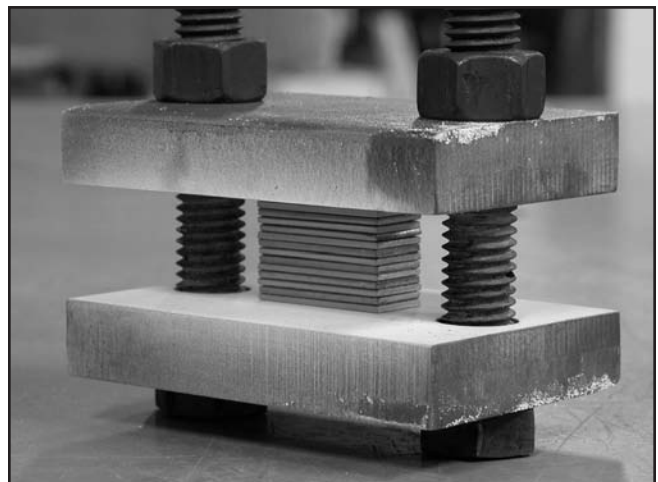


Figure 8: The stack in the torque plate assembly

The torque plate assembly is now ready for firing but protection from the highly oxidizing environment in the kiln must be provided. We make a protective envelope from a stainless steel foil (Figure 9). The foil,

because of its low thermal mass, will heat up very rapidly and capture much of the oxygen inside the bag on its surface. It will also act as an effective barrier that will keep the oxygen in the air in the kiln from coming inside and making contact with the stack. Filling the bag with granular charcoal will provide a reducing atmosphere in the bag. As the charcoal is heated to over 1000°F, it combines with any trace of oxygen to produce carbon monoxide gas (CO) which will reduce surface oxides on the metal stack. The charcoal also combines with any oxygen that leaks into the bag to prevent it from oxidizing the stack as it is raised to the diffusion temperature.

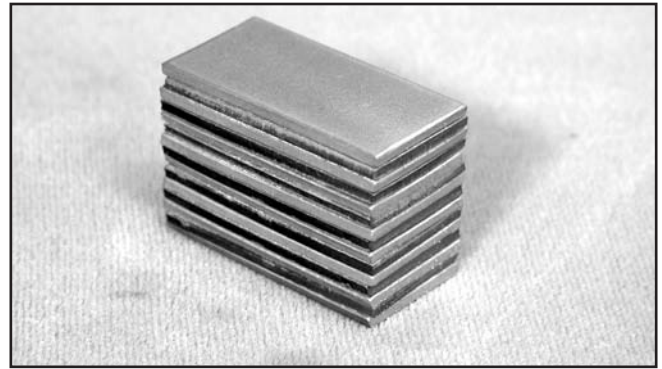


Figure 11: The laminated stack



Figure 9: Assembly inside the bag

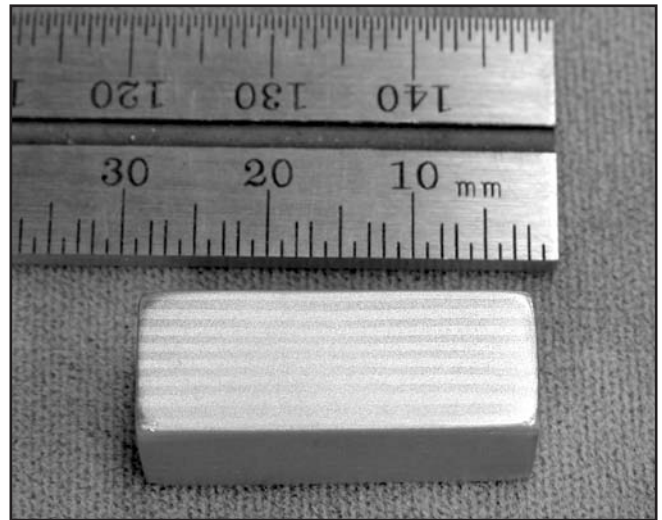


Figure 12: Milled laminate



Figure 10: Bag in the kiln

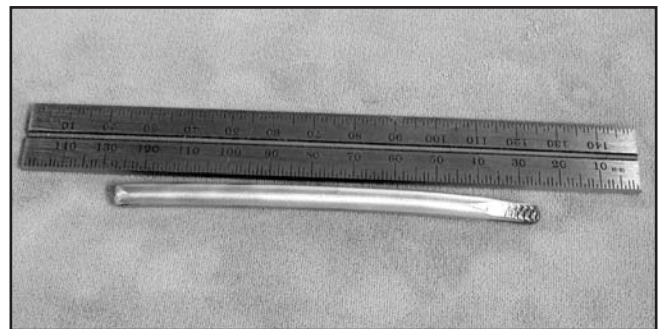


Figure 13: Drawn 6mm diameter rod

Firing temperatures need to be between 50% and 80% of the solidus of the metals being laminated. Firing times will depend on the size and thermal characteristics of the bag, torque plate stack, and the kiln but are typically in the 1hour to 8hour range. In this case the temperature was 1700°F for 3 hours.

Once the bag is removed from the kiln and cooled to room temperature, the diffusion-welded billet can be removed from the torque plates and other operations can begin. In this case the laminate was reduced to a 10 mm x 10 mm square section bar and then rolled and drawn to a 6 mm diameter rod before the patterning process was begun.



Figure 14: Flux coated ring

After patterning was completed, a ring blank was cut and soldered and then an inner lining of 950 Pt Ru was installed. Since torch soldering takes place in an oxygen rich environment, easy platinum solder and 19k white gold solder were used to try to limit the temperature and therefore, the amount of oxidation of the iron but still have an acceptable color match to the laminate. A heavy flux coat was also used to limit the oxidation of the iron.

After cleanup the ring was etched and polished (Figure 15). The light grey of the platinum against the blue grey of the iron exhibits a beautiful, subtle contrast.



Figure 15: Pt-Fe ring

## Other Applications of Diffusion Welding

Mokume gane is not the only way to utilize the diffusion welding process in studio jewelry manufacturing. By developing the proper fixtures, it is possible to use diffusion welding to assemble jewelry without solder.

An example of how a multi metal ring can be joined with a fairly simple fixture is shown in Figure 16. In this case the fixture assembly consists of a bolt and nut and two cylindrical fixtures that hold the parts of the ring blank in alignment. The parts of the fixture that come in contact with the ring and the threads of the bolt should be coated with a high temperature ceramic release agent such as aluminum oxide paint. As in the mokume gane laminate, the parts to be joined must be free of any contamination and oxides. Once the fixture is assembled, it is placed in a furnace for welding. The firing time will depend on several factors though the mass of the fixture and the furnace response time will probably have the most impact on firing time. The range can be from tens of minutes to several hours.

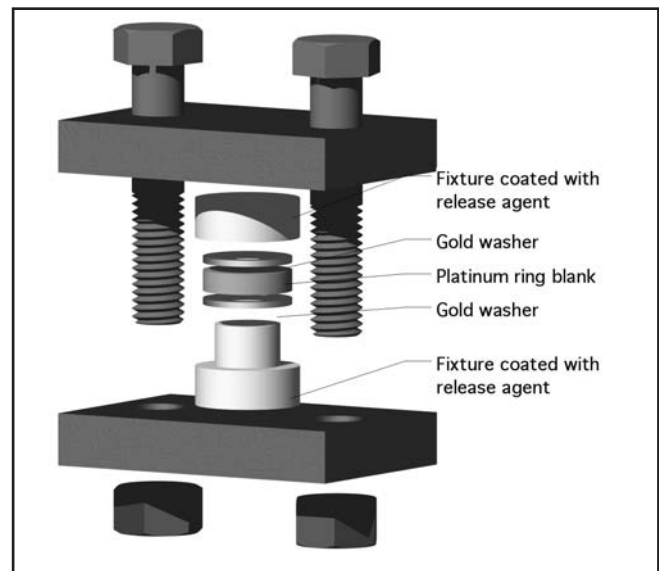


Figure 16: Fixture for diffusion welding a ring blank

The furnace atmosphere must provide either an inert or reducing environment to prevent oxidation of the parts. This can be achieved with the foil bag approach or a controlled atmosphere furnace. Another factor to be considered is the thermal expansion coefficient of all the parts of the fixture. The bolt and nut material should have a lower thermal expansion coefficient than the cylindrical fixtures and the ring parts. If the bolt has a greater thermal expansion, the assembly will loosen in firing and will result in either a weak bond or a complete failure of the weld.

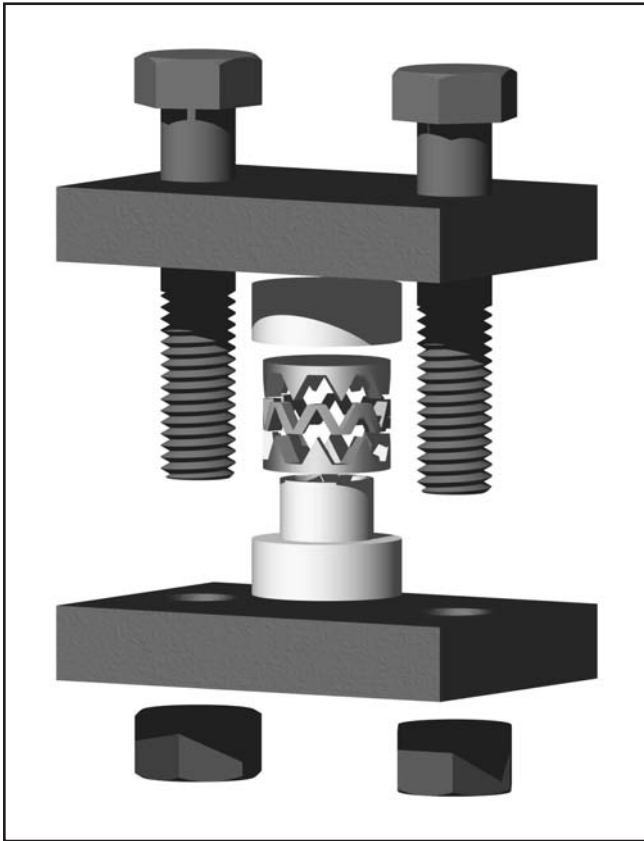


Figure 17: A more complex assembly

The simplicity of the band in Figure 16 might not justify the time and money to make the laminating fixture. However, if the blank is to be machined after laminating, having a joint that will not have voids from incomplete solder flow could justify the expense as the parts to be joined become more complex than the cost of building the laminating fixture becomes more acceptable. The biggest drawback to diffusion welding for jewelry assembly is the requirement for a very precise fit of the parts being assembled. This need for precision favors machined parts rather than hand fabricated or cast sub assemblies.

## CONCLUSION

Diffusion welding is certainly not the answer for all platinum bonding situations. However, it does allow for the production of precisely aligned multi-part assemblies without the use of solder and its associated clean up. It also allows for the production of bonds that can be cold worked in ways that cannot be duplicated with solder. I believe that it has a place in the process repertoire of the studio jeweler.

<sup>1</sup>Midgett, Steve "Mokume Gane A Comprehensive Study" *Earthshine Press* 2000

<sup>2</sup>Binnion, James and Chaix, Bryan "Old Process, New Technology: Modern Mokume Gane" *The proceedings of the 16th Annual Santa Fe Symposium on Jewelry Manufacturing Technology* 2002

<sup>3</sup>Hadfield, Sir Robert A. "Faraday and His Metallurgical Researches" *Chapman & Hall Ltd* 1931

<sup>4</sup>Faraday, Michael and Stoddart, James "Experiments on the alloys of Steel, with a View to its Improvement" *Quarterly Journal of Science* 1820