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Electron Beam Welding Study on U-Nb-Zr Alloy: Final Report

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ABSTRACT

An electron beam welding study was conducted on Mulberry alloy. Mulberry is a uranium alloy containing 7.5% niobium, and 2.5% zirconium. The study was conducted on 0.080-in. (0.203-cm) and 0.250-in. (0.635-cm) thick sheet stock. The purpose of the study was to determine what effect the variation of welding parameters would have on weld characteristics in partial penetration welds. The use of a straight beam of electrons or ac deflection results in weld spiking and cold shut area in the 0.250-in. (0.635-cm) thick material. Circle generation drastically reduced the number of weld defects. The 0.080-in. (0.203-cm) thick Mulberry welded easily except when ac deflection was used where the amount of weld porosity in the fusion area was high.

INTRODUCTION

An electron beam welding research study was conducted on Mulberry alloy. Mulberry is a uranium alloy containing 7.5% niobium, and 2.5% zirconium. The major problem associated with electron beam welding Mulberry is weld spiking at the weld root. Other problems are weld cold-shuts at the weld root and porosity in the fusion zone. The welding study was conducted using sample thicknesses of approximately 0.080 in. (0.203 cm) and 0.250 in. (0.635 cm). There were two objectives in this study: to overcome spiking and porosity problems, and to determine what effects variation of welding parameters would have on the sample material. There has been a lot of work done at various agencies on the weld spiking problem with only limited success. A Hamilton Standard high velocity electron beam welder with a power output of 6 kW was used to weld all the samples in this welding study.

SAMPLE PREPARATION

The Mulberry alloy sheet stock was descaled by machining all the surfaces flat and smooth. The sheet stock was then cut into weld samples 1.00 in. (2.54 cm) wide x 3.00 in. (7.62 cm) long. The material thicknesses were approximately 0.080 in. (0.203 cm) and 0.250 in. (0.635 cm). The sample edges were all machined smooth and square. Just prior to welding the two interfaces were metallographically polished with 600 grit silicon carbide paper to remove any oxide formations that may have appeared. The samples were immediately degreased with acetone, placed into an EB vacuum chamber and butt welded when the pressure reached approximately 10^{-4} torr. A complete chemical analysis of the material is given in Table 1.

EXPERIMENTATION

Straight Beam of Electrons

It has been well established that the use of a straight beam of electrons would yield many weld spikes in thicker sections of Mulberry alloy. It was decided to use a weld made this way as a standard for comparing other welds.

Partial penetration welds were made with a straight beam in the 0.080-in. (0.203-cm) and 0.250-in. (0.635-cm) thick materials. The thinner material

Table 1

CHEMICAL ANALYSIS OF MULBERRY ALLOY

Element	Concentration
Oxygen	50 ppm
Nitrogen	20 ppm
Hydrogen	10 ppm
Carbon	55 ppm
Niobium	7.0%
Zirconium	3.0%
Copper	20 ppm
Iron	90 ppm
Aluminum	100 ppm
Chromium	100 ppm
Silicon	10 ppm
Nickel	Not detectable if present
Lead	Not detectable if present
Uranium	Remainder

yielded only a few small voids while the 0.250-in. (0.635-cm) thick material yielded an average of 48 spikes/in. (Figures 1 and 2). The number of imperfections was determined by breaking the 3.00-in. (7.62-cm) butt weld down the center and measuring the number of imperfections in the center inch of the sample. This method would minimize the effect of weld start-up and stop. The average weld penetration on the 0.250-in. (0.635-cm) material was 0.150 in. (0.381 cm). A section of the sample was mounted for analysis on the electron microprobe analyzer, to see if there was any local segregation of materials during the welding operation that would have any bearing on the spiking problems. Microprobe analysis showed no detectable variation in the composition in the fusion zone or in the parent material.

The types of weld defects appearing in the 0.080-in. (0.203-cm) and 0.250-in. (0.635-cm) material were different. All the weld defects in 0.080-in. Mulberry were in the form of areas of porosity while the defects in the 0.250-in. thick material contained weld spiking, cold shuts, and a few voids. This observation agrees very well with results of work done by Dr. Henry Tong[1] at the University of California/Davis. He noted that the weld mechanism changes between a shallow and deep penetration weld. The deep penetration weld is influenced by the oscillation of the weld cavity size. Dr. Tong suggests that when the weld cavity is wide open (filled with vaporized metal) the weld penetration will increase. As the amount of molten weld metal increases, it obstructs the stream of electrons and the weld penetration decreases.

Variation of Circle Frequency

The electron beam welder used in this study has a variable frequency circle generator attachment. This feature allows one to deflect the electron beam around in a circular path at various frequencies. Using a beam circle of 0.060-in. (0.152-cm) diam, frequencies of 50, 100, 200, 300, 400, and 500 cps were used in making the welds. A heat input of approximately 1600 J/in. was used in welding the 0.080-in. (0.203-cm) thick material, while 3680 J/in. was used for the 0.250-in. (0.635-cm) thick material. Table 2 gives a complete list of all the welding parameters used on this part of the study. The results indicate that indeed one can reduce weld spiking by using circle generation at various frequencies (Figures 3 and 4). This may be due only to the fact that the

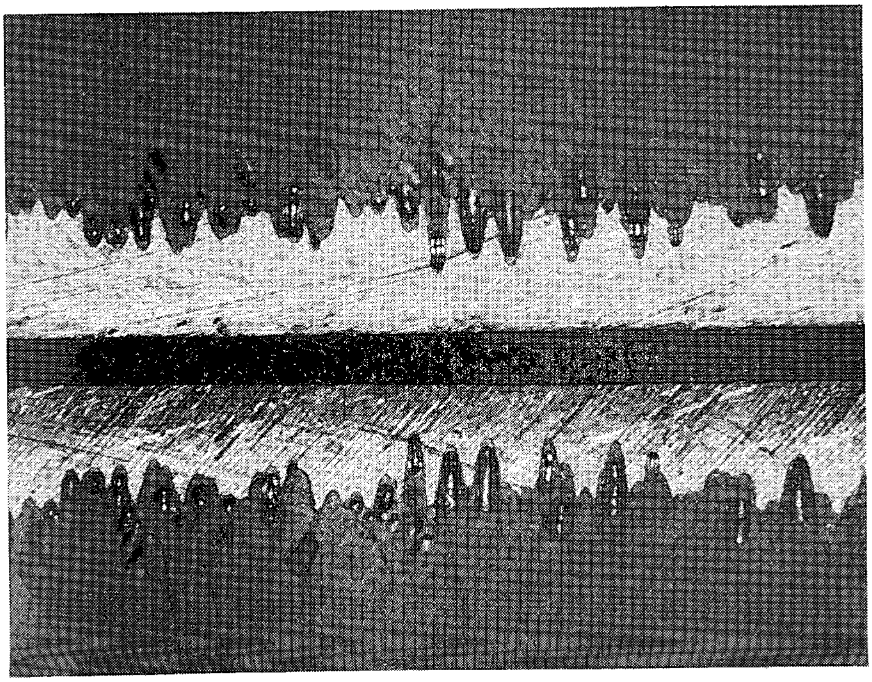

FIGURE 1 - Fractured surface of weld made by use of straight beam of electrons showing weld spikes and cold shuts (11.5 X).

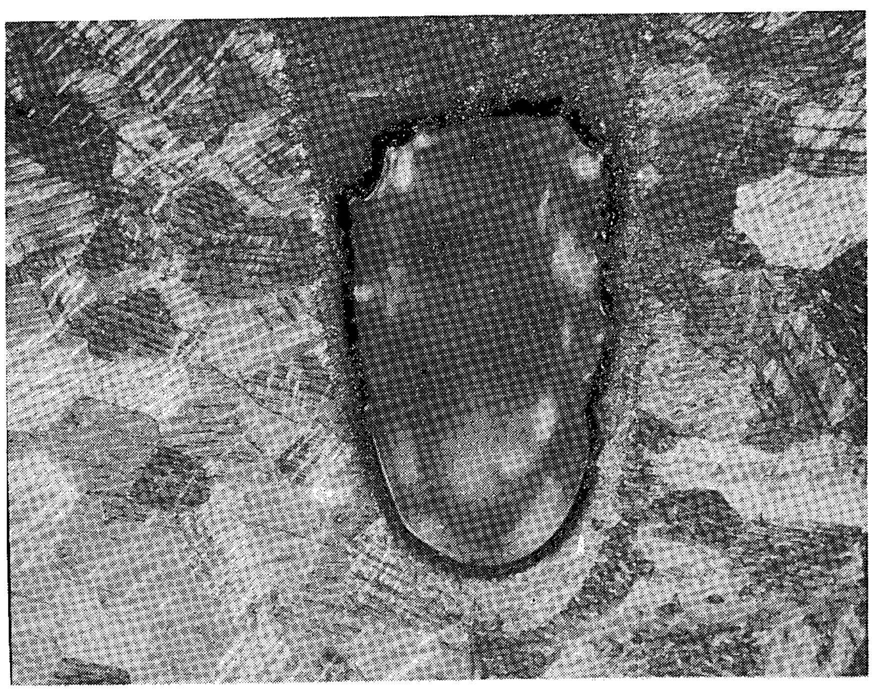

FIGURE 2 - Porosity at the bottom of a weld spike from Figure 1 (200 X).

Table 2

WELDING PARAMETERS USED IN VARIATION OF CIRCLE FREQUENCY STUDY[a]

kV	mA	Circle Frequency (cps)	Heat Input (J/in.)
140	13.0	50	3680
140	13.0	100	3680
140	13.0	200	3680
140	13.0	300	3680
140	13.0	400	3680
140	13.0	500	3680
100	8.5	50	1601
100	8.5	100	1601
100	8.5	200	1601
100	8.5	300	1601
100	8.5	400	1601
100	8.5	500	1601

[a]Circle diam = 0.060 in. (0.152 cm); and speed = 30 in. (76.2 cm)/min.

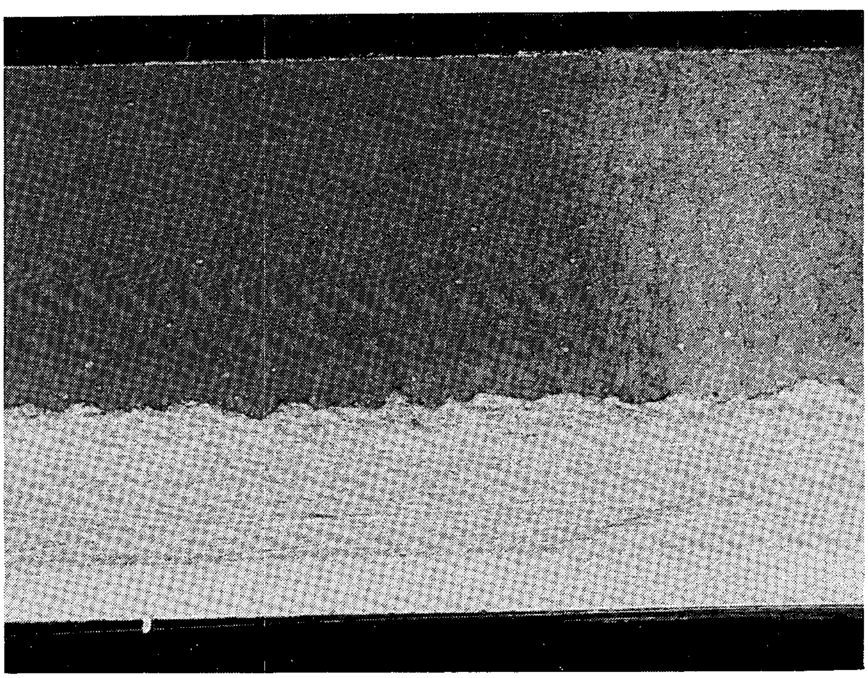

FIGURE 3 - Longitudinal section of weld made using welding parameters of 140 kV, 13 mA, 0.060-in. (0.152-cm) circle diam at 200 cps oscillation, and 30 in. (76.2 cm)/min (11.5 X).

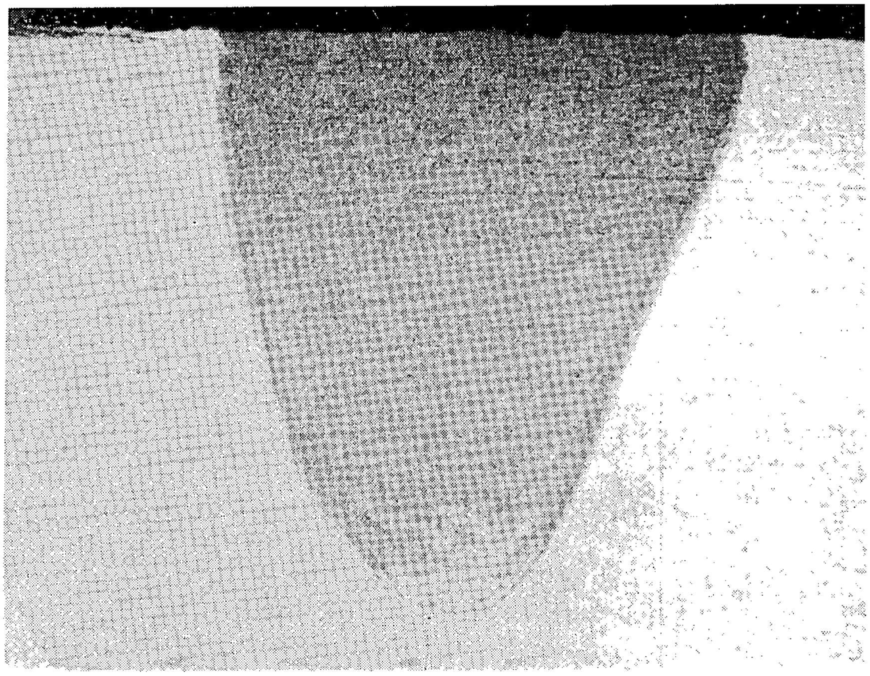

FIGURE 4 - Cross section of weld shown in Figure 3 (20 X).

power density in the weld bead is lower when using a circle. As can be seen from the graphs in Figures 5-7, the weld penetration, weld depth/width ratio, and welding defects were all lower in the 200-400 cps range. It is not understood why these conditions should exist, but it is significant that the weld penetration only dropped about 26% maximum in this region while the number of weld defects dropped about 90% from the number observed at 50 cps on the 0.250-in. (0.635-cm) thick material. This indicates that the use of circle generation is probably better than a straight beam in welding Mulberry alloy and that the quality of the weld is frequency dependent. However, to yield a given weld penetration more heat input is required using circle generation than with a straight electron beam. This condition will be a limiting factor when the heat input is very critical.

A similar condition, i.e., 200-400 cps, was observed with the 0.080-in. (0.203-cm) thick specimens as can be seen from the curves in Figures 5-7. The reduction in the weld defects in this material was negligible and within experimental error. This substantiates the theory that two different welding mechanisms occurred in welding thin and thick materials. Figure 8 shows a typical weld made at 300 cps with 1600 J/in. heat input.

Circle Diameter Variations

In the next part of the welding study the effect of variation in circle diameter was investigated. Circle diameters of 0.030 in. (0.976 cm),

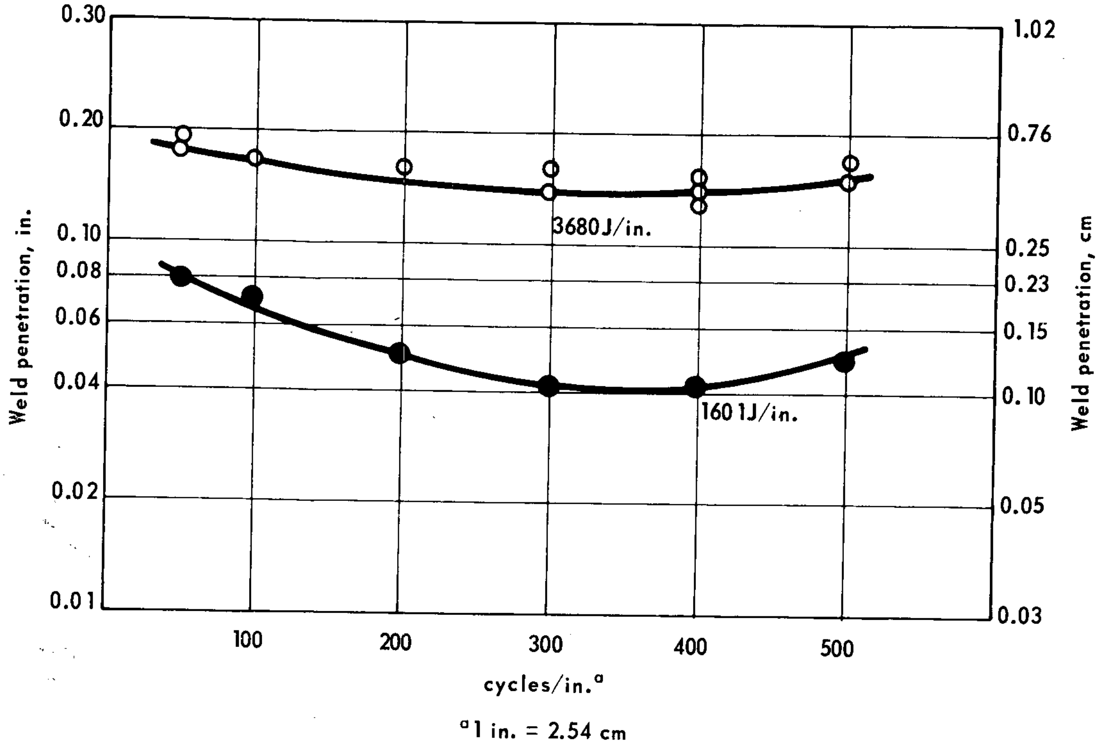

FIGURE 5 - Electron beam weld penetration results using various circle frequencies.

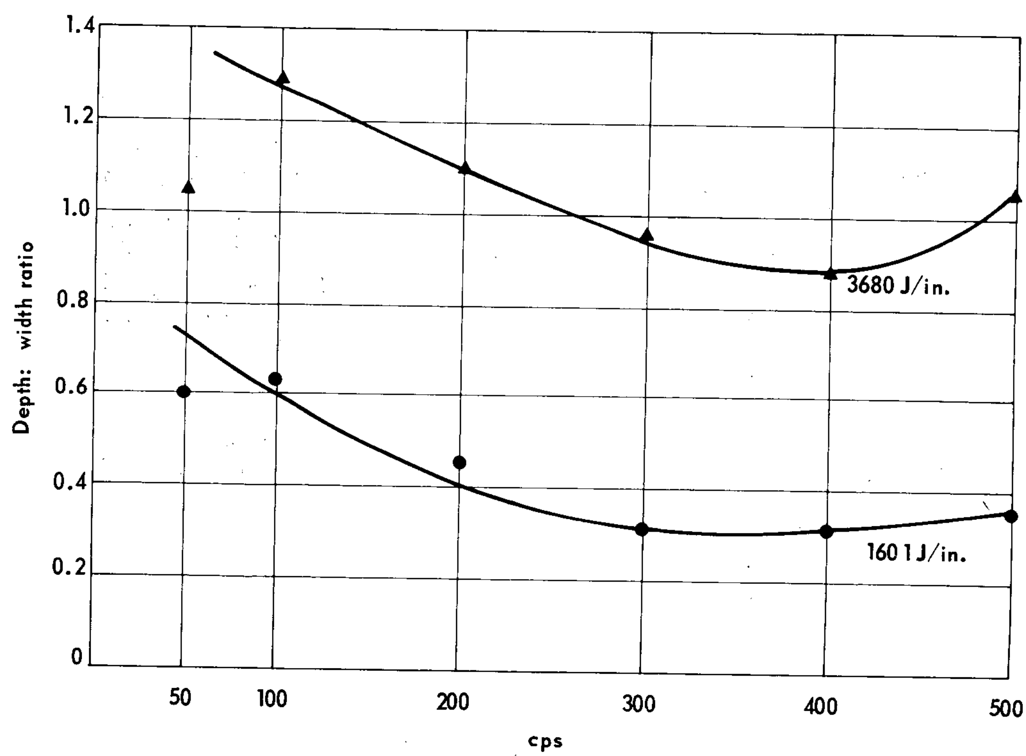

FIGURE 6 - Depth-to-width ratio of electron beam welds using variations in circle frequency.

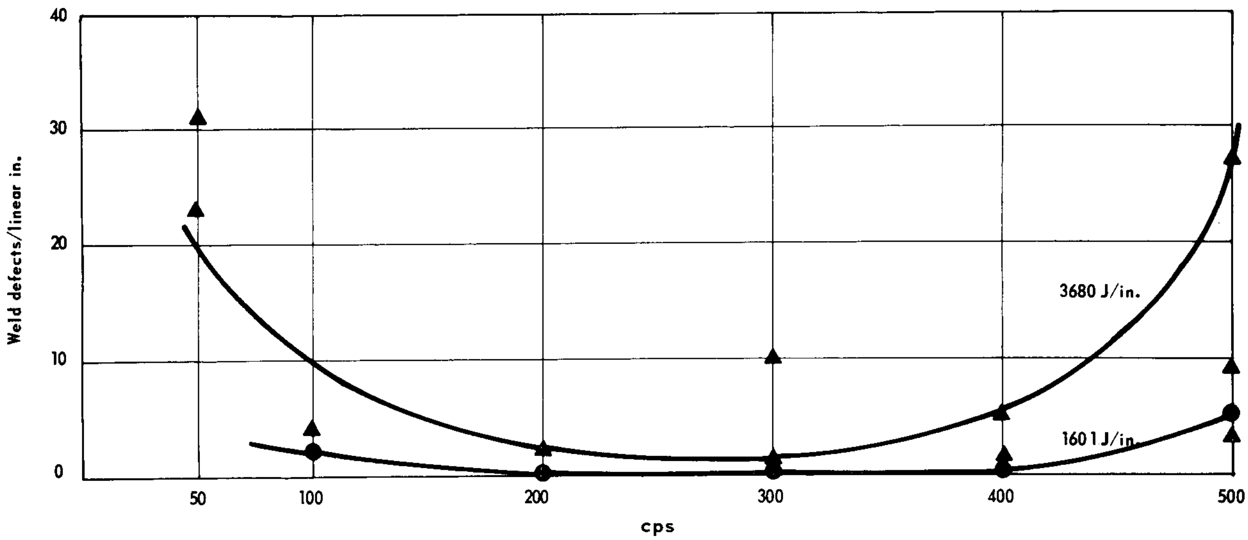

FIGURE 7 - Weld defects observed using variation of circle frequency.

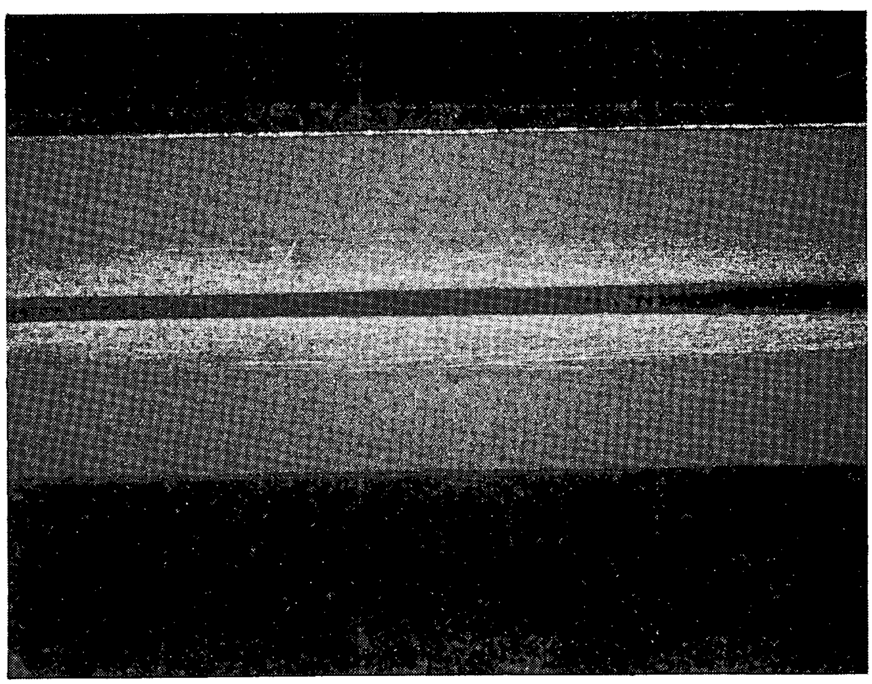

FIGURE 8 - Longitudinal section of weld made on 0.080-in. (0.203-cm) thick Mulberry at 300 cps (11.5 X).

0.045 in. (0.114 cm), 0.060 in. (0.152 cm), 0.075 in. (0.191 cm) and 0.090 in. (0.229 cm) were chosen. These circle sizes were run on the 0.080-in. (0.203-cm) thick material at 60 cps circle frequency and 1300 J/in. heat input. The same circle sizes were used on the 0.250-in. (0.635-cm) thick material at 500 cps circle frequency and 3920 J/in. heat input. The results were about as expected and are shown in Figure 9-13. As the circle diameter increased, the weld penetration, number of weld defects, and weld depth-to-width ratio decreased. However, no defects were observed in any welds on the thin Mulberry at 1300 J/in. heat input. It can be seen from the various curves shown that the data are somewhat scattered. The curves are indicative of what is happening, but the numbers plotted should not be used as absolute values. Reproduction of a given weld penetration was found to be very difficult.

Variations in A.C. Deflection

The last part of the welding study was to determine the effect of deflecting the beam of electrons across the weld joint at 60 cps. Deflection widths of 0.030 in. (0.076 cm), 0.045 in. (0.114 cm), 0.060 in. (0.152 cm), 0.075 in. (0.191 cm) and 0.090 in. (0.229 cm) were used. The various deflection widths were run on both the 0.080 in. (0.203 cm) and 0.250 in. (0.635 cm) thick Mulberry. Heat inputs of 1100 J/in. and 2800 J/in. were used on the thin and thick materials respectively. Figures 14-17 describe the weld characteristics observed. There are no data available on depth/width ratios for the thick Mulberry welded using 2800 J/in. heat input. Again the data are rather scattered; also the data on weld defects are so scattered that they are impossible to graph

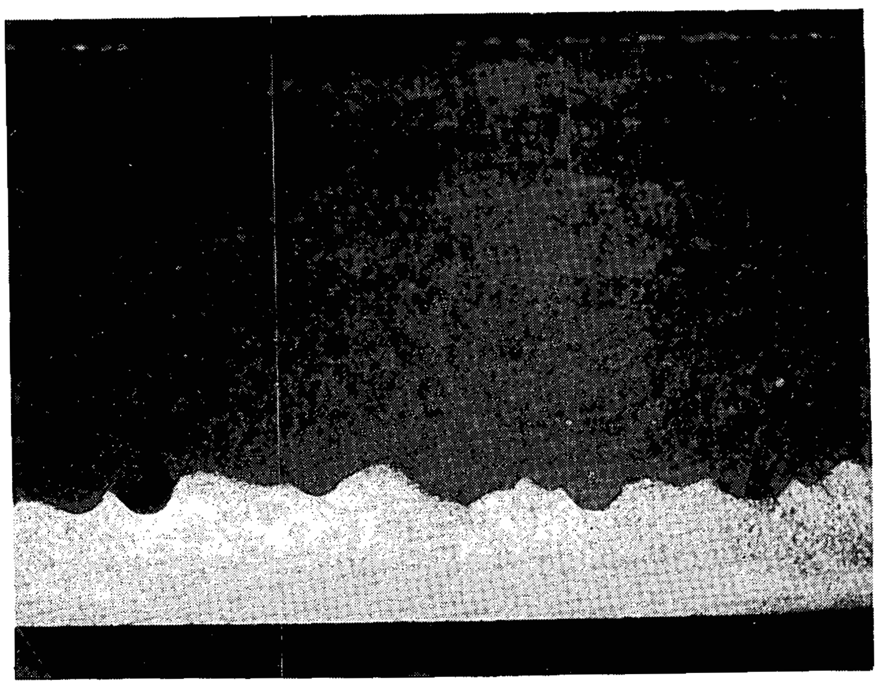

FIGURE 9 - Longitudinal section of weld made on 0.250-in. (0.635-cm) thick Mulberry at 140 kV, 14 mA, circle diam of 0.045 in. (0.114 cm) at 500 cps oscillation, at 30 in. (76.2 cm)/min (11 X).

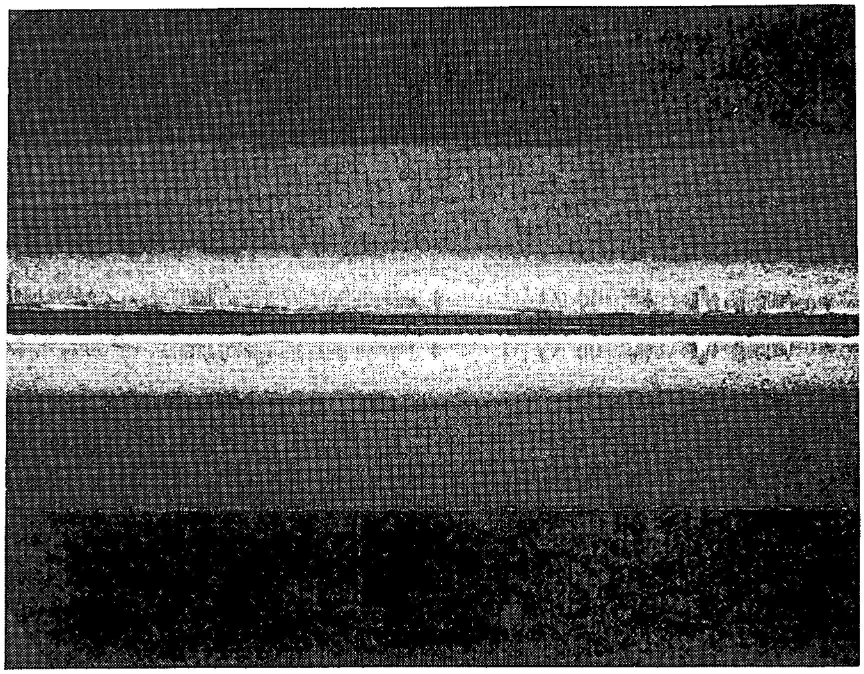

FIGURE 10 - Longitudinal section of weld made on 0.080-in. (0.203-cm) thick Mulberry at 100 kV, 6.5 mA, circle diam of 0.060 in. (0.152 cm) at 60 cps oscillation, and 30 in. (76.2 cm)/min (11.5 X).

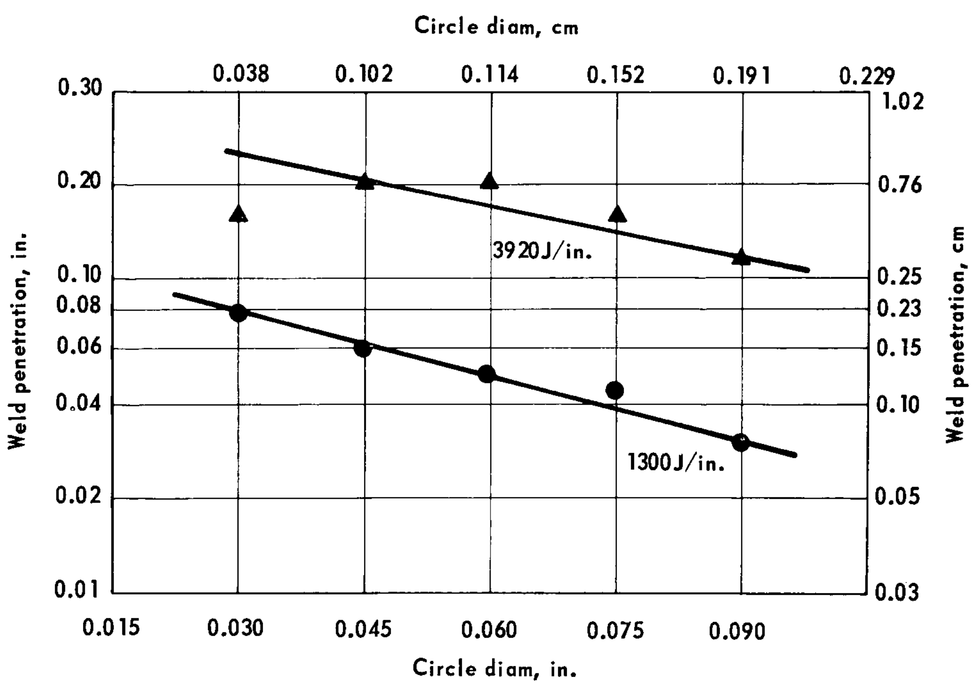

FIGURE 11 - Electron beam weld penetration results using variations in circle diameters.

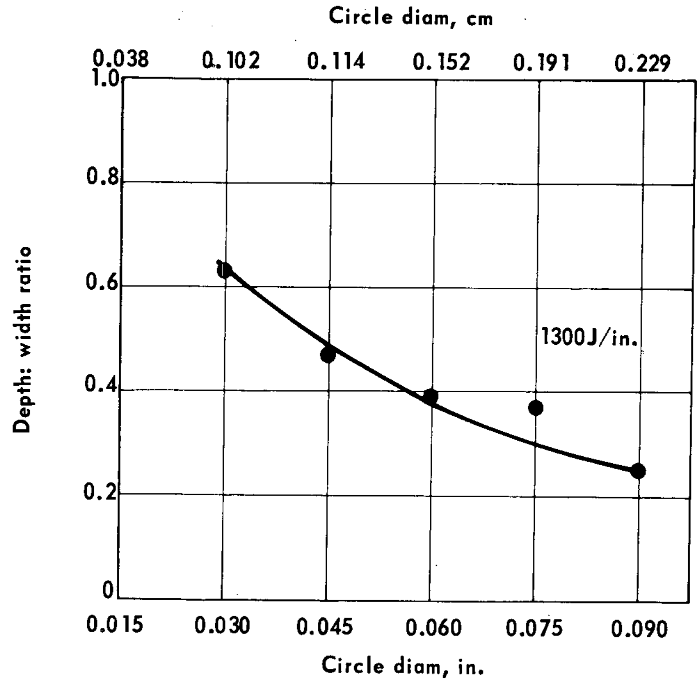

FIGURE 12 - Depth-to-width ratio of electron beam welds using variation in circle diameter.

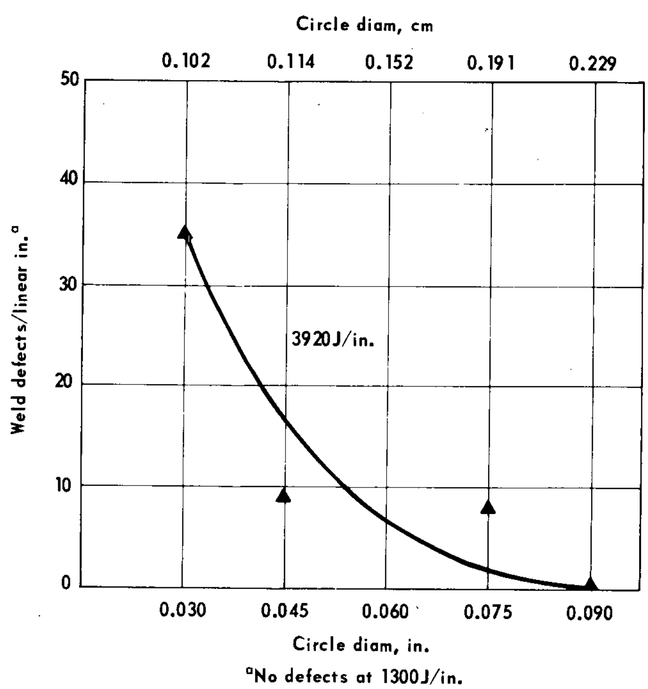

FIGURE 13 - Defects in electron beam welds using variation in circle diameter.

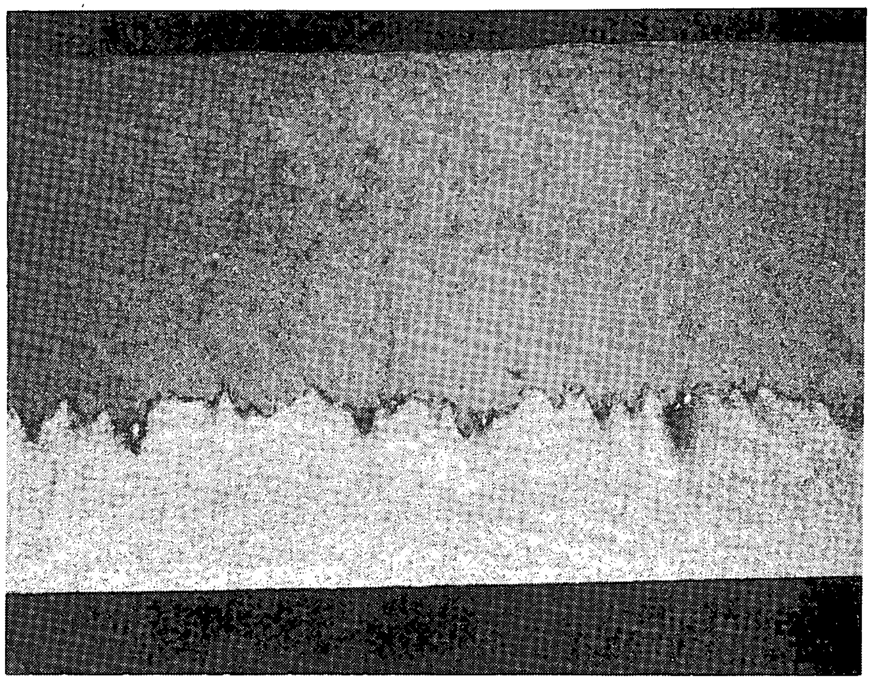

FIGURE 14 - Longitudinal view of fractured surface of weld on 0.250-in. (0.635-cm) thick Mulberry. Weld parameters used were 140 kV, 10 mA, 30 in. (76.2 cm)/min, 0.060 in. (0.152 cm) ac deflection across the weld joint (11 X).

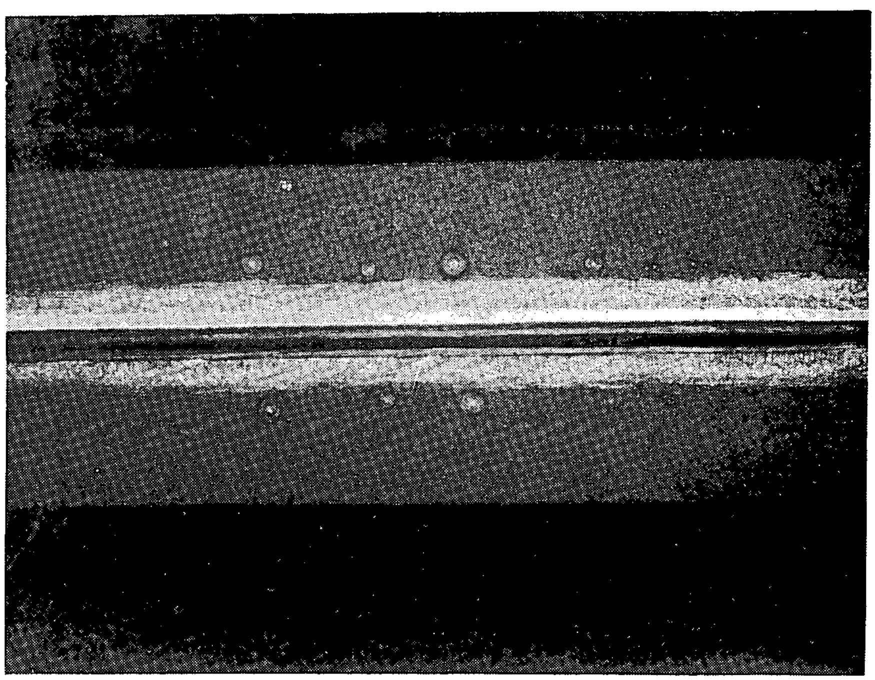

FIGURE 15 - Longitudinal view of fractured surface of weld on 0.080-in. (0.203-cm) thick Mulberry. Weld parameters used were 100 kV, 5.5 mA, 30 in. (76.2 cm)/min ac deflection across the weld joint (11.5 X).

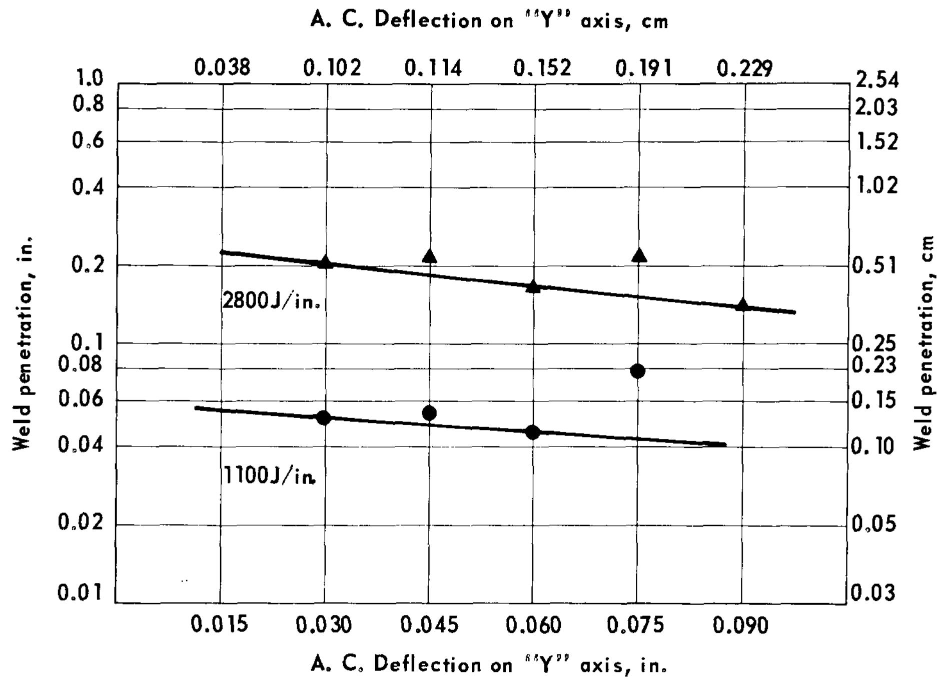

FIGURE 16 - Electron beam weld penetration results using variations in ac deflection.

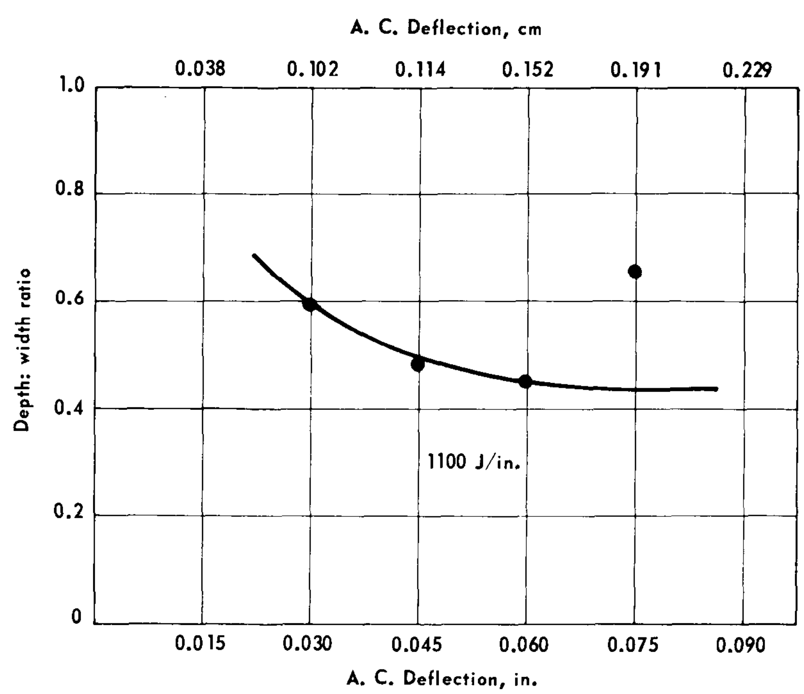

FIGURE 17 - Depth-to-width ratio of electron beam welds using variation in ac deflection.

However, the significant point is that there are fewer defects observed in the use of a circle than observed with the use of a straight beam for a given weld penetration. The number of defects per linear inch of weld in the thick Mulberry ranged from 4 to 37 with most welds in the high twenties. These defects were in the form of weld spikes and cold shuts.

The number of defects per linear inch of weld in the thin Mulberry ranged from 13 to 36. The defects for thin Mulberry were in the form of weld porosity. There was more porosity in welds made by use of ac deflection across the weld joint than there was by welding with a straight beam of electrons. All the other data came out much as would be expected.

CONCLUSIONS

The welding defects observed in partial penetration electron beam welds on 0.080-in. (0.203-cm) thick Mulberry alloy were all in the form of porosity. The use of ac deflection of the beam across the weld joint yields more porosity than other electron beam welding techniques.

The welding defects observed in partial penetration electron beam welds on 0.250-in. (0.635-cm) thick Mulberry alloy were in the form of weld spiking and cold shuts at the weld root.

The use of the variable frequency circle generator and a circle diameter of 0.060 in. (0.153 cm) yields the best welds in Mulberry alloy. However, more heat input is required to obtain a desired weld penetration using a circle than using a straight beam.

Circle frequencies of 200-400 cps in conjunction with a 0.060-in. (0.153-cm) diam circle yielded less weld defects than other circle frequencies.

REFERENCES

1. H. Tong, Reports and Meeting Minutes for Interagency Mechanical Operations Group, Subgroup on Joining: March 1969, SC-DR-68-842 (11), Sandia Corporation, Albuquerque, New Mexico, pp 8-16.