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Westinghouse Astronuclear Laboratory

AN IMPROVED ELECTRON BEAM WELD PROCESS
FOR CONTROL DRUM ASSEMBLY

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AN IMPROVED ELECTRON BEAM WELD PROCESS
FOR CONTROL DRUM ASSEMBLY

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SUMMARY

An improved high voltage electron beam weld process has been developed and a production facility established within the Westinghouse Astronuclear Laboratory Materials Department. This procedure has eliminated many of the periodic weld defects produced by an outside vendor.

The preplacement of 4043 aluminum alloy filler material, which was proven feasible in previous work (TME-625), was successfully applied to reduce weld crack sensitivity. While the fusion zone was slightly larger with the new weld parameters, distortion level during joining was not adversely affected. The very close control of end to end length and axial alignment maintained by the process permits all final machining to be accomplished before welding.

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INTRODUCTION

WANL-TME-625 defined the development and application of the electron beam welding process to the fabrication of aluminum alloy (6061) control drum assemblies. This joining process had been selected because the application placed severe limitations on weld build-up, weld width, and distortion control. Use of electron beam welding permitted critical bearing surfaces on each end cap to be premachined and hard coated prior to welding and kept in alignment during welding. This consideration was extremely important because maintaining cleanliness of the final assemblies, should post weld machining have been required, was virtually impossible. Additionally, some assemblies had to be instrumented prior to welding and thus could not be subjected to machining without damaging the instrumentation.

As production progressed (welding was being conducted at Electron Beam Techniques, Inc., Plainville, Connecticut) weld defects in the form of cracks occurred periodically. Such cracks were never over 1/16" length but were revealed in the required dye penetrant examination. A procedure had been developed for surface type weld repairs which was successfully applied in these cases also. Alignment was not seriously affected by the repair procedure but periodically end to end shrinkage was excessive.

The possibility of cracking due to hot shortness of the 6061 aluminum alloy had been considered when the original weld development program was initiated. However, extensive test welding and early production welding indicated that the problem did not occur with proper weld joint design and high welding speed (150" min.).

Concurrent with the early production of control drums, the Westinghouse Astronuclear Laboratory had established within the Materials Department a basic electron beam welding capability. The possibility for damage to vital parts and instruments during shipment of the assembled unit presented a major reliability problem. The decision was thus made to weld these units in-house to improve control and reduce the handling and shipping problems. Since the transfer of the welding to the Westinghouse Astronuclear Laboratory facility required an

adaption of the process to the WANL machine and requalification, it was further decided to attempt to modify the welding technique to eliminate the tendency for crack formation, and to apply the modified process to all units.

This report documents the welding development effort required to arrive at an improved welding process and the establishment of the production welding capability within the Materials Department.

WELD PROCEDURE DEVELOPMENT

Selecting a New Approach

Filler material such as 4043 or 5356 is used in conventional welding of 6061 aluminum to reduce cracking tendency. The addition of filler of this type in the high-voltage electron beam welding process is very difficult. Preplacement is the only feasible approach, and had been demonstrated in repair welding on control drums as defined in TME-625. Repairs which fused 4043 filler wire into the weld had been completely successful, with no recorded occurrence of the crack defects appearing again.

Various techniques were considered for preplacement of a filler material as a basic feature of the process. The following sketches illustrate some of those considered:

The method shown in Sketch A was discarded because of anticipated handling problems in locating the small, soft aluminum washer required. Since alignment after welding was completely dependent on dimensional control of all parts, slight kinking, or non-uniform thickness of the washer could result in an out-of-tolerance assembly after welding.

Sketch B shows another approach which was discarded once again due to anticipated dimensional control problems. The filler must fit tightly into the joint or it will not fuse into the weld. Thus interference in original fit up was a strong possibility.

The approach shown in Sketch C was selected as the most practical. Advantages were that existing part drawings would not have to be modified (the groove below the weld joint was already part of the design), a number of parts machined to this configuration were already available and a minimum effect on weld technique was expected.

Establishing Weld Parameters

Aluminum alloy 4043 (5% silicon) was selected as the filler material. Experience with other fusion processes suggested that this alloy would have a maximum effect in reducing crack sensitivity. The size of the filler for preplacement under the weld was established by etching a heavy wire in progressive steps until it fit snugly into the available groove without interfering with joint fit up. The diameter arrived at and used as a standard for tests and subsequent production was .025". It was further determined, through experience on the test welds, that the gap between ends of the filler must be maintained below 1/64". Wider separation resulted in a depression on the face of weld.

The first step in developing actual weld parameters was to determine the extent to which vendor experience could be related to the electron beam welding equipment at the Westinghouse Astronuclear Laboratory. While the equipments were very similar, some performance variations were possible. Test welding with parameters established at the vendors, however, indicated that with the same speed, voltage, and current levels exactly the same weld bead penetration and configuration were obtained.

A series of test welds was then produced under varying speed and energy conditions. The intent was to arrive at energy levels at which the beam penetrated into, and fused, the filler wire. Further, the weld speed should be slow enough to permit back flow of the molten filler upward into the weld joint.

As previously noted in TME-625, preweld cleaning was very important. Smooth uniform flow of weld metal was obtained when cleaning and chemical removal of oxide was accomplished within 48 hours prior to welding. The procedure applied to both base metal and filler wire was as follows (Reference WANL PS 294524):

- (a) Solvent wipe or vapor degrease.
- (b) Place in 20% volume solution of Oakite 33 operated at 120°F and hold for 1-2 minutes.
(Alternate: Swab 2-3 minutes in room temperature bath.)
- (c) Rinse in cold water.
- (d) Place in 1 lb/gal. solution of Oakite 34M operated at room temperature and hold for 1-2 minutes.
- (e) Rinse in cold water followed by hot water (approximately 150°F).

A separate set of weld parameters was established with the work placed at each of two different gun to work distances. Each produced satisfactory joints. These conditions were as follows:

<u>Welding Speed</u>	<u>Voltage</u>	<u>Current</u>	<u>Gun to Work Distance</u>
39 in/min (20 sec/rev)	80 KV	5.2 MA	1"
39 in/min (20 sec/rev)	100 KV	5.8 MA	6-1/2"

Figures 1, 2 and 3 show welds produced with these conditions along with that previously obtained when no filler was present. The weld fusion zone is obviously larger with the new conditions, particularly at the greater gun to work distance. The preplaced filler has been fused and drawn into the weld, leaving the original underbead groove intact.

Instrumented control drum assemblies, when ready for welding, have a reel attached to one end upon which the long thermocouple lead wires have been wrapped. The diameter of this reel dictated the use of the longer gun to work distance on at least a portion of the production joints. The welds produced at the greater distance were comparable in quality (the surface finish was actually smoother and thus better for dye penetrant examination) and it was decided to use the longer gun to work distance on all production welding.

As noted earlier, the level of weld shrinkage and possible distortion was extremely important. Test welding had to demonstrate that the new weld conditions would give similar shrinkage values to those obtained with the smaller welds generated at higher speeds with no filler backup. The following data compare shrinkage obtained at the two conditions on typical sample joints. The data represent the change in length occurring from a single weld on short length assemblies at six equally spaced points on the drum circumference.

	Original Conditions (80 KV, 7.5 MA, 156 in/min) No Filler	New Conditions (100 KV, 5.8 MA, 39 in/min) Filler Added
A	.0045	.003
B	.004	.004
C	.003	.004
D	.003	.004
E	.004	.0045
F	.004	.004

It can be seen that shrinkage is comparable for the two conditions even though the welds differed considerable in total heat input.

All test welds were visually inspected at 30X magnification, dye penetrant examined and sectioned for penetration evaluation. At no time was cracking observed even with very minimal fusion of the filler material.

PRODUCTION WELDING

Fixturing and Weld Sequence

It was necessary to accommodate the long control drum assembly and weld fixture in the Westinghouse Astronuclear Laboratory electron beam weld chamber. An extension was designed and built along with needed handling equipment. Figures 4 and 5 show the total equipment set-up with a drum in the fixture ready for insertion into the chamber.

The production weld sequence was as follows:

1. Place drum assembly into fixture.
2. Insert fixture into chamber.
3. Align joint under beam.
4. Evacuate chamber to 10^{-3} mm of Hg (max.)
5. Weld.
6. Remove from chamber.
7. Reverse fixture.
8. Reinsert into chamber, evacuate, align, and weld.

Results

In producing a simulated drum as a full size tooling trial and in welding the first production part, a condition of surging beam current and periodic beam arc-over and cut-off occurred. The resulting welds contained small areas of undercut from higher beam current, and face depressions at the point of beam cut-off. This condition was most likely due to vaporization of the aluminum and backstreaming of vaporized metal into the electron beam gun.

The actual cause of the erratic weld conditions noted could not be definitely established. It was found by experimentation, however, that a low energy seal weld pass applied to the joint prior to the full penetration weld, eliminated the problem completely. The parameters

established for this seal weld were:

<u>Gun to Work Distance</u>	<u>Voltage</u>	<u>Current</u>	<u>Welding Speed</u>
6-1/2"	100 KV	3 MA	39 in/min (20 sec/rev)

Macro sections of the weld indicated that the prior weld pass had no effect on the final joint.

Inspection of the twenty production joints produced to date has shown the welds to be completely free of dye penetrant indications of any type. Dimensional checks have shown that end to end axial alignment was maintained within tolerance ($^{+}.001$ inch) and that overall length was also within tolerance ($^{+.012}_{-.000}$ inch).

Weld Penetration Control

The weld joint design is such that weld penetration cannot be determined by non-destructive tests such as x-ray or ultrasonics. Sample joints welded immediately prior to production runs at the Westinghouse Astronuclear Laboratory were used to provide assurance that equipment was functioning properly and that penetration was satisfactory. The use of sample end caps, however, is very costly.

A review of the factors influencing control of the process indicated that preweld joint condition and fixture performance could best be established on each part just prior to welding. The portion of the process that had to be verified by actual preproduction welding related to the quality of the electron beam (i.e., energy of electrons, stability of focus, density, etc.). As long as an adequate correlation was established, any piece of metal could be used (with appropriate observations) to verify beam quality. Sections of control drum tubing were available and represented the most direct correlation. Thus, a series of tests were run to establish a correlation between electron beam weld energy and penetration achieved on sample control drum tubular material.

It was found that the weld voltage and current settings which produced a satisfactory actual weld would give 100% penetration through a sample consisting only of control drum tube material (.050 thick) when the speed was 110 inch/min. (7 sec/rev). The reduction in

penetration as weld energy was reduced and speed held at this level was also observed.

Figure 6 shows information obtained. Thus assurance that the proper amount and density of beam energy is available (i.e., that the power supply, optics, etc., are operating correctly) can now be achieved simply by running a beam trace at the standard power settings on tubing material at 110 in/min. speed and observing the penetration that results.

CONCLUSIONS

1. Using the process described in this report, approximately twenty production welds have been made without the observance of cracks whereas a high incidence of cracking had occurred using the vendor developed procedure.
2. Addition of a preweld sealing pass (which is obliterated by and does not effect the subsequent production weld) eliminated beam surge and arc over.
3. The improvements have been accomplished without sacrificing dimensional control.
4. Weld bead surface (hence inspectability) was improved when the gun - workpiece distance was increased (to permit welding of instrumented units).
5. Filler metal addition was accomplished without the need for rework of existing subassemblies.
6. Effective penetration control was established using a simple, readily available tubular specimen thereby eliminating the need for extra, difficult-to-obtain end caps which contributed nothing to the test. This control approach will be incorporated in WANL PS 294524 (Fabrication of Control Drum).

FIGURE 1 - Control Drum Weld Made at High Speed with No Filler Material Added. Standard Weld Settings That Had Been Used on Production Parts (156 in/min., 80 KV, 7.5 Milliamperes) 50X

FIGURE 2 - Control Drum Weld Made at Reduced Speed with .025" Diameter Filler Wire Pre-placed Under the Joint. 50X
(39 in/min., 80 KV, 5.2 Milliamperes, 1" Gun to Work Distance)

FIGURE 3 - Control Drum Weld Made at Reduced Speed with .025"
Diameter Filler Wire Pre-placed Under the Joint. 50X
(39 in/min., 100 KV, 5.8 Milliampères, 6-1/2" Gun to Work Distance)

Note: This weld was established as standard for all future production.

FIGURE 4

FIGURE 5

A. Standard Control Drum Weld Energy Setting
100 KV, 5.8 Milliampères, 6-1/2" Gun to
Work Distance, 110 in/min Weld Speed
50X

B. Reduced Weld Energy
100 KV, 5.5 Milliampères, 6-1/2" Gun to
Work Distance, 110 in/min Weld Speed
50X

C. Reduced Weld Energy
100 KV, 5 Milliampères, 6-1/2" Gun to
Work Distance, 110 in/min Weld Speed
50 X

FIGURE 6 - Electron Beam Weld Penetration Study 6061 Aluminum
Control Drum Tubing .050" Thick, 4" Diameter