WELDABLE SILVER ALLOY

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ABSTRACT

Historically, the high thermal and electrical conductivities of traditional sterling silver alloys have made these metals difficult to weld. However, newer firestain-resistant silver alloys incorporating germanium have proven to be much more weldable, as was most recently presented at the Eleventh Santa Fe Symposium. This paper will take a more detailed look at welding firestain-resistant silver alloys incorporating germanium, with particular emphasis on resistance welding.

Key Words
germainum, heat affected zone, nugget; electrode, high frequency inverter, linear DC, capacitor discharge, alternating current, molybdenum, tungsten, copper-tungsten, silver-tungsten, weld head, brittle, upslope, downslope, workpiece, millisecond, firestain, resistant, conductivity, resistance, follow-up, direct welding, series welding, indirect welding, interface, vaporize, laser, plasma arc, forged, melting, crystalline structure, deformation, bond, braze, forge, fusion, diffusion

Introduction

Traditional sterling alloys remain among the most difficult metals to weld. By comparison, adding small amounts of germanium (Ge) to silver greatly improves it's welding properties. These silver germanium alloys represent a major breakthrough in welding, by providing new and substantially improved fabricating capabilities to jewellery manufacturing.

This exclusive innovation will change how designers, engineers, metalsmiths, and even equipment manufacturers regard the welding of sterling silver. After the discovery of silver germanium alloys, welding could even approach the versatility of traditional torch soldering methods. This study introduces applied resistance welding techniques for joining AgGe alloys. Prepare to revise your thinking concerning the welding of silver.

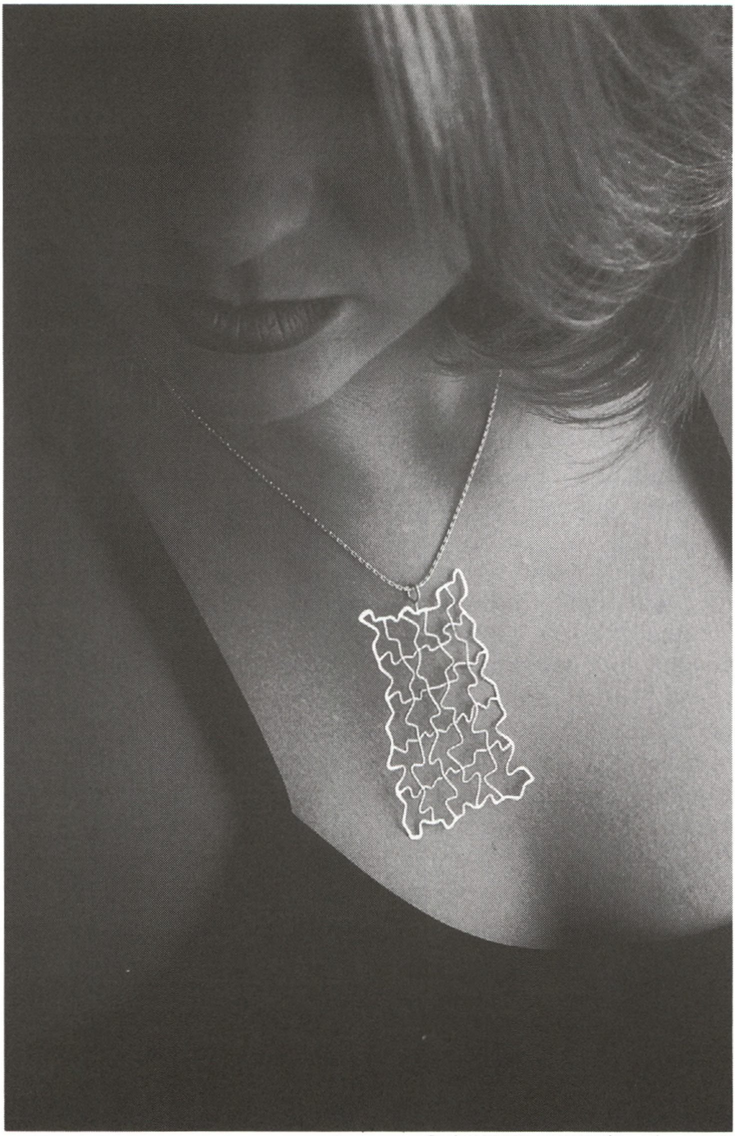
Weldable Silver Alloy

Peter Johns of Middlesex University, in collaboration with Metaleurop S.A., has developed silver alloys which incorporate germanium to produce firestain-resistant alloys.† As shown in his patent, filed in 1993, Johns' silver alloys incorporate 1.1% germanium, producing a protective layer of transparent germanium oxide (GeOx), bringing about tremendous contributions to silver's firestain resistance [1].

Two key factors in its contribution to welding are decreased conductivity and decreased oxidation. On the International Annealed Copper Scale (IACS) scale, copper is 100% conductive and traditional sterling is 96% conductive. Metals with high conductivity require tremendous amounts of energy, introduced quickly and accurately, to combat rapid heat losses from the weld site. These rapid heat losses have made welding traditional silver alloys extremely difficult. Johns' research determined that 1.1% Ge was the minimum required to maintain firestain resistance. The lower conductivity of these AgGe alloys dramatically improves their welding characteristics. At 165 Vickers hardness (HV), conductivity measures 53.6% IACS, or 3.21 micro ohms cm and 67.6% IACS, or 2.55 micro ohms cm in 70 HV hardness.†† This lower oxidation potential reduces, if not eliminates, the requirement for inert cover gas.

† Patent granted in Europe, pending in the U.S. and other territories worldwide.

†† 1998 Peter Johns, Private Communication



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Pendant

Applied Welding Equipment

Several types of welding equipment were demonstrated in Peter Johns' research, i.e. plasma arc, laser, and resistance welding. Recognizing that equipment costs could limit interest in welding, Johns' research suggests sufficient economic, efficiency and esthetic benefits are available in the lower cost AC resistance welding system. (See Types of Welding Equipment). For this study, high frequency inverter welding equipment was selected for its greater versatility in weld pulse shape and control over output (Figure 1).

Electrode Alloys For Silver Germanium Alloys

Because of the increased resistivity of silver germanium alloys, copper alloy welding electrodes can be used. Conductive sterling alloys most often require resistive electrode materials like tungsten or molybdenum to help contain heat in the weld. Silver germainum alloys accommodate the use of both conductive and resistive electrode materials.

Fundamentally, conductive electrodes are used when welding resistive metals. As resistive metals resist the flow of current, welding temperatures are generated quickly. Conductive electrodes helps pull excess heat away from the electrode/workpiece interface. Excessive temperatures at this interface will result in electrode sticking and/or deformation to the workpiece. (See Electrode Deformation) Electrode deformation may be resistance welding greatest disadvantage compared to soldering methods. Techniques to minimize deformation are established (Figure 2).
Some manipulation of the surface may be necessary to effectively eliminate deformation (Figure 3). Rollerprinting or some means of texturing may prove effective to neturalize deformation (Figure 4).

Welding Process Outline

Tests were made using a high frequency inverter power supply and manual (foot-pedal operated) weld head with offset opposed electrodes.
Using Class 2 copper chromium electrode materials cross wire welds with silver germanium alloy were easily performed. More common tungsten or molybdenum needed to maintain heat in the weld site can be substituted for less expensive copper electrode alloys. Copper based alloys are easier to shape providing a distinct cost savings. GeOx also allowed welds to be made without the use of inert cover gases. Commonly, silver requires inert cover gasses such as argon to control the rapid growth of surface oxides.

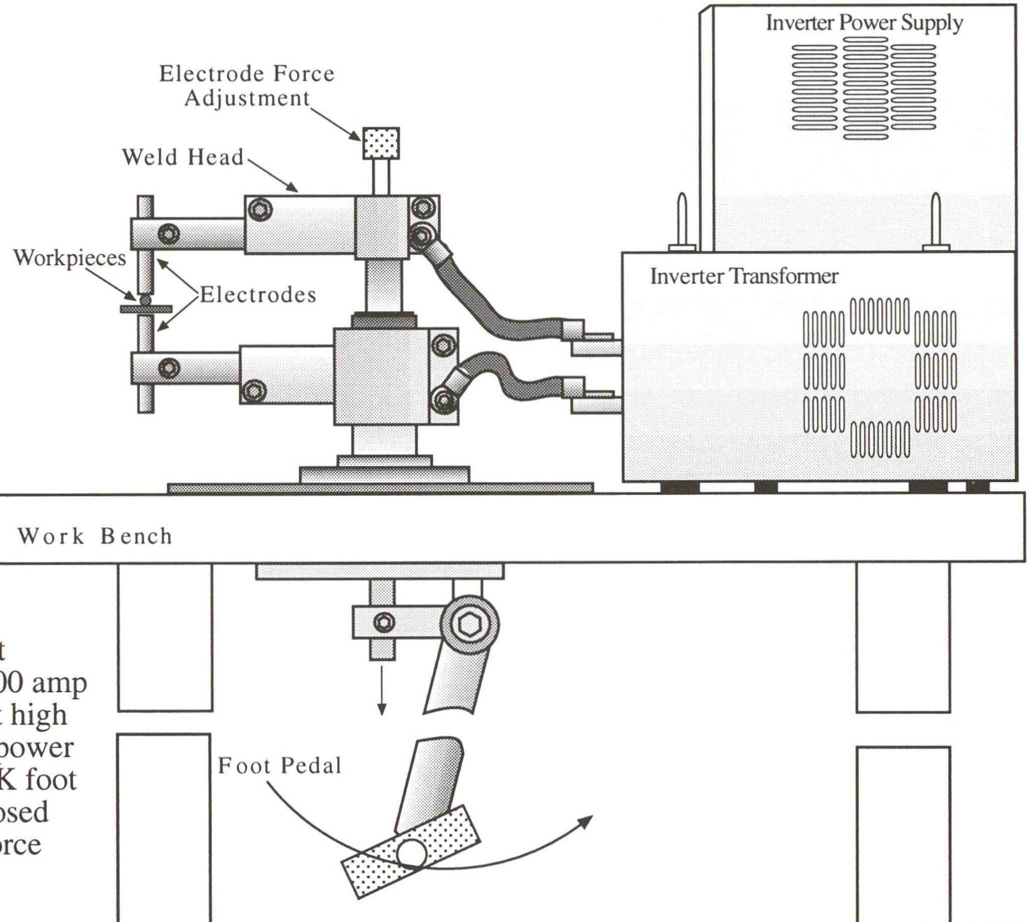


Figure 1.
Welding Equipment
Seiwa SIW-340 8000 amp short circuit current high frequency inverter power supply with I80BBK foot pedal actuated opposed weld head with a force range of 1-15kgf.

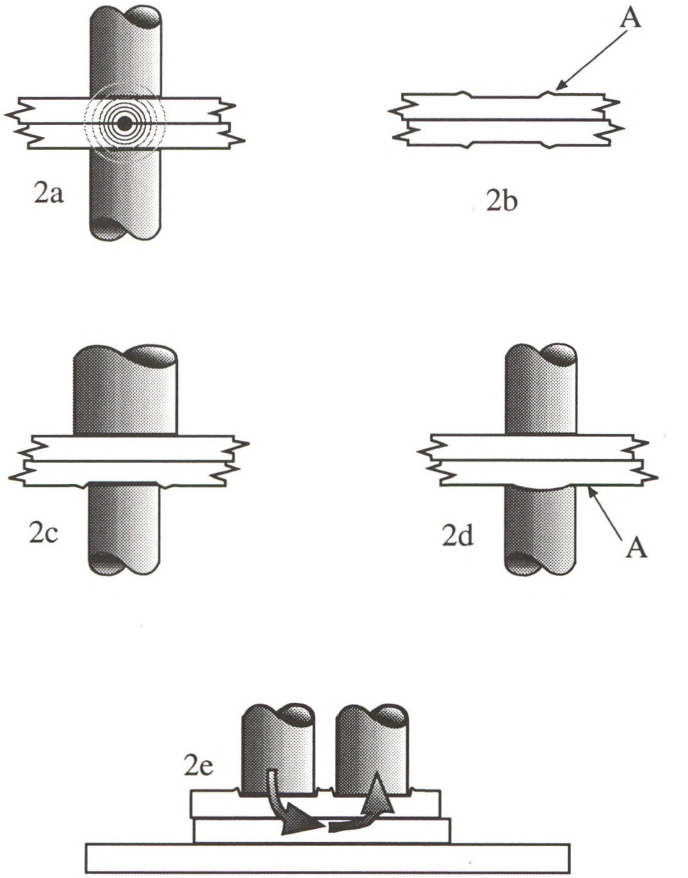
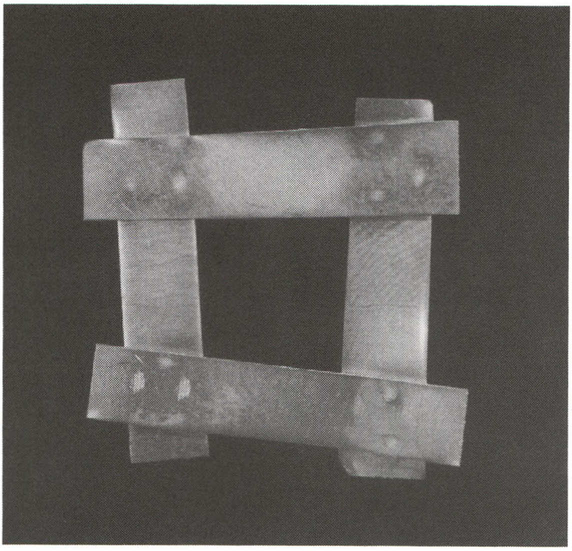
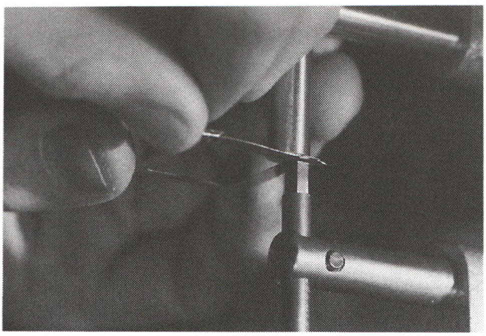


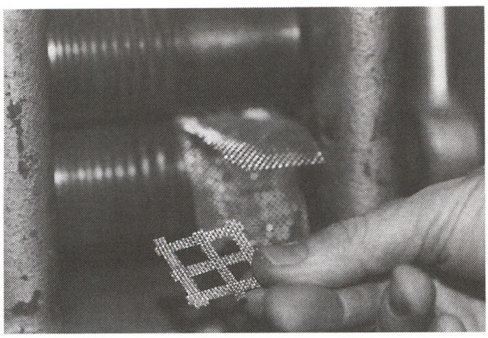
Figure 2. Electrode Deformation.
Heat is generated in all directions (2a). Under electrode forces metal expansion is restricted to the horizontal plane. Under these conditions a slight ridge forms around the periphery of the weld (2b-A). A larger electrode diameter on one side of the workpiece can limit deformation to the opposite side (2-c). A small depression in one of the electrode surfaces can also be used to prevent surface deformation (2d-A). Indirect welding, limits deformation to one side of the workpiece (2e).



3a. Evidence of electrode marking



3b. Welding



3c. Rollerprint

Figure 3. Electrode Marking
Electrode marks (3a) are common aspects of welding (3b). Manipulation of the surface with abrasives or texturing the surface are effective methods used to resolve deformation issues (3c).

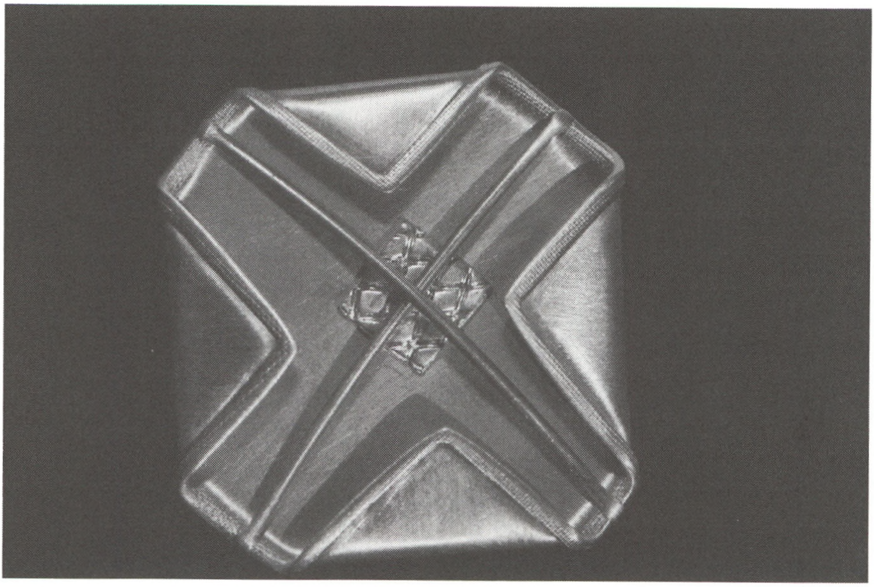


Figure 4. Brooch .850 X. 90” (21 X 23mm).

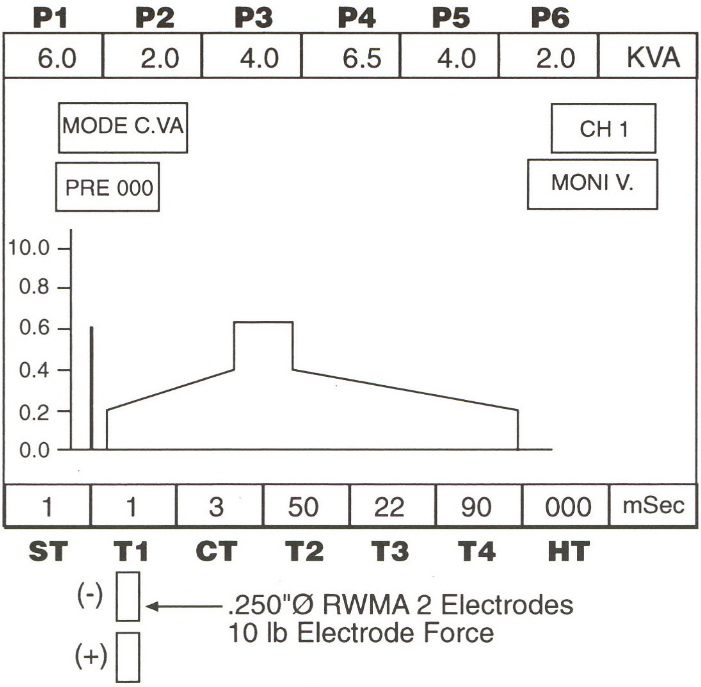


Figure 5. Power supply settings as seen on the screen, plus electrode size, material and force settings for welding .022"Ø (.55mm) AgGe wire.

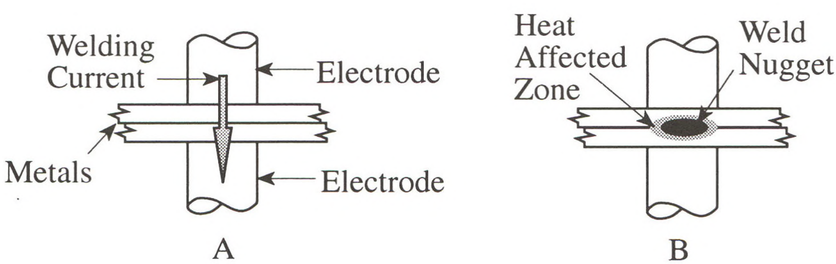


Figure 6. Heat Affected Zone.
Welding temperatures are created by the resistance of the metals to the flow of an electrical current (A). The Weld Nugget represents the area where metal has become molten and then re-solidifies to form the weld The area around the weld nugget is called the Heat Affected Zone (HAZ). The HAZ is the metal adjacent to the nugget that did not become molten, but whose grain structure was altered (B).

Metal Hardness

Silver germanium is susceptible to rapid heating and cooling resulting in subsequent brittleness. The application of upslope and downslope welding current provided the best solution to this problem. Upslope and downslope profiles allow the workpiece to gradually heat and cool reducing the brittle affects of welding temperatures. Upslope/downslope notably have three distinct sections, upslope time and current, peak time and current, and downslope time and current. Utilizing a weld profile with upslope and downslope is recommended and proved crucial to minimizing brittle conditions. When welding 165 HV AgGe wire, brittleness was reduced with the following constant voltage weld profile: upslope 2.0KVA to 4.0KVA for 50 milliseconds with peak weld time and current of 22 milliseconds at 6.5KVA immediately followed by a 90 millisecond downslope period of 4.0KVA to 2.0KVA (Figure 5). Weld schedule settings are best derived from destruct testing or pull test data. Careful analysis will reveal at what point the weld failed, how it failed, and whether the weld is brittle.

Heat Affect

Although welding temperatures anneal or harden metal in and around the weld, overall annealing effect is minimal compared to soldering. Solder temperatures rapidly dissipate throughout the workpiece, effectively altering hardness with each solder operation. Welding eliminates exposure to soldering's annealing temperatures. Minimal heat affect remains one of welding's most important features for fabricating lightweight sterling jewellery without the negative aspects of annealing (Figure 6). Welding AgGe is elementary in its annealed condition and can easily be achieved with less expensive AC and CD welding systems. In harder conditions welds are more susceptible to embrittlement from rapid heating and cooling, thus slower heating/cooling rates are required to minimize this brittle attribute.

Summary of Welding Performance

Wire to wire, sheet to wire, and sheet to sheet welds can be made in both annealed and hardened conditions with very little difficulty. Without question, welding AgGe is less demanding in its annealed condition, but this is true for most metals. Wire to wire welds are the easiest, due to the rapid development of welding temperatures caused by high initial contact resistance between the wires (Figure 7a - 7j).

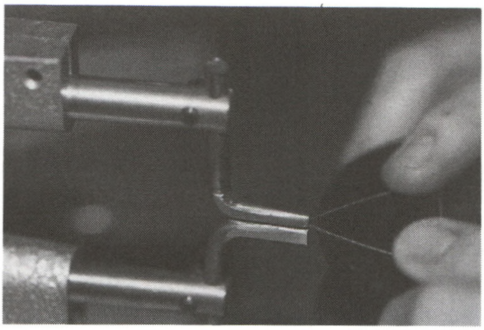


Figure 7a. Cross wire weld

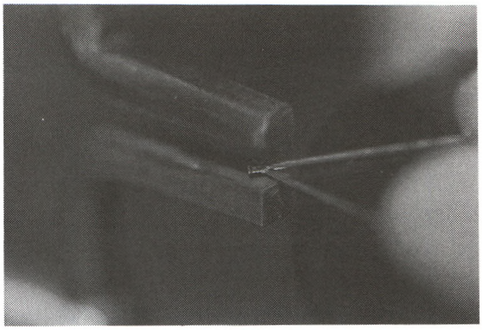


Figure 7b. After welding

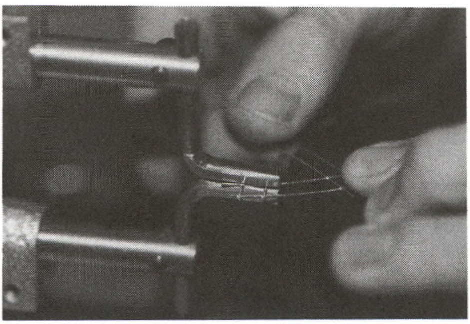


Figure 7c. Weld additional wires

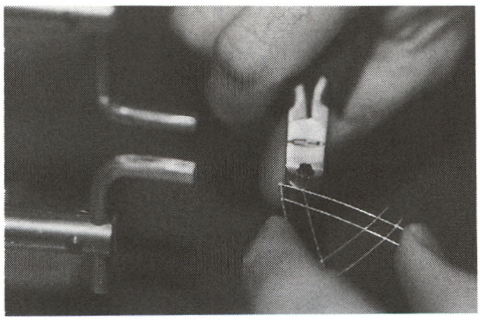


Figure 7d.Trim excess wire

Figure 7e. Hammer welds to match individual wire height.

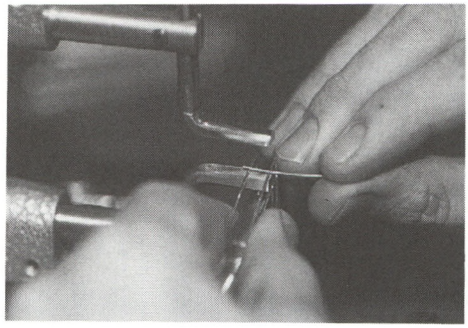


Figure 7f. Position wire for welding

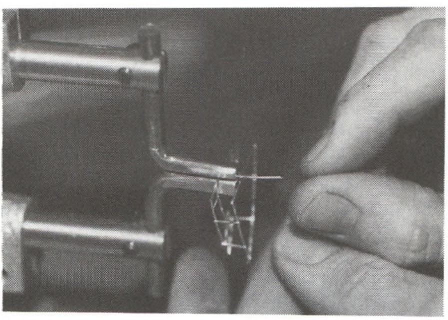


Figure 7g. Release wire just before welding. Any load on the part when the weld is made can cause distortion.

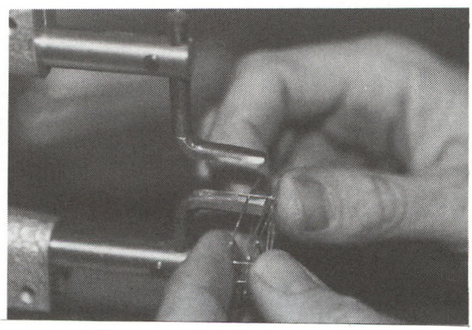


Figure 7h. A small length of wire should extend beyond the weld site.

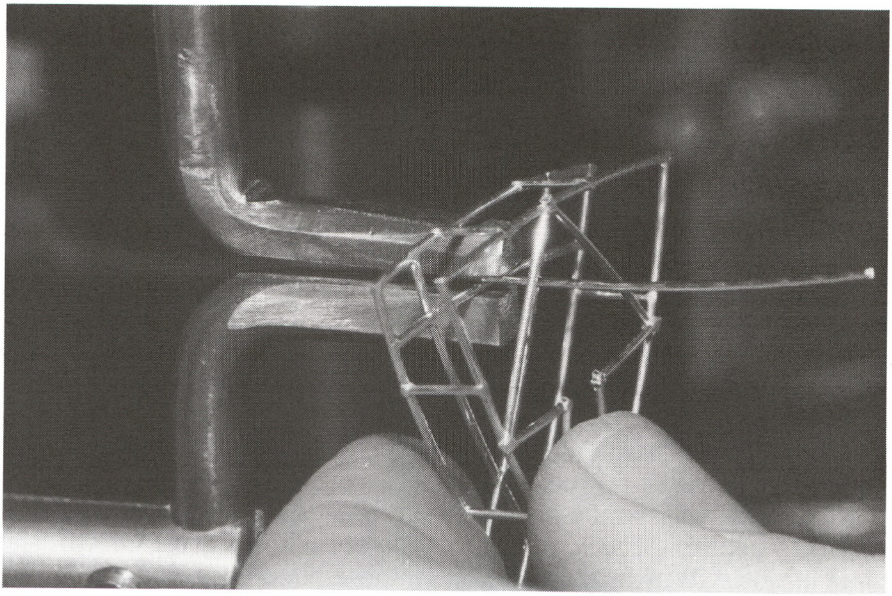


Figure 7i. Weld ear wire.

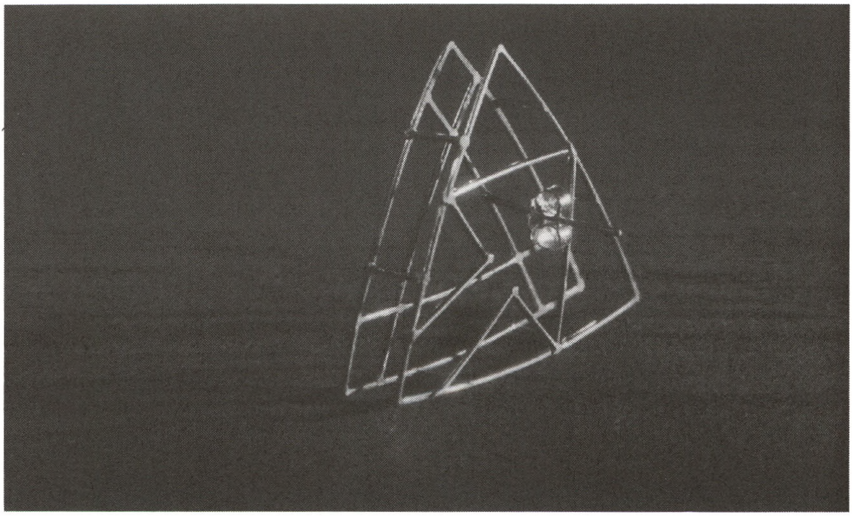


Figure 7j. Finished Piece (earring)

Possibly one of resistance welding's greatest benefits is its ability to minimize the annealing effects in the workpiece. Resistance welding permits fabrication of intricate designs in thin gauge wire & sheet without the associated annealing effect from soldering temperatures. AgGe alloys can be welded in a hard state, allowing the manufacture of stronger, lighter, larger jewellery. Controlling electrode marking and/or deformation requires steadfast process control. With careful product design and consideration of welding's attributes, electrode deformation may be controlled within acceptable limits (Figure 8a-8d).

Welding applications for jewellery fabrication will naturally progress as manufacturers explore its advantages and begin to design for its application. Welding has many additional benefits. It eliminates solder, related fumes, subsequent pickling procedures and disposal of pickling solutions. It favors a lower operator skill level. It is a substantially faster joining process. It can be adapted to automation. Welding can not replace soldering in all instances, but those who are willing to design for its applications will invariably gain from these benefits.

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Below is a basic overview of the process and equipment types common to welding equipment as they relate to the jewellery and manufacturing industries.

Resistance Welding: an Overview

Although resistance welding was first discovered in 1877 and patented in 1886, no substantial change in resistance welding took place until 1930. Even now, the basic principles of welding remain the same[3]: metals held under electrode pressure generate heat as they resist the flow of current passing through them. Resistance of metals to current flow is utilized to either melt or reach a plastic state at the weld interface. When the flow of current stops, electrode pressures are maintained for a fraction of a second, cooling the weld.

Since 1930, improvements in power supply and weld head technology do provide greater control over the welding process[4]. These improvements in HFI and LDC resistance welding technology account for its expanded application in jewellery manufacturing today[5,6] (Figure 9). Tack welding for subsequent soldering and brazing, which can be achieved with relatively lower costs. AC and CD equipment is arguably resistance welding's greatest strength in jewellery manufacturing. Although HFI and LDC technology costs are generally two to three times higher than AC and CD equipment, they remain less than half the cost of their laser counterparts.

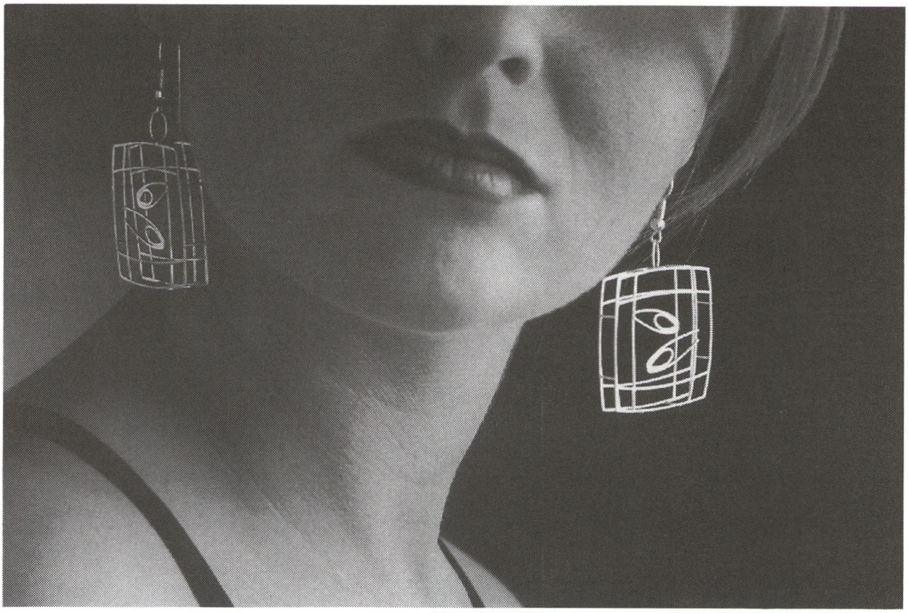

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Figure 8a. Earrings
1.5 X 1.5 X .26” (38 X 38 X 6.6mm)

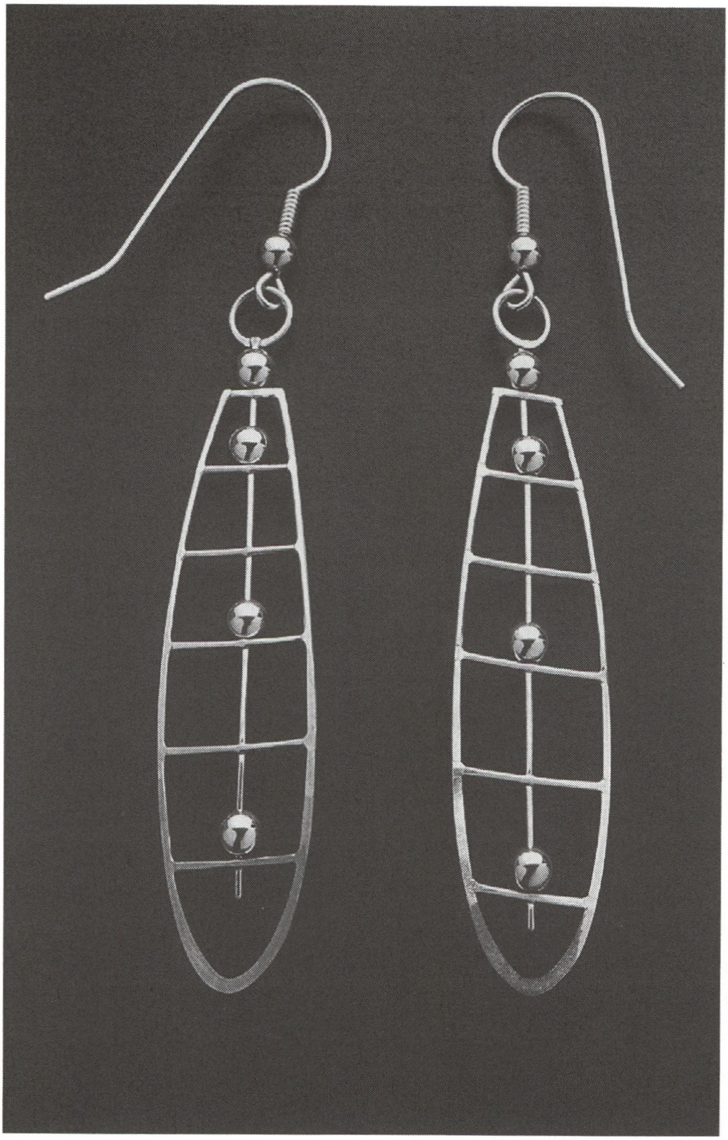

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Figure 8b. Earring
.45 X 3.25" (11.4 X 82.5mm)

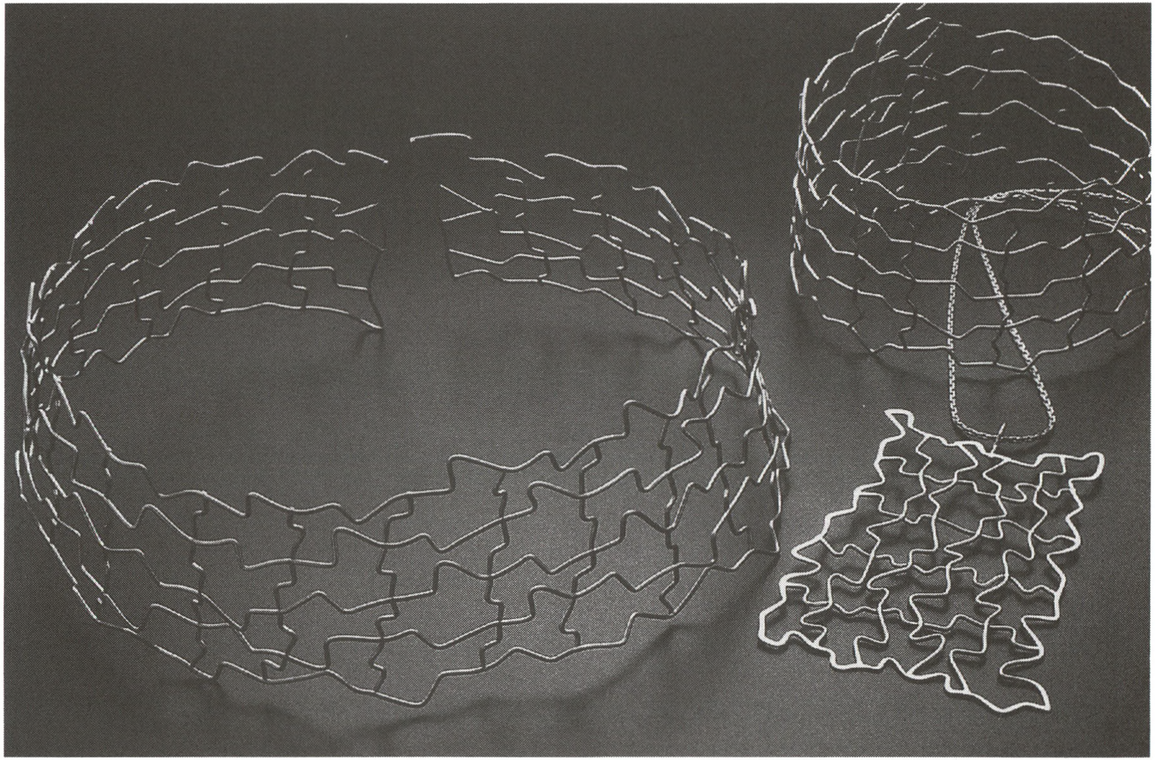

Figure 8c. Choker, Bracelet & Necklace

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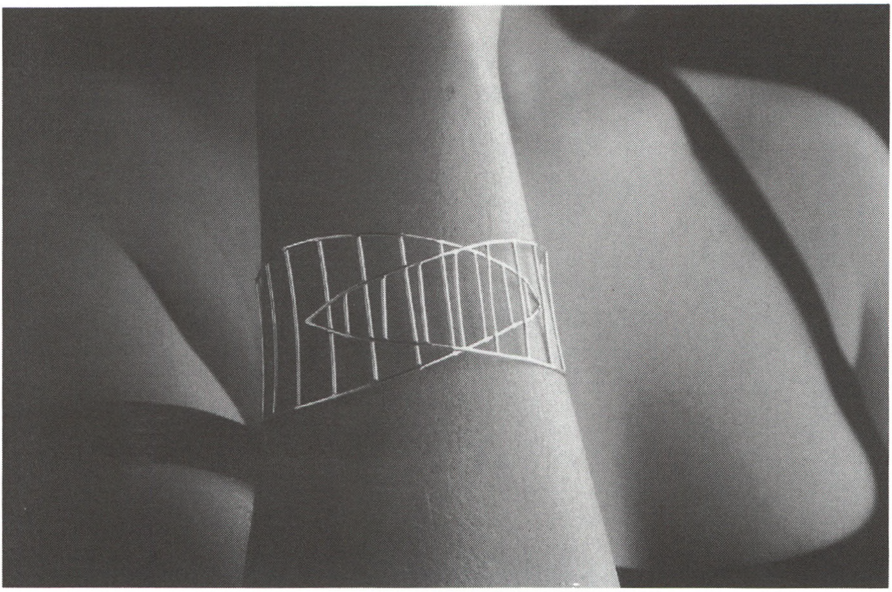

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Figure 8d. Bracelet

Resistance Welding Fundamentals

Resistance welding equipment consists of a power supply and weld head. The power supply regulates welding current and time. The weld head generates electrode pressure and provides rapid follow-up (the ability of the electrode to maintain force during weld formation) of the electrodes.

Weld Heads

Welding with a manual system involves positioning the workpieces between the electrodes and simply applying even foot pedal pressure until welding forces are reached. Once the weld is made, the foot pedal is returned to its natural position. Electrode pressure controls contact resistance between both the workpiece-to-workpiece and electrode-to-workpiece interfaces (Figure 10). Both contact resistance and the metal's resistance are overriding considerations in successfully generating welding temperatures. Controlling contact resistance is vital to consistent weld strength.

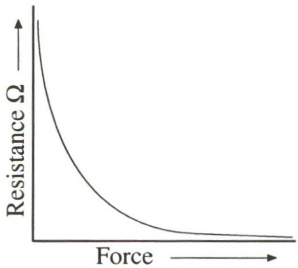

Figure 10. Contact Resistance vs. Force

Electrode Configurations and Materials

Direct and indirect are terms used to describe how welding currents are introduced (Figure 11). Electrodes are commonly configured for single spot, multiple spot, seam, projection, or series welding. Direct *single spot* welds consist of a top and bottom electrode clamping from two opposing sides of the workpiece. Indirect welds, commonly referred to as *series welding*, introduce both electrodes from one side of the workpiece.

† With manually-actuated weld heads, operators can influence electrode forces and thus contact resistance. If the operator actuates the weld head with a "kicking" motion, variable peak welding forces will result. Welding may initiate at the set force but higher forces reached during weld formation can cause inconsistent contact resistance and variable weld strength. Air-actuated weld heads are commonly used to reduce the operator variable and provide uniform weld forces.

Figure 9. Blackhills gold leaves welded to Jostens ring.

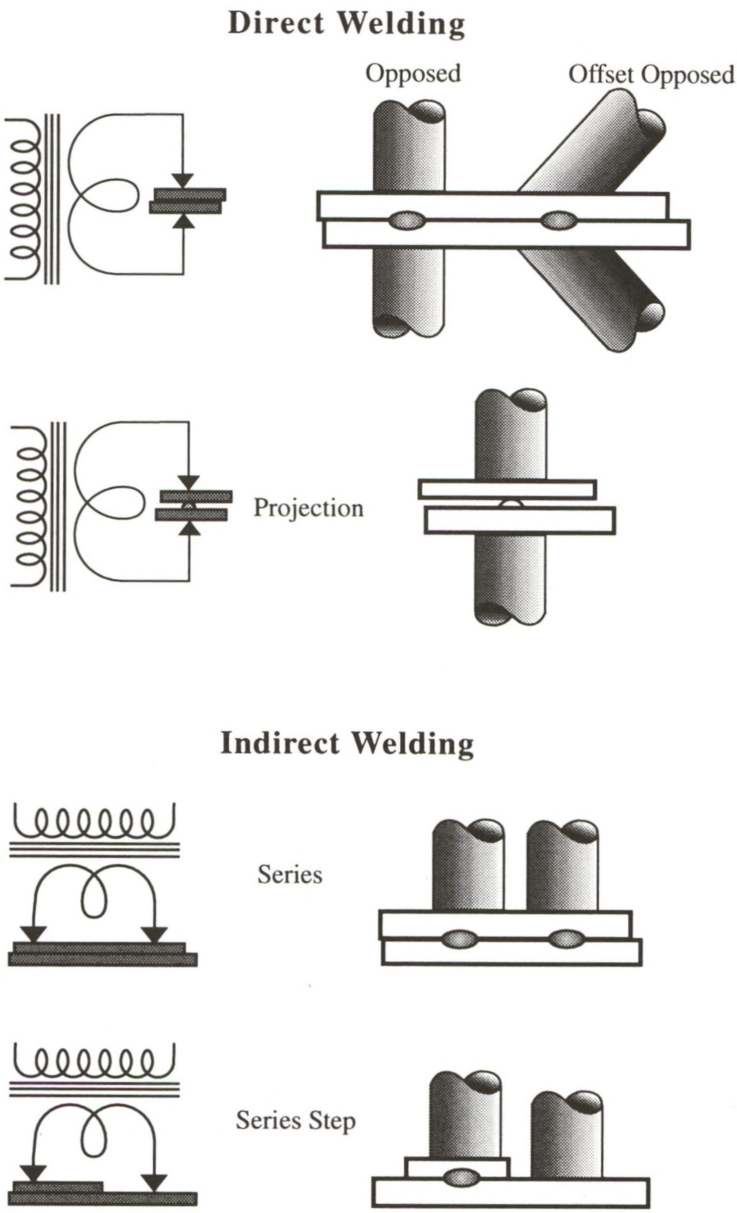

Figure 11. Direct and Indirect welding methods

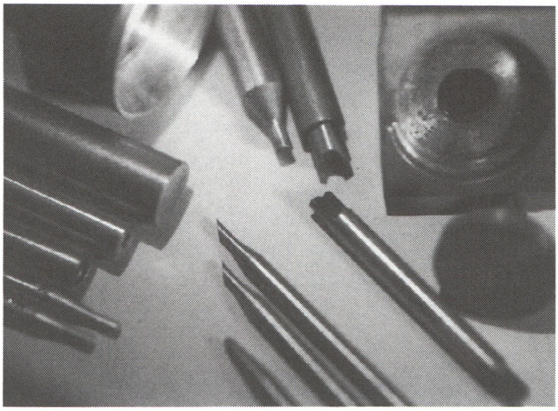

Figure 12.
Electrode shapes

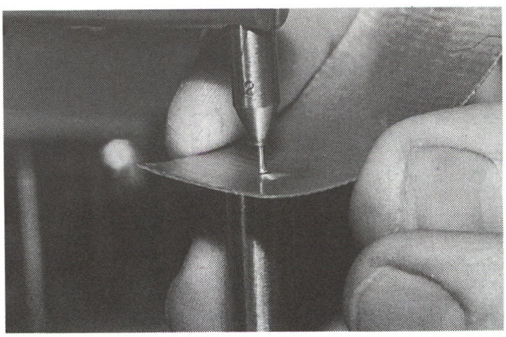

Figure 13.
Hollow electrodes used to weld post backs.

A rule of thumb in electrode material selection is that one should use a conductive electrode alloy when welding resistive metals, and a resistive electrode alloy when welding conductive metals. Established standards for electrode alloys accommodate a range of conductivity and resistivity to meet welding requirements. In certain cases electrode materials may be selected solely for their wear resistance. Some electrode materials, such as silver tungsten or copper tungsten, have combined properties. These combinations provide the high wear resistance of tungsten with the added conductivity of copper or silver.†

Electrode size and shape influences temperature in the electrode/ workpiece interface. With equal energy settings, increasing or decreasing the electrode surfaces affects welding temperatures. Increasing the contact surface of the electrode can be used to minimize deformation and/or improve heat transfer away from the workpiece.

Types of Electrodes

Flat, angle, hollow, insert, and saddle describe common electrode shapes (Figure 12). Opposed flat electrodes are perhaps the most common shape and configuration. Angled electrodes are required when electrode access is restricted. Hollow electrodes allow the workpiece to extend inside the electrode and can be used to join post or pin backs (Figure 13).
More expensive electrode materials are typically inserted into copper shanks to efficiently deliver welding current to the weld site while reducing costs. Saddle-shaped electrodes made to match a particular diameter are designed to minimize deformation or effectively correct heat balance issues because saddle shaped electrodes contact larger areas of the workpiece being welded.

Types of Welding Equipment

There are four fundamental types of resistance welding equipment: direct energy (alternating current- AC), stored energy (capacitor discharge- CD), high-frequency inverter (HFI), and linear DC (LDC). HFI and LDC offer the greatest control over welding current and have the highest equipment cost. AC welding provides less output control at relatively lower costs. CD unipolar power supplies deliver an exact, fast rise time pulse of weld energy ideal for tack welding. Upslope/downslope features are common to AC, HFI and LDC equipment. (See Metal Hardness)

† Always fabricate electrodes using resistance welding alloys.

Basic Bonds of Resistance Welding

- Braze/soldered bond: resistance heating of the workpieces produces sufficient heat to melt a third metal, such as gold or silver solders.
- Forge weld: workpieces are "forged" together without any evident melting. This is typically accomplished with a very short weld time. This bond is advantageous when joining two dissimilar materials with radically different crystalline structures.
- Diffusion weld: surfaces at the workpiece interface are heated to the plastic state. Although there is no melting, there is an evident mixing of crystals from both workpieces. This bond is typical of short pulse welding and is ideal for dissimilar metals with similar crystalline structure.
- Fusion weld: melting points of both workpieces are reached at the interface. Subsequent cooling and solidification of the metals forms a "nugget" which contains alloys of the two materials. This type of bond is typical of long pulse welding and is ideal for welding similar materials.

Electrode Deformation

An important factor in electrode deformation is heat shrinkage. When metals are heated, they tend to expand in all directions. Under electrode pressure vertical expansion is restricted, which causes all local expansion to occur in the horizontal plane. The result is a slight ridge around the periphery of the weld. When the weld cools, the resulting contraction takes place predominantly in the vertical plane, further complicating the effort to limit deformation. A common method of avoiding deformation is to use a larger electrode on the side where marking is to be eliminated.

If it remains difficult to reduce marking to acceptable levels, one of the electrodes can be shaped to reduce marking. However, some periphery depression around the weld may still remain. Indirect welding methods limit marking to one side of the workpiece and have proven effective in jewellery applications[1].

Electrode Cleaning

An important aspect of welding success is the periodic cleaning of electrode surfaces. This ensures a reliable flow of welding current. Uneven or worn electrode surfaces may cause marks in the workpiece's surface. When cosmetic welds are essential, electrode surfaces must be cleaned at regular intervals.

The required cycle of cleaning is specific to each application. Periodic cleaning maintains good electrode surface conditions and ensures minimal deformation.†

Laser Welding: an Overview

The laser (an acronym for Light Amplification by Stimulated Emission of Radiation) system was invented in the late 1950s and has rapidly evolved into a safe and efficient tool with uses ranging from delicate surgery to industrial materials processing. The laser's intense beam of coherent light can be precisely directed to heat, melt, or vaporize select areas of almost any type of material. An important feature of the laser is that the finely focused beam results in a minimal heat-affected zone (HAZ). (In welding, the HAZ is metal adjacent to a weld that does not become molten, but whose grain structure is altered from exposure to welding temperatures.) The availability of such a precision heat source opens the door for unique design possibilities.

Contemporary laser welding equipment is found in small, portable workstations, building a bridge between cutting-edge technology and jewellery's hands-on manufacturing nature. As relatively high laser equipment costs become justified with increased efficiency, use of laser welding is gaining popularity in the jewellery industry.

What Technology Is Best

The ideal equipment depends on the type of bond and degree of process control required. Some of the important issues to consider when determining which welding technology to use are cost effectiveness, weld strength, deformation, and sufficient technical support from the equipment manufacturer. Most equipment suppliers provide complimentary weld evaluations which allow users to test compatibility with customer materials.

Laser and resistance welding have already yielded a long list of innovations in metal joining, but the ultimate success of any welding process is limited only by the ingenuity and determination of the end user. What were once considered rules of welding are often revised by those willing to advance applied welding techniques.

† Electrodes should be shaped with a file, but only cleaned with emery paper, 400 grit or finer.

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