The Small-Scale Resistance Spot Welding of Refractory Alloy 50Mo-50Re Thin Sheet

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This paper is a review of the recent studies of small-scale resistance spot welding (SSRSW) of a refractory alloy 50Mo-50Re thin sheet (0.127 mm thick). The effects of seven important welding parameters—hold time, electrode material, electrode shape, ramp time, weld current, electrode force, and weld time—were studied systematically in an attempt to optimize the welding quality. The diameter of a weld nugget was found to be only 30–40% of the electrode diameter in SSRSW. This was due to the relatively low electrode force used in SSRSW compared with the high electrode force employed in large-scale resistance spot welding (LSRSW) where the diameter of the nugget was almost 100% of the electrode diameter. Large pores often found in the nugget during SSRSW could result from shrinkage during solidification due to fast cooling or fromdue to agglomeration of residual volatile elements absorbed during powder metallurgy processing of the material.

INTRODUCTION

In this study, resistance spot welding (RSW) was employed to join 50Mo-50Re thin sheet which was used in a heating element in traveling tubes for the microwave telecommunication industry.[1] Because of their high melting points, however, the fusion welding of refractory alloys is difficult. To the knowledge of the authors, there are few reports on fusion welding of Mo-Re alloys in the open literature. For example,[2] molybdenum sheet was successfully welded by automatic arc welding with a good plasticity of welded joints by using rhenium as a filler metal. Using electron beam welding, an Mo-44.5 wt.%Re alloy was welded successfully, with the welds having an ultimate strength of 821.8–885.3 MPa and elongation of 12–16%.[3]

The 50Mo-50Re sheet used in this study was very thin, typically 0.127 mm. Little work has been reported in open literature about RSW of such thin sheet, which is also called small-scale RSW (SSRSW). In typical engineering practices of SSRSW, the parameters used are usually scaled down from those of large-scale RSW (LSRSW). However, the parameters applicable to LSRSW may not be applicable to SSRSW because of many differences between SSRSW and LSRSW, as mentioned by D. Steinmeier[4] and Y. Zhou et al.[5,6] Much lower electrode force and weld current, along with shorter weld time, may need to be carefully adjusted to meet the weld quality of SSRSW.

This paper presents results about the effects of key welding parameters (hold time, electrode material, electrode shape, ramp time, weld current, electrode force, and weld time) on the welding quality of 50Mo-50Re thin sheet (0.127 mm thick). Microstructures of the welded sheet were also studied.

See the sidebar for experimental procedures.

How would you…

…describe the overall significance of this paper?

In this study, small-scale resistance spot welding was employed to join 50Mo-50Re alloy thin sheet, which was used in a heating element in traveling tubes for the microwave telecommunication industry. The strength of the weld was improved from 100 N to 184.7 N after welding parameters were optimized in this work. The improved welding quality gave rise to the overall improvement in quality of the traveling tubes.

…describe this work to a materials science and engineering professional with no experience in your technical specialty?

This paper reports the efforts made to optimize small-scale resistance spot welding (SSRSW) of refractory alloy 50Mo-50Re thin sheet by adjusting seven important welding parameters: hold time, electrode material, electrode shape, ramp time, weld current, electrode force, and weld time. The diameter of a weld nugget was found to be only 30–40% of the electrode diameter, due to the relatively low electrode force used in SSRSW. Large pores in the nugget during SSRSW could be due to solidification shrinkage or agglomeration of residual volatile elements.

…describe this work to a layperson?

In this study, small-scale resistance spot welding was employed to join 50Mo-50Re thin sheet, which was used in the structure of a heating element in traveling tubes for the microwave telecommunication industry. Because of the high melting point of the refractory alloy, however, the fusion welding of the 50Mo-50Re alloy becomes difficult. This paper reports the efforts made to optimize small-scale resistance spot welding of the 50Mo-50Re alloy thin sheet by adjusting seven weld parameters.

RESULTS AND DISCUSSION

Effects of Welding Parameters on Welding Quality

Hold Time

In this study, hold time was found to have a significant effect on the welding quality of the 50Mo-50Re thin sheet.[1] The strength of the weld was enhanced from 100.0 N to 113.0 N when the hold time was increased from 50 ms to 999 ms. Fractography and energy dispersive spectroscopy (EDS) of the welds processed by using 50 ms and 999 ms hold times, respectively, showed the beneficial effect of the extended hold time on weld quality due to a higher cooling rate for the longer hold time immediatly after welding.[1,7]

Electrode Material

When using 25Cu-75W (wt.%) rods with diameters of 1.524 mm as the top and bottom electrodes, significant sticking between the electrodes and the workpieces occurred due to the relatively low melting point of the copper alloy, as compared with that of an Mo-Re alloy. Therefore, refractory metals manufactured from commercial-purity molybdenum and tungsten were used as electrodes in the SSRSW of the Mo-Re alloy.

Electrode Shape

To study the effect of electrode shape on welding quality, a molybdenum flat mandrel and a molybdenum rod of 1.524 mm diameter were used as the positive bottom electrode in this study. The nugget generated with the flat mandrel electrode was highly asymmetric, while with the rod-shaped electrode it was nicely symmetric and located at the center of the two workpieces. The asymmetrical nugget produced when the bottom electrode was flat occurred because the electric current distribution (i.e., the heat distribution) was asymmetrical during SSRSW. Using the molybdenum rod bottom electrode, the current density in both the upper and lower workpieces was more symmetric. The strength of the welded samples with a symmetrical nugget was 125.8 N compared with 113.0 N in the asymmetric nugget case.

Ramp Time

When the ramp time was increased from 0 ms to 16 ms, the strength of the welded samples increased from 125.8 N to 171.9 N. An 8 ms ramp time gave rise to the highest strength at 184.7 N, 58.9 N higher than that of the weld with the ramp time being zero. The power input was increased relatively gradually at a longer ramp time (8 ms or 16 ms), compared with a spike in the power input curve at 0 ms ramp time.[1] During welding, it was also observed that molten metal expulsion occurred at 0 ms ramp time, whereas there was almost no expulsion taking place at a weld current of 500 A and a ramp time of 8 ms. The upslope, gradually introducing current to the workpieces to be joined, not only minimized the metal expulsion but also reduced the variation in contact resistance between the electrodes and workpieces.[8] Therefore, it was preferable to use a weld current profile with a ramp time of several milliseconds to improve welding of this alloy.

Weld Time

Figure 1 shows the effect of weld time with 8 ms ramp time and other default welding parameters, as shown in Table A. The peak load of the weld increased with weld current in a similar way, for different weld times (2 ms,

EXPERIMENTAL PROCEDURES

Figure A shows the typical microstructure of the 50Mo-50Re alloy in a stress-relieved condition synthesized by a powder metallurgy method, illustrating the elongated grains along the rolling direction (RD). Details of the processing procedure were described in Reference 1.

Pairs of samples with a lap-shear geometry were welded using a Unitek Peco Model DC25 linear direct current distance welding machine. Welding parameters were varied in order to evaluate their effects on the welding quality. Figure B schematically shows profiles of electrode force and weld current during resistance spot welding. If not specified, the default welding parameters were those listed in Table A.

Tensile-shear tests of the welded samples were conducted on an Instron 8802 Testing System with a 0.2 mm/min. tension rate at room temperature. An average of the peak loads of five samples in the load-displacement curves was used to evaluate the welding quality in this work. Metallographic observations of the fracture surfaces and cross sections of the welded samples were conducted by optical microscopy and three-dimensional surface profiler.

Table A. Default Welding Parameters

Squeeze Time: 150 ms	Weld Time: 2 ms
Hold Time: 999 ms	Current: 900 A
Bottom Electrode: Mo rod (+)	Top Electrode: W rod (–)
Electrode Force: 8.90 N	Electrode Diameter: 1.524 mm

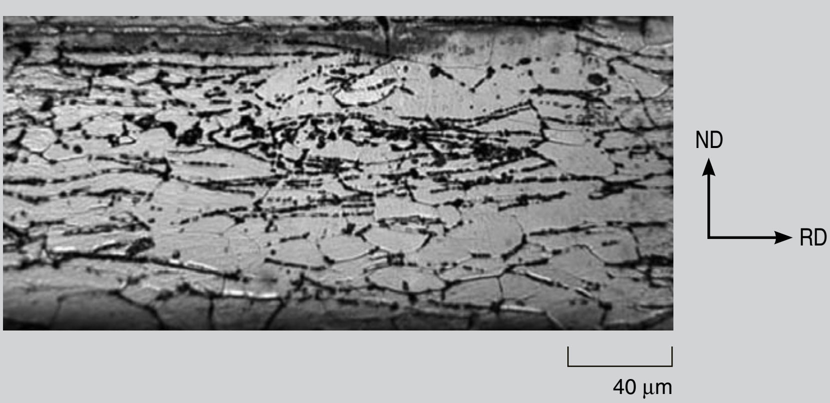

Figure A. The microstructure of the 50Mo-50Re alloy matrix along the rolling direction (RD).

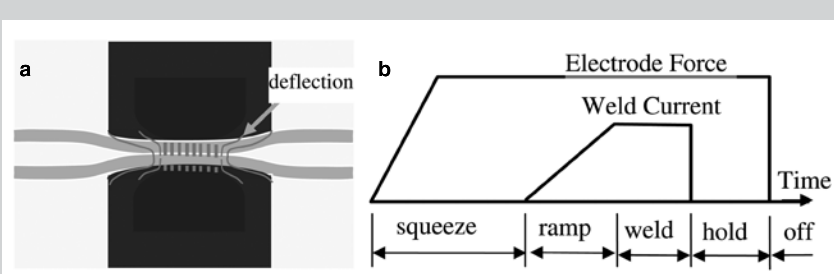

Figure B. (a) A schematic of small-scale resistance spot welding, (b) profiles of current and electrode force in resistance spot welding using ramp time.

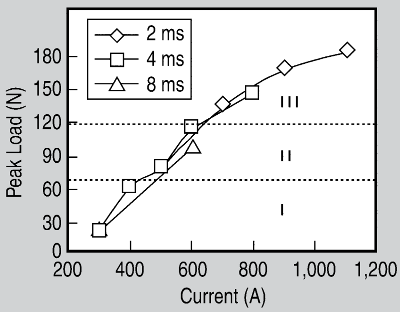

Figure 1. Plots of peak load versus weld current at different weld times: 2 ms, 4 ms, and 8 ms. Zone I, no electrode sticking and no expulsion; zone II, minor to medium level of electrode sticking and medium level of expulsion; zone III, high level of electrode sticking and severe expulsion.

4 ms, and 8 ms) used, respectively. The extent of sticking and expulsion was also observed in the similar trend for the weld times used at 2 ms, 4 ms, and 8 ms, respectively. The possible reason for a less significant role of weld time in influencing the welding quality was that 2 ms weld time with a 8 ms ramp time generated enough heat to weld the workpieces. With longer weld time, the contact resistance decreased to be almost negligible; therefore, the generated heat did not increase substantially. In SSRSW of a mild steel AISI 1100,[5] the nugget was substantially formed at the first three cycles of 60 Hz alternating current power. Longer weld time did not seem to increase the nugget size of the steel.

Weld Current and Electrode Force

The strength increased with increasing weld current at different electrode forces. Using an electrode force of 17.80 N, the strength was relatively lower than those obtained using electrode forces of 4.45 N and 8.90 N at 500 A weld current. The strength at 17.80 N electrode force, however, surpassed those at 4.45 N and 8.90 N when using 1,100 A weld current. A larger electrode force could reduce the contact resistance at the sheet/sheet (S/S) and sheet/electrode (S/E) interfaces. Thus, less heat was generated at the S/S and S/E interfaces at a high electrode force. The resultant nugget size was therefore smaller when using a larger electrode force, especially at a lower weld current (e.g., 500 A). Although higher weld current produced larger nugget diameter in welds a stronger tendency for electrode sticking and molten metal expulsion limited the use of these parameters in SSRSW.

Microstructures of Weld Nuggets

Since thin sheet could be easily deflected under electrode pressure, as schematically shown in Figure Ba, a much lower electrode force is typically applied in SSRSW compared to that used in LSRSW. The area of thin sheet under the electrode tip is commonly indented and curved to a certain degree, even when very low electrode force is applied. For example, in this study, the curved area covered by the electrode at a 8.89 N electrode force is shown in Figure 2a. Figure 2b shows the topographic profile along a line shown in Figure 2a. It demonstrates a 3 μm depth of indentation spreading over a distance of 0.6 mm. Local area, especially in the center of the electrode tip, was welded first since the current accordingly concentrated in this area. The welded interface provided a conductive tunnel for further current concentration, which rendered a nugget with a maximum size being only approximately 30–40% of the electrode diameter. The nugget with 90% penetration in the direction of thickness was produced in this condition, as demonstrated in Figure 3. This phenomenon was consistent with the results from theoretical and experimental work on SSRSW of a mild steel AISI 1010.[5]

As shown in Figure 3, pores formed in the nugget under all the welding conditions tested in this work. Pores were mostly formed in the center of the weld nugget, though they were also occasionally found on the edges. A weld produced in the condition under which the expulsion was not observed tended to contain a big pore, as shown in Figure 3. The expulsion, therefore, might not necessarily contribute to the formation of the porosities in SSRSW of the 50Mo-50Re sheet. During the welding, the molten pool typically was expanded due to the different densities between liquid and solid phases. In the

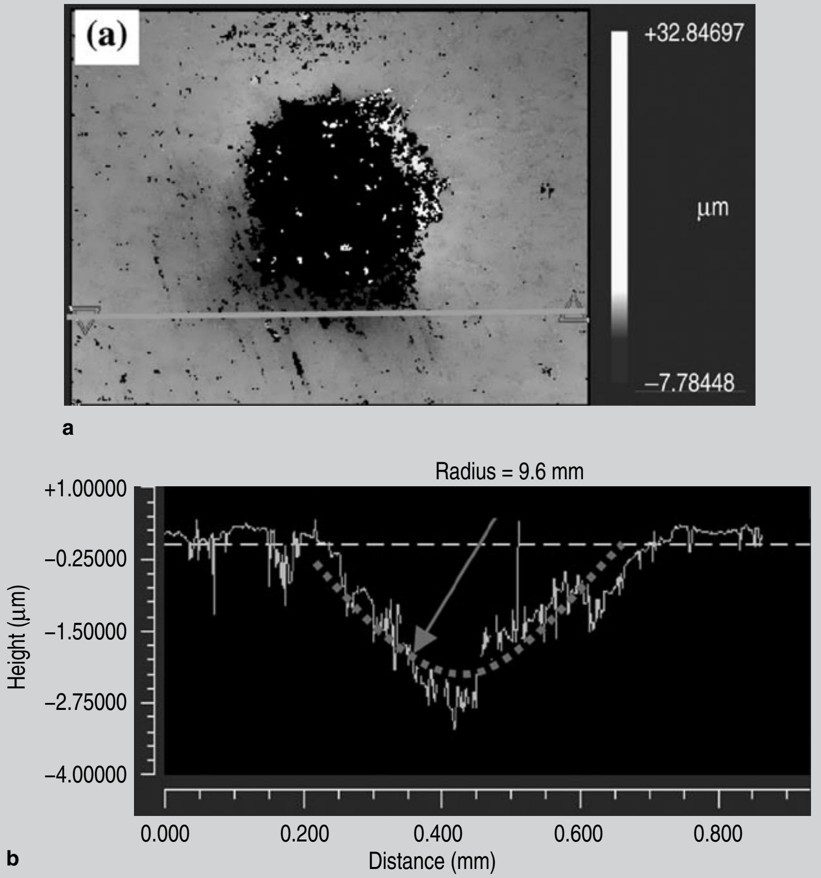

Figure 2. (a) A micrograph of the surface of a workpiece after SSRSW; (b) the topographic profile along the line in (a).

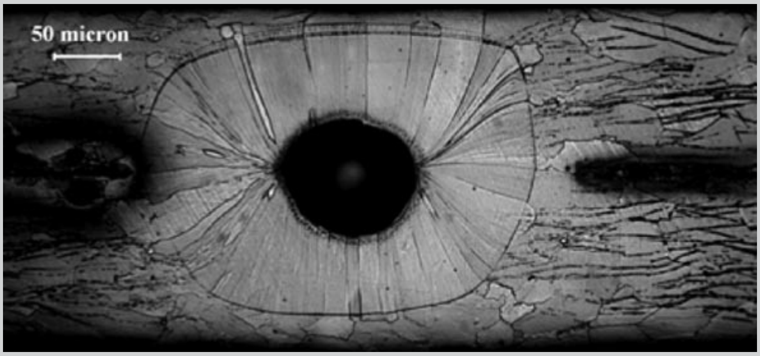

Figure 3. The microstructure of the nugget cross-section when using 500-A weld current with 2 lb electrode force and other optimized welding parameters. No expulsion was observed under this welding condition.

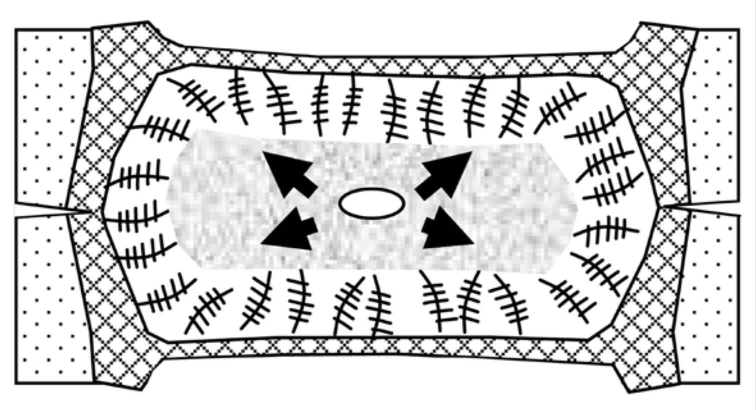

Figure 4. A schematic diagram of porosity formation by shrinkage in SSRSW of 50Mo-50Re alloy.

subsequent solidification, the periphery of the molten pool was solidified first. This was because the cooling rate of this area was higher than that of the inside, as schematically shown in Figure 4. The solidified periphery, therefore, confined further solidification inside. High gas pressure in the molten pool pushes the metal liquid to be solidified to the periphery. A big pore is finally formed in the center of the pool. In addition to the obvious heat expansion and cooling contraction processing, the weld joints in alloys produced by powder metallurgy often contain voids due to residual volatile elements absorbed during powder preparison.[9]

CONCLUSIONS

By adjusting seven major welding parameters (hold time, electrode shape, electrode material, ramp time, weld current, electrode force and weld time), the quality of SSRSW of refractory alloy 50Mo-50Re thin sheet was improved significantly. A low electrode force in SSRSW of the 50Mo-50Re alloy produced a maximum nugget size of only 30–40% of the electrode diameter. Porosities formed during SSRSW due to shrinkage and/or residual volatile elements in the alloys.

ACKNOWLEDGEMENT

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References

1. J. Xu et al., "Optimization of Resistance Spot Welding on the Assembly of Refractory Alloy 50Mo-50Re Thin Sheet," *J. Nucl. Mater.*, 366 (2007), pp. 417–425.
2. V.V. D'yachenko et al., *NASA Technical Memorandum*, NASA TM-77491 (1970).
3. D.P. Kramer et al., *Proceedings of 35th Intersociety Energy Conversion Engineering Conference* (Piscataway, NJ: IEEE, 2000), paper no.: AIAA-2000-2971.
4. D. Steinmeier, "Downsizing in the World of Resistance Welding," *Welding Journal*, 77 (7) (1998), p. 39.
5. B.H. Chang, M.V. Li, and Y. Zhou, "Comparative Study of Small Scale and 'Large Scale' Resistance Spot Welding," *Sci. Technol. Weld. Join.,* 6 (5) (2001), p. 273.
5. K.J. Ely and Y. Zhou, "Microresistance Spot Welding of Kovar, Steel, and Nickel," *Sci. Technol. Weld. Join.,* 6 (2) (2001), p. 63.
7. E.P. Degarmo, J.T. Black, and R.A. Kohser, editors, *Materials and Processes in Manufacturing,* 9th edition (New York: John Wiley & Sons, 2003).
8. E.E. Ferrenz, A. Amare, and C.R. Arumainayagam, "An Improved Method to Spot-Weld Difficult Junctions," *Rev. Sci. Instrum.,* 72 (2001), p. 4474.
9. L.B. Lundberg, "*Tungsten and Refractory Metals 3,*" ed. A. Bose and R.J. Dowding (Princeton, NJ: MPIF: 1995), p. 145.

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