

WASTE-PACKAGE FABRICATION AND CLOSURE- WELD DEVELOPMENT FOR THE YUCCA MOUNTAIN PROJECT

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ABSTRACT

The US Department of Energy, Office of Civilian Radioactive Waste Management, is studying the suitability of siting the proposed repository at Yucca Mountain, Nevada. The waste packages are being designed to hold bare spent fuel assemblies, canistered fuel, and other high-level wastes after their emplacement in the repository drifts, where they will be isolated from the environment for thousands of years.

Framatome Technologies (FTG), as part of the Civilian Radioactive Waste Management System (CRWMS) – Management & Operating (M&O) Contractor, has been actively involved in developing waste-package fabrication and closure-weld techniques since 1995. From a basic development of welding parameters for carbon steel and nickel-based alloys, FTG has progressed to fabrication of scaled waste packages for demonstrations of remote closure welding and non-destructive examinations. This paper describes the fabrication of double-wall, shrink-fit cylinders with narrow-groove weld preparations that allow the closure lids to be single-bead welded. The development of remote hot-wire gas-tungsten arc welding and non-destructive examination techniques is also discussed.

INTRODUCTION

The US Department of Energy (DOE), Office of Civilian Radioactive Waste Management, is studying the suitability of siting the proposed repository at Yucca Mountain, Nevada. The waste-package (WP) fabrication and closure-weld development program is part of a larger engineering development program to develop waste package designs. The purpose of the larger program is to develop proposed WP designs that the Nuclear Regulatory Commission will find acceptable and will license for disposal of 70,000 metric tons of heavy metal from spent nuclear fuel (SNF), non-fuel components, and vitrified high-level waste (HLW) within the monitored geologic repository (MGR). The SNF will arrive at the repository either as bare fuel assemblies or in sealed dual-purpose or multipurpose SNF canisters. Each SNF canister will be disposed of as appropriate: the canister will be determined to be suitable for disposal and then placed into a disposal container (empty waste package) or the canister will be opened and the SNF assemblies removed for direct placement into a disposal container. Once sealed and emplaced in the repository drifts, the waste packages will isolate the high-level wastes from the environment for thousands of years.

Individual SNF assemblies are contained in a proposed disposal container consisting of an outer barrier of corrosion allowance material, an inner barrier of corrosion-resistant material, internal structural supports (basket), and criticality control material (neutron absorber), if necessary. This design configuration is called an uncanistered SNF disposal container. Canisters suitable for placement directly into a disposal container, canistered SNF, DOE SNF, Naval SNF, and non-fuel component canisters will require a disposal container consisting of inner and outer barriers. The defense high-level waste (DHLW) disposal container is designed to contain several HLW pour-canisters that contain vitrified glass high-level waste (and possibly DOE SNF). (It should be noted that a disposal container is defined as the barriers [and attachments] plus any internal components; a waste package is a disposal container with a waste form placed inside and acceptable closure welds.)

Once the waste has been placed into the disposal container, the inner barrier lid and the outer barrier lid will be remotely welded into place and inspected to establish each corrosion barrier as a continuous unit. The measure of closure-weld quality will be the weld and heat affected zone (HAZ) corrosion characteristics relative to the corrosion barrier base materials. (Note that the barriers do not function as a pressure vessel.)

OBJECTIVE

The objective of the WP fabrication and closure-weld development program was (1) to prove that the shrink fit method of fabrication was a viable fabrication method to join the inner and outer cylinders, and (2) to determine how much contact was obtained between the cylinders, by fabricating a full circular mock up with approximately the same thickness and diameter as a typical waste package and approximately one-fourth as long. Also, the lid welding and non-destructive examination (NDE) development tasks had to demonstrate that the two (inner and outer) circular lids could be successfully welded in place and inspected using remote equipment.

SCOPE

The WP fabrication and closure-weld development program scope of work included all efforts required to develop and demonstrate a single welding process and weld joint design that would be suitable to close the disposal container. The scope was purposely narrowly defined (to demonstrate the remote weld and NDE processes) as it is expected that more optimal processes and refinements may be realized over time. (It will be a number of years until the first disposal containers are loaded, closed, and inspected at the repository, currently scheduled for the year 2010). The scope of work included the following tasks:

- a. Evaluation of the shrink-fit method of manufacture for the inner and outer cylinders;
- b. Development of the remote hot-wire, automatic gas-tungsten arc weld;
- c. Development of the remote NDE process for weld inspection;
- d. Observation (measurement) of residual stresses;
- e. Welding of both the inner and outer lids;
- f. Reporting of the results.

FABRICATION OF THE MOCK UP

The mock up fabrication consisted of one outer barrier, one inner barrier, an inner lid top and bottom, and an outer lid top and bottom. Figure 1 delineates the completed mock up. The outer barrier cylinder was made from rolled and welded plate. The outer cylinder was made from 114.3-mm (4.5-in.) thick SA-516 Grade 70 carbon steel plate. The ends of the plate were laid out and heated to approximately 899°C (1650°F) and crimped to a 752.50-mm (29.626-in.) inside radius. Layout of the length and bevel for the weld preparation followed, and the ends of the plate were flame cut to 30-degree bevels. The plate was then heated to approximately 899°C (1650°F) and hot rolled to a 1739.90-mm (68.50-in.) outside diameter (OD). The plate was then fit to an outside circumference of 5487.97 mm (216.062 in.) and tack welded. Submerged arc weld was used to weld the seam on the inside, and then the outside of the weld was backgouged to sound metal and magnetic-particle inspected. The outside of the seam was then welded by the submerged arc method and both the inside and the outside surfaces of the weld seam were ground smooth. The cylinder was then re-rolled and heat-treated at 593° to 621°C (1100° - 1150°F) between a minimum time of 2 hours and 45 minutes and a maximum time of 3 hours, above 593°C (1100°F). Machining of the outer cylinder lower end was completed in accordance with drawing requirements. Magnetic-particle and ultrasonic inspections were also completed over a 152.4-mm (6-in.) length that covered the weld preparation area for the outer lid; these inspections showed the material was acceptable. The outer cylinder was then dimensionally inspected and held for the shrink-fit operation.

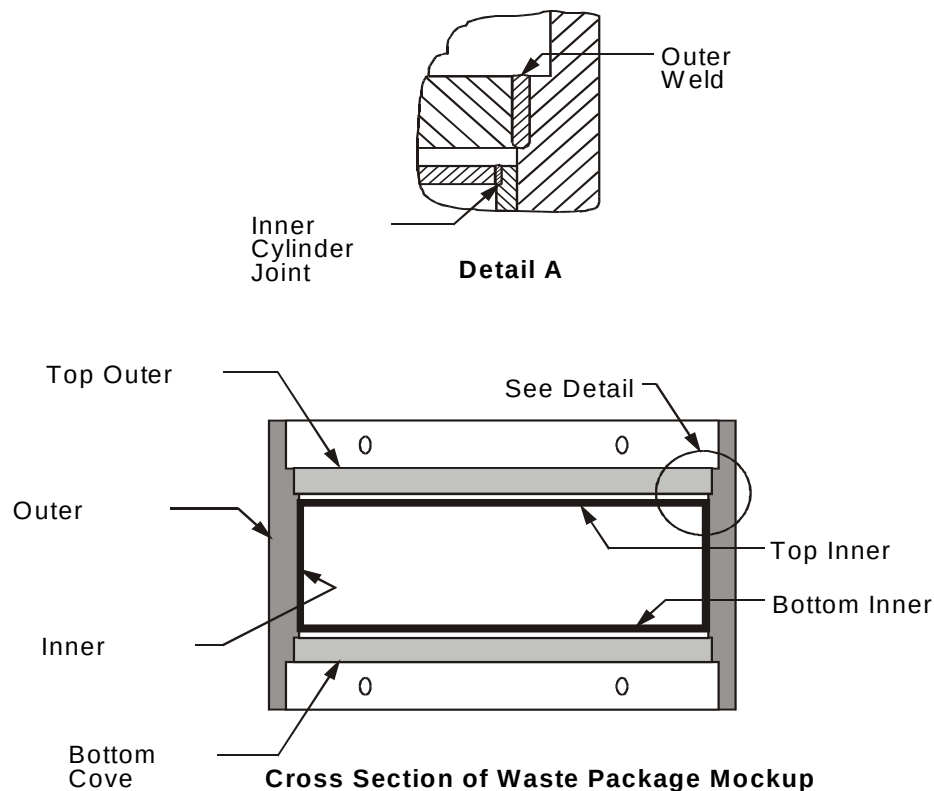


Figure 1. Mock Up Sketch

The inner cylinder was made from two plates, which were first welded together and then rolled and welded to form the cylinder. The material was 31.75-mm (1.25-in.) thick ASME SB-575 Alloy 22 plate. Machining the two plates to 25.4 mm (1 in.) and grinding a 30-degree bevel on

the edge of each plate began the inner cylinder fabrication. The plates were fit together and welded on one side by the manual shielded metal arc weld (SMAW) method. The weld was then backgouged to sound metal and liquid-penetrant inspected. Welding to complete the seam was accomplished using the manual SMAW method. The weld seam was then ground smooth on both sides and the plate was laid out and crimped on the ends to make it suitable for rolling. The plate was cold rolled to a 1473.2-mm (58.0-in.) inside diameter (ID), fit together, and welded on the inside with the manual SMAW method. The outside of the weld was backgouged to sound metal and liquid-penetrant inspected. Welding of the outside of the seam was completed using the manual SMAW method. The weld seams were ground smooth and the cylinder was sized to a 1525.78-mm (60.07-in.) OD. Machining of the length and the diameter was completed. The weld seams were liquid-penetrant inspected and the 50.8 mm (2 in.) at the end of the cylinder where the inner lid would be welded were ultrasonically inspected. The inner cylinder OD and the outer cylinder ID were machined to a 125 AA finish or better, and dimensionally inspected in preparation for the shrink fit.

The outer lids were made from 101.6-mm (4-in.) thick ASME SA-516 Gr. 70 carbon steel plate. The plates were ultrasonically inspected for defects within 101.6 mm (4 in.) of the weld preparation area. All inspections had acceptable results. The weld preparation was machined on the plates and dimensionally and magnetic-particle inspected.

The inner lids were fabricated from 25.4-mm (1-in.) thick ASME SB-575 Alloy 22 plate. The plates were ultrasonically inspected for defects within 50.8 mm (2 in.) of the weld preparation area. The weld preparation was machined on the plates and dimensionally and dye-penetrant inspected.

SHRINK FIT OF THE CYLINDERS

Following fabrication of the two cylinders as described above, the shrink fit of the inner and outer cylinders was performed. The outer cylinder was heated to approximately 371°C (700°F) using natural gas flame rings and flame logs. The inner cylinder was then lowered into the outer cylinder. The entire assembly was allowed to cool down by sequentially turning the flame rings off from the bottom up. This allowed the inner cylinder to be “locked” in place at the correct position. Thermocouples attached to the inner cylinder showed that its temperature was raised from room temperature to approximately 260°C (500°F) before starting to cool. Following cool down, machining of the weld preparation area was then completed on both the inner and outer cylinders on the lower end. Liquid-penetrant inspection was also performed on the inner-cylinder weld preparation area, with acceptable results.

MAPPING OF THE GAP BETWEEN THE CYLINDERS

Ultrasonic testing (UT) was selected as the non-destructive method for determining if a gap existed between the cylinders. Framatome Technologies, Inc. (FTI) developed the method, and the testing was performed at their Lynchburg, VA facility in accordance with FTI procedure No. 54-ISI-112 Rev. 9, *Ultrasonic Examination for Thickness Measurement Using Pulse-Echo Techniques*. This method was used after the shrink-fit operation but before the heat treatment of the first (bottom) lid welds, and again after heat treatment. The second UT was to determine if the heat treatment had any affect on the shrink fit of the cylinders. For both of the inspections, the method used was the same.

A square grid pattern was laid out on the outer cylinder outside surface over the area of contact between the inner and outer cylinders (note: the inner cylinder is only 558.8 mm [22 in.] long, less than half the length of the outer cylinder). Each test area was 38.1 mm x 38.1 mm, or 14.52 cm² (1.5 in. x 1.5 in. [2.25 sq. in.]). UT was then used to check for interface contact at the point of intersection of each of the grid lines. All measurements were obtained with the transducer on the outside of the carbon steel outer cylinder surface. The type of examination utilized produced essentially a spot reading (i.e., a relatively small area) through the material thickness; thus, the results were a grid of readings over the entire interface area.

A total of 2160 locations (a grid pattern of 144 x 15) was tested around the cylinder. Ultrasonic back-wall reflection, resulting from penetration of the inner cylinder Alloy 22 surface, was observed at all test locations. Assuming that the spot locations tested were representative of the entire cylinder contact area, this would correspond to 100 percent of the area with ultrasonic back-wall reflections through both the carbon steel and Alloy 22 materials. The outer cylinder inside surface and the inner cylinder outside surface were finished, machined to a 125 AA surface finish or better. During the GFY97 development program, the mock up formed an oxide layer on the inner- and outer barrier cylinders as a result of furnace heating to a nominal 538°C (1000°F) in an air atmosphere. Because heating during the GFY98 program was only to 371°C (700°F), an oxide layer did not form on this mock up. This was believed to have resulted in an improved interface condition, giving a 100-percent return signal for UT inspection, which would indicate 100 percent contact between the cylinders.

A method employed to corroborate the UT results was to drill a total of three holes through the two cylinders. Two of the holes were drilled through both of the cylinder walls at mid-height at 180° and 315°. These two holes were broached to produce one-inch slugs that could be examined for the interface surface. The third hole was a one-inch drill hole, located at 45° and 317.50 mm (12.50 in.) from the end surface of the mock up. This location corresponded to the root of the first (bottom) outer lid weld and allowed for inspection of the weld root. The surfaces of the holes were polished and etched for the purpose of identifying the interface. Visual examination indicated that there was no discernable separation (gap) between the cylinders at any of the three holes.

WELDING OF THE INNER LIDS

The upper and lower lids were welded using the same technique and procedure. The mock up was rotated and the weld head was essentially stationary. All of the welding and UT for the inner and outer lids were performed remotely, although the set up for the operations was not. The inner barrier lids (Alloy 22) were welded with the narrow-groove gas-tungsten arc welding (NG-GTAW) process, utilizing hot-wire feed. A chamber covering the entire top of the mock up was used to improve gas coverage. The weld joint geometry utilized was developed during the GFY96 development program and modified in an earlier phase of this GFY97 closure-weld development program. The geometry is illustrated in Figure 2. The filler metal used was 1.143-mm (0.045-in.) diameter ERNiCrMo-10, which conforms to ASME specification SFA 5.14 (2). The shielding gas used was a helium/argon (75 %/25 %) mixture; the trailing gas used was argon. The electrode was a 2% ceriated tungsten electrode with a 6.35-mm (0.25 in.) diameter.

Inner Barrier Weld Groove

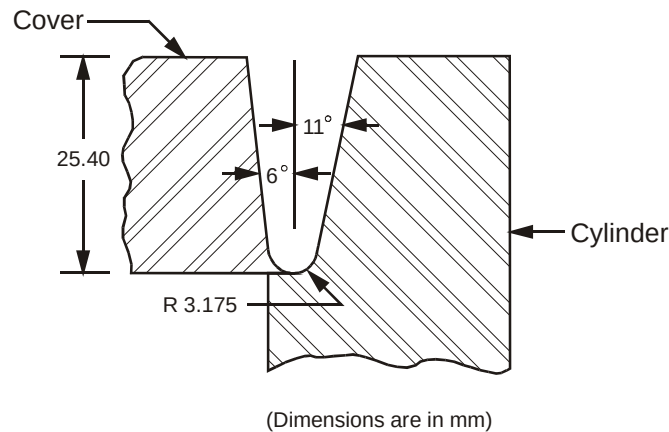


Figure 2. Inner Lid Narrow Groove Weld Joint Geometry

The fit-up of the lids resulted in a uniform 13.87-mm (0.546-in.) groove opening at the top of the joint. The weld joint was tack welded (machine welded) at 8 equally spaced locations. The tack welds were approximately 50.8 mm (2 in.) long and were performed with the NG-GTAW weld system with cold-wire feed. Cold-wire feed results in a small weld bead due to a low metal deposition rate, which is only a fraction of the hot-wire deposition rate; the small weld bead is desirable so as to obtain a uniform weld bead profile for the first layer weld with hot-wire feed.

To maintain the uniform groove width, three one-quarter length (hot wire) root passes were welded. The first was from approximately 0° to 90° , the second was from 180° to 270° , and the third from 90° to 180° . After the three one-quarter length root tacks were placed, the arc was initiated at 270° for the last quarter of the root weld, and then continued for the entirety of the weld. Once this last (fourth) arc initiation occurred, the weld was continuous with no more arc starts for the remainder of the weld, which validated the design objective of non-stop lid welding. The weld joints were completed utilizing nine weld passes and one final conditioning pass where filler metal was not added. The conditioning pass was performed to produce a weld surface conducive to the subsequent ultrasonic inspection. The conditioning pass was centered in the existing weld metal and did not fuse any base material. Arc time for a typical weld pass was approximately 23 minutes, which resulted in a calculated arc time of less than 4 hours for the complete weld.

Inner lid welding parameters are shown in Table I. Only small adjustments in voltage were made to the welding system during the weld to accommodate the small changes in the groove width. With the exception of the first pass, the hot-wire feed system was also consistent with respect to the hot-wire parameters listed in Table I.

Ultrasonic testing of the completed inner lid welds revealed no defects in either lid weld. (Note: the terms “defect” and “flaw” by the American Welding Society definition means discontinuities that are rejectable; discontinuities are interruptions in the typical structure of the material but are not necessarily defects.)

Remote UT was also conducted on the inner lid welds to test the feasibility of the process. The remote UT was performed using a semi-automatic process. The UT equipment was manually affixed and aligned to the mock up after each weld and remotely operated. The equipment performed the UT scan using a square wave radial pattern at four different angles (0° , 45° , 60° , and 70°). Although the main intent was not to acquire UT test data but to demonstrate process feasibility, the results also showed no defects in the lid welds. A manual UT to verify the results followed. In summary, both the weld groove design and the weld process were found to be acceptable for the inner lid weld.

Table I. Inner Lid Hot Wire Welding Parameters

Weld Parameter	Alloy 22
Amperage (A)	330 — 335 (280 for Tack Welds*)
Voltage (V)	12.1 — 13.0 (12.1 for Tack Welds*)
Ave. Travel Speed (in./min.)	8.0 (4.0 for Tack Welds*)
Wire Feed (in./min.)	160 – 168 (55 for Tack Welds*)
Ave. Deposition Thickness/Pass (in.)	0.10
Calculated Arc Time (including tacks) (hr)	4.5
Hot Wire Amperage (A)	72 — 83
Shield Gas (He/Ar) Flow (CFH)	45
Trail Gas (Ar) Flow (CFH)	20

*Note: Tack welds performed with cold wire welding

WELDING OF THE OUTER LID

Welding of the outer barrier lid was also completed with NG-GTAW, utilizing hot-wire feed. The weld groove geometry utilized was originally developed in the GFY96 phase of this program and was modified as a result of lessons learned in the GFY97 phase. This geometry is illustrated in Figure 3. The filler metal used was 1.143-mm (0.045-in.) diameter ER70S-6, which conforms to ASME specification SFA 5.18 (2). The shielding gas used was a helium/argon (75%/25%) mixture; the trailing gas used was argon. The electrode was a 2% ceriated tungsten electrode with a 6.35-mm (0.25-in.) diameter. The outer barrier lid weld was made without the addition of pre- or post-heat.

Outer Barrier Weld Groove

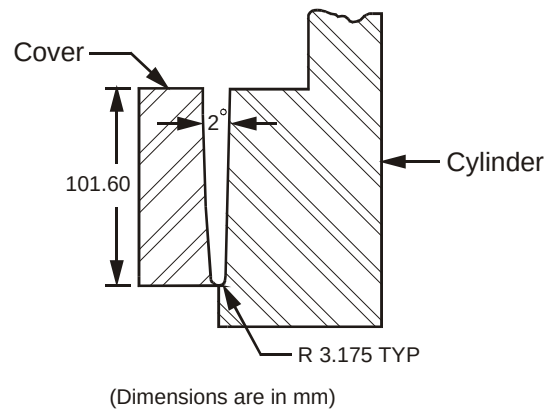


Figure 3. Outer Lid Narrow Groove Weld Joint Geometry

The fit-up of the outer lid resulted in a uniform 12.83-mm (0.505-in.) wide opening at the top of the weld joint. The weld joint was tack welded (machine welded) in 8 equally spaced locations. The tack welds were approximately 50.80 mm (2 in.) long and were performed with the NG-GTAW weld system with cold-wire feed. These tacks were required to keep a uniform weld groove width while the first beads were deposited.

Welding of the first layer (root pass) for the outer lid was initiated from one of the tack welds to eliminate the potential for burning through the lip at the bottom of the lid. Welding was accomplished with single-bead layers from the root pass to the final pass. This was an improvement from the GFY97 program in which it was necessary to use double-bead layers to ensure side-wall fusion after approximately half of the weld groove had been filled.

Increases in electrode life were experienced with the 6.35-mm (0.25-in.) tungsten electrode as compared to the GFY97 program. Selection of a larger electrode size, modification of the water-cooled gas box to eliminate the water from cooling the welding power cables as well as the gas box, and better gas coverage allowed for longer electrode life. The four arc starts (resulting from tungsten electrode changes) experienced on the first outer lid weld were primarily due to electrode degradation, which was caused by contamination. In an effort to reduce the electrode degradation and reduce the total number of arc starts, the filler wire for the second outer lid weld was stripped and cleaned. As stated above, the first outer lid was welded using standard ER70S-6 filler material. The second outer lid also used ER70S-6 filler but the wire was stripped of the copper protective coating and extensively cleaned to eliminate all possible contamination. The amount of noticeable contamination was reduced by this change.

Outer lid welding parameters are shown in Table II. Only small adjustments in voltage were made to the welding system during the weld to accommodate the small changes in the groove width as a result of weld distortion.

Table II. Outer Lid Hot Wire Welding Parameters

Weld Parameter	SA-516 Carbon Steel
Amperage (A)	425 – 470 (275 for Tack Welds*)
Voltage (V)	12.0 — 13.6 (12.0 for Tack Welds*)
Ave. Travel Speed (in./min.)	7.0 (4.0 for Tack Welds*)
Wire Feed (in./min.)	160 – 184 (60 for Tack Welds*)
Ave. Deposition Thickness/Pass (in.)	0.10
Calculated Arc Time (hr)	22
Hot Wire Amperage (A)	80 – 95
Shield Gas (He/Ar) Flow (CFH)	45
Trail Gas (Ar) Flow (CFH)	20

*Note: Tack welds performed with cold wire welding

Ultrasonic testing of both of the outer lid-to-outer cylinder welds was performed as follows. The first (bottom) outer lid weld and adjacent base material were examined with the 0° longitudinal and angle beam (45°, 60°, and 70°) transducers from the lid surface. A 0° longitudinal wave examination was also performed from the OD surface of the cylinder. A total of 13 indications were detected in the weld fusion zone with an additional 3 indications (laminations) detected in the adjacent base metal. The indications were detected with the 0° longitudinal wave from the OD cylinder scan. The indications were not detected with the angle beam examinations from the lid. This occurred because of the depth position of the indications with respect to the opposite surface and the data collection window widths.

Three of the 13 indications were classified as laminations in the carbon steel outer-cylinder base metal. The remaining indications were classified as potential lack of fusion because of their position at the weld fusion zone and orientation with respect to the weld.

All 16 indications were detected at random depths from the weld crown and were located at random spacing around the weld circumference. The indications appeared to be essentially planar with respect to the weld groove orientation.

The second (top) outer lid weld and adjacent base material were examined using the same technique as the bottom end welds. Three indications were detected in the weld fusion zone. The indications were detected with the 0° longitudinal wave from the OD cylinder scan, and the 45° and 60° angle beams from the lid surface. The indications were detected at 144°, 182°, and 226°. It is believed that a gap in the fusion line at the base of the weld root area caused the signal. This presumption is based on a simple penetrant test (PT) completed on a cross-sectioned sample of weld removed from an inner weld mockup (*Note: The sample was an available section that was*

similar to, but does not precisely represent, the outer weld geometry). The PT indicated that the “fused” metal region did not start at the base or root of the weld. It occurred just slightly above the root, which formed a small curved reflector. It is believed that this geometry was the origination point of this signal.

All 3 indications were detected at approximately the same depth (i.e., 88.9 mm or 3.5 in.) from the weld crown and located equidistant within a 90° section of the top outer closure lid. The indications appeared to be essentially planar with respect to the weld groove orientation. Because of their location in the weld fusion zone and orientation with respect to the weld, the indications were classified as a potential lack of fusion.

TEST WELD EQUIPMENT

Previous mock up (GFY97) welding for the WP closure-weld development program was performed with a hot-wire automatic GTAW process, but was not performed remotely. The use of hot-wire GTAW remote equipment was proposed for the GTAW process while maintaining the same or similar narrow-groove weld geometry used with the cold-wire technique used in the GFY96 mock ups. Framatome welding personnel believed the hot-wire process to be the most appropriate for the high production and high quality requirements of the production system to be used for welding the closure lids to the waste package. A Jetline HWP-200B was selected as the hot-wire power supply.

A welding power source was also acquired for the purposes of mock up testing. The welding power supply had to be capable of 500 amp, 100% duty cycle and have advanced control functionality for system integration. The Hobart Talon 500 power source was selected based on these criteria. The balance of the weld system utilizes existing Framatome equipment with the addition of a custom NG torch, a wire manipulator, and a gas box that fully covered the end of the mock up. A gas box that fully covered the end of the mock up was used for the first time on this year’s program to promote a complete inert atmosphere for welding. This was done to extend the life of the electrode, as any contamination is detrimental to the electrode. The existing equipment used for the mock up welding included a Jetline side beam, which provided travel for straight-line groove development, a Jetline CWF-23B cold-wire feeder converted for hot-wire, and a Jetline ALC-101E Arc Length Control. Integration of the Talon 500 power supply and the hot-wire power supply was an advancement made as part of the current development program. Consequently, the weld process was automated with the operator having the capability of making small adjustments to wire feed rate, arc voltage, hot-wire power supply settings, and travel, using a vision system. The mock up was rotated via a floor-mounted turning fixture.

It was desired that the production system be capable of continuous welding from root to cap. As such, the custom NG torch assembly needed a mean time between failure for changing or sharpening the tungsten electrode (MTBF) rate greater than 20 continuous arc-hours. The Framatome hot-wire NG technique from the GFY97 program required electrode replacement after 2 to 5 passes. The gas box assembly designed for the current year program utilized improved water cooling, a larger electrode, and higher levels of gas purity. The electrode was specified as a 6.35-mm (0.25-in.) diameter electrode versus the 4.763-mm (0.1875-in.) diameter electrode used previously in the hot-wire NG system. The alloying element remained 2% ceriated tungsten (versus 2% thoriated from early development work) to further enhance the electrode

service life. The electrode and electrode extension assembly were designed to maintain the cartridge feature, which facilitated the use of an automated tool changer for routine replacement.

The hot-wire process uses higher travel speeds than conventional cold-wire GTAW, and with the elevated amperages, the molten pool extends beyond the gas coverage of the welding torch. Therefore, additional shielding in the form of a trail gas box was provided to maintain the inert atmosphere until the weld pool solidified. The wire block and wire guide were fabricated from beryllium-copper alloy, chosen for its high electrical conductivity and good mechanical properties.

The design objective of a single electrode from root to cap was accomplished on both of the inner lid welds. However, the electrode required replacement after an average of 9.75 passes on the outer lid welds. This was due to the elevated amperage requirements of the carbon steel weld (~500 amps) versus the Alloy 22 inner lid welds (~350 amps). This does represent an improvement from the previous year's program in which electrode replacement was required after 2 to 5 weld passes.

CONCLUSIONS

The Waste Package Closure Methods development program described in this report has met the objectives of the GFY98 development program. The shrink-fit method of manufacturing had been proven to be a technically viable and cost-effective method of assembling the WP inner and outer barrier cylinders during the GFY97 development program. The GFY98 program proved that it was possible to do the shrink fit at a much lower temperature to avoid formation of an oxide coating and to consequently achieve 100% contact between the two barriers. The temperature measurements on the inner barrier at the time of the shrink fit proved that it would be possible to shrink fit more than two barriers together if that is required by future design changes.

The measurements necessary to compute post-weld residual stresses were obtained and provided to the structural engineering personnel for validation of their analyses. The additional residual stress measurements using the strain gage method added a quantifying number to the residual stress measurement.

Development of the narrow-groove hot-wire automatic GTAW proved to be successful in reducing weld times and improving longevity of the tungsten electrode (as compared to the GFY97 development program). The weld system assembled by Framatome performed well on the circular narrow groove, demonstrating that it is feasible to perform the closure welds remotely for the WP preliminary design configurations.

The UT indications detected in both the first and second outer lid closure welds exceed the reference calibration level and must be evaluated to the acceptance criteria listed in article NB-5330 subparagraphs (a) and (b) of the ASME Code (3). Subparagraph (a) states that imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding 19.05 mm (0.75 in.) for weld thickness greater than 57.15 mm (2.25 in.). None of the detected indications exceed the allowable length. If this were the only acceptance criterion, then both outer closure welds would be acceptable; however this is not the case.

Subparagraph (b) states the indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length. As mentioned earlier, the likely cause of the indications is lack of fusion.

The weld system will require further work to develop a totally remote capability. Additional development work is also needed to increase the life of the tungsten electrode, especially for the higher amperage outer barrier carbon steel weld. If other barrier materials are selected for the WP designs, they will need to be proven. Regardless of the materials, weld data acquisition, digital imaging, and other feedback systems will need to be developed to make the welding operation even more operator independent.

Testing of the interface contact between the inner and outer barriers was not conclusive in the GFY97 development program. The GFY98 program showed that it is possible to achieve 100% contact between the two barriers and maintain it through stress relief operations.

The GFY98 program also proved that it is possible to ultrasonically inspect the closure welds by remote methods. This was verified by performing a manual ultrasonic inspection immediately after the remote inspection and obtaining the same results.

Diametrical measurements on the diameter of the inner cylinder before and after shrink fit and after the stress relief showed that the inner cylinder is in compression after the shrink fit and that the compression lessens after stress relief.

One of the major changes in the development program from GFY97 to GFY98 was the use of a chamber that covered the entire top of the mock up. This change allowed for better gas coverage of the weld. This was a result of lessons learned in the hot wire automatic GTAW development. This chamber not only provides a better welding environment but also provides the possibility of shielding most of the weld equipment from ionizing radiation during WP welding.

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