SRNS-STI-2009-00564 Rev.1

INVESTIGATION OF THE POTENTIAL FOR CAUSTIC STRESS CORROSION CRACKING OF A537 CARBON STEEL NUCLEAR WASTE TANKS

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Publication Date: October 2009

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DOCUMENT: SRNS-STI-2009-00564 Rev.1
TITLE: Investigation of the Potential for Caustic Stress Corrosion Cracking of A537 Carbon Steel Nuclear Waste Tanks

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SRNS-STI-2009-00564 Rev.1

Table of Contents

List of Tables

List of Figures

EXECUTIVE SUMMARY

The evaporator recycle streams contain waste in a chemistry and temperature regime that may be outside of the current waste tank corrosion control program, which imposes temperature limits to mitigate caustic stress corrosion cracking (CSCC)[1]. A review of the recent service history (1998-2008) of Tanks 30 and 32 showed that these tanks were operated in highly concentrated hydroxide solution at high temperature. Visual inspections, experimental testing, and a review of the tank service history have shown that CSCC has occurred in uncooled/un-stress relieved F-Area tanks[2]. Therefore, for the Type III/IIIA waste tanks the efficacy of the stress relief of welding residual stress is the primary corrosion-limiting mechanism. The objective of this experimental program is to test carbon steel small scale welded U-bend specimens and large welded plates (12×12×1 in.) in a caustic solution with upper bound chemistry (12 M hydroxide and 1 M each of nitrate, nitrite, and aluminate) and temperature (125 °C). These conditions simulate worst-case situations in Tanks 30 and 32. Both as-welded and stress-relieved specimens have been tested. No evidence of stress corrosion cracking was found in the U-bend specimens after 21 days of testing. The large plate test was also completed after 12 weeks of immersion in a similar solution at 125 °C except that the aluminate concentration was reduced to 0.3 M. Visual inspection of the plate revealed that stress corrosion cracking had not initiated from the machined crack tips in the weld or in the heat affected zone (HAZ). NDE ultrasonic testing (UT) also confirmed subsurface cracking did not occur. Based on these results, it can be concluded that the environmental condition of these tests was unable to develop stress corrosion cracking within the test periods for the small welded U-bends and for the large plates welded with an identical procedure as was used in the construction of Savannah River Site Type III nuclear waste tanks in the 1960s. The observations of no evidence of stress corrosion cracking or general corrosion in the laboratory specimens indicate that the Type III/IIIA nuclear waste tanks, in particular, Tanks 30 and 32 (which are Type III tanks), are not susceptible to highly caustic solutions up to 12 M hydroxide at 125 °C when sufficient nitrite inhibitor is present.

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1 "CSTF Corrosion Control Program," WSRC-TR-2002-00327, Rev. 4, December 2007.

2 "An Assessment of the Service History and Corrosion Susceptibility of Type IV Waste Tanks," B. J. Wiersma, SRNS-STI-2008-00096, September 2008.

1. INTRODUCTION

The service history of Tank 30 (3H evaporator drop tank) and Tank 32 (3H evaporator feed tank) from 1998 to 2008 showed that the nitrate concentration $[NO_3^-]$ decreased to less than 1 M while the hydroxide concentration $[OH^-]$ remained as high as 12 M [1]. The temperatures in these tanks were also approaching 80 to 100 °C. This condition exceeded the current waste tank corrosion control program, which imposes temperature limits (60 °C) to mitigate caustic stress corrosion cracking (CSCC) [1,2]. It was concluded by an electrochemical experiment [3,4] with solutions consisting of 10 M $[OH^-]$ and up to 2 M $[NO_3^-]$ and at temperatures from 60 to 95 °C, that low-carbon steels may be susceptible to caustic stress corrosion cracking (CSCC). That set of experimental data suggested that, at a reduced $[NO_3^-]$ level, the corresponding corrosion potential (E_{corr}) was unable to suppress the initial active-passive transition peak. Therefore, it led to a conclusion that Tanks 30 and 32 might rely solely on the relief of welding residual stress to provide protection against CSCC by diminishing the internal driving force to cause cracking in the heat affected zone (HAZ). The heat treatment for stress relief also resulted in the formation of an oxide film which would further delay the stress corrosion cracking (SCC) in the waste tanks.

The chemistry and temperature histories of Tanks 30 and 32 in the past ten years can be seen in Figures 1 and 2 (reproduced from Ref. [1]). The most critical location can be identified at Tank 32 Bottom Plate (see Fig. 1, curve in cyan), where a high temperature above 120 °C occurred for an extended period of time. Note that Tank 30 experienced a much higher temperature surge (Fig.2, yellow curve), but that temperature dissipated quickly because there is no sludge in Tank 30 to provide latent heat as in the case of Tank 30.

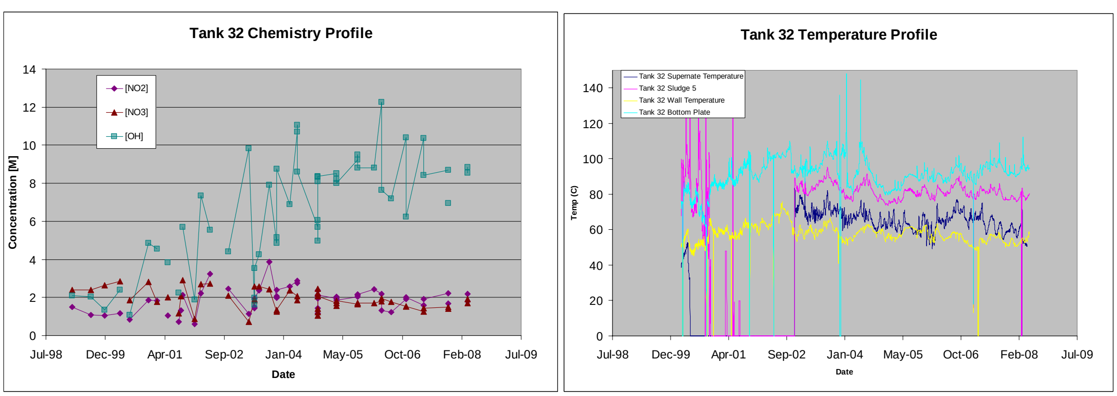


Figure 1 Chemistry and temperature profiles for Tank 32 [1].

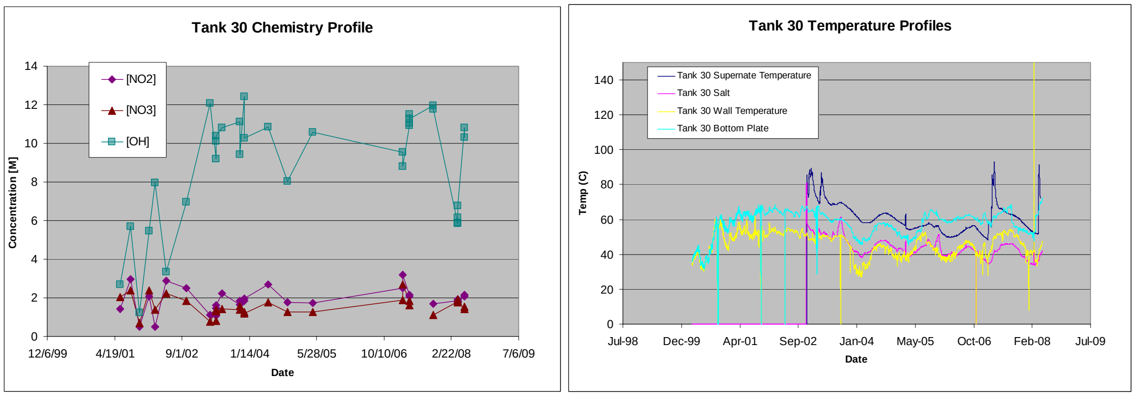


Figure 2 Chemistry and temperature profiles for Tank 30 [1].

In an earlier study[†] [5] sponsored by Westinghouse Savannah River Company High Level Waste Division [6] and by the U. S. Department of Energy Office of Science [7], the nitrate stress corrosion cracking in A285 carbon steel for Types I and II waste tanks was shown to be effectively eliminated by relieving the welding residual stress through heat treatment. Figure 3 shows the stress corrosion cracks growing from the initial, machined seed cracks in an as-welded, non-heat treated A285 plate, which was submerged in a 5 M sodium nitrate solution at 90 °C. Meanwhile, no cracking could be found even by ultrasonic testing in the companion test plate which had been heat treated. The stress corrosion cracking was initiated from the seed cracks as early as two weeks following immersion in the aggressive solution (no inhibitors were present).

Front Side Back Side

Figure 3 Nitrate stress corrosion cracking of the as-welded A285 plate for Types I and II waste tanks (reported in 2002) [5].

[†] The work was also sponsored by the U. S. National Science Foundation Grant CMS0116238 to the University of South Carolina (PI: Professor Y. J. Chao) in welding simulation, residual stress calculation, and fracture mechanics analysis to quantify the extent of stress corrosion cracking.

Following a similar approach, a representative material of construction for Type III waste tanks, A537 carbon steel, was used to fabricate the test specimens (small scale welded U-bends and the large welded plates). These were tested in a highly caustic solution defined by the bounding chemistry conditions of Tanks 30 and 32 (i.e., 12 M hydroxide and 1 M each of nitrate, nitrite, and aluminate) and a temperature of 125 °C, which may be close to the boiling temperature of the solution. The objective of the current investigation is two-fold: 1) to determine if CSCC can indeed occur under the test environment; and 2) if CSCC takes place in the as-welded specimens, it is necessary to confirm the efficacy of residual stress relief so the current state of Tanks 30 and 32 are temporarily protected from CSCC.

No cracking was found in the U-bend specimens within the scheduled 21-day test. Some U-bend specimens were left in the test station for up to 95 days and yet no SCC was observed. It should be noted that during the extended test, the concentrations of the test solution was changed to unknown states (more concentrated) and became sludge-like resulting from evaporation. Condensers were installed, but were not intended for very long testing beyond 21 days. The temperature was maintained at or slightly above 125 °C.

The large plate test has been concluded after 12 weeks of immersion in a 125 °C caustic solution composed of 12 M hydroxide, 1 M nitrate, 1 M nitrite, and 0.3 M aluminate (slightly modified from the U-bend test solution which contained 1 M aluminate). No surface stress corrosion cracking, as shown in Figure 3, was found by visual inspection. Ultrasonic testing was also conducted for the as-welded and the heat-treated plates. No stress corrosion cracking inside the plates was detected.

These test results lead to the conclusion that the chemistry environment for the testing at 125 °C provided a favorable condition for A537 to inhibit stress corrosion cracking. The cracking might have been retarded by the nitrite ions, which are strong oxidizing agents, and may have allowed the continuous formation of a protective oxide film on the test specimen surfaces. This has been demonstrated through the freshly exposed areas where Clarke's solution was used immediately before immersion to remove the oxide formed at the machined crack tips at which stress corrosion cracking is most likely to occur.

Careful examination of the specimen conditions found that many distinct surface features originally on the mill sheet remained visible on the specimens after testing, and the detailed appearance of the weld beads was essentially unchanged. The specimen thinning was immeasurable with a micrometer. Therefore, the general corrosion is negligible for A537 carbon steel which has been exposed to 12 M caustic solution for extended period of time.

It has been shown through the laboratory testing that stress corrosion cracking did not occur in the small welded U-bend specimens and in the large plates fabricated with an identical welding procedure as was used in the construction of Savannah River Site (SRS)

Type III tanks in the 1960s. The observations of no evidence of stress corrosion cracking or general corrosion in the laboratory specimens indicate that the Type III/IIIA nuclear waste tanks, in particular, Tanks 30 and 32 (which are Type III tanks), are not susceptible to highly caustic solutions up to 12 M hydroxide at 125 °C when sufficient nitrite inhibitor is present.

2. EXPERIMENTS

Two types of specimens were used: 1) small scale U-bends (Fig. 4) with a before-bent dimensions of 5-in. long, 1 in. wide, and ⅛ in. thick; and 2) large plate (12×12×1 in., formed by welding two 6×12×1 in. sections together) with machined seed cracks (Fig. 5). Each specimen contained a weld. Heat treatment to relieve the welding residual stress was applied to half of the specimens. Both sets of the specimens (as-welded and heat-treated) were submerged side by side in the same caustic solution at 125 °C.

Figure 4 U-bend specimen (Ref. [10,13]).

Figure 5 Large-plate specimen (Ref. [4]).

2.1 Test Solutions

The test condition was chosen to bound the chemistry and temperature histories since 2002 for Tanks 32 and 30, respectively, as shown in Figures 1 and 2. The test solution was made from 12 M hydroxide $[OH^-]$, 1 M nitrate $[NO_3^-]$, 1 M nitrite $[NO_2^-]$, and 1 M (for the U-bend test) or 0.3 M (for the large plate test) aluminate $[AlO_2^-]$ by dissolving salts of NaOH, $NaNO_3$, $NaNO_2$, and $2(NaAlO_2)•3H_2O$ at above-room temperature. After the solution was transferred to the immersion test vessels, the temperature was raised to the target 125 °C in three 1.6-liter Teflon beakers for the U-bend test and a 6-gallon Hastelloy (C-276) test tank for the large plate test.

An adequate ratio of solution volume to specimen surface area was maintained. The ASTM G 123-00 (Reapproved 2005), “Standard Test Method for Evaluating Stress Corrosion Cracking of Stainless Alloys with Different Nickel Content in Boiling Acidified Sodium Chloride Solution,” suggests that the ratio be 5 ml/cm^2 or 33 ml/in^2 (G 123 Paragraph 10.6). The corrosion product build-up due to general corrosion during this CSCC experiment was not expected to affect the test environment (solution) as much as that under the conditions specified in ASTM G 123. Therefore, using the ratio recommended in ASTM G 123 was considered appropriate.

2.2 Test Material Selection

The SRS Type III and Type IIIA Tanks were constructed with carbon steels ASTM A516-70 or A537 [8-12]. These two carbon steels have similar carbon contents and yield strength ranges [11]. In addition, they have been shown to exhibit comparable SCC resistance [13]. Therefore, welded A537 was chosen as the test material for investigating CSCC behavior in the evaporator recycle streams in Tanks 30 and 32, which were made of A516-70. This material selection was in parallel with a previous study for the determination of corrosion inhibitor criteria for Type III/IIIA tanks during salt dissolution [14]. The nominal composition of A537 carbon steel is provided in Ref. [11] and is reproduced in Table 1. The carbon content of A537 used in Type IIIA tanks ranged from 0.14 to 0.23 wt.% [10,11].

Table 1 Nominal Composition of A537 Class I carbon steel (wt.%)[11]

C	Cr	Cu	Mn	Mo	Ni	P	S	Si
0.24 (max.)	0.25 (max.)	0.35 (max.)	0.65-1.4	0.08 (max.)	0.25 (max)	0.035 (max.)	0.04 (max.)	0.13-0.55

For comparison, the composition of the original material of construction for Tanks 30 and 32 (A516-70 carbon steel) is listed in Table 2 [9]. The actual Material Certificates for the A537 carbon steels used for fabricating the U-bend specimens and for the two large plates (as-welded and stress-relieved) are in Appendices 1 and 2, respectively.

Table 2 Composition of A516-70 carbon steel (wt.%) [9]
(Steels procured by Nooter Corporation from U. S. Steel Corporation)

C	Mn	P	S	Si
0.20-0.27	0.96-1.09	0.008-0.016	0.014-0.024	0.21-0.24

Yield strength: 43,100 - 60,900 psi
Ultimate strength: 70,100 – 79,300 psi
Elongation (gage= 8 in.): 19 – 29%

2.3 U-bend Test

The U-bend specimens were first cut from A537 mill sheet, ground from the original ⅜ in. to the desired ⅛ in., then welded perpendicular to the rolling direction. Shielded Metal

Arc Welding (SMAW) was applied with single pass on each side of the specimen [15]. The welding electrode certificate is shown in Appendix 3. This welded plate was then machined into a strip with dimensions of 5 in. long, 1 in. wide, and ⅛ in. thick [11,14,15] with the weld in the center of the strip in the longitudinal direction. The strip was bent around a mandrel with a radius of 0.505 in. [14] to form a U-bend specimen. Figure 6 (from Refs. [11,15]) shows the schematic of fabricating the U-bend specimen that contains a weld in the mid-section lengthwise. The specimen fabrication and assembly are consistent with ASTM G 30 - 97 (Reapproved 2003) entitled "Standard Practice for Making and Using U-Bend Stress-Corrosion Test Specimens."

Prior to submerging in the test solution, each pair of the specimen legs was bent approximately parallel. To maintain the shape without relaxing the elastic tensile strain, the legs were tightened by nuts and a screw which are properly insulated with Teflon washers and sleeve to avoid the galvanic effects between two different materials (Fig. 4).

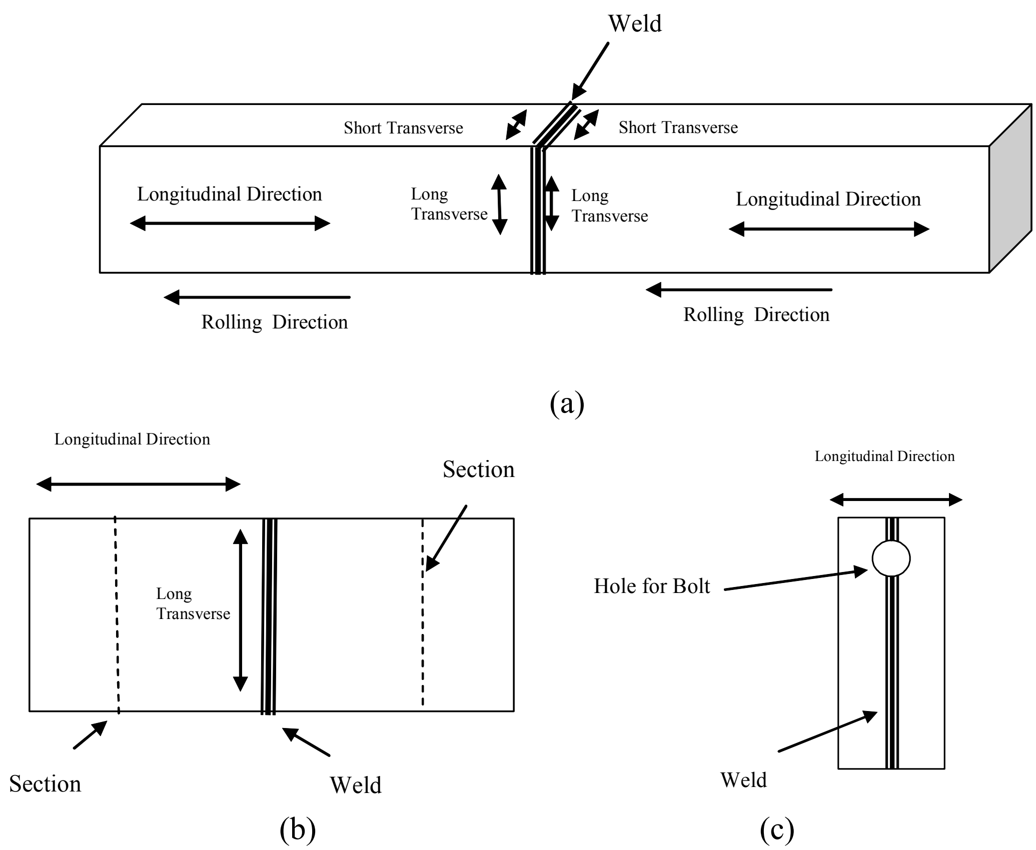


Figure 6 (a) Schematic of the two welded plates from mill sheet, (b) schematic of the weld and the orientation for the U-bend specimen, (c) side view of the final U-bend specimen after bent around a mandrel [11,15].

2.3.1 Stress Relief Heat Treatment for U-bend Specimens

Two sets of U-bend specimens were tested simultaneously: (1) as-welded and (2) heat-treated for welding residual stress relief. The heat treatment was guided by 1968 ASME Boiler and Pressure Vessel Code Section VIII, Paragraph UCS-56, which was used in the construction of SRS nuclear waste storage tanks in the 1960s. Based on the recommendation of Ref. [16], the heat treatment procedure is summarized as follows:

(1) The heat treatment is conducted in air.
(2) Heating from ambient to 1100 °F at a rate of 90 °F/hour.
(3) Holding at 1100 °F for 60 minutes.
(4) Cooling to ambient at a rate of 115 °F/hour.

2.3.2 U-bend Test Setup and Procedure

The testing used a total of eight U-bend specimens (Figs. 4 and 6), four of which were as-welded (fabricated and assembled per ASTM G 30) and the other four were heat treated (Section 2.3.1) prior to assembling. These eight specimens were submerged in three commercially available Teflon beakers filled with the pre-mixed caustic solution (Section 2. 1). These specimens were deployed in three beakers in the following manner to reduce the potential of experimental errors caused by any changes of solution concentrations and the fluctuation of the heater temperatures:

Beaker 1: one as-welded and two heat treated U-bend specimens
Beaker 2: two as-welded and one heat treated U-bend specimens
Beaker 3: one as-welded and one heat treated U-bend specimens

Figure 7 shows these specimens suspended with Teflon wires from the hooks that were built as part of the glass cap of the Teflon beaker. The glass cap has opening ports to accommodate the condenser and two thermocouples (Fig. 8). In addition, an extra port is available as needed, so a thermometer, for example, can be inserted to directly measure the solution temperature independent of the digital temperature controller readings. Each Teflon beaker was heated with an electric mantle to maintain the test temperature at 125 °C. A glass condenser (Graham type, see Fig. 9) was fabricated for each of the beakers to recover the water vapor and to maintain constant salt concentrations in the test solution.

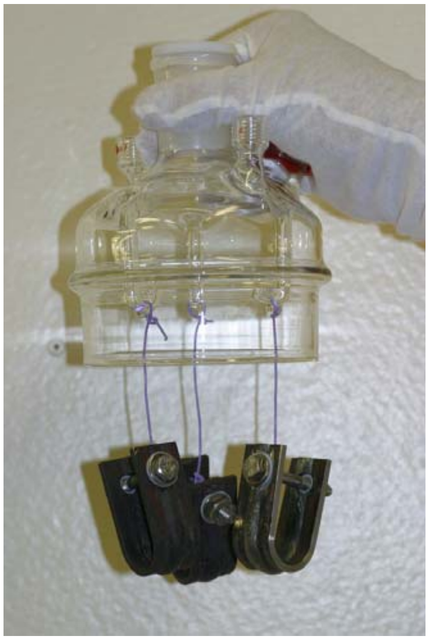


Figure 7 U-bend specimens are suspended from the hooks inside the glass cap to the beaker.

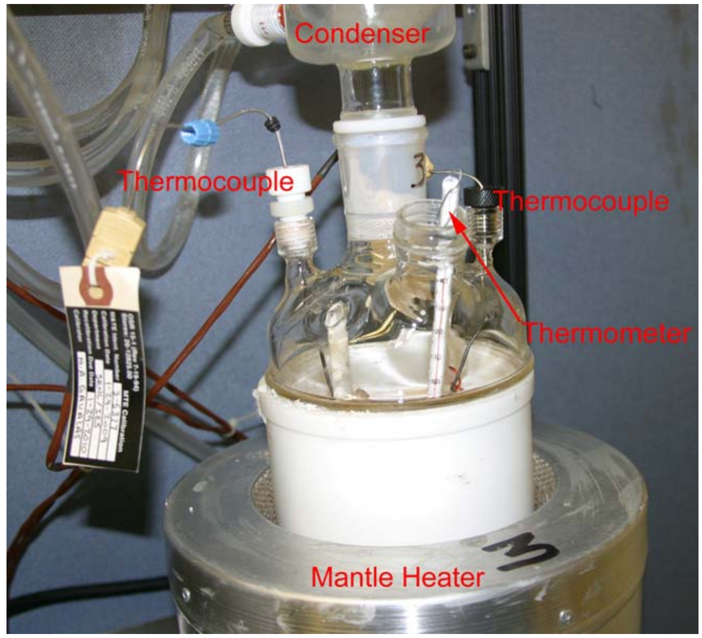


Figure 8 The assembly of the test beaker.

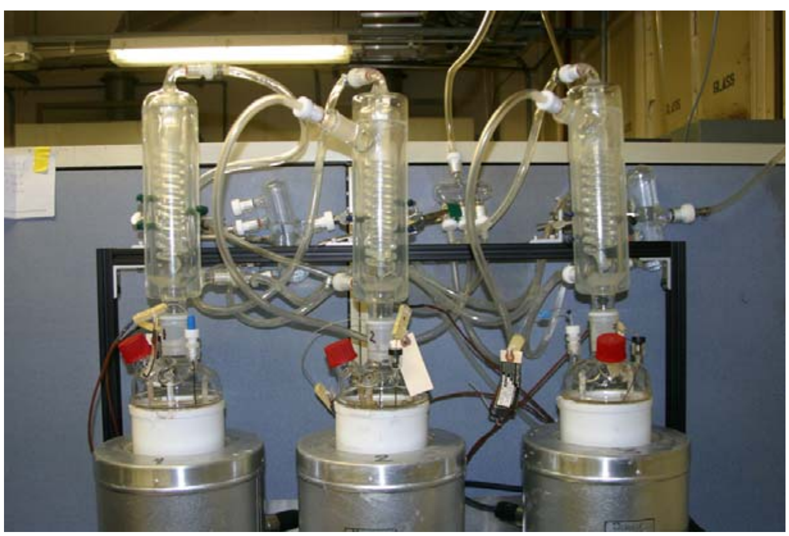


Figure 9 Graham Condensers on top of the test beakers.

The overall laboratory setup can be seen in Figure 10. The duration of the testing was 21 days. The U-bend specimens were examined periodically for cracking during the test period.

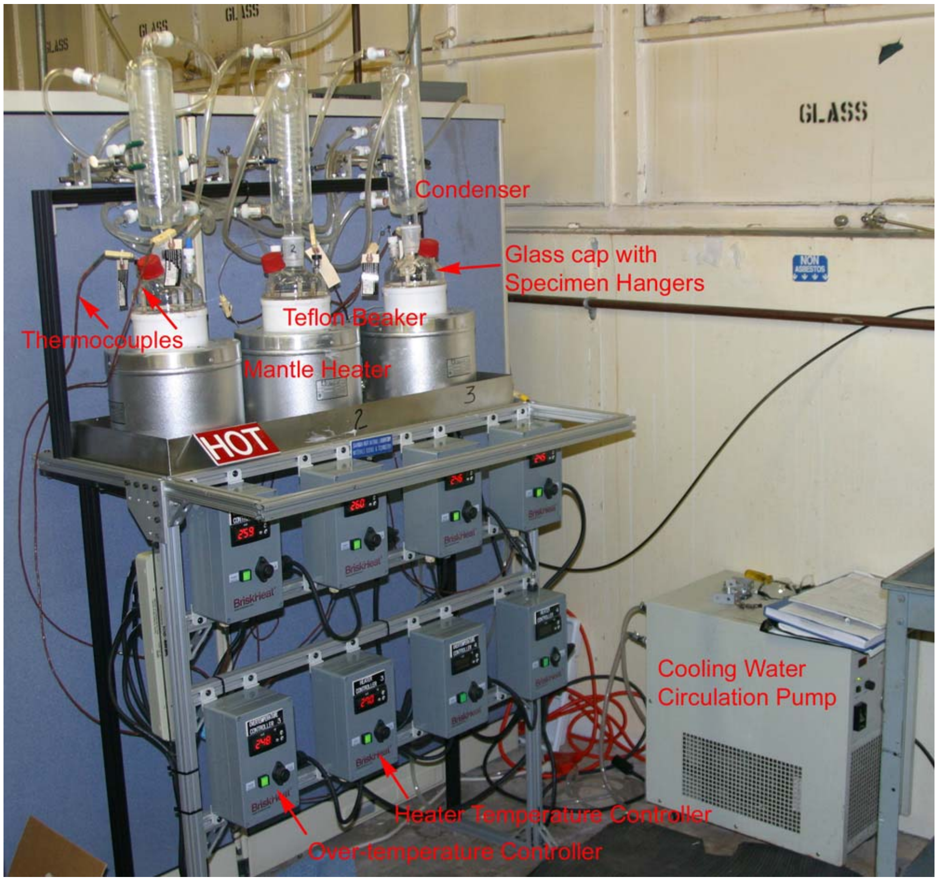


Figure 10 U-bend test station

2.4 Large Plate Test

The large plate test was designed to simulate the corrosion response of welded waste tanks (in particular, Tanks 30 and 32) with highly caustic waste form at very high temperature. The size of the plate specimen allows the use of the actual waste tank wall thickness and the actual welding practice as specified in the original engineering drawings [17]. The welding of the large plate also provides a constraint which is inherent to a large structure when welding is performed in-situ during construction. This constraint may affect the severity of welding residual stress that is developed in the heat affected zone. Similar to the U-bend test, an as-welded and a stress-relieved specimen were used. Identical heat treatment was used to relieve welding residual stress, as in the case of U-bends (see Section 2.3.1 and Ref. [16]). However, in the large plates, seed cracks (both through-the-plate and part-through cracks) were introduced across the weld and in the HAZ to create favorable SCC initiation sites [5]. The composition of the test solution was adjusted for the large plate test, that is, the aluminate concentration was changed to 0.3 M from the 1 M solution used in the U-bend test.

The test period for the large plate test was 12 weeks. The stress corrosion cracking, if any, could be observed visually by periodic inspection during the test. The magnetic particle test (MT) would be an option at the end of test to reveal the details of surface cracking. Non-destructive UT would be used to detect the presence of internal cracking. A baseline UT was performed prior to the beginning of testing to aide in evaluation of any cracking detected at the conclusion of test. By comparing the pre- and post-test UT data, any cracking, either internal or exposed to the surface, could be detected and sized more accurately; and its initiation site, and the cause of subsequent orientation and arrest, could be identified.

2.4.1 Large Plate Specimen Fabrication and Welding Procedure

The plate specimens were fabricated in a manner similar to those used in the previous nitrate SCC testing for Type I and II waste tanks (welded A285 carbon steel plates in 5 M sodium nitrate solution at 90 °C [5-7]). To be consistent with the U-bend specimens, the weld orientation was chosen to be perpendicular to the rolling direction of the steel mill sheet. Therefore, two 6 in. × 12 in. plates were cut from an one-inch thick A537 sheet as schematically shown in Figure 11 and then butt-welded to form a 12 in. × 12 in. specimen plate. Such an arrangement ensures that the weld is in the desired orientation.

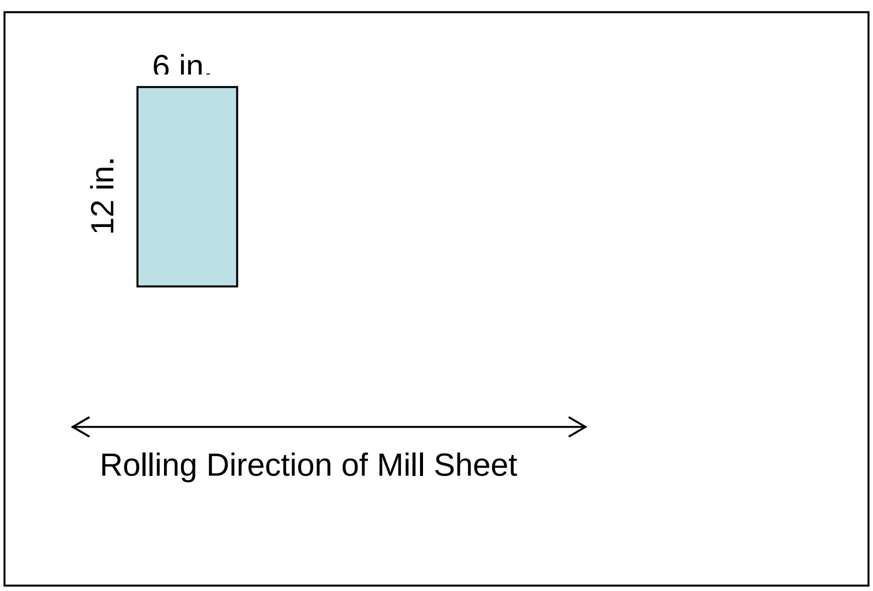


Figure 11 The 6 in. × 12 in. plate is cut from an A537 mill sheet – the 6-inch side is parallel to the rolling direction of the mill sheet.

The thickness of the large plate specimen is one (1) inch, which was chosen based on the thickness of the plate at the location where the highest service temperature was found in Tank 32, near the bottom knuckle [1]. Within that bottom plate, the most susceptible area for CSCC to occur is the vertical seam, Weld No. 26, which is marked in red in Figure 12 (as part of the Blue Print File 211620 [17]). The original welding document from Nooter Corporation (in 1964, see Appendix 4) specified that the SMAW was used in butt-joining the tank wall with a double K-notch. The Oxweld 65 (brand name for ER70S-2 wire, see Appendix 5) was used for the initial weld between the closest point along the double-K notch; and the filler metal, coated E-7018 (Appendix 6), was used to complete the weld on one side of the tank wall (as many passes as necessary). This process was repeated for the other side of the tank wall. The same welding procedure and parameters were adopted to fabricate the plate specimens for the CSCC experiment. However, there were slight differences in the actual welding of the two plates, for example, the length of each pass and the number of passes. Appendices 7 and 8 document the actual welding processes and parameters for the as-welded plate and for the heat-treated plate, respectively.

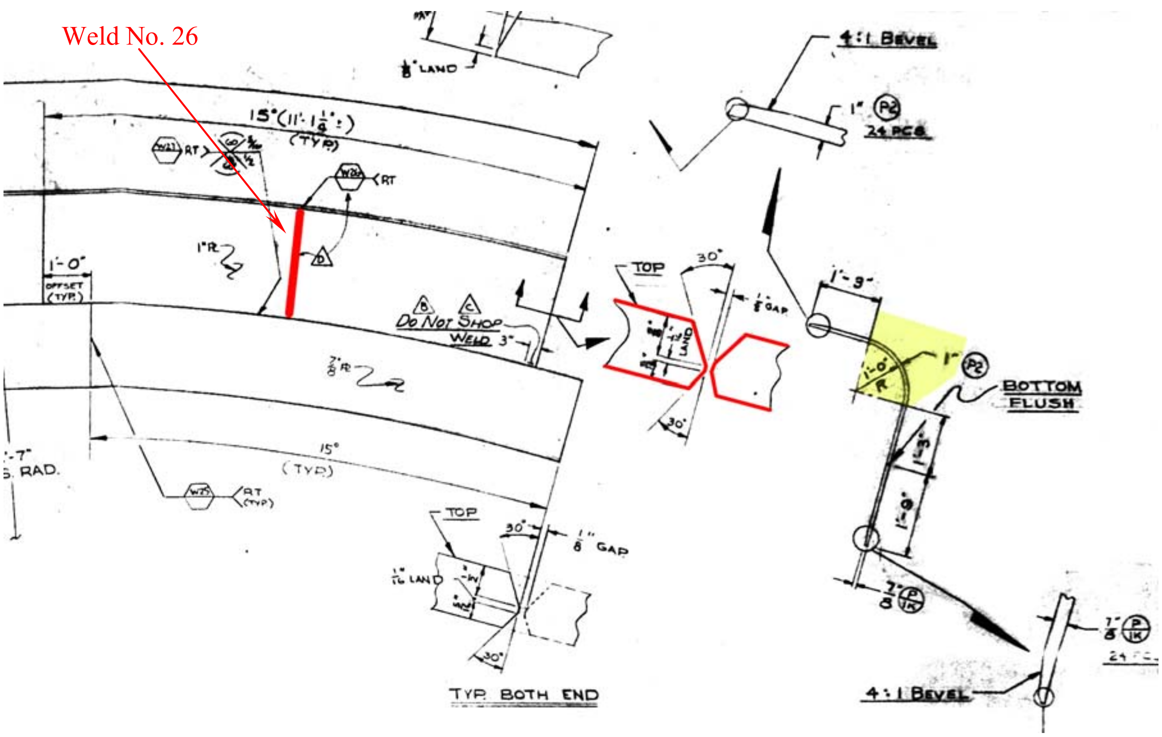


Figure 12 Vertical seam weld No. 26 in the bottom knuckle area (thickness: 1 inch).

2.4.2 Stress Relief Heat Treatment for the Large Plate Specimen

The same heat treatment was applied to the large plate specimen as described in Section 2.3.1 for the U-bend specimens. This information is repeated below:

(1) The heat treatment is conducted in air.
(2) Heating from ambient to 1100 °F at a rate of 90 °F/hour
(3) Holding at 1100 °F for 60 minutes.
(4) Cooling to ambient at a rate of 115 °F/hour.

However, during the heat treatment at the vendor site, the oven was found to have lost power at about 950 °F during the ramp-up stage (from ambient to 1100 °F). It is estimated from the heat treatment chart (Fig. 13) that it took about 105 minutes to reheat to 950 °F (when the power failure occurred) and finally reached the maximum temperature, 1100 °F, in the next 150 minutes. Because the temperature excursion occurred in the heating stage, it is considered as non-detrimental and this plate specimen was not re-fabricated.

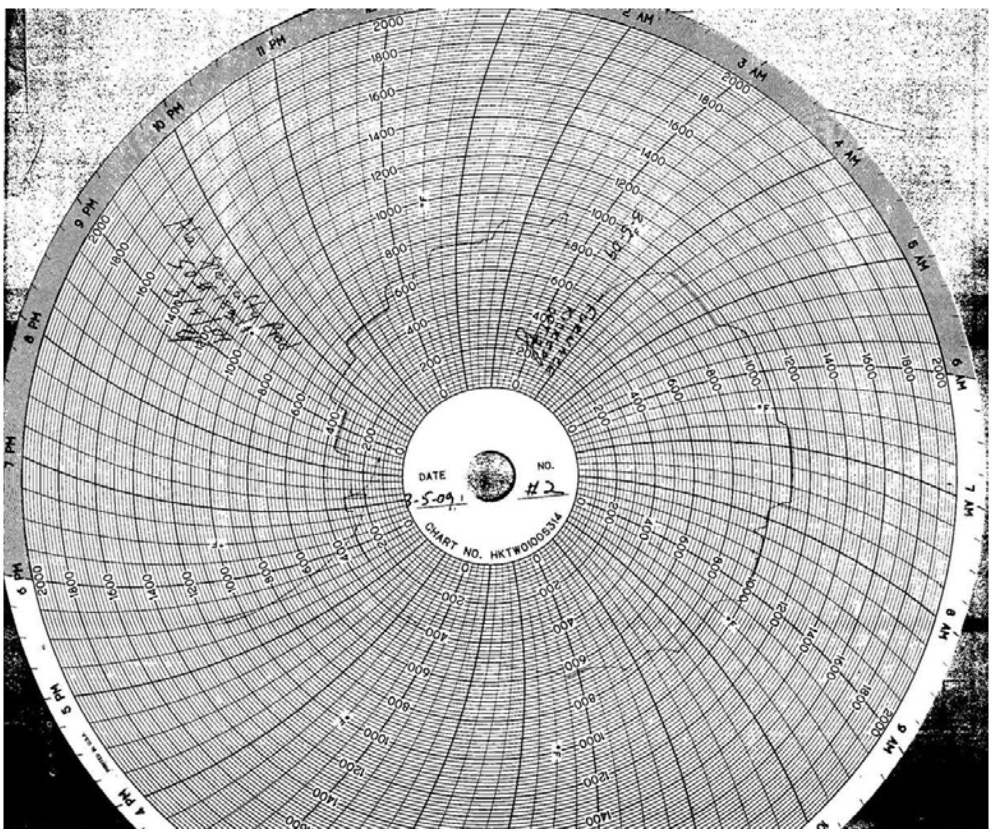


Figure 13 Heat treatment temperature history.

2.4.3 Seed Cracks

Unlike the U-bend specimens, seed cracks were machined into the large plate specimens and serve as the initiation sites for stress corrosion cracking. Note that for the stress-relieved plate specimen, the heat treatment must be performed prior to machining the seed cracks.

The schematic seed crack placement and crack types can be seen in Figure 14. The actual seed cracks are shown in the insets of the figure. The electric discharge machining (EDM) was used to fabricate these cracks so the crack tips can be as sharp as possible. Due to the EDM wire or electrode size, the crack tip maintains a small but finite radius (e.g., 0.015 in.).

The three types of machined cracks are (see Figure 14):

1) V1, V2, and V3: vertical cracks through the thickness of the plate and across the weld (Fig. 15);
2) V4, V5, and V6: vertical cracks partly through plate in the heat affected zone perpendicular to the weld (Fig. 16); and
3) P1, P2, and P3: cracks parallel to the weld and partly through plate in the HAZ along the edge of the weld (Fig. 17).

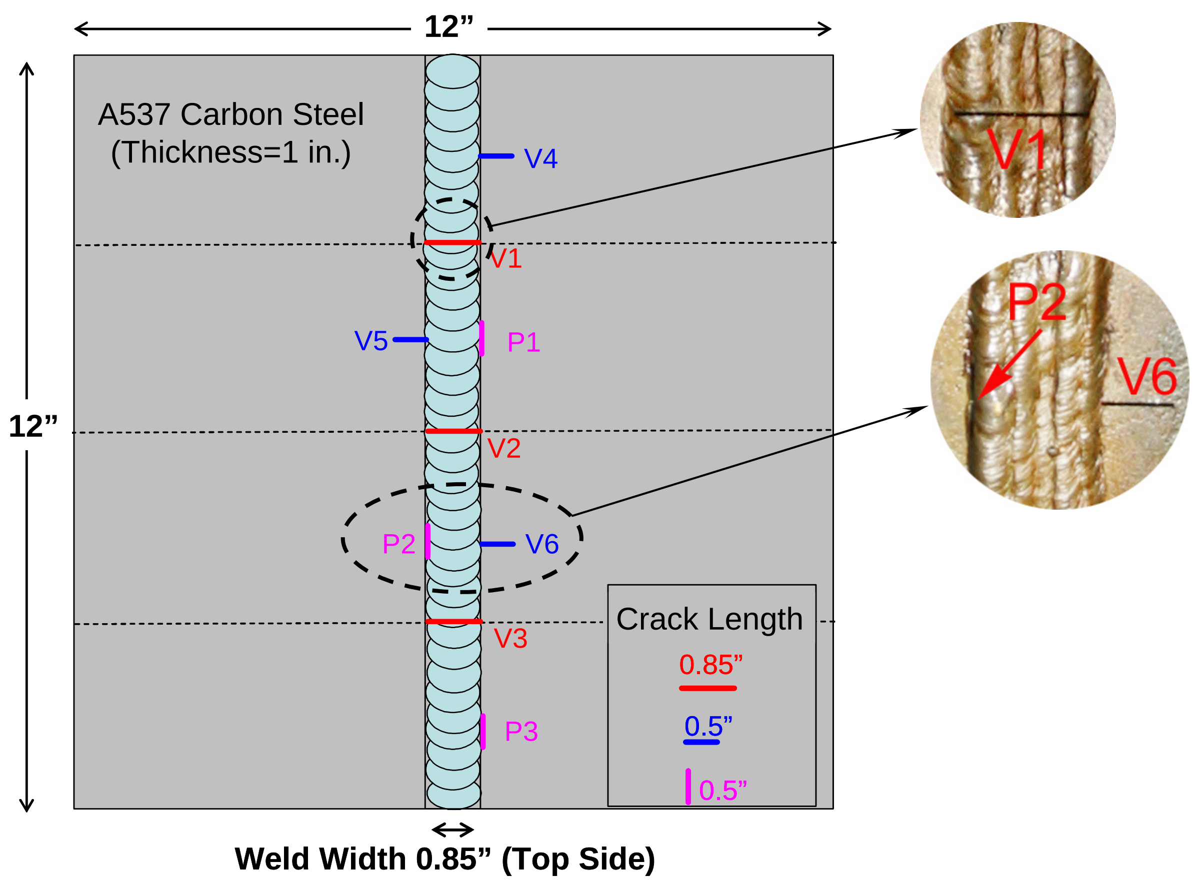


Figure 14 Welded large plate specimen with machined cracks.

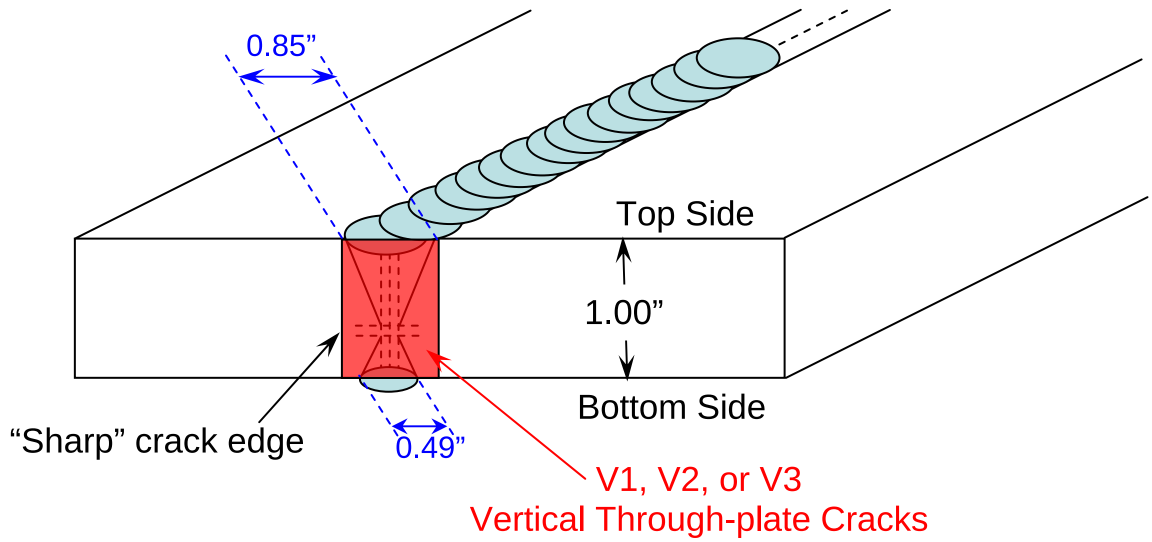


Figure 15 Through-the-plate cracks across the weld (V1, V2, and V3).

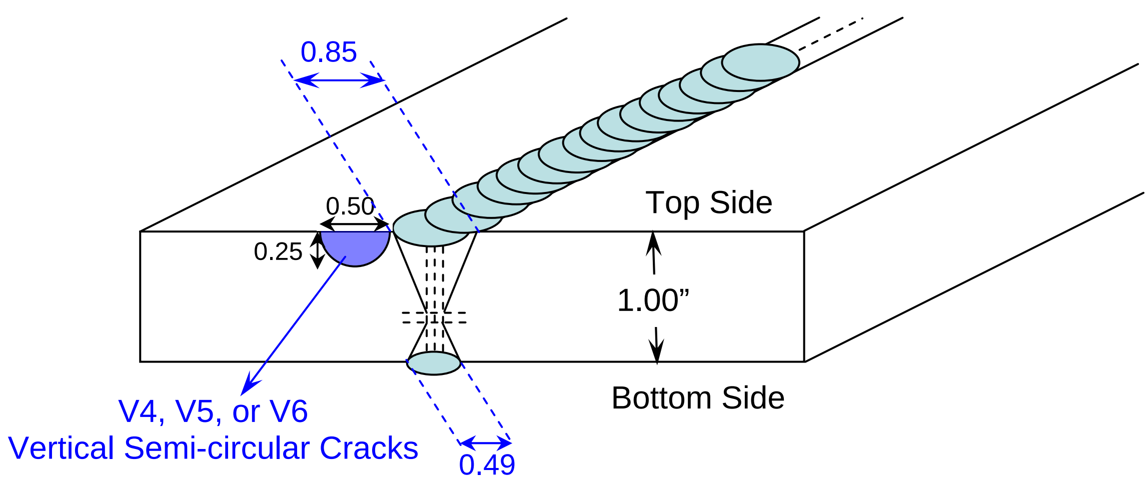


Figure 16 Semi-circular surface cracks perpendicular to the weld (V4, V5, and V6).

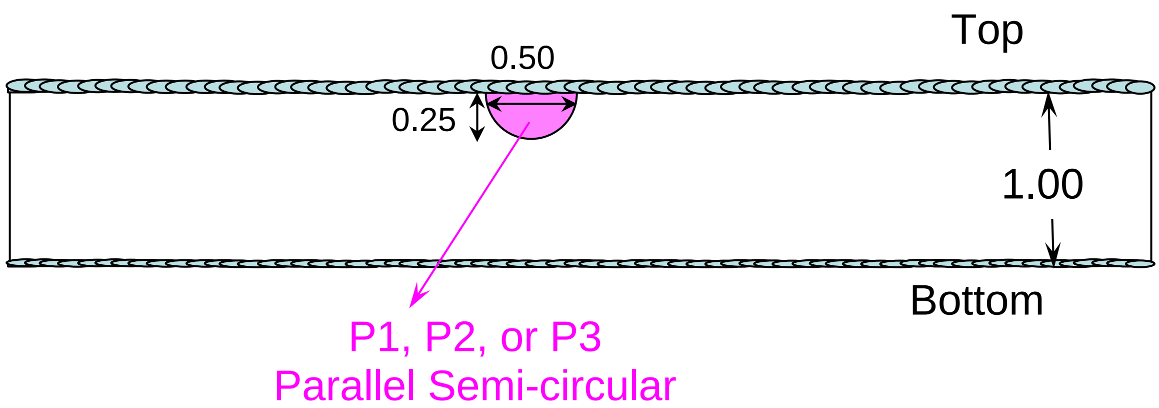


Figure 17 Semi-circular surface cracks parallel to the weld (P1, P2, and P3).

2.4.4 Large Plate Test Tank and Experimental Station

Typical stainless steels, especially their weldment, may corrode significantly during long exposure to highly caustic solutions at temperature as high as 125 °C (or slightly above, because the temperature control is of oscillatory nature). As a result, the nickel-molybdenum-chromium alloy, Hastelloy (i.e., C-276), was selected for constructing the immersion tank. This material, along with its welds, is known to be corrosion-resistant in highly caustic solutions at high temperatures. The design of the immersion tank was based on the specimen dimension (12 in. × 12 in. × 1 in.) and the ratio of solution volume to specimen surface area (i.e., 5 ml/cm^2 or 33 ml/in^2, suggested by ASTM G 123, see Section 2. 1). The tank is 18-in. high with a cross-section of 18 in. × 6.5 in. with a total volume of 34.5 liters (9.1 gallons) which could accommodate 6 gallons of the test solution required by ASTM G 123. The thickness of the tank wall is ⅜ inches. The test tank was designed in such a manner that none of the C-276 plate edges (i.e., end-grains) would be exposed to the solution, which makes the test tank even more corrosion-resistant. An engineering drawing of the tank construction along with the welding requirements can be seen in Figure 18. The test solution is not filled to the top of the tank. A 2½ inch headspace is left when the test plates and hangers (racks) (Figure 19) are in position with a liquid volume of 25 liters (6.6 gallons).

A heating unit with controller was designed to maintain the test temperature at 125 °C for an extended period of time. The heaters are housed in flexible silicone which adheres to the sides of the test tank. They are rated to function up to 232 °C (450 °F) but the adhesive is only rated at 149 °C (300 °F). Two (2) adhesive-backed thermocouples have been placed on the tank surface at the heater location to make sure the adhesive does not exceed this temperature during the startup process. When the temperature reaches the setpoint and stabilizes, thermocouple plugs may be disconnected from the heater thermocouples and connected to the thermocouples monitoring the liquid. This arrangement verifies liquid temperature after keeping the heater's adhesive within its desired temperature range.

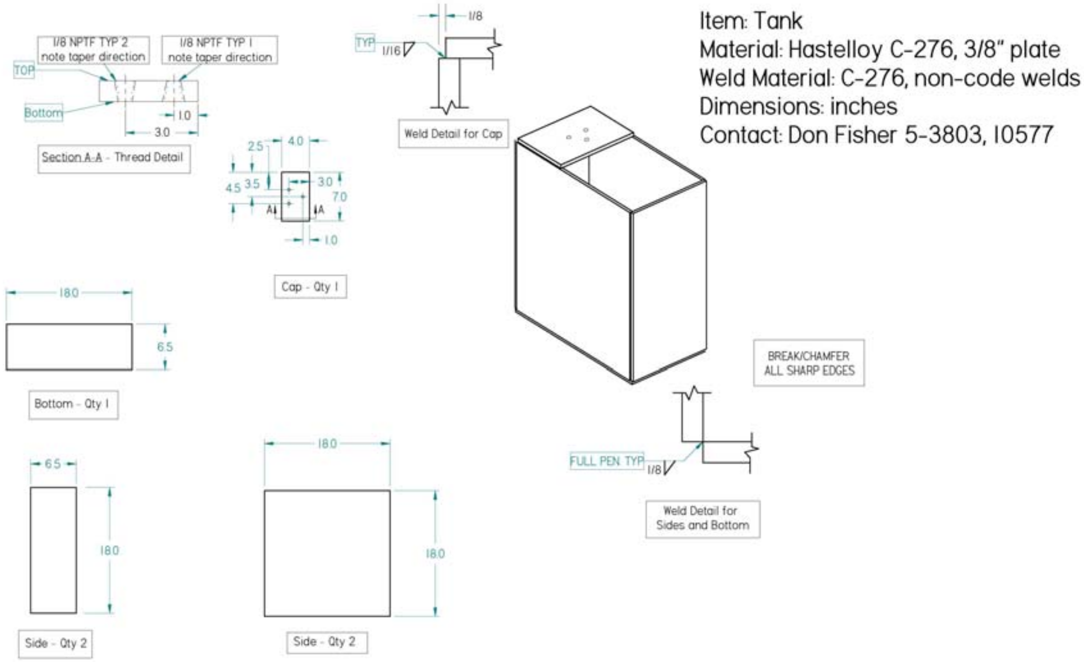


Figure 18 Construction drawing for the Hastelloy (Alloy C-276) immersion tank.

The heaters operate simultaneously and are controlled by a simple temperature controller backed up by a programmable digital over-temperature controller. Each has an independent thermocouple input. A high temperature, corrosion resistant level sensor (float) will cut off the power supply to the heaters if the liquid level drops below 14 inches measured from the bottom. Figure 20 is the inside view of the tank where the thermocouples are used to monitor the solution temperature and the level switch (float) is visible.

The controller (the assembly of all the electronic equipment) and heaters are protected by a ground fault circuit interrupter (GFCI) which switches power off within 5 milliseconds of any current fault. A fast-blow fuse protects the solid state relay and all heater power wiring.

Because the weight of each large plate specimen is about 40 lbs and the specimens are lifted periodically above the heated caustic solution for visual inspection for cracking, a small manual rigging device is included in the design for safe operation during the test. Each carbon steel plate is suspended in a cradle (i.e., hanger or rack, see Fig. 19). The rack is made of stainless steel. Therefore, it is insulated from the A537 carbon steel plate by wrapping Teflon tapes throughout the rack/holder (Fig. 21). Furthermore, two notches were machined on the bottom edge of each test plate so the rack will catch the test plate securely. Because of the presence of the notches, the holder may get caught inside the notches and therefore is unable to provide an insulated barrier between the bottom edge of the test plate (A537) and the bottom of the test tank (Alloy C-276). A Teflon plate was placed on the bottom of the tank to avoid direct contact of A537 and C-276.

Figure 19 Positioning of the test plate on the rack (hanger).

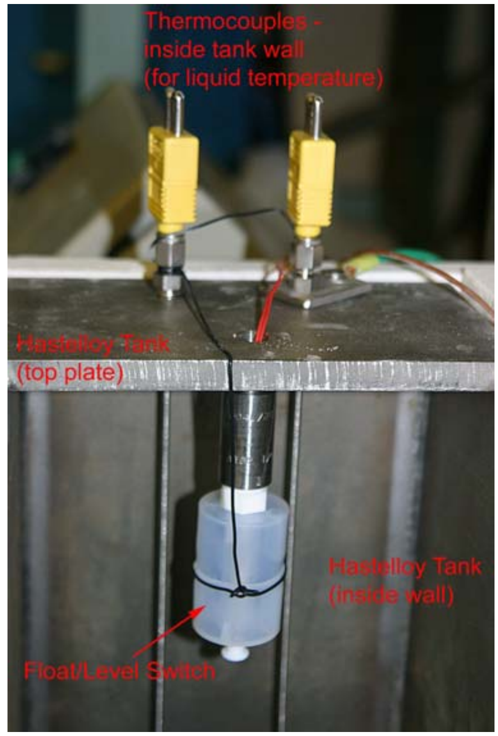


Figure 20 Thermocouples for monitoring the solution temperature and the level float switch (inside test tank).

Figure 21 Insulating of rack with Teflon tapes.

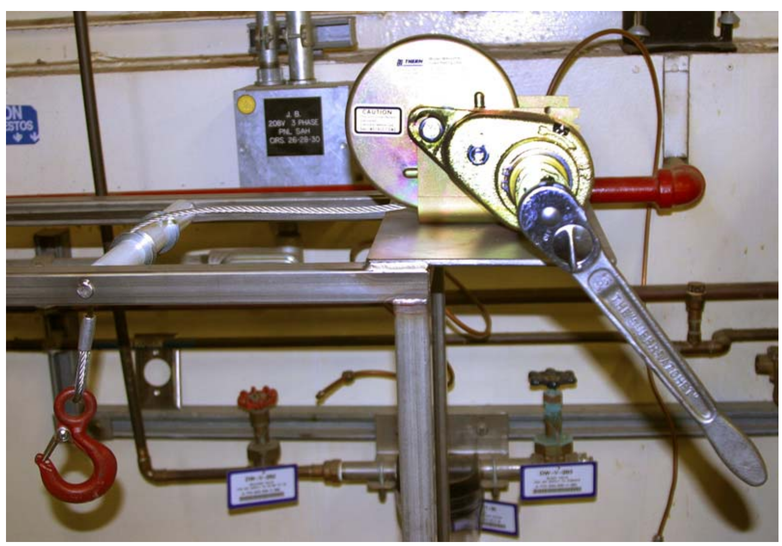


Figure 22 Winch assembly for lifting and lowering the plate specimens.

The test plate and the rack (holder) were designed to be lifted with a winch (Fig. 22) from or lowered into the solution in the test tank which has been filled with highly caustic solution and at high temperature. The winch is equipped with a brake and clutch and must be manually powered up and down. The test tank is supplied with a lid which may be replaced once one plate is brought above the top of the test tank. This eliminates the possibility of corrosive material splashing out if objects are accidentally dropped into the test solution.

Secondary containment is required for any testing involving aggressive solutions. Secondary containment for these tests was constructed of stainless steel with a volume of 44.3 liters (11.7 gallons), which is sufficient to contain all the liquid should the test solution release from the test tank. The rapidly dropping temperature of the released liquid as it becomes exposed to ambient conditions allows the use of stainless steel for this application (i.e., the material of the test tank, Hastelloy C-276, is not needed for the temporary storage of low temperature caustic solution).

All the components of the large plate experimental station and the laboratory layout are shown in Figure 23.

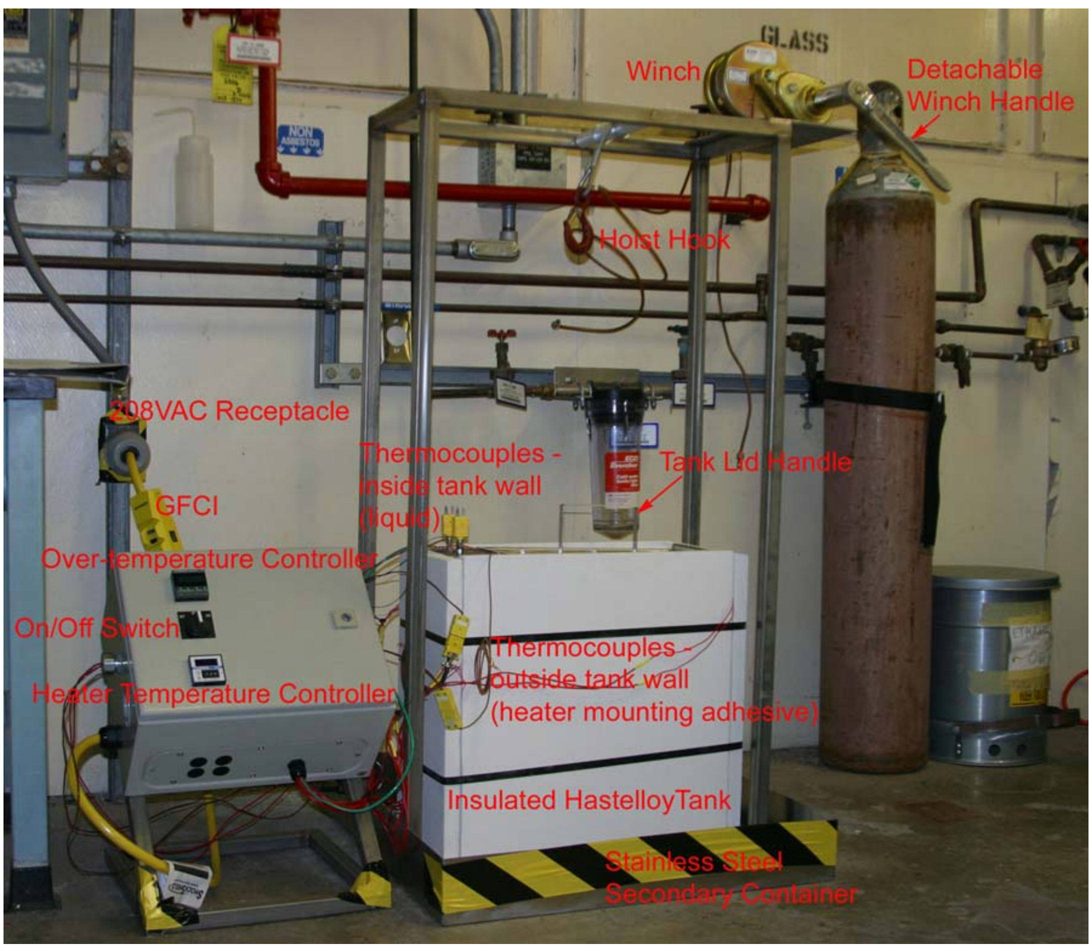


Figure 23 Large plate experimental station.

2.4.5 Large Plate Test Procedure

Pre-test UT has been performed to characterize the initial flaw sizes of the machined cracks. After the test is complete, a second UT scan will be performed and data are compared with the baseline so any interior cracking can be detected.

Prior to submerging the large plate specimens into the caustic solution, the machined cracks were cleaned with Clarke's solution to remove the corrosion products (oxide) on the crack surfaces that would have formed naturally in the atmosphere. This treatment ensured that the caustic test solution will directly attack the fresh metal surface of the cracks, and the obstructing oxides will not interfere, especially at the crack tip where the welding residual stress is operating and tends to open the crack.

The Clarke's solution can be prepared by dissolving 20 grams of Sb_2O_3 and 50 grams of $SnCl_2$ in 1000 ml of concentrated HCl (see ASTM G 1 – 03 "Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens," Annex A1, Designation C.3.1 for iron and steel). A small amount of Clarke's solution was applied to the cracks on the specimen plate surface with a slurry (eyedropper). The treated area was rinsed with distilled water and then with ethanol to remove the residual chlorides trapped in the cracks. Like the test tank which contains highly caustic solution, this treatment of applying the Clarke's solution also required a secondary container to catch the spills.

After the plate specimen was submerged in the test solution, periodic inspections were performed by lifting the plate above the test solution with the winch and hoist hook (Fig. 24). The total exposure time of the large plate specimen was set to 12 weeks. No evaporation control was attempted (e.g., such as the condensers in the U-bend test). However, a small amount of insulation material was used to cover the seam around the lid of the test tank after the lid was closed. This practice has proven to be very effective in minimizing evaporation. To maintain the test temperature at 125 °C, distilled water must be replenished periodically because the electrical power to the heaters will be cut off when the liquid drops below the preset level (14 in. above the tank bottom).

Non-destructive UT and magnetic particle test (MT) may be conducted at the end of the large plate test. The MT will reveal the fine details of the cracking pattern on the plate surface and the UT will detect the subsurface crack propagation.

Figure 24 Periodic inspection for cracking by lifting plate above the test solution.

3. TEST RESULTS

The U-bend test has been completed. The test was planned for 21 days, but some specimens were actually left under the test conditions for an extended period of time. No cracking was found throughout the entire time of exposure. Table 1 lists the specimen numbers in each test beaker and the actual duration of the testing. The photographs of welds in the pre- and post-test specimens are shown in Section 3.1.

Table 3 U-bend specimens and exposure times

Beaker Number	Specimen Number	Specimen Type	Starting Day	End Date	Actual* Exposure Days	Actual* Exposure Hours
1	242	heat-treated	May 26, 2009	July 8, 2009	44	1039
	244	heat-treated				
	248	as-welded				
2	243	heat-treated	May 26, 2009	August 31, 2009	95	2255
	245	as-welded				
	247	as-welded				
3	241	heat-treated	May 26, 2009	June 18, 2009	24	558.5
	246	as-welded				

* Actual exposure time: The system downtime has been taken into consideration.

The large plate test is in progress. None of the plates (the as-welded and the heat-treated) had exhibited any indication of stress corrosion cracking. The photographs that were taken at the end of the sixth week are shown in Section 3.2.

3.1 U-Bend Test Results

The photographs of the specimens are grouped according to the Beaker Number, or the exposure time. The test time for Beaker No. 3 (24 days) is close to the planned 21 days (Section 3.1.1). Since there was no cracking at the end of the scheduled test duration, the testing in Beaker No. 1 (Section 3.1.2) and No. 2 (Section 3.1.3) was extended beyond the originally scheduled 21 days. However, it should be noted that the salt concentrations might have been altered due to the loss of water. In fact, when the test was finally terminated (44 days for Beaker No. 1 and 95 days for Beaker No. 2), the solution had become sludge-like and salt cakes had formed thickly around the test specimens. In all cases, no stress corrosion cracking could be found in the U-bend specimens. During the first 21 days of testing, all specimens were inspected once a week for evidence of cracking.

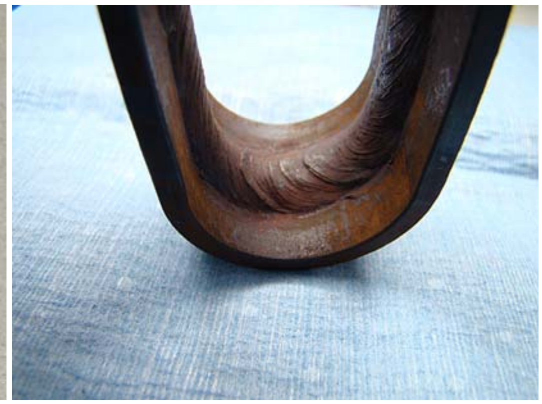
3.1.1 Exposure for 24 Days (Beaker No. 3)

The actual exposure time for these specimens in the caustic solution (12 M hydroxide) was 24 days, or more precisely, 558.5 hours. The test temperature was at least 125 °C. The pre- and post-exposure photographs of these specimens are placed side-by-side for comparison (Figs. 25-26). Both the outer side of the U-bend (tensile side) and the inner side (compressive) are documented. Although the SCC on the compressive side is highly improbable, it is reported here for completeness.

(a) Tensile side of U-bend before exposure

(b) Tensile side of U-bend after exposure

(c) Compressive side of U-bend before exposure



(d) Compressive side of U-bend after exposure

Figure 25 As-welded Specimen No. 246 exposed to caustic solution for 24 days.

(a) Tensile side of U-bend before exposure

(b) Tensile side of U-bend after exposure

(c) Compressive side of U-bend before exposure

(d) Compressive side of U-bend after exposure

Figure 26 Heat-treated Specimen No. 241 exposed to caustic solution for 24 days.

3.1.2 Exposure for 44 Days (Beaker No. 1)

The actual exposure time for specimens in the caustic solution was 44 days, or more precisely, 1039 hours. The test temperature was at least 125 °C. The pre- and post-exposure photographs of the specimens are placed side-by-side for comparison (Figs. 27-29). The outer side of the U-bend (tensile side) is shown below along with the inner side (compressive), although SCC is unlikely under compressive stress.

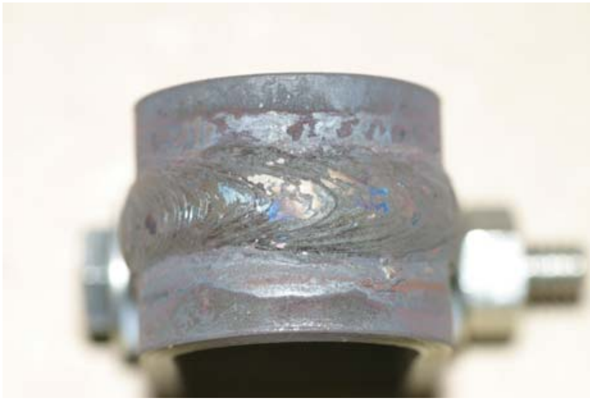
(a) Tensile side of U-bend before exposure

(b) Tensile side of U-bend after exposure

(c) Compressive side of U-bend before exposure

(d) Compressive side of U-bend after exposure

Figure 27 As-welded Specimen No. 248 exposed to caustic solution for 44 days.



(a) Tensile side of U-bend before exposure

(b) Tensile side of U-bend after exposure

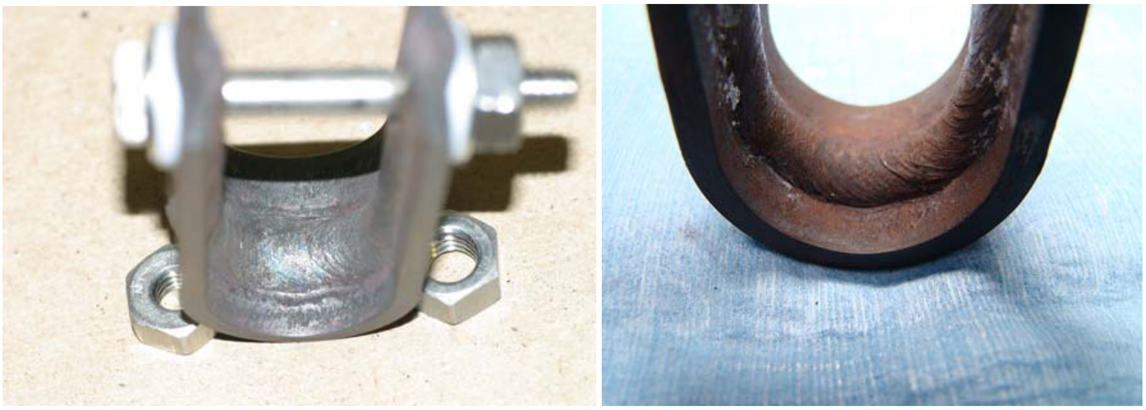
(c) Compressive side of U-bend before exposure

(d) Compressive side of U-bend after exposure

Figure 28 Heat-treated Specimen No. 242 exposed to caustic solution for 44 days.

(a) Tensile side of U-bend before exposure

(b) Tensile side of U-bend after exposure



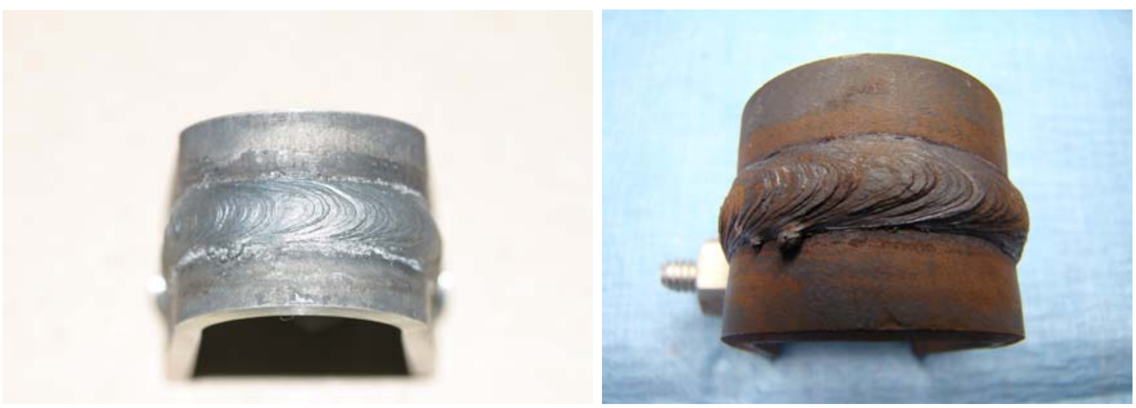
(c) Compressive side of U-bend before exposure

(d) Compressive side of U-bend after exposure

Figure 29 Heat-treated Specimen No. 244 exposed to caustic solution for 44 days.

3.1.3 Exposure for 95 Days (Beaker No. 2)

The actual exposure time for specimens in the caustic solution was 95 days, or more precisely, 2255 hours. The test temperature was at least 125 °C. The pre- and post-exposure photographs of these specimens are placed side-by-side for comparison (Figs. 30-32). Both the outer side of the U-bend (tensile side) and the inner side (compressive) are reported. Although cracking is unlikely on the compressive stress field; the result is included in this section for completeness.



(a) Tensile side of U-bend before exposure

(b) Tensile side of U-bend after exposure

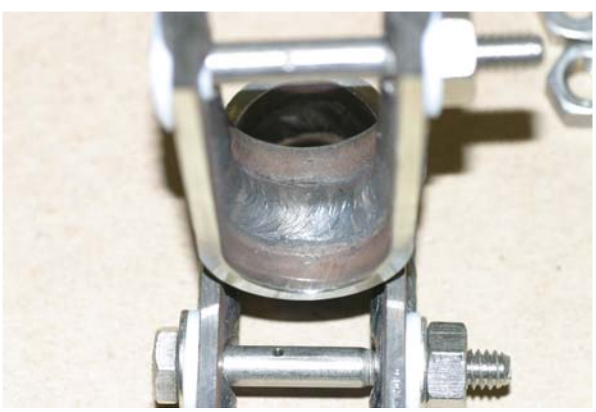
(c) Compressive side of U-bend before exposure

(d) Compressive side of U-bend after exposure

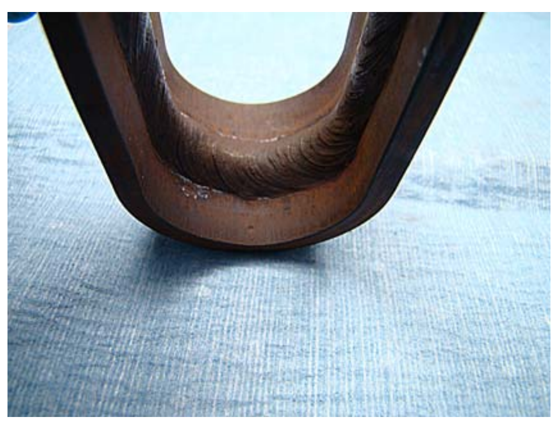
Figure 30 As-welded Specimen No. 245 exposed to caustic solution for 95 days.

(a) Tensile side of U-bend before exposure

(b) Tensile side of U-bend after exposure



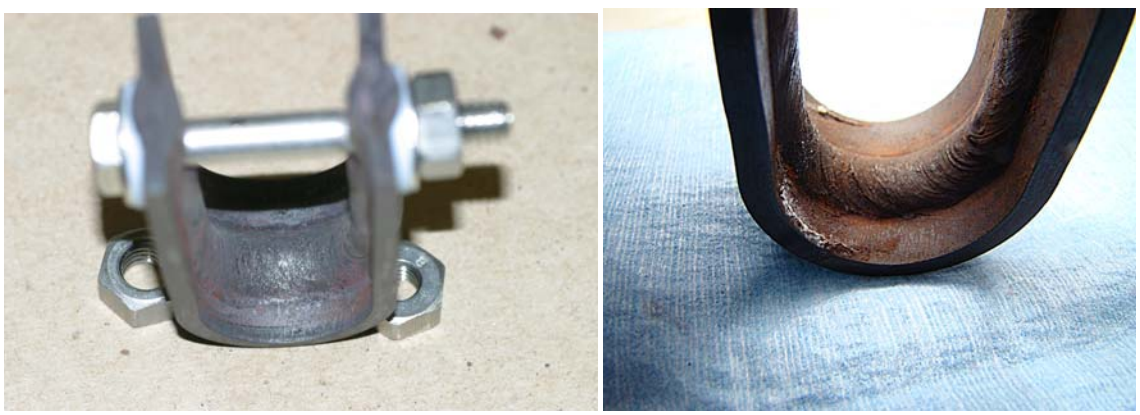
(c) Compressive side of U-bend before exposure



(d) Compressive side of U-bend after exposure

Figure 31 As-welded Specimen No. 247 exposed to caustic solution for 95 days.

(a) Tensile side of U-bend before exposure (b) Tensile side of U-bend after exposure



(c) Compressive side of U-bend before exposure (d) Compressive side of U-bend after exposure

Figure 32 Heat-treated Specimen No. 243 exposed to caustic solution for 95 days.

3.2 Large Plate Test Results

The large plates had been submerged in the test solution at 125 °C for 12 weeks at the end of the test. No stress corrosion cracking was found either in the as-welded plate or in the stress relieved/heat treated plate. The pre-exposure conditions of the plates are shown in Figures 33 and 34, respectively, for the as-welded and the heat-treated plates. Figures 35 and 36 are, respectively, the front and back sides of the as-welded plates after exposure for 12 weeks. The close-ups of the nine machined cracks in their post-test condition are shown in the insets. For the heat-treated plate, the post-test photographs are shown in Figures 37 (front side) and 38 (back side). Note that in Figures 35 to 38, V1, V2, and V3 are through-the-plate cracks and are across the width of the weld (vertical cracks); V4, V5, and V6 are also vertical cracks (perpendicular to the weld) but they are partly through plate (¼ in. deep thumbnail cracks) in the HAZ; and P1, P2, and P3 are part-through plate (¼ in. deep thumbnail cracks) cracks parallel to the weld and in the HAZ. On the back side of each plate, only three through-the-plate cracks can be seen. These machined cracks were schematically described earlier in Figure 14, and their designed dimensions were illustrated in Figures 15 to 17.

(a) Front side before exposure (b) Back side before exposure

Figure 33 As-welded plate before exposure.

(a) Front side before exposure (b) Back side before exposure

Figure 34 Heat-treated (stress-relieved) plate before exposure.

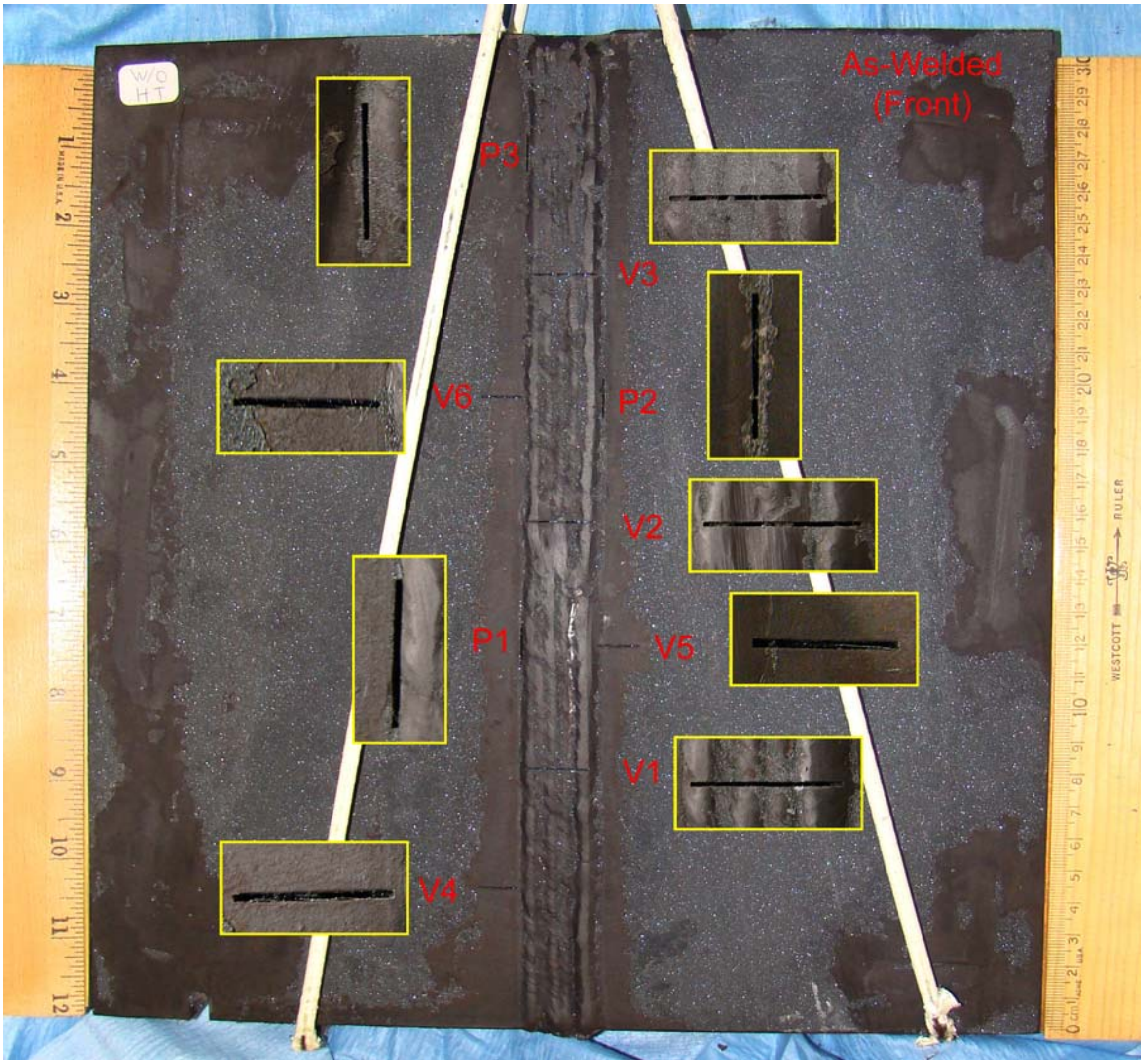


Figure 35 As-welded plate after exposure to test solution for 12 weeks
(Front side, insets show close-up of the machined cracks).

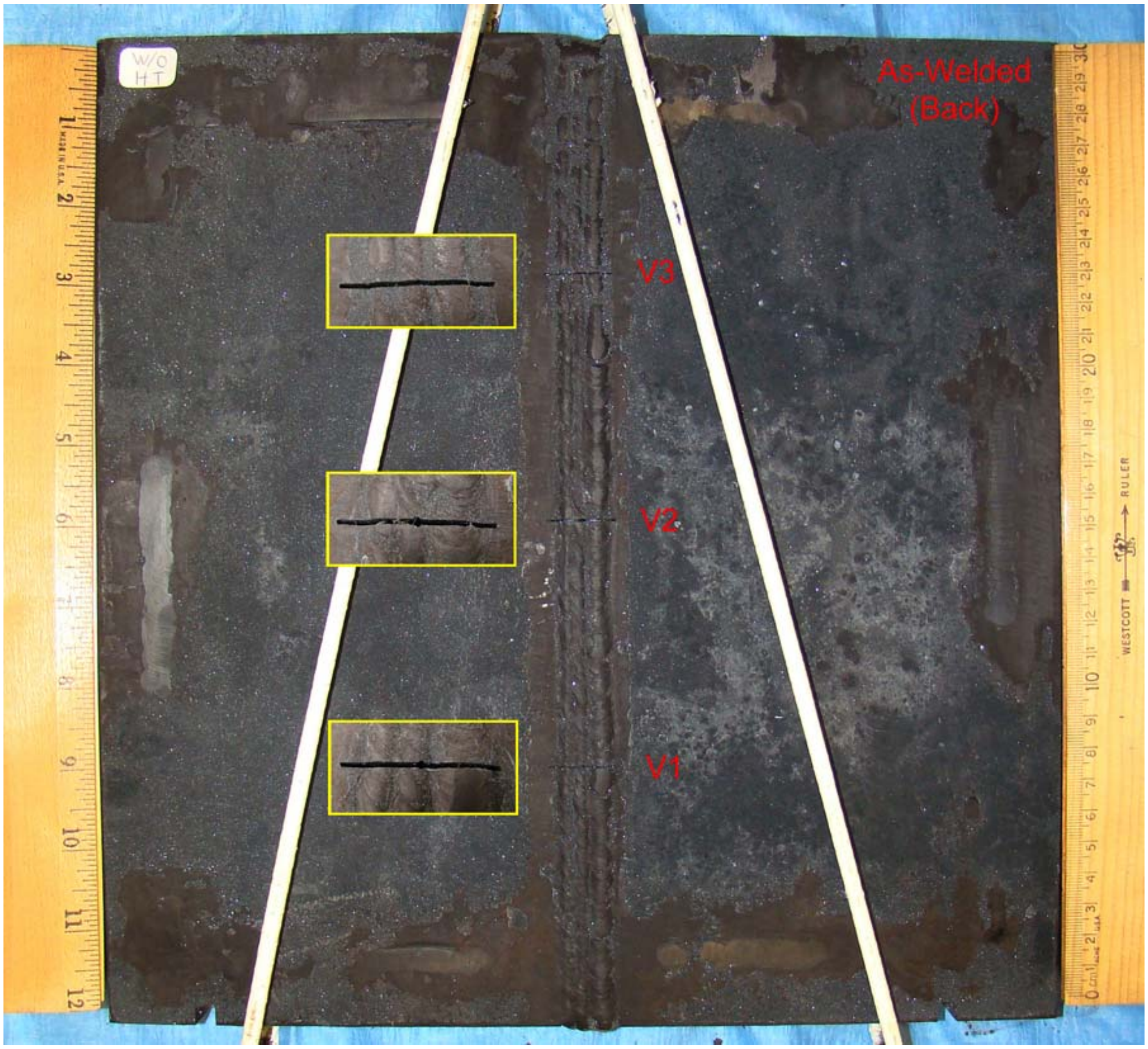


Figure 36 As-welded plate after exposure to test solution for 12 weeks
(Back side, insets show close-up of the machined cracks).

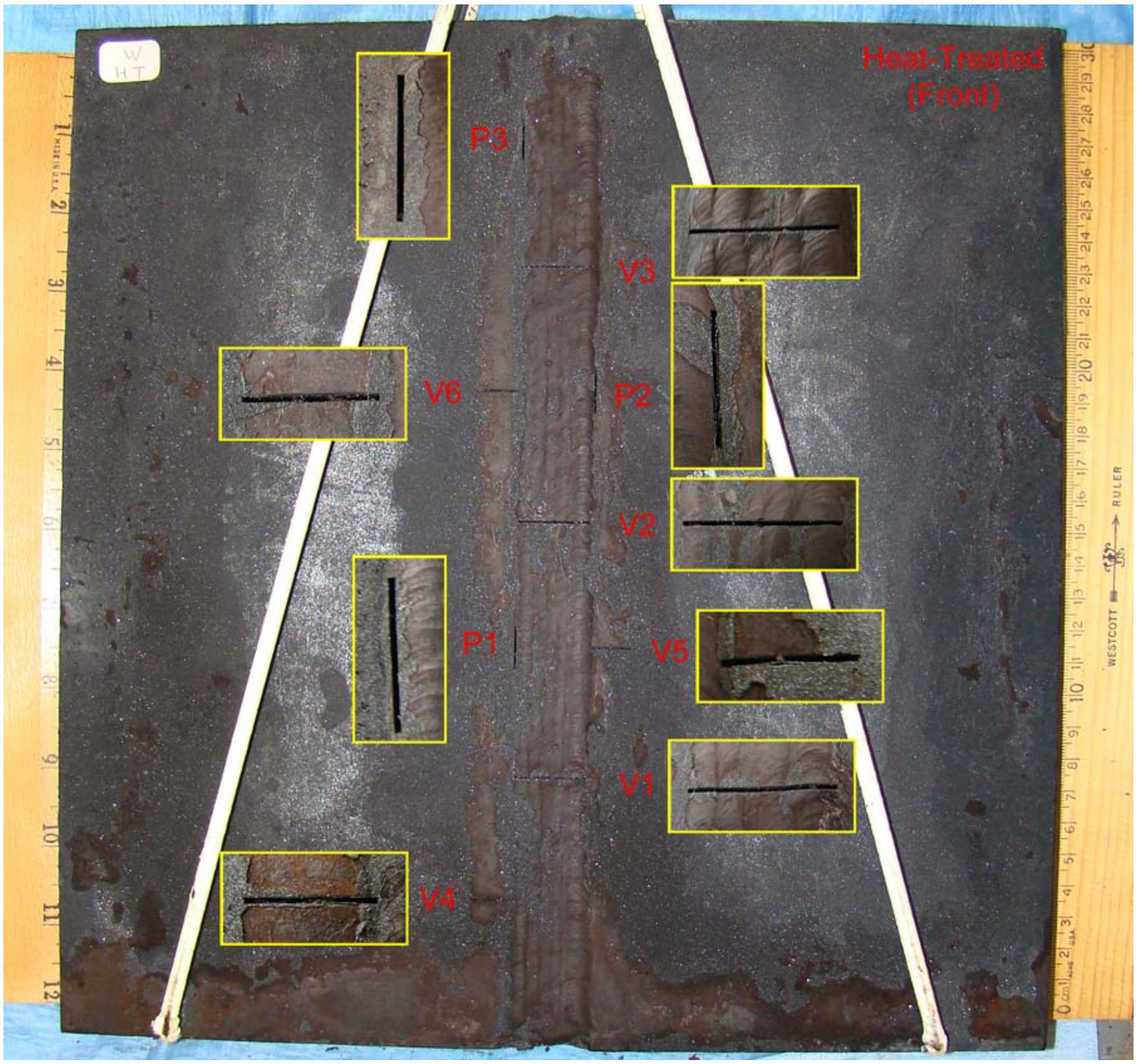


Figure 37 Heat-treated plate after exposure to test solution for 12 weeks (Front side, insets show close-up of the machined cracks).

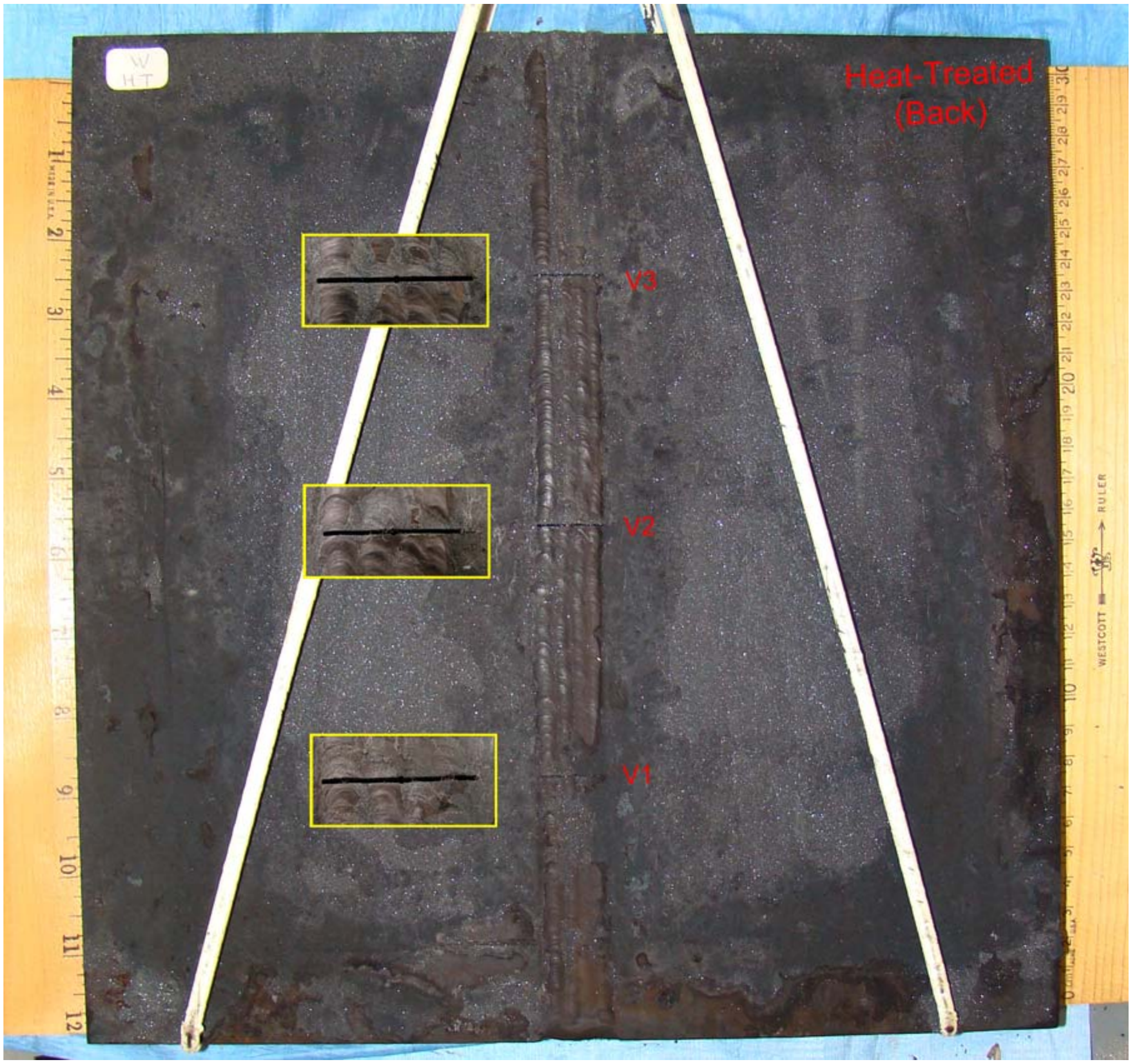


Figure 38 Heat-treated plate after exposure to test solution for 12 weeks (Back side, insets show close-up of the machined cracks).

The post-test large plates were visually inspected carefully for evidence of stress corrosion cracking on the specimen surfaces. The close-up photograph of each individual crack can be seen in the inset in Figures 35 to 38. In addition, nondestructive testing was conducted prior to and at the completion of exposure. Volumetric (ultrasonic shear wave) inspections were performed in search of cracking either parallel or perpendicular to the weld. NDE inspections confirmed visual findings that there was no stress corrosion cracking or increase in crack length of the machined notch. Because no cracking was found, the magnetic particle testing (MT) was not performed.

P-scan images in Figures 39 and 40 indicate that no caustic stress corrosion cracking had grown in the direction parallel to the weld, for both the as-welded and the heat-treated plates. Several machined cracks were marked on the figures (hatched rectangles) for convenience to identify the actual position of the ultrasonic signals on the plate. These figures also indicate that there were no crack length changes for the parallel machined cracks P1, P2, and P3. P-scan also performed parallel to the weld to detect any cracking perpendicular to the weld (see Fig. 41 for the as-welded plate). As concluded earlier by Figures 39 and 40, Figure 41 also shows no evidence for stress corrosion cracking. Since the ultrasonic scans in all directions indicate no cracking, it can be concluded that stress corrosion cracking did not occur inside the plates.

It should be noted that the P-scan applied directly over the uneven surface of the weld beads is impractical and therefore was not performed. Should stress corrosion cracking occur in machined cracks V1, V2, and V3 (through-the-plate cracks across the weld) , the indication of crack extension would have been detected by the scans in the heat-affected zone immediately next to the weld (such as in Figs 39 to 41).

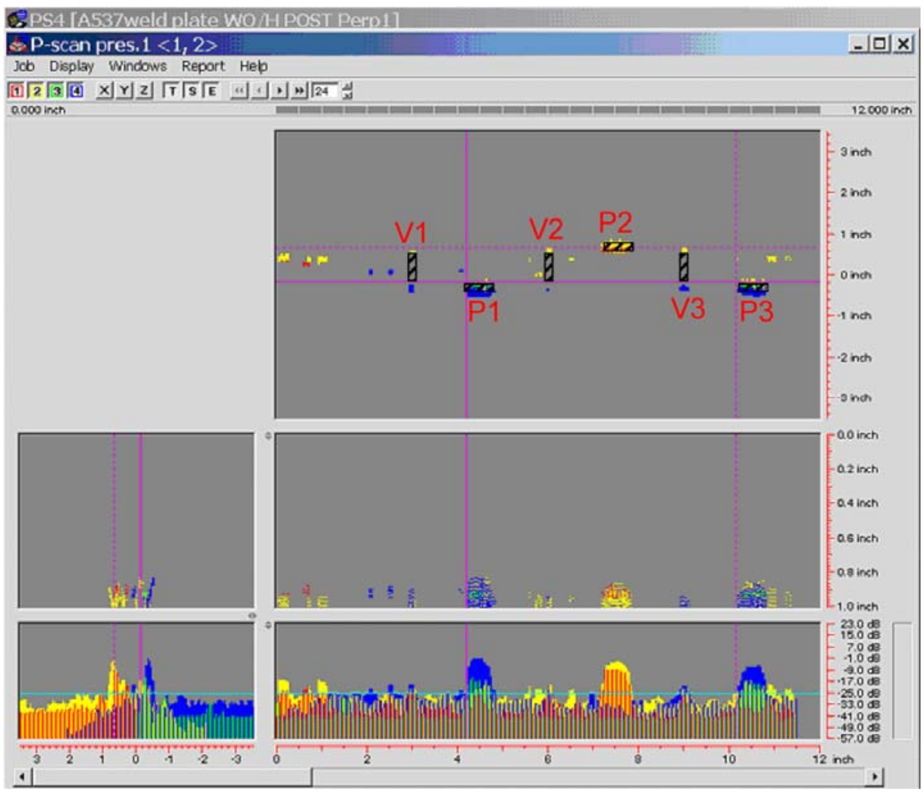


Figure 39 P-scan for stress corrosion cracking parallel to the weld for the as-welded plate.

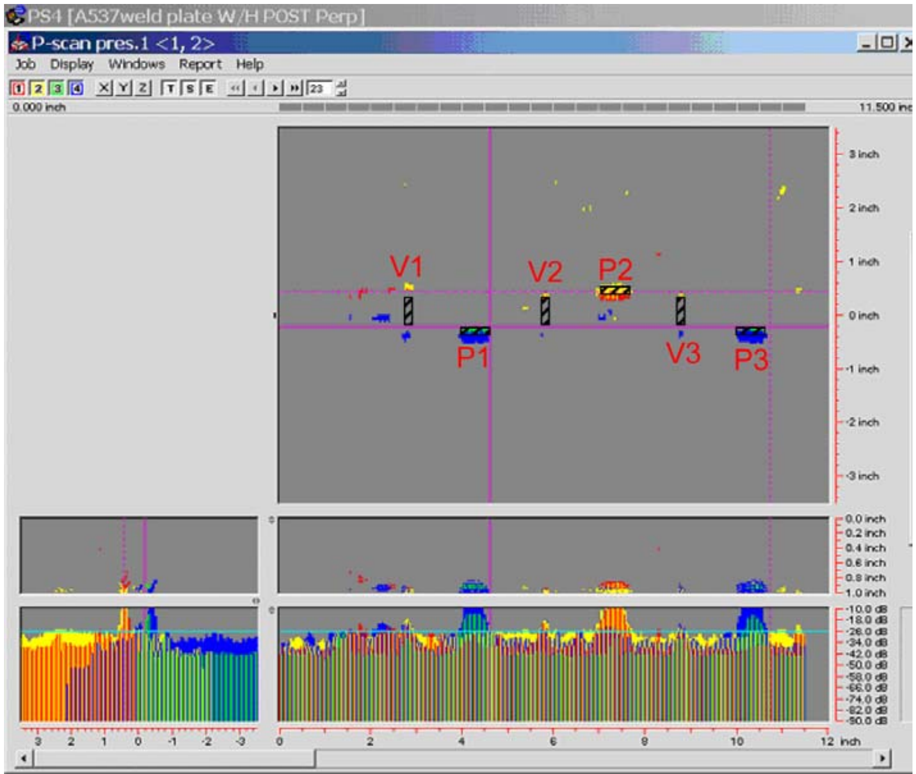


Figure 40 P-scan for stress corrosion cracking parallel to the weld for the heat-treated and stress relieved plate.

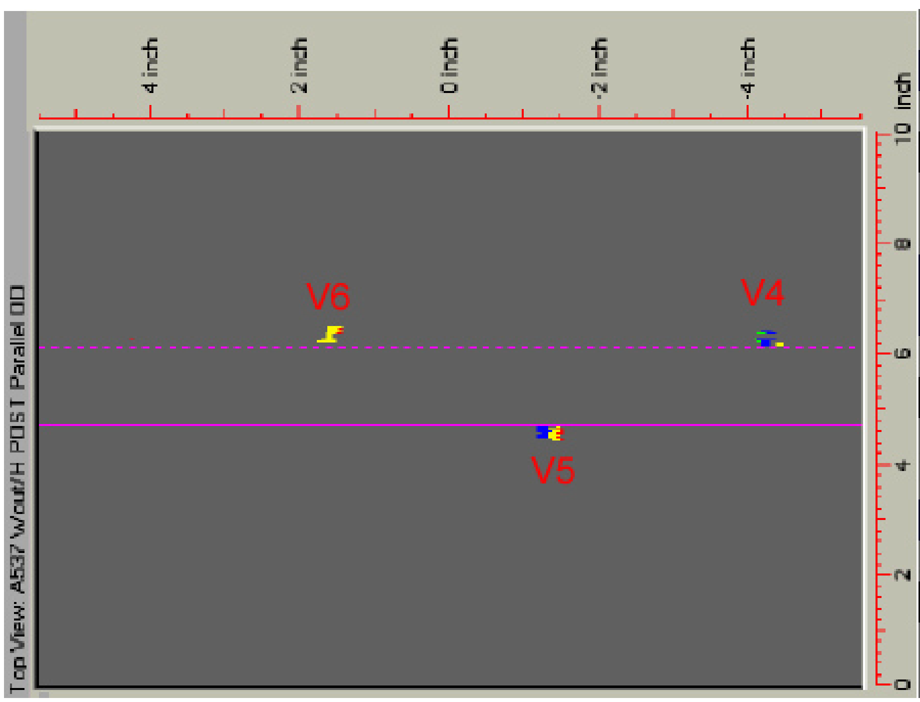


Figure 41 P-scan for stress corrosion cracking perpendicular to the weld for the as-welded plate.

4. CONCLUSIONS

Based on the test results of the U-bend specimens and the large plates, it is concluded that stress corrosion cracking of A537 carbon steel did not take place in the high temperature (125 °C) caustic solution, which was composed of 12 M hydroxide, and 1 M each of nitrate, nitride, and aluminate (in the case of large plate test, the aluminate concentration was 0.3 M). The actual temperature of the solution during the tests might be slightly higher than the target temperature of 125 °C but was below the boiling point. The lack of caustic stress corrosion cracking indicates that the inhibitors, such as $[OH^-]$ and $[NO_2^-]$, maintain their adequate levels even when the solution temperatures are much higher than that specified in the waste tank corrosion control program. It is also possible that the nitrite ions, which are strong oxidizing agents, under this chemistry condition allow the formation of protective films on A537 carbon steel, even on the freshly exposed areas such as the Clarke's solution-treated machined cracks where the oxide was removed immediately before immersion. These mechanistic details may be addressed and resolved by electrochemical testing.

Careful examination of the specimen conditions found that many distinct surface features originally on the mill sheet remained visible on the specimens after testing, and the appearance of the weld beads was essentially unchanged. The specimen thinning was immeasurable with a micrometer. Therefore, the general corrosion is negligible for these specimens in 12 M caustic solution for extended period of time.

The laboratory testing has demonstrated that stress corrosion cracking did not occur in the small welded U-bend specimens, as well as in the large plates where the welding procedure was identical to that used to construct the SRS Type III waste tanks in the 1960s. The observations of no evidence of stress corrosion cracking or general corrosion in the laboratory specimens indicate that the Type III/IIIA nuclear waste tanks, in particular, Tanks 30 and 32 (which are Type III tanks), are not susceptible to highly caustic solutions up to 12 M hydroxide at 125 °C when sufficient nitrite inhibitor is present.

ACKNOWLEDGMENTS

The U-bend experimental station was designed, assembled and maintained by Mr. Craig S. Stripling. The large plate test tank assembly was designed, constructed, and maintained by Mr. Donald L. Fisher and was operated by Mr. Stripling. The NDE ultrasonic testing of the large plates was performed by Mr. James B. Elder III. Their contributions are essential to the success of the CSCC experimental project. Ms. Tina M. Stefek provided her experience on the safety and controls in the large plate testing for nitrate stress corrosion cracking, which we carried out from 2002 to 2004 for A285 carbon steel nuclear waste tanks. Ms. Robbie S. Garritano's assistance in mixing the test solutions and miscellaneous laboratory tasks is greatly appreciated. Thanks also go to

Drs. John I. Mickalonis and Bruce J. Wiersma for their technical advice and continuing encouragements.

REFERENCES

[1] K. H. Subramanian and B. J. Wiersma, "Stress Corrosion Cracking Susceptibility of High Level Waste Tanks Exposed to Evaporator Recycle Waste," WSRC-TR-2008-00192, June 2008, DRAFT.
[2] B. J. Wiersma, "Determination of Temperature Limits for Radioactive Waste Tanks," WSRC-TR-98-00131, June 1999.
[3] K. H. Subramanian and J. I. Mickalonis, "Anodic Polarization Behavior of Low-Carbon Steel in Concentrated Sodium Hydroxide with Sodium Nitrate Additions," WSRC-TR-2004-00292, October 2004.
[4] K. H. Subramanian and J. I. Mickalonis, "Anodic Polarization Behavior of Low-Carbon Steel in Concentrated Sodium Hydroxide and Sodium Nitrate Solutions," Electrochimica Acta, Vol. 50, pp. 2685-2691, 2005.
[5] P.-S. Lam, C. Chang, Y. J. Chao, R. L. Sindelar, T. M. Stefek, and J. B. Elder, III, "Stress Corrosion Cracking of Carbon Steel Weldments," PVP2005-71327, Proceedings of ASME Pressure Vessels and Piping Conference, Denver, Colorado, 2005.
[6] P.-S. Lam, "Dependence of Intergranular Stress Corrosion Cracking on Weld Residual Stress," SRTC Strategic R&D (sponsored by the WSRC High Level Waste Division), 2002.
[7] W. G. Reuter, F. A. McClintock, and P.-S. Lam, "Increasing Safety and Reducing Environmental Damage Risk from Aging High-level Radioactive Waste Tanks," U. S. Department of Energy Office of Science, Environmental Management Science Program (EMSP), 2002-2004.
[8] B. J. Wiersma, "An Assessment of the Service History and Corrosion Susceptibility of Type IV Waste Tanks," SRNS-STI-2008-00096, September 2008.
[9] W. B. DeLong to S. P. Rideout, "Properties of A516-70 Steel Used in Waste Tanks 29-32", September 10, 1974.
[10] W. B. Delong to R. G. Garvin, "FY '74 Waste Tanks Proj. 1463", August 6, 1975.
[11] B. J. Wiersma, "Re: Task Plan for the Determination of Corrosion Inhibitor Criteria for Type III/IIIA Tanks During Salt Dissolution Operations," SRNL-MTS-2005-50019, August 10, 2005.
[12] J. K. Thomas, "Failure Strain and Mechanical Property Data for the Type IIIA Waste Tanks Liners", WSRC-RP-92-859, June 1992.
[13] J. A. Donovan and R. S. Ondrejcin to A. A. Kishbaugh, "Relative Resistance to Nitrate Cracking of A537 Class I and A516 Grade 70 Normalized Steels", WSRC-RP-2004-00198, March 23, 1977.
[14] B. J. Wiersma and J. I. Mickalonis, "Determination of Corrosion Inhibitor Criteria for Type III/IIIA Tanks during Salt Dissolution Operations," WSRC-STI-2006-00029, September 2007.

[15] B. J. Wiersma, "Waste Management Experimental Programs," WSRC-NB-99-00247, Laboratory Notebook, pp. 59-77, 1997.
[16] R. J. Landrum, "Analysis of Stress Relief Heat Treatment of Waste Storage Tanks," Materials Engineering - #950974-10, May 21, 1969.
[17] BFF 211620 "Nooter Corporation High Level Waste Storage Tanks, Primary Knuckle Assemblies," E. I. Du Pont Nemours Co., Wilmington, DE, Job No. D4600, Sheet 17 of 18, January 10, 1968.

APPENDICES

APPENDIX 1
Material Certificate of A537 for U-bend Specimens

WSRC-NB-99-00247
p. 68

07/15/2005 From: AMERICAN ALLOY STEEL To: ALABAMA SPECIALTY PRODUCTS, INC.
P.O.# :70162 S.O.# :252636 AA PL#:8027522
Item :1 (1 PC) 3/8" X 25" X 161" AS-IS EXISTING REM
:

ISG PLATE INC. T E S T C E R T I F I C A T E

SHIP TO:
AMERICAN ALLOY STEEL, INC.
C/O STORAGE & PROCESSORS, INC.
8500 CLINTON DR./TRACK 23-430
DLV. CARRIER-PT. TERM RR-<150"
HOUSTON TX 77240

PAGE NO: 01 OF 02
FILE NO: 0284-01-11
MILL ORDER NO: 21662-001
MELT NO: U4911
SLAB NO: 388
DATE: 04/19/05

SOLD TO:
AMERICAN ALLOY STEEL, INC
P. O. BOX 40469
HOUSTON TX 77240-0469

SEND TO:
AMERICAN ALLOY STEEL, INC
P. O. BOX 40469
ATTN: HOMER GARZA
HOUSTON, TX 77240-0469

03-C

P L A T E D I M E N S I O N S / D E S C R I P T I O N

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	.375"	96"	480"	RECTANGLE	49010

C U S T O M E R I N F O R M A T I O N

CUSTOMER PO: 59652

S P E C I F I C A T I O N (S)

THIS MATERIAL HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH PURCHASE ORDER REQUIREMENTS AND SPECIFICATION(S).

API 2H-8TH-EDITION YR 99 GR 50 S1 S3 S5
SUPPL. PARA. S5 APPLIES.
SPEC MOD FOR CARBON
SPEC MOD FOR PHYSICALS
ASTM A633 01 GR C, ASME SA537 01 ED CL 1 MOD
.04 MAX CB, ABS PART-2-SECT-5 03 GRS EH/DH36
& MIL S-22698C GR DH36
MATERIAL PRODUCED UNDER A CERTIFIED QUALITY MGMT SYSTEM COMPLYING WITH ISO 9001 ABS-QE CERT. NO. 30130

Certified a true copy of the original, retained in our file.
AMERICAN ALLOY STEEL, INC.
DG 5/3/05

C H E M I C A L C O M P O S I T I O N

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:U4911	.14	1.44	.008	.003	.14	.29	.11	.09	.04

	V	TI	B	AL	CB	CA	N	CEF	PCM
MELT:U4911	.003	.003	.0003	.021	.030	.002	.0099	.42	.240

PCM FORMULA (PCM)
PCM = C + (SI / 30) + ((MN + CU + CR) / 20)
+ (NI / 60) +(MO / 15) +(V / 10) + (5 * B)

CARBON EQUIVALENT FORMULA (CEF)
CEF = C + (MN * .1667) + ((CR + MO + V) * .2000) + ((CU + NI) * .0667)

M A N U F A C T U R E

FINELINE - VACUUM DEGASSED - FINE GRAIN PRACTICE

H E A T T R E A T C O N D I T I O N

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PL/TEST	NORMALIZE	1660F	24	AIR COOL

AMERICAN ALLOY PLATE # 800702

MAT'D I.D. NO. AD481 P.O. NO. 70162
SPEC. A537 CL 1 INITIAL JB

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

QUALITY ASSURANCE LABORATORY
COATESVILLE, PA 19320

SUPERVISOR - TEST REPORTING
ELINORE ZAPLITNY

07/20/2005 08:38 AMERICAN ALLOY STEEL → 912563584515 NO.250 D02

Appendix 1 (continued)

WSRC-NB-99-00247 p. 69

07/15/2005 From: AMERICAN ALLOY STEEL To: ALABAMA SPECIALTY PRODUCTS, INC.
P.O.# :70162 S.O.# :252636 AA PL#:0027522
Item :1 (1 PC) 3/8" X 25" X 161" AS-IS EXISTING REM :
:

ISG PLATE INC. TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0284-01-11
MILL ORDER NO: 21662-001
MELT NO: U4911
SLAB NO: 3BB
DATE: 04/19/05

TENSILE PROPERTIES

SLAB NO.	LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%
3BB	BOT.	TRANS.	669	844	8.00"	22.0

CHARPY V-NOTCH IMPACT RESULTS

SLAB	LOC	DIR	TEMP	SIZE	FT. LBS.		
3BB	BOT.	TRANS.	-40F	3/4	46	49	53

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
A.B.S. Q.A. CERTIFICATE 04-HHPQA-263.
MATERIAL HAS BEEN VACUUM DEGASSED AND CALCIUM TREATED
FOR SULFIDE SHAPE CONTROL.
FINELINE MOD FOR SULPHUR
TEST CERTS. ARE PREPARED IN ACCORD. WITH PROCEDURES
OUTLINED IN DIN 50049 3.1.B/EN 10204 3.1.B.

B/L #75657 TTPX 804066

Certified a true copy of the original, retained in our file.
AMERICAN ALLOY STEEL, INC.

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

QUALITY ASSURANCE LABORATORY
COATESVILLE, PA 19320

SUPERVISOR - TEST REPORTING
ELINORE ZAPLITNY

07/20/2005 08:38 AMERICAN ALLOY STEEL → 9125653584515 NO.250 P03

APPENDIX 2
Material Certificate of A537 for Large Plate Specimens

02/04/2009 From: AMERICAN ALLOY STEEL To: ALABAMA SPECIALTY PRODUCTS, INC.
P.O.# :89112 S.O.# :339632 AA #L#:8039636
Item :1 (1 PC) 1" X 70" X 32" (32" IN DOR)
:TAG: (GRADE/HEAT/SLAB/MILL).. DOR

QUALITY ASSURANCE REPORT OF TEST AND ANALYSES

SHIPMENT NO	DATE SHIPPED	CAR OR VEHICLE NO		PAGE
801-15452	09-16-08	TRK-MCCOO-RMHF	TTPX 080284	9

SOLD TO: AMERICAN ALLOY STEEL INC, PO BOX 40469, HOUSTON TX 77040-0465

SHIPPED TO: AMERICAN ALLOY STEEL INC, HWY TR# 7226 MILE 66.4 LN RNG 452, 6230 N HOUSTON ROSSLYN RD, HOUSTON TX

SERIAL NUMBER	PAT NO.	HEAT NUMBER	NO. PCS.	THICKNESS INCHES	WIDTH OR DIA INCHES	LENGTH INCHES	WEIGHT POUNDS	YIELD POINT PSI	TENSILE STRENGTH PSI	ELONG IN	RED. %
A030146		813B66970	1 1		96	360	9801	53900	75000	8 24	

QUALITY STEEL MELTED & MANUFACTURED IN THE U. S. A.
PLATES - API -2H GR 50 INTERIM 2006 EDITION
MOD C.18 MAX S1,S3,S4,S5,S12
CE=.25% PER PCM & .42% PER IIW
FORMULA, ASME A633-01 GR C, ABS HRD DH/EH36 REV 2006, ASME SA537
PVQ 2006 EDIT MOD CB.04MAX CL 1, MIL-S-22698C GR DH36, CH-V 2085
PLT F 30/25 FTLBS AT -40F, TRNS TEST PER API-2H S4, NOT API-2H PLT
NO BREAK AT -30F. UT A578 LEVEL A 100%, PROD ANAL ON HT-PLT NORM
& COOLED IN STILL AIR-TEST CERTS PREPARED IN ACCORDANCE WITH
PROCEDURE OUTLINED IN EN10204:2004 PARA 3.1
NO WELD REPAIR WAS PERFORMED ON BELOW PLATE(S)
----PLATE PASSED NOT API-2H NO BREAK AT -30F----
CO# 75822 OH 361-6505G
PLATES HEAT TREATED - TEST SPECIMENS ATTACHED & YIELD STRENGTH @ .5% EUL
PLATES ULTRASONICALLY TESTED PER ATTACHMENT
OUTSIDE INSPECTION BY AMERICAN BUREAU OF SHIPPING

CE1058888

55
60

N. 1650 DEG F - 49 MIN

MATL I.D. NO. AH 730 P.O. NO. 89112 SPEC. A537(1) INITIAL

WE HEREBY CERTIFY THAT THE MATERIAL DESCRIBED HEREIN HAS BEEN MADE BY THE ARCELORMITTAL BH PLANT TO THE APPLICABLE SPECIFICATION BY AN APPROVED PROCESS AND HAS BEEN TESTED IN ACCORDANCE WITH THE REQUIREMENTS OF THE AMERICAN BUREAU OF SHIPPING RULES FOR THE INSPECTION AND TESTING OF MATERIALS TO THE SATISFACTION OF THE SURVEYORS.

SERIAL NUMBER	PAT NO.	HEAT NUMBER			THICKNESS INCHES	TYPE	SIZE	OR	TEST TEMP F	IMPACT FT LBS 1	2	3
A030146		813B66970			1.000	V	FULL	T	-40	115	132	124

AMERICAN BUREAU OF SHIPPING — ROBERT THOMPSON

HEAT NUMBER	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	Al	B	Ti	N	Ca
813B66970	.14	1.38	.012	.006	.288	.022	.01	.09	.056	.001	.002	.030	.0002	.032	.006	.005

CE .40 PCM .23 CA .0021

Certified a true copy of the original, retained in our file.
AMERICAN ALLOY STEEL
05/11/2008

D. W. ELWOOD MGR.
SUP. QUALITY ASSURANCE

AMERICAN ALLOY PLATE# 8039636

APPENDIX 3
Certificate of Welding Electrodes for U-bend Specimens

HOBART BROTHERS

Certificate of Conformance
to Requirements for Welding Electrode Hobart

Customer:
Customer P.O. No.:
Order No.:
Stock Number: S119944-035
Lbs. Shipped:
Date Generated: 8/1/2005
Lot Nos. Shipped: 26F522

Product Type: HOBART 418 1/8 50 CAN
Classification: E7018 H4R
Specifications: AWS A5.1/A5.1M:2004
Diameter Tested:
Date Tested: 2/26/04
Diameter Shipped: 1/8X14 in

This is to certify that the product named above and supplied on the referenced order number is of the same classification, manufacturing process, and material requirements as the material which was used for the test that was concluded on the date shown, the results of which are shown below. All tests required by the specifications shown for classification were performed at that time and the material tested met all requirements. It was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO9000, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings

Amps	Volts	Size	Polarity	Preheat	Interpass	Travel Speed
200	26 1/2 - 24 1/2	5/32X14 in	AC	225 F (107 C)	300 F (149 C)	+- 1 in/min
200	26 1/2 - 24 1/2	5/32X14 in	DCEP	225 F (107 C)	300 F (149 C)	+- 1 in/min
325	28-29	1/4X18 in	DCEP	225 F (107 C)	300 F (149 C)	+- 1 in/min
350	28-29	1/4X18 in	AC	225 F (107 C)	300 F (149 C)	+- 1 in/min

Mechanical Properties - Tensile

Size / Polarity	Ref. No.	Testing Conditions	Ult. Tensile Strength	Yield Strength	Elong.% in 2"
1/4X18 in / DCEP	PA0744	As Welded	74,000 psi (507 Mpa)	60,000 psi (416 Mpa)	30
1/4X18 in / AC	PA0745	As Welded	78,000 psi (536 Mpa)	65,000 psi (447 Mpa)	28
5/32X14 in / AC	PA0707	As Welded	78,000 psi (535 Mpa)	61,000 psi (423 Mpa)	28
5/32X14 in / DCEP	PA0708	As Welded	75,000 psi (520 Mpa)	61,000 psi (421 Mpa)	29

Mechanical Properties - Impact

Size / Polarity	Ref. No.	Testing Conditions	Test Temp.	Individuals	Average	Type
1/4X18 in / DCEP	PA0744	As Welded	-20 F (-29 C)	203,204,133 ft.lb	180 ft.lb (244 J)	Charpy-V-Notch
1/4X18 in / AC	PA0745	As Welded	-20 F (-29 C)	94,98,90 ft.lb	94 ft.lb (127 J)	Charpy-V-Notch
5/32X14 in / AC	PA0707	As Welded	-20 F (-29 C)	122,129,118 ft.lb	123 ft.lb (167 J)	Charpy-V-Notch
5/32X14 in / DCEP	PA0708	As Welded	-20 F (-29 C)	265,268,267 ft.lb	266 ft.lb (361 J)	Charpy-V-Notch

Size / Polarity	Ref. No.	Radiograph	Fillet Weld Test					
1/4X18 in / DCEP	PA0744	Conforms	Horizontal :	Conforms	Overhead :		Vertical :	
1/4X18 in / AC	PA0745	Conforms	Horizontal :	Conforms	Overhead :		Vertical :	
5/32X14 in / AC	PA0707	Conforms	Horizontal :		Overhead :	Conforms	Vertical :	Conforms
5/32X14 in / DCEP	PA0708	Conforms	Horizontal :		Overhead :	Conforms	Vertical :	Conforms

Chemical Analysis

Size / Polarity / Ref. No.	C	Mn	P	S	Si	Cu	Cr	V	Ni	Mo	Al	Ti	Nb	Co	B	W	Sn	Fe	Sb	N	Mg	Zn	Be
5/32X14 in / DCEP / PA0708	0.02	1.06	0.010	0.015	0.50		0.05	0.01	0.07	0.01													
1/4X18 in / DCEP / PA0744	0.03	1.30	0.012	0.014	0.52		0.05	0.01	0.09	0.01												-	

Steve Knostman, Quality Engineer

Stan Wen, Development Engineer

SPEC. MAT'L I.D. NO. 7018

BJW 8/11

The information contained or otherwise referenced herein is presented without guarantee or warranty and Hobart Brothers expressly disclaims any liability incurred from any reliance thereon. Data for the above supplied product are those obtained when welded and tested in accordance with the above specification with electrode of the same manufacturing processes and material requirements. All tests for the above classification were satisified. Other tests and procedures may produce different results. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Hobart Brothers produces welding consumables under continuing quality assurance programs audited and approved by American Bureau of Shipping (ABS). ** Please refer to Hobart Brothers Web Site (http://www.hobartbrothers.com) for current MSDS information.

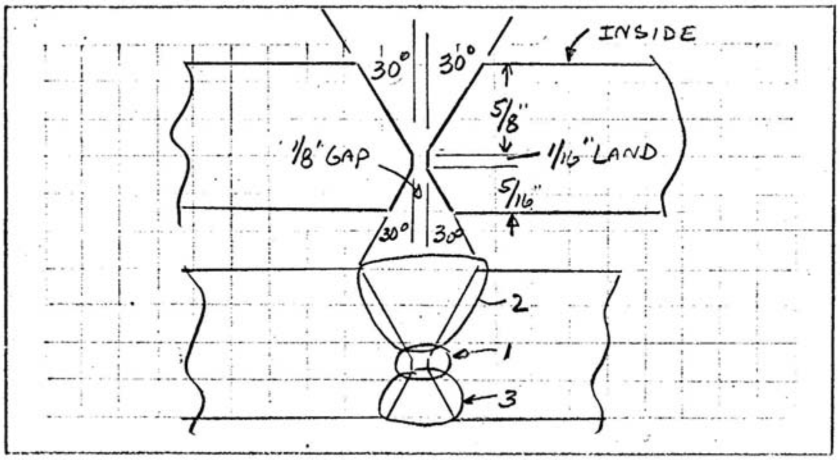
WSRC-NB-99-00247 p. 70

APPENDIX 4
Welding Procedure for SRS Type III Nuclear Waste Storage Tanks

NOOTER CORPORATION
ST. LOUIS 4, MO.

BY F. BARKER DATE
CHKD. BY DATE
SUBJECT WELD DETAILS
SHEET No. OF
JOB No. D-4600
E.I. DuPont de Nemours 4 High Level Waste Storage Tanks AXC-25993½

△ REV. 9/22/67 G.L.



WELD NO.
W-26

LOCATION	O.S. KNUCKLE BUTT WELD PRIMARY		
WHERE MADE	FIELD △ SHOP		
MATERIAL	ASTM A-516 GR 70		
PROCESS	MIG DROP. THRU MANUAL COATED ROD		
TECHNIQUE	DOUBLE 1G & 4G △ 3G		
RADIOGRAPH	YES	HEAT TREAT	YES
PROCEDURE QUAL. NO.	#8C #8B △	WELDER QUAL. NO.	

SPECIAL NOTES:

Weld #1 use MIG manual - .035 Oxweld 65 - C25 gas

Weld #2 use coated rod E-7018 as many passes as necessary for completed weld

Back grind or gouge weld #1 to clean metal

Weld #2 use coated rod E-7018 as many passes as necessary for complete weld

211620

Appendix 4 (continued)

D-4600 - Procedure Qualification #8B

SPEC. NO. 1-1-41
Re-Issue Date 5/18/66

NOOTER CORPORATION

WELDING PROCEDURE SPECIFICATION AND QUALIFICATION RECORD

On work performed under the A.S.M.E. Code, the welding procedure to be used in fabrication and the qualification of this procedure shall be in strict conformance with the Code. The information furnished is required by Section IX of the A.S.M.E. Boiler and Pressure Vessel Code. (References to Paragraphs and Tables in any of the following statements refer to those in Section IX of the A.S.M.E. Boiler and Pressure Vessel Code.)

Procedure Specification for METAL INERT GAS AND MANUAL METALLIC ARC WELDING OF P-1 MATERIALS

Specification No. 1-1-41 Procedure Date MARCH 18, 1964

Welding Process METAL INERT GAS AND MANUAL METALLIC ARC

Material A-212 GR B to A-212 GR B of P-No. 1 to P-No. 1

Thickness (if pipe, diameter and wall thickness) 1 Thickness Range 3/16 to 2

FILLER METAL

Filler Metal Group No. F - 4

Weld Metal Analysis No. A - 1

Describe Filler Metal if not included in Table Q-11.2 or QN-11.2 OX 65

FLUX or ATMOSPHERE

Flux Trade Name or Composition

Inert Gas Composition 75% ARGON 25% CO_2

Trade Name C25 Flow Rate 30-40 CFH

WELDING PROCEDURE AND TECHNIQUES

Single or Multiple Pass MULTIPLE Single or Multiple Arc SINGLE

Position of Groove 3-G(VERTICAL) Is Backing Strip Used? NO

Preheat Temperature Range ROOM TEMPERATURE (APPROXIMATELY 70° F.)

Postheat Treatment 1100 - 1200° F. HOLD ONE HOUR AND FURNACE COOL

Joint dimensions accord with succeeding sketches

REDUCED SECTION TENSILE TEST

SPECIMEN NO.	DIMENSIONS		AREA	ULTIMATE TOTAL, LB.	ULTIMATE STRENGTH, PSI.	CHARACTER OF FAILURE AND LOCATION
	WIDTH	THICKNESS				
	1.494	.853	1.274	96,200	75,600	PLATE
	1.497	.849	1.271	96,400	75,900	PLATE

ALL WELD METAL TENSION TEST

DIAMETER	AREA	YIELD, PSI	ULTIMATE STRENGTH, PSI.	% ELONGATION	FRACTURE

BEND TESTS / ADDITIONAL TESTS

TYPE	RESULTS	TYPE	RESULTS
4 SIDE	ACCEPTABLE		

Welder's Name C. BOYER Clock No. 541

Test Conducted by NOOTER CORPORATION Laboratory-Test No. B-101

We certify that the statements in this record are correct and that the test welds were welded in accordance with this procedure and tested in accordance with the requirements of Section IX of the Code.

Procedure Qualification Date MARCH 18, 1964 Signed NOOTER CORPORATION (MANUFACTURER)

lh By

Appendix 4 (continued)

D-4600 Procedure Qualification (#8C)

EC. NO. 1-1-41
Re-Issue Date 5/18/66

NOOTER CORPORATION

WELDING PROCEDURE SPECIFICATION AND QUALIFICATION RECORD

On work performed under the A.S.M.E. Code, the welding procedure to be used in fabrication and the qualification of this procedure shall be in strict conformance with the Code. The information furnished is required by Section IX of the A.S.M.E. Boiler and Pressure Vessel Code. (References to Paragraphs and Tables in any of the following statements refer to those in Section IX of the A.S.M.E. Boiler and Pressure Vessel Code.)

Procedure Specification for METAL INERT GAS AND MANUAL METALLIC ARC WELDING OF P-1 MATERIALS

Specification No. 1-1-41 Procedure Date MARCH 18, 1964
Welding Process METAL INERT GAS AND MANUAL METALLIC ARC
Material A-212 GR B to A-212 GR B of P-No. 1 to P-No. 1
Thickness (if pipe, diameter and wall thickness) 1 Thickness Range 3/16 to 2

FILLER METAL

Filler Metal Group No. F - 4
Weld Metal Analysis No. A - 1
Describe Filler Metal if not included in Table Q-11.2 or QN-11.2 OX 65

FLUX or ATMOSPHERE

Flux Trade Name or Composition
Inert Gas Composition 75% ARGON 25% CO_2
Trade Name C25 Flow Rate 30-40 CFH

WELDING PROCEDURE AND TECHNIQUES

Single or Multiple Pass MULTIPLE Single or Multiple Arc SINGLE
Position of Groove 4-G OVERHEAD Is Backing Strip Used? NO
Preheat Temperature Range ROOM TEMPERATURE (APPROXIMATELY 70° F.)
~~Postheat Treatment 1100 - 1200° F. HOLD ONE HOUR AND FURNACE COOL~~
~~Joint dimensions accord with succeeding sketches~~

REDUCED SECTION TENSILE TEST

SPECIMEN NO.	DIMENSIONS		AREA	ULTIMATE TOTAL, LB.	ULTIMATE STRENGTH, PSI.	CHARACTER OF FAILURE AND LOCATION
	WIDTH	THICKNESS				
	1.501	.851	1.276	100,000	78,300	PLATE
	1.503	.847	1.272	98,800	77,700	PLATE

ALL WELD METAL TENSION TEST

DIAMETER	AREA	YIELD, PSI	ULTIMATE STRENGTH, PSI.	% ELONGATION	FRACTURE

BEND TESTS / ADDITIONAL TESTS

TYPE	RESULTS	TYPE	RESULTS
4 SIDE	ACCEPTABLE		

Welder's Name C. BOYER Clock No. 541
Test Conducted by NOOTER CORPORATION Laboratory-Test No. B-101

We certify that the statements in this record are correct and that the test welds were welded in accordance with this procedure and tested in accordance with the requirements of Section IX of the Code.

Procedure Qualification Date MARCH 18, 1964 Signed NOOTER CORPORATION (MANUFACTURER)

lh

By [signature]

NOOTER 352

Appendix 4 (continued)

D-4600 Procedure Qualification #8

SPEC. NO. 1-1-41
Re-issue Date 5/18/66

NOOTER CORPORATION

WELDING PROCEDURE SPECIFICATION AND QUALIFICATION RECORD

The following paragraphs describe details which are not Essential Variables. Changes in these details may be made without setting up a new Procedure Specification provided they are recorded as revisions.

PREPARATION OF BASE MATERIAL

The edges or surfaces of the parts to be joined by welding shall be prepared by:

Grinding [ ] Machining [X] Shearing [ ] Sawing [ ] Burning [ ] Plasmarc Cutting [ ]
Arc Airing [ ] Chipping [ ] Burning followed by grinding [ ] Arc Airing followed by grinding [ ]
Plasmarc Cutting followed by grinding [ ] Sandblasting [ ]

The edges or surfaces of the parts to be joined by welding shall be cleaned of all oil or grease and excessive amounts of scale or rust.

ELECTRICAL CHARACTERISTICS

The current shall be D. C. [X], A. C. [ ]. The polarity used shall be straight [ ], reverse [X]

APPEARANCE OF WELDING LAYERS

The welding current and manner of depositing the weld metal shall be such that there shall be practically no undercutting on the side wall of the welding groove or the adjoining base material.

CLEANING

All slag or flux remaining on any bead of welding shall be removed before laying down the next successive bead.

DEFECTS

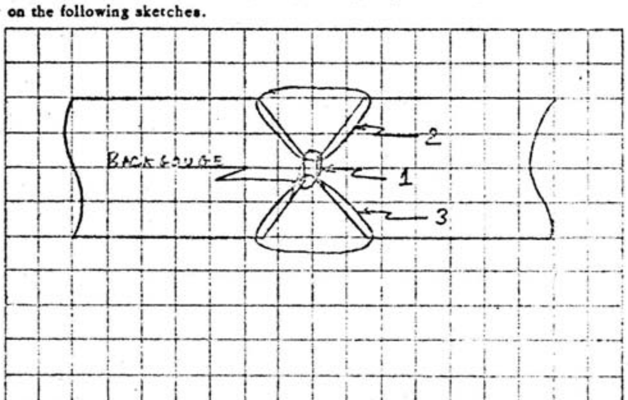
Any cracks or blow holes that appear on the surface of any bead of welding shall be removed by chipping, grinding, or gouging before depositing the next successive bead of welding.

TREATMENT OF UNDERSIDE OF WELDING GROOVE

THE UNDERSIDE OR SECOND SIDE OF THE WELDING GROOVE SHALL BE BACK GOUGED TO SOUND METAL PRIOR TO WELD DEPOSIT.

JOINT WELDING PROCEDURE

The welding technique, such as joint geometry, sequence of operations and/or welding processes, etc., shall be substantially as shown on the following sketches.



1ST PASS METAL INERT GAS
2ND PASS COATED ROD
BACKGOUGE
3RD PASS COATED ROD

Original Procedure Date MARCH 18, 1964

Signed NOOTER CORPORATION
Manufacturer

By [signature]

lh

NOOTER 353

APPENDIX 5
Certificate of Welding Electrodes EM 70S-2 for Large Plate Specimens

AMERICAN FILLER METALS

6015 Murphy • Houston, Texas 77033
Phone: 713-649-8785 • 1-800-394-4550 • Fax: 713-644-9628 • www.amfiller.com

ACTUAL MATERIAL TEST REPORT

Customer: ALABAMA WELDING SUPPLY
1715 C PLEASANT GROVE RD
DOLLOMITE, AL 35061

PO: 9876 Ship Date: 10/28/2008 Net Weight: 33#

Product: EM 70S-2 MI Dimensions: .035 X 33

Heat #: 2712332 Specification: AWS A5.18 ER70S-2

Al	C	Cr	Cu	Mn	Mo
.079	.05	.02	.16	1.15	.01
Ni	**P**	**S**	**Si**	**Ti**	**V**
.01	.015	.005	.54	.076	.001
Zr					
.05					

MAT'L I.D. NO. AH455 P.O. NO. 87550
SPEC. INITIAL 2B
ER70S-2 .035" DIA MIG WIRE

*We certify that the chemical analysis as recorded conform to the specification listed above as contained within the records of AFM. This material is free from mercury, radium, or alpha particle contamination. Meets EN 10204 3.1.

Authorized Representative

Sustaining Member

APPENDIX 6
Certificate of Welding Electrodes E-7018 for Large Plate Specimens

The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199

CERTIFICATE OF CONFORMANCE
(APPLIES ONLY TO U.S. PRODUCTS)

LINCOLN ELECTRIC

[1 Year]

Product: Excalibur® 7018 MR
Classification: E7018-H4-R
Specification: AWS A5.1-2004, ASME SFA-5.1
Test Completed: June 12, 2008

Operating Settings	AWS/ASME Requirements	RESULTS			
Electrode Size		5/32 inch	5/32 inch	3/16 inch	3/16 inch
Polarity		AC	DC+	AC	DC+
Plate Thickness, mm (in.)		19 (3/4)	19 (3/4)	19 (3/4)	19 (3/4)
Current, amps		185	160	230	210
Passes/Layers		16/8	14/7	14/7	14/7
Preheat Temp, °C (°F)	(225 min.)	120 (250)	120 (250)	120 (250)	120 (250)
Interpass Temp, °C (°F)	(225 - 350)	165 (325)	165 (325)	165 (325)	165 (325)
Mechanical properties of the weld deposits (in the as-welded condition)					
Tensile Strength, MPa (ksi)	(70 min.)	530 (77)	520 (75)	560 (82)	550 (80)
Yield Strength, 0.2% offset MPa (ksi)	(58 min.)	440 (64)	430 (62)	470 (69)	460 (67)
Elongation, %	22 min.	31	32	28	32
Average Hardness Rockwell B	Not Required	86	83	87	87
Avg. Charpy V-notch Impact Properties		211 (155)	(see Note)	136 (101)	136 (100)
Joules @ -29 °C (ft-lbf @ -20 °F)	(20 min.)	206,210,216 (152,155,159)	209,358,368 (154,264,264)	123,141,145 (91,104,107)	117,142,149 (86,105,110)
Chemical composition of the weld deposit					
(weight %)					
C	0.15 max.	0.04	0.04	0.05	0.04
Mn	1.60 max.	1.10	1.13	1.11	1.12
Si	0.75 max.	0.43	0.45	0.51	0.52
S	0.035 max.	0.006	0.006	0.007	0.007
P	0.035 max.	0.014	0.014	0.010	0.010
Cr	0.20 max.	0.03	0.02	0.03	0.03
Ni	0.30 max.	0.02	0.02	0.04	0.04
Mo	0.30 max.	0.01	0.01	0.01	0.01
V	0.08 max.	0.00	0.00	0.01	0.01
Mn+Ni+Cr+Mo+V	1.75 max.	1.16	1.18	1.20	1.21
Coating Moisture % - as received	0.3 max.	0.1		Not Required	
- exposed	0.4 max.	Not Required			

The coating moisture result for 3/32 inch is 0.1. The 9 hour absorbed moisture result for 3/32 inch is 0.3.
The electrode diameters required to be tested for this classification are 5/32 in., 3/16 in., and 1/4 in. The 3/32 in., 1/8 in. and 7/32 in. sizes will also meet these requirements.
NOTE: One or more of the reported impact values exceeded the machine capacity of 358 Joules (264 ft-lbf) or is greater than 80% (286 Joules (211 ft-lbf)) of the machine capacity. These values are reported as approximate and should not be averaged, per ASTM E23.
This certificate complies to the requirements of EN 10204, Type 2.2.
Radiographic Test: Grade 1: Met requirements. Fillet Weld Test: (positions as required): Met requirements.
Test assembly constructed of ASTM A36.
Results below the detection limits of the instrument or lower than the precision required by specification are reported as zero.
Strength values in SI units are reported to the nearest 10 Mpa converted from actual data. Preheat and interpass temperature values in SI units are reported to the nearest 5 degrees.

MAT'L. I.D. NO. AH729 P.O. NO. 89139
SPEC. ______ INITIAL JR
7018 A1 3/32 DIA STICK Rod

Page 1 of 2

Cert. No. 31758

APPENDIX 6 (continued)

The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199

CERTIFICATE OF CONFORMANCE
(APPLIES ONLY TO U.S. PRODUCTS)

LINCOLN ELECTRIC

[1 Year]

Product: Excalibur® 7018 MR
Classification: E7018-H4-R
Specification: AWS A5.1-2004, ASME SFA-5.1
Test Completed: June 12, 2008

Operating Settings	AWS/ASME Requirements	RESULTS	
Electrode Size		1/4 inch	1/4 inch
Polarity		AC	DC+
Plate Thickness, mm (in.)		25 (1)	25 (1)
Current, amps		340	320
Passes/Layers		18/9	18/9
Preheat Temp, °C (°F)	(225 min.)	120 (250)	120 (250)
Interpass Temp, °C (°F)	(225 - 350)	165 (325)	165 (325)
Mechanical properties of the weld deposits (in the as-welded condition)			
Tensile Strength, MPa (ksi)	(70 min.)	560 (81)	540 (79)
Yield Strength, 0.2% offset MPa (ksi)	(58 min.)	470 (68)	460 (67)
Elongation, %	22 min.	33	29
Average Hardness Rockwell B	Not Required	86	87
Avg. Charpy V-notch Impact Properties		184 (136)	187 (138)
Joules @ -29 °C (ft-lbf @ -20 °F)	(20 min.)	172,188,192 (127,139,142)	174,180,207 (128,133,153)
Chemical composition of the weld deposit			
(weight %)			
C	0.15 max.	0.05	0.05
Mn	1.60 max.	1.40	1.40
Si	0.75 max.	0.48	0.48
S	0.035 max.	0.007	0.007
P	0.035 max.	0.008	0.007
Cr	0.20 max.	0.02	0.02
Ni	0.30 max.	0.02	0.02
Mo	0.30 max.	0.01	0.01
V	0.08 max.	0.00	0.00
Mn+Ni+Cr+Mo+V	1.75 max.	1.46	1.46
Coating Moisture % - as received	0.3 max.	0.1	
- exposed	0.4 max.	0.3	

Diffusible Hydrogen, mL/100g at STP (AWS A4.3-93)				Abs. Humidity
Size (in)		Requirement	Results	(gr/lb)
3/32 in.	DC+	4.0 max.	1.9	28
1/4 in.	DC+	4.0 max.	3.7	44

This is to certify that the product named above and supplied on the referenced order number is of the same classification, manufacturing process, and material requirements as the material which was used for the test that was concluded on the date shown, the results of which are shown. All tests required by the specifications shown for classification were performed at that time and the material tested met all requirements. It was manufactured and supplied according to the Quality System Program of the Lincoln Electric Company, Cleveland, Ohio, U.S.A., which meets the requirements of ISO9001, NCA3800, ANSI/AWS A5.01, JIS Z9902, and other specification and Military requirements, as applicable. The Quality System Program has been approved by ASME, ABS, and VdTUV.

Phillip J. Woodring, Certification Supervisor — Date: June 13, 2008

David A. Fink, Manager, Compliance Engineering, Consumable R&D Department — Date: 16 June 2008

Page 2 of 2.

Cert. No. 31758

APPENDIX 7
Welding Parameters for the As-welded Plate

Alabama Specialty Products, Inc.	WPS 09.02.04-04
Weld Procedure Specification	SMAW P1 to P1
SAVANNAH RIVER NUCLEAR MIG/SMAW WELD BLOCK A537CL1 W/O HT	Revision -New-

Joint Design	Double K-Notch Butt Weld		
Backing Type	N/A	Groove Type	N/A
Backing Material	N/A		

Base Metals

P. No.	Group	UNS	Common Name or Designation	Thickness	Diameter
1		K02400	ASTM A537 CL1	1/8" to 1"	to
1		K02400	ASTM A537 CL1	1/8" to 1"	to

Filler Metals

SFA Number		A5.5
AWS Class	ER70S-2	E7018
F-Number		4
A-Number		2
Size of Filler	.035"	3/32"
Thickness Range	1/8" – 1"	1/8" – 1"
Consumable Insert	N/A	

Electrical Characteristics

Current Type	DC	Polarity	Positive
Current (Range)			See attached
Volts (Range)			See attached
Tungsten Electrodes	Size		N/A
Tungsten Electrodes	Type		N/A
GMAW	Transfer Mode		N/A
GMAW	Wire Feed Speed		N/A

Positions

Position(s) of Groove	1-G
Welding Progression	Flat
Position(s) of Fillet	N/A

Preheat

Preheat Temperature	250* F
Interpass Temperature	N/A
Preheat Maintenance	N/A

Post Weld Heat Treatment

Temperature Range	N/A
Time Range	N/A

Gas

	Gas(es)	% Mixture	Flow Rate
Shielding	Argon/CO2	95/5	35CFH
Trailing	N/A		
Backing	N/A		

Technique

Bead Type	String
Gas Orifice/Cup Size	N/A
Cleaning	See attached
Back Gouging	N/A
Oscillation	N/A
Contact to Work Distance	N/A
Passes per Side	See attached
Number of Electrodes	See attached
Travel Speed Range	See attached
Peening	N/A

Other Information

	Name	Signature	Date
Author	Bart Smith	Signature on file	3/19/09
Approval	Larry Braden	[signature]	3/19/09

APPENDIX 7 (continued)

WELD PROCESS
FOR
SAVANNAH RIVER
WELD BLOCK #A537CL1 W/O HT

WELD:
Double K-Notch Butt Weld using ER70S-2 MiG wire for initial weld between closest points, followed by SMAW 7018 weld filler passes on both sides of block to fill notched area.

Base Material: A537CL1, 1" thick, material lot #AH730
Root Filler: ER70S-2, .035" dia., material lot #AH455
Filler: 7018, 3/32" dia., material lot #AH729

Pre-heat: 250 degrees F.

ROOT (1st) PASS:
Volts: 21.5 – 22.5
Amps: 115 – 120
Arc Radius: ¼" – 3/8"
Weld Pass Length: 12 ¼"
Welding Speed: 8 – 10 IPM
Weld Time: 1:20

FILLER & CAP PASSES:
Volts: 22 – 24
Amps: 95 – 100
Arc Radius: ¼" – 5/16"
Weld Pass Length: See pass info below
Welding Speed: 5 – 6 IPM
Weld Time: 1:00

Pass #	Weld Lengths: Side #1	Rods
2	4 ¾", 5", 2 ½"	3
3	5", 5", 2 ¼"	3
4	6 ½", 5 ¾"	2
5	7", 5 ¼"	2
6	5", 5", 2 ¼"	3
7	7", 5 ¼"	2
8	6 ½", 5 ¾"	2
9	5", 5", 2 ¼"	3
10	6 ½", 5 ¾"	2
11	6 ½", 5 ¾"	2
12	5", 5", 2 ¼"	3

Appendix 7 (continued)

WELD PROCESS
FOR
SAVANNAH RIVER
WELD BLOCK #A537CL1 W/O HT

Pass #	Weld Lengths: Side #1	Rods
13	5", 5 ¼", 2"	3
14	6 ¼", 6"	2
15	6 ¼", 6"	2
16	6 ¼", 6"	2
17	5", 5", 2 ¼"	3
18	6 ¼", 6"	2
19	5 ½", 6 ¾"	2

After welding 1st side, root pass was ground, then Liquid Dye Penetrant tested for discontinuities. None found.

FILLER & CAP PASSES:
Volts: 22 – 24
Amps: 95 – 100
Arc Radius: ¼" – 5/16"
Weld Pass Length: See pass info below
Welding Speed: 5 – 6 IPM
Weld Time: 1:00

Pass #	Weld Lengths: Side #2	Rods
2	5 ½", 6 ¾"	2
3	5", 5", 2 ¼"	3
4	4 ¼", 6 ½", 1 ½"	3
5	6 ¼", 6"	2
6	6 ¼", 6"	2
7	5 ½", 6 ¾"	2
8	5 ¼", 5", 2"	3
9	5", 4 ½", 2 ¾"	3
10	4 ½", 4 ½", 3 ¼"	3
11	4 ½", 4 ½", 3 ¼"	3
12	6 ¼", 6"	2
13	6 ¼", 6"	2
14	6 ½", 5 ¾"	2
15	3", 5 ¼", 4"	3

APPENDIX 8
Welding Parameters for the Heat-Treated Plate

Alabama Specialty Products, Inc.	WPS 09.02.04-03
Weld Procedure Specification	SMAW P1 to P1
SAVANNAH RIVER NUCLEAR MIG/SMAW WELD BLOCK A537CL1 W/HT	Revision -New-

Joint Design	Double K-Notch Butt Weld		
Backing Type	N/A	Groove Type	N/A
Backing Material	N/A		

Base Metals

P. No.	Group	UNS	Common Name or Designation	Thickness	Diameter
1		K02400	ASTM A537 CL1	1/8" to 1"	to
1		K02400	ASTM A537 CL1	1/8" to 1"	to

Filler Metals

SFA Number		A5.5
AWS Class	ER70S-2	E7018
F-Number		4
A-Number		2
Size of Filler	.035"	3/32"
Thickness Range	1/8" – 1"	1/8" – 1"
Consumable Insert	N/A	

Electrical Characteristics

Current Type	DC	Polarity	Positive
Current (Range)			See attached
Volts (Range)			See attached
Tungsten Electrodes	Size		N/A
Tungsten Electrodes	Type		N/A
GMAW	Transfer Mode		N/A
GMAW	Wire Feed Speed		N/A

Positions

Position(s) of Groove	1-G
Welding Progression	Flat
Position(s) of Fillet	N/A

Preheat

Preheat Temperature	250° F
Interpass Temperature	N/A
Preheat Maintenance	N/A

Post Weld Heat Treatment

Temperature Range	N/A
Time Range	N/A

Gas

	Gas(es)	% Mixture	Flow Rate
Shielding	Argon/CO2	95/5	35 CFH
Trailing	N/A		
Backing	N/A		

Technique

Bead Type	String
Gas Orifice/Cup Size	N/A
Cleaning	See attached
Back Gouging	N/A
Oscillation	N/A
Contact to Work Distance	N/A
Passes per Side	See attached
Number of Electrodes	See attached
Travel Speed Range	See attached
Peening	N/A

Other Information

	Name	Signature	Date
Author	Bart Smith	Signature on file.	3/19/09
Approval	Larry Braden	Larry Braden	3/19/09

Appendix 8 (continued)

WELD PROCESS
FOR
SAVANNAH RIVER
WELD BLOCK #A537CL1 W/HT

WELD:
Double K-Notch Butt Weld using ER70S-2 MiG wire for initial weld between closest points, followed by SMAW 7018 weld filler passes on both sides of block to fill notched area.

Base Material: A537CL1, 1" thick, material lot #AH730
Root Filler: ER70S-2, .035" dia., material lot #AH455
Filler: 7018, 3/32" dia., material lot #AH729

Pre-heat: 250 degrees F.

ROOT (1st) PASS:
Volts: 21.5 – 22.5
Amps: 115 – 120
Arc Radius: ¼" – 3/8"
Weld Pass Length: 12 ¼"
Welding Speed: 8 – 10 IPM
Weld Time: 1:20

FILLER & CAP PASSES:
Volts: 22 – 24
Amps: 95 – 100
Arc Radius: ¼" – 5/16"
Weld Pass Length: See pass info below
Welding Speed: 5 – 6 IPM
Weld Time: 1:00

Pass #	Weld Lengths: Side #1	Rods
2	5 3/16", 7"	2
3	5 ½", 5 ½", 1 ¼"	3
4	5 ¾", 6 ½"	2
5	6", 6 ¼"	2
6	6 ½", 5 ¾"	2
7	4 ½", 6", 2"	3
8	5 ½", 6 ¾"	2
9	5", 5", 2 ¼"	3
10	6 1/8", 6 1/8"	2
11	6 1/8", 6 1/8"	2
12	6 ¼", 6"	2

Appendix 8 (continued)

WELD PROCESS
FOR
SAVANNAH RIVER
WELD BLOCK #A537CL1 W/HT

Pass #	Weld Lengths: Side #1	Rods
13	4 ¾", 5 ¾", 1 ¾"	3
14	5 ¾", 6 ½"	2
15	6", 6 ¼"	2
16	6", 6 ¼"	2
17	6 ¼", 6"	2
18	4 ½", 5 ½", 2"	3

After welding 1st side, root pass was ground, then Liquid Dye Penetrant tested for discontinuities. None found.

FILLER & CAP PASSES:
Volts: 22 – 24
Amps: 95 – 100
Arc Radius: ¼" – 5/16"
Weld Pass Length: See pass info below
Welding Speed: 5 – 6 IPM
Weld Time: 1:00

Pass #	Weld Lengths: Side #2	Rods
2	4 ½", 6", 1 ¾"	3
3	4", 4 ½", 3 ¾"	3
4	5 ½", 6 ¾"	2
5	4 ½", 5 ¼", 2 ½"	3
6	6", 6 ¼"	2
7	5 ½", 6 ¾"	2
8	7 ¼", 5"	2
9	7 ¼", 5"	2
10	7 ½", 4 ¾"	2
11	6 ¾", 5 ½"	2

DISTRIBUTION

SAVANNAH RIVER SITE

N. C. Iyer, 773-41A
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