An improved method to spot-weld difficult junctions

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Recent advances in spot-welding technology such as high frequency direct current inverter welders provide an improved and reproducible method to spot-weld difficult junctions. The importance of removing the oxide layers on metal surfaces, accurately delivering the weld pulse profile, and controlling the force applied to the materials during the welding process are discussed in the context of resistance spot-welding a molybdenum crystal to a tantalum loop and attaching a tungsten–rhenium thermocouple to the crystal.
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Resistance spot-welding, the application of an electric current to metals while under pressure, thereby causing localized heating and the formation of a weld, is an important technique in fields as diverse as medical device manufacturing, the aerospace industry, and surface science. Often, such applications require spot-welding difficult junctions. For example, Ref. 1 has delineated a special method involving electrochemical cleaning for spot-welding a molybdenum (Mo) crystal to a W-5% Re/W-26% Re thermocouple and to tantalum (Ta). In this article we report the use of power supplies with dual pulse capability, programmable weld schedules with feedback loops, and air-actuated weld heads to spot-weld these same junctions. In contrast to the method reported previously,[1] the technique described herein could be easily modified to spot-weld other difficult junctions.

Molybdenum is extremely difficult to weld because of its high melting point of 2600 °C, its propensity to form an oxide layer on the surface, and its tendency to become brittle when heated and cooled quickly.[2] One method to diminish the difficulties associated with spot-welding Mo to another refractory metal such as tungsten is to use platinum as an intermediate material.[3] A common method of reducing additional oxidation is to weld under a drop of isopropyl alcohol or an inert gas blanket. The removal or breakdown of the oxide layer found on Mo surfaces is necessary to obtain a quality weld. Previous studies have suggested electrochemically cleaning the Mo surface and then performing the spot-weld with the aqueous NaOH solution left in place.[1] However, this procedure introduces extraneous material into the weld site and may cause hazardous spattering of the solution. The highest quality welds are likely obtained using clean surfaces combined with the accurate delivery of weld settings.

Breakdown of the oxide layer without the introduction of contaminants may be achieved by using a spot-welding with dual pulse capability. In a dual pulse spot-weld, a prepulse applied prior to the weld pulse collapses the oxide layer at the interface and increases surface contact at the joint to create an effective weld.

In addition to removing the oxide layer, as described previously, attention must be paid to weld energy and weld time, the two primary variables controlled by the power supply of a spot-welding instrument. The extent of control over these parameters depends on the type of welding instrument. The new high-frequency direct current inverter (HFDC) systems, incorporating advanced power switching technology, are highly programmable instruments that use feedback loops, updated at time intervals as short as tens of microseconds, to accurately deliver the specifications of a welding schedule.[4]

We have used a high frequency direct current inverter (Unitek Equipment HF25) to execute five different spot-welds as illustrated in Fig. 1. The constant current feedback mode was used to perform these welds as shown in Table I.[5] Very short weld times (~5 ms) were used to minimize embrittlement in the refractory metals used in our experiments. The first three welds were performed with a single-pulse schedule since the desired weld quality was obtained without use of a dual pulse. The weld schedule used to execute the Mo crystal to Ta loop weld incorporates a dual pulse (Fig. 2). The first phase of the weld schedule, the upslope, slowly introduces current to the parts to be joined, minimizing weld splash (the ejection of material from the weld site). In addition, this initial phase of the weld schedule seats the parts to be joined, reducing contact resistance. The next phase incorporates a prepulse at a constant current of 500 A to remove the oxide layer. Another upslope in current reaches the weld current of 1300 A at which point the weld forms. Because the feedback technology of the HFDC corrects variations in the current during the weld schedule, accurate and reproducible welds can be consistently obtained. Moreover, the real-time measurement of actual current, provided by the built-in weld monitor, reduces the need for destructive testing of welds.

In addition to the careful control of the weld current and weld time, the execution of quality welds also requires the control of the position of the welding tips and the physical

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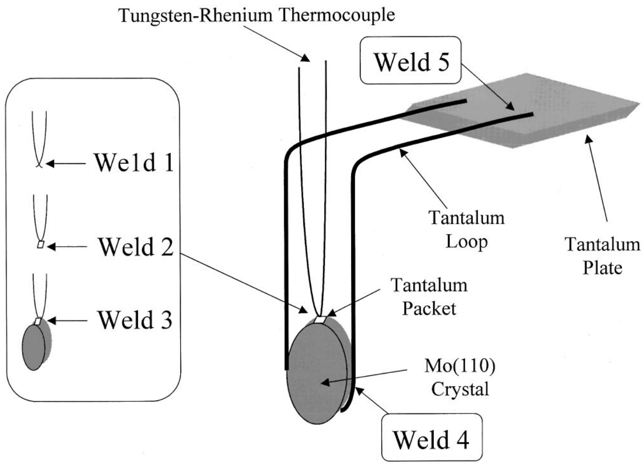

FIG. 1. Schematic diagram depicting how the Mo crystal is mounted. Five different spot-welds were used to (1) make a W-5% Re/W-26% Re thermocouple (0.005 in. diameter), (2) encase the thermocouple junction in a Ta sheet (0.003 in. thick) packet, (3) attach the thermocouple packet to a Mo single crystal (8 mm diameter; 2 mm thickness), (4) mount the crystal on a Ta wire (0.03 in. diameter) loop, and (5) attach the Ta loop to a Ta plate.

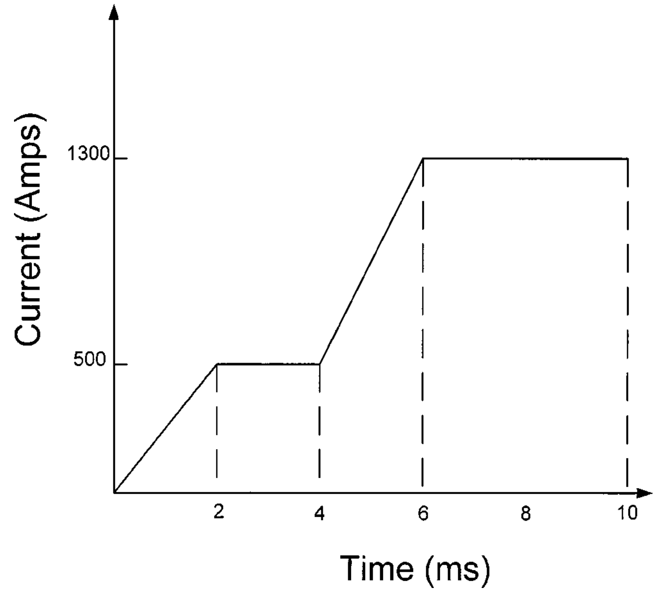

FIG. 2. The graph depicts the weld profile (current vs time) used to mount a Mo crystal for surface science studies.

force applied to the weld site because electrode force controls the contact resistance.[6] Welding handpieces rely on the operator's ability to choose and maintain the position of the tips and the level of the force throughout the weld schedule. In contrast, a "force fired," air-actuated weld head triggers the weld when the force exceeds a predefined value, controls the force with which materials are brought into contact, reduces operator variability, and increases reproducibility of quality welds. Electromagnetic weld heads, more advanced than the air-actuated weld heads discussed above, allow for programmable weld force.

We have used a force fired, air-actuated weld head (Unitek Equipment Thin-Line Weld Head Series 80 with the EZ-Air option) with an opposed electrode configuration to perform the spot-welds described previously. The specifications of the forces used to execute these welds are summarized in Table II. To ensure a stable electrode force during welding we have used a squeeze time (the time interval between the force exceeding the predefined value and the application of the weld current) of 150 m. We have used a hold time (the additional time for which the weld head applies force after the weld current pulse is complete) of 1 m to enable the electrodes to cool the samples. The down speed of the top electrode was minimized to reduce impact force and ringing.

While weld current, weld time, and electrode force represent the primary variables in spot-welding, electrode material and geometry are important secondary variables. In accordance with the rule of thumb that suggests the use of conductive electrodes to weld resistive materials, we have used a 1/8-in. diameter GlidCop (dispersion strengthened copper with 0.15% aluminum oxide) straight electrode (Unitek Equipment ES0450).

We have not investigated the role of polarity (Peltier effect) in spot-welding the Mo crystal to the thermocouple wires and the Ta loop.[7]

Because the electrical resistance of the material determines the heat generated in a spot-weld, the material's composition, geometry, and surface condition represent another set of secondary variables important for spot-welding. For example, the angle between the two thermocouple wires is significant in determining the optimum current, time, and force. Hence the resistance-welding schedule presented in this article can serve only as a guideline even when spot-welding the same junctions.

In summary, a prepulse to remove the oxide layer prior to the weld pulse, a high frequency direct current inverter using feedback loops to accurately deliver the weld pulse, and an air-actuated weld head to control the force during welding provide for stronger and more consistent welds as

TABLE I. Weld current specifications for mounting a molybdenum crystal.

	Prepulse			Weld pulse		
Type of weld	Upslope (ms)	Weld (ms)	Current (A)	Upslope (ms)	Weld (ms)	Current (A)
W–Re thermocouple wires				2	2	175
Thermocouple wires - Ta packet				2	2	175
Thermocouple packet - Mo crystal				2	2	700
Mo crystal - Ta loop	2	2	500	2	4	1300
Ta loop - Ta base plate	2	2	500	2	4	1300

TABLE II. Weld force specifications for mounting a molybdenum crystal.

	Force specifications		
Type of weld	Squeeze time (ms)	Force (lbs)	Hold time (ms)
W–Re thermocouple wires	150	1.5	1
Thermocouple wires - Ta packet	150	1.5	1
Thermocouple packet - Mo crystal	150	2.5	1
Mo crystal - Ta loop	150	8.2	1
Ta loop - Ta base plate	150	8.2	1

well as a significant decrease in time spent performing spot-welds.

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[5] Because of the oxide layer on Mo the constant power mode may have been a better choice.
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[7] Polarity refers to the direction of current flow through the two materials to be spot-welded.