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CLOSURE WELDING OF PLUTONIUM BEARING STORAGE CONTAINERS (U)

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BACKGROUND

A key element in the Department of Energy (DOE) strategy for the stabilization, packaging and storage of plutonium-bearing materials involves closure welding of DOE-STD-3013 Outer Containers (3013 container). The 3013 container provides the primary barrier and pressure boundary preventing release of plutonium-bearing materials to the environment. The final closure (closure weld) of the 3013 container must be leaktight, structurally sound and meet DOE STD 3013 specified criteria.

In February, 2001, the Savannah River Technology Center (SRTC) supplied a welding system to the Hanford Plutonium Finishing Plant (PFP), located near Richland, Washington, for the closure of 3013 containers. The effort to supply this system included development, qualification and demonstration of an automatic Gas Tungsten Arc Welding (GTAW) process for making the closure weld. GTAW was chosen for its demonstrated history in critical applications, ease of remote operation and ability to make high-integrity welds.

The 3013 container, made of Type 316/316L stainless steel and measuring almost 5 inches in diameter and approximately 10 inches in length, is closure-welded at the lid/container interface (Figure 1.).

The corner-joint is formed by pressing an interference-fit lid into the 3013 container, creating a square-groove, weld preparation. The closure is made autogenously (without addition of filler) using a modified AMI©, 9 series orbital weld head with a Model 227 power supply. The modified weld head (Figure 2.) includes an integral chill block.

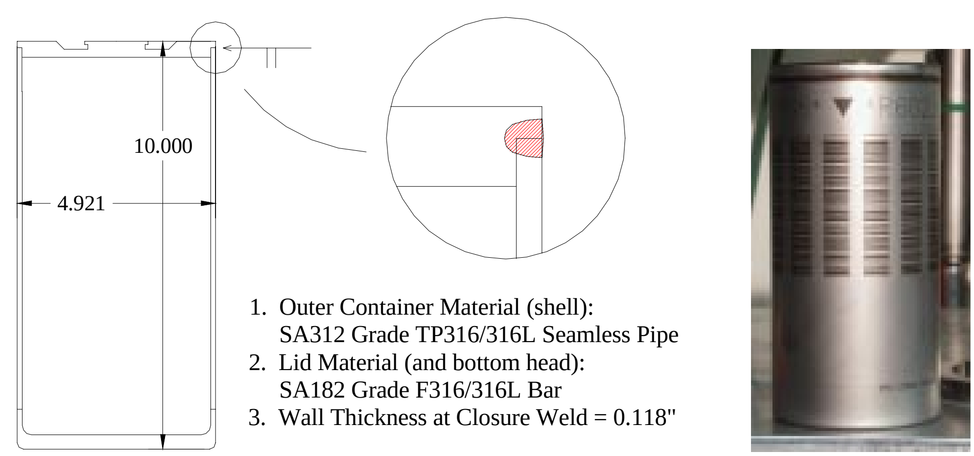


Figure 1. Sketch of 3013 Outer Container (left) and Photo of Container after Welding

An encoder and shunt have been added for weld travel speed and arc current measurements, respectively. In addition, the weld head rotor has been adapted to receive a specially designed snap-in tungsten electrode for ease of replacement.

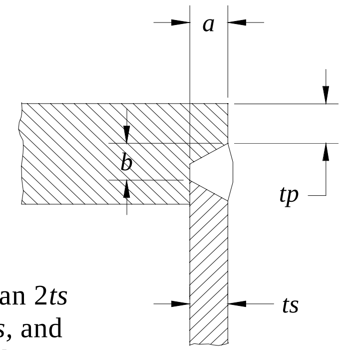
This paper focuses on the development, qualification and demonstration of the welding process for the closure welding of Hanford PFP 3013 outer containers.

Figure 2. Modified Orbital Weld Head

WELD PROCESS PARAMETER DEVELOPMENT

Weld Performance Objectives/Acceptance Criteria

Process development was driven by weld acceptance criteria specified in the DOE Standard 3013-99 [1] and customer-defined requirements for waste acceptance. These documents specify requirements for weld leak tightness, soundness, strength and bead geometry. Good weldability and weld quality for the 3013 container/lid materials using the GTAW process has been demonstrated many times over the years. The primary challenge consisted of developing the process to meet specific ASME Section VIII, as-welded dimensional criteria (Figure 3.).



1. *a* + *b* not less than 2*ts*
2. *a* not less than *ts*, and
3. *tp* not less than the smaller of *ts* or 1/4 inch

Figure 3. ASME Section VIII, Division 1, Figure UW-13.2 (d), Weld Cross Section Geometry Requirements

GTAW weld beads are typically characterized by relatively low bead depth to width values (aspect ratio). Because of the relative thinness of the lid flange, achieving full penetration without consuming the top corner was considered the primary challenge and therefore much of the development effort centered on weld bead aspect ratio.

Target Welding Parameter Development

Welding-arc energy (power density) can have a significant effect on bead penetration and shape, as a result, readily-controllable variables having a direct influence on arc energy were identified for evaluation. Various tungsten alloy types, tip geometries and shielding gases were tested to characterize their relative effect on bead geometry. Initial welding parameters based on standard GTAW practices, shown in Table 1, were utilized for this welding. This weld schedule employs a pulsed-step welding current, with travel occurring on the background pulse.

Table 1. Initial Welding Parameters

Primary Pulse Current	150 A @ 0.25 S
Background Pulse Current	40 A @ 0.20 S

Arc Gap	0.070”
Travel Speed	0.62 RPM During Background Pulse Only

The Table 2. matrix lists the variables and changes studied, their effect on weld bead geometry and the final values (parameters) selected.

Table 2. Effect on Weld Bead Geometry with Changes to Welding Variables. The Variable Changed for Each Group is Identified by Bold and Italicized Characters.

Shielding Gas	**Tungsten Alloy**	**Angle (^{0})**	**Depth of Penetration**	**Bead Width**	**Aspect Ratio**
Group 1 – Changes in Tungsten Tip Included Angle (No significant effect on Aspect Ratio noted)					
Argon	Ce	***30***	0.076	0.209	**.36**
Argon	Ce	***60***	0.073	0.204	**.36**
Argon	Ce	***90***	0.077	0.204	**.38**
Group 2 – Changes in Tungsten Type (No significant effect on Aspect Ratio noted)					
Argon	***Th*** (2%)	60	0.083	0.210	**.40**
Argon	***Ce*** (2%)	60	0.073	0.204	**.36**
Argon	***La*** (1.5%)	60	0.083	0.202	**.41**
Group 3 – Changes in Shielding Gas (Significant effect on Aspect Ratio noted)					
Ar/H_2 (95/5)	Ce	60	0.122	0.183	**.67**
Ar/He (75/25)	Ce	60	0.087	0.202	**.43**
He/Ar (90/10)	Ce	60	0.139	0.217	**.64**
Group 4 – Changes in Tungsten Alloy Type with Ar/H_2 Shielding Gas (No significant effect on Aspect Ration)					
Ar/H_2 (95/5)	***Ce***	60	0.119	0.193	**.62**
Ar/H_2 (95/5)	***Th***	60	0.119	0.183	**.65**
Ar/H_2 (95/5)	***La***	60	0.120	0.186	**.65**
Final Parameter Values Selected and Weld Bead Geometry					
Ar/H_2 (95/5)	***Th***	***60***	**0.119**	**0.183**	**.65**

Welds were made on test pipes and evaluated by metallography – Figure 4 is typical of these welds. The selected parameters were further evaluated and subsequently modified through a series of test welds using mockups of actual 3013 containers. During the course of this effort, the need for additional weld bead control was recognized and a chill block was added to the process. Chill block design considered material thermal properties, chill block mass, surface finish and the force applied at the chill block/lid interface. Figure 5 provides a sketch of the chill block and details the pertinent design and operational criteria. Having added the chill block to the process, a set of target welding parameters was

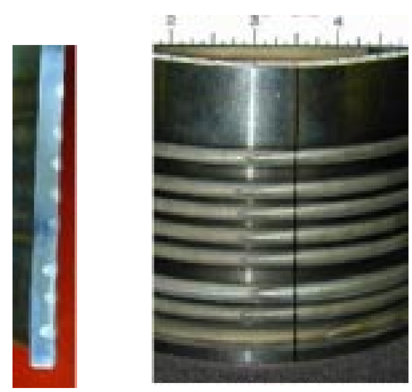


Figure 4. Metallography on Welded Test Pipes

established that produced the desired weld bead shape - see Figure 6.

With the target welding parameters identified, the following series of test welds, designed to identify the overall process and operational windows, was conducted.

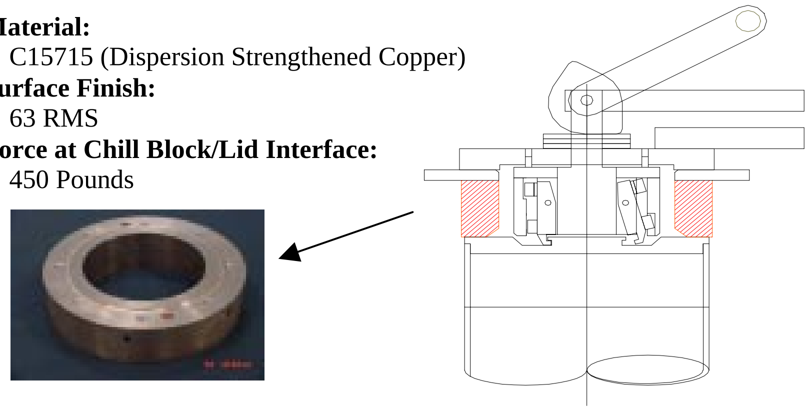


Figure 5. Chill Block Sketch and Details

Statistical Evaluation of Target Welding Parameters

A series of test welds was conducted to explore the impact of variation in weld current, arc gap and travel speed. In the first set of these welds, each target parameter was varied over a range judged likely to bound typical process variation, based on process tolerances. Specifically, the primary weld current was varied +/- 5 amps, the arc gap was varied +/- 0.007 inch, and the travel speed was varied +/- 0.02 rpm. The eight possible combinations of these extremes were tested, along with three replicate conditions and one at the baseline condition. All of these welds exhibited full penetration and acceptable aspect ratio.

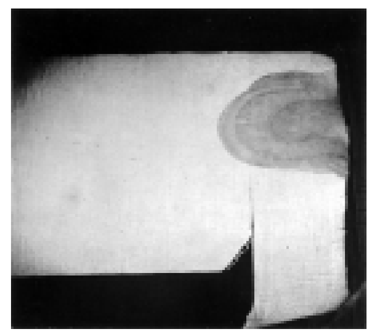


Figure 6. Weld Cross-Section

The second set of welds was made after preliminary evaluation showed that all welds in the first set were acceptable. The parametric ranges were expanded to identify potential margins that existed with respect to the operating range. In these expanded ranges, the primary current was varied by up to +15 / -25 amps, the arc gap was varied +/- 0.010 inch, and the travel speed was varied by up to 0.04 rpm. These ranges were designed such that the change in energy input from the increased primary current approximately offset that from the increased travel speed. Alternatively, the impact on total energy input from a combination of increased primary current and slower travel speed is additive. In this set of test welds, ten combinations were tested, with two replicates. All of these welds exhibited full penetration and acceptable aspect ratio.

The final set of test welds repeated eight of the parameter combinations from the second set. These eight welded containers were burst tested. In each case, a maximum pressure was reached as the container sidewall began to balloon out. The test was stopped prior to rupture. All containers sustained a maximum internal pressure of 4340 to 4510 psig.

These three sets of test welds identified two parameter combinations with a potential to produce upset conditions. A combination of high current and large arc gap consumed the top edge of the lid in some cases, leading to loss of dimensional control. A subsequent change in the chill block material from UNS C18200, chrome-copper to UNS C15715, aluminum-oxide dispersion strengthened copper (improved thermal properties) eliminated this problem. A combination of high current and small arc gap led to the electrode touching the weld. This particular combination was considered when establishing the final operating parameters by selecting values that provided ample margin to avoid such conditions.

The data from these welds were evaluated using various statistical models/tools to optimize the target parameters within the established ranges. Figure 7. illustrates the ability of one of these tools to help identify optimum welding parameter settings. This particular contour plot, developed from the weld data, provides a graphical representation of weld bead penetration as a function of primary arc current and arc gap.

Statistical analysis of the weld data led to a shift in the original target parameter settings to what was then identified as the production welding parameters – See Table 3.

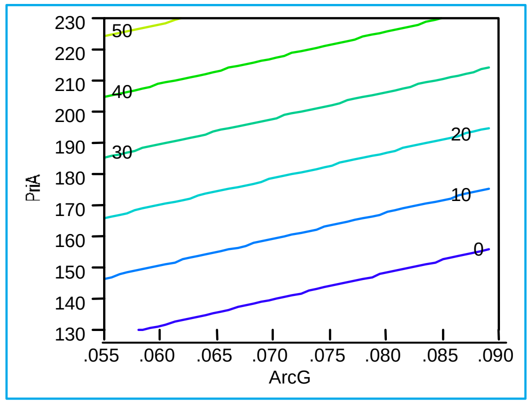


Figure 7. Contour Plot (Penetration in excess of defined full penetration as a function of Arc Gap (inches) and Primary Current (amps))

Table 3. Production Welding Parameters

Primary Pulse Current	180 A @ 0.45 S
Background Pulse Current	40 A @ 0.20 S
Arc Gap	0.066"
Travel Speed	0.60 RPM During Background Pulse Only

Discussion

In addition to development of the welding parameters noted above, other process conditions affecting weld quality were evaluated and are summarized as follows:

Container internal pressure and venting: The lid, when pressed into the container, creates a seal by virtue of a designed interference fit at the lid-plug/container-wall interface. Immediately prior to closure welding, the loaded 3013 container is backfilled with helium to facilitate post-weld, sensitive leak testing. To evaluate the container's ability to adequately vent or relieve expanding internal gases during the course of welding, several test welds were performed with can/lid combinations at the maximum design interference fit. In addition, container internal-pressure behavior during welding was characterized by use of a pressure transducer. It was observed that the pressure builds to a value of nearly 0.3 psig and then vents, through the unwelded portion of the weld joint, to some equilibrium pressure established between the internal backfill and external shielding gases. This pressure fluctuation repeats several times throughout the weld. It was concluded from this evaluation that container internal-pressure behavior does not adversely affect the quality of the closure-weld.

Chill block development and qualification: As noted above, a chill block was added to the process to protect the lid's top corner from being consumed by the weld. The chill block, placed in direct contact with the top surface of the lid, limits bead width by removing excess welding heat.

Finite element analysis was performed to identify a pressure or compressive stress at the chill block/lid interface sufficient to ensure continuous contact during welding and hence maintain good thermal transfer. A minimum contact stress of 43 psig was specified along with a maximum surface roughness at the lid/chill block interface of 63 micro-inch. The material selected for the chill block is a dispersion-strengthened copper alloy, UNS C15715. This material has equivalent mechanical properties to the more common chrome-copper alloys typically utilized for such applications, but has considerably better thermal properties.

Chill block force is applied to the lid by a specially designed tool that grips the center (pintel) of the lid. The pintel is engaged by three jaws when the tool lever is rotated and force is applied by pulling the cam-action lever over the top of the tool. In addition to its thermal function, the chill block, which is integral to the weld head, helps to align or center the can with respect to the orbiting tungsten and provides a mechanical stop automatically locating the cross-seam position of the tungsten tip.

Tacking and Weld Start Conditions: A tacking sequence was implemented to maintain axial and radial fit-up of the weld joint during welding. Seven small tacks (approximately 3/16 inch in length and 0.040 inch deep) are deposited evenly around the can at 45-degree intervals with the weld beginning at the eighth octant - see Figure 8.

Figure 8. Typical Tack

During weld development it was observed that bead penetration was somewhat less at the weld start than in the remainder of the weld. To compensate for this, a preheat was added to the start of the weld by holding the arc stationary for several seconds.

Base Metal Chemistry Evaluation: The effects of low levels of sulfur on bead penetration and shape in fusion-welded austenitic stainless steels are well documented. As noted previously, controlling weld bead geometry was of primary importance, therefore the effects of base metal chemistry were closely considered. Weld bead penetration and shape were correlated to the different levels of sulfur as supplied by the various heats of container and lid materials used in the development testing. The full range of sulfur, as specified in the ASME material specification, was not available for direct evaluation. Results of the tested levels however, when combined with information from the welding literature provided sufficient data to prescribe specific sulfur levels for this application. In addition to bead geometry, sulfur levels at the upper end of the material's specified range were evaluated for their potential deleterious effect on weld bead solidification. Sulfur levels specified: Container Shell = 50 to 250 ppm S; Lid = 100 to 250 ppm S.

QUALIFICATION OF THE PROCESS WELDING PARAMETERS

Formal Qualification Testing

Having identified the production welding parameters, the process was then subjected to weld qualification testing as required in the DOE 3013 standard. Table 4 lists the various tests performed along with their results – all testing met specified acceptance criteria. Figures 9 and 10 provide photographs of drop and burst testing, respectively.

Table 4. Qualification Test Matrix and Results

TEST	NUMBER	ACCEPTED	SOURCE REQUIREMENT
Leak Check	Each Can	All Cans	DOE Standard 3013
Dimensional Check	Each Can	All Cans	DOE Standard 3013
Drop Test	12	12	DOE Standard 3013
Proof Test	3	3	DOE Standard 3013
Sensitization (CE)	1	1	DOE Standard 3013
Metallography	1	1	DOE Standard 3013
Burst Test	3	3	Waste Acceptance
Crush Test	6	6	Waste Acceptance
Radiographic Test	1	1	Waste Acceptance
Stacking Test	3	3	Waste Acceptance

Demonstration of the Qualified Welding Process

Reliability Testing: Following the qualification activities, a run of 100 test welds was made to test the durability of the equipment and to evaluate various process upset conditions. Upset conditions were selected based on their perceived likelihood of being encountered under production operations. Table 5 lists the upset conditions, evaluation technique and results. In general, the process responded well to the various conditions. Wide variations in welding current were easily accommodated. Loss of weld shielding gas and residual container internal pressure led to poor welds, as one might expect. Overall, the process was deemed robust and capable of producing acceptable closure welds, even under some off-normal conditions.

Top Corner

Figure 9. Container Prepared for the 30-Foot Drop (left). Tested Container

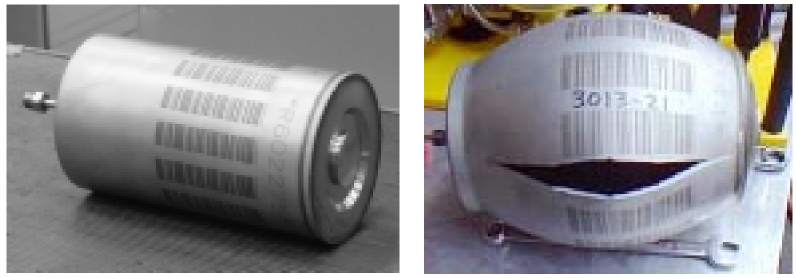


Figure 10. Prepared Container (left), Tested Container (failure completely outside of closure weld)

Table 5. Process Upset Conditions Evaluated

Upset Conditions	Evaluation Technique	Results
Lid/Can Separation	VT and Metallography	Tolerant
Oil Contamination at Weld Joint	VT and Metallography	Tolerant
Purge and Shield Gas Variations	VT and Metallography	Intolerant to extremes
Simulated Electrical Faults	VT and DAS	Tolerant
Backfill Gas Pressure Variations	VT	Intolerant to extremes
Reduced Chill Block Clamp Force	VT and Metallography	Tolerant
Low and High Weld Current - 140 to 225 A	VT and Metallography	Tolerant

Customer Acceptance Testing: Prior to delivery of the closure welding system, five 3013 containers were welded using qualified operators under mock production conditions in accordance with QA-approved procedures. In addition, full oversight was provided by the Hanford Authorized Inspector for these tests. The completed welds were subjected to leak, radiographic and metallographic testing. All testing met specified criteria. Figure 11 shows the completed and installed OCW system.

Figure 11. Installed OCW System

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REFERENCES

[1] *Stabilization, Packaging, and Storage of Plutonium-Bearing Materials*, DOE Standard 3013-99, November 1999