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Revision 0

WELD REPAIR OF A STAMPED PRESSURE VESSEL IN A RADIOLOGICALLY CONTROLLED ZONE

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

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INTRODUCTION

In September 2012 an ASME B&PVC Section VIII stamped pressure vessel located at the DOE Hanford Site Effluent Treatment Facility (ETF) developed a through-wall leak. The vessel, a steam/brine heat exchanger, operated in a radiologically controlled zone (by the CH2MHill PRC or CHPRC), had been in service for approximately 17 years. The heat exchanger is part of a single train evaporator process and its failure caused the entire system to be shut down, significantly impacting facility operations.

This paper describes the activities associated with failure characterization, technical decision making/planning for repair by welding, logistical challenges associated with performing work in a radiologically controlled zone, performing the repair, and administrative considerations related to ASME code requirements.

The Vessel

The vessel, shown in Figure 1, is a two pass shell and tube heat exchanger with an outside diameter of 36 inches and a length of just under 18 feet. Steam on the shell side of the vessel transfers heat to chemically and radioactively contaminated brine on the tube side. Solids in the boiling brine stream are concentrated as it is pumped through the vessel via an axial flow recirculation pump at about 6000 gpm. The brine side of the vessel, including the tubes, is constructed from Inconel Alloy 625 (ASME SB-443 625), and the steam

Figure 1. Overall view of the ETF Heat Exchanger – repair area is at the far end.

side is constructed from 304L stainless steel.

Initial Inspection

After discovery of the leak and removal of the insulation, location of the through-wall failure was identified (from the shell OD) to be approximately 3 inches from the channel blind flange on the west side and aligned with the fillet welds attaching the pass partition plate to the shell ID. The channel blind was removed to allow visual examination of the vessel ID. Initial examination revealed cracking on both sides of the vessel at the shell / pass partition plate welds (Figures 2).

Figure 2. Cracking at the shell / pass partition plate welds.

Cracking extended from the end of the pass partition plate (at the blind) four to six inches along the weld passing through base, HAZ and weld metal. In addition, a linear region of affected base material, running in a circumferential direction near the end of the shell was noted (Figure 3).

To better assess the condition/integrity of the vessel shell, the ID in the area of interest was subjected to a rigorous cleaning. Visual examination was again performed, followed by Liquid Penetrant (PT) examination to determine the extent of the indications open to the surface. Ultrasonic Examination (UT) was performed from the OD to assess the shell condition (wall thinning, if any) at the partition plate / shell ID interface between the two fillet welds. UT results indicated no significant wall thinning or loss of material from the ID. The full extent of cracking however could not be determined without removal of the partition

Figure 3. Circumferential, linear indication – affected base metal.

plate at the shell ID; this was done and is discussed below.

The "linear" region of affected base material noted above, appeared to be weld metal burn through; this region lined up directly behind the OD flange to shell fillet weld. It is believed this condition originated during initial fabrication welding of the vessel.

TECHNICAL DECISION MAKING AND PLANNING

The CHPRC prime contractor did not have the National Board certification (R-Stamp) required for repair of a coded (or stamped) vessel. Obtaining such certification can be a lengthy and time consuming process, so doing this was ruled out as an option. Several local companies had the proper certifications, including one of the CHPRC teaming partners – Fluor. It was decided that since several of the key welding and materials engineering positions within the CHPRC organization were held by Fluor personnel, some efficiency in cost and schedule could be realized by using the Fluor R-Stamp program. In addition, the Fluor personnel were already trained and cleared for entry into the radiologically controlled zone where the vessel is located. The Authorized Inspection Agency Fluor had contracted with (Hartford Steam Boiler Inspection and Insurance Company, HSB), had an Authorized Inspector (AI) available at the Hanford Site that was also trained and cleared to enter the facility. Given the above reasons, along with the fact that this type of repair had not been previously performed at the Hanford Site, CHPRC elected to use the Fluor, which had the proper program certifications and experience for this type of work.

Use of the "in-house" contractor did not however, come without its challenges. The R-stamp program is very prescriptive by nature; roles and responsibilities are clearly defined, and are limited to employees of the company holding the certification. This called for careful planning and integration with the ETF facility organizations to ensure all program requirements (both R-stamp and facility) would be met. A matrix or cross-walk, describing the activities, functions, and documentation, for both the R-stamp and the facility quality programs, was established to help coordinate the two quality programs.

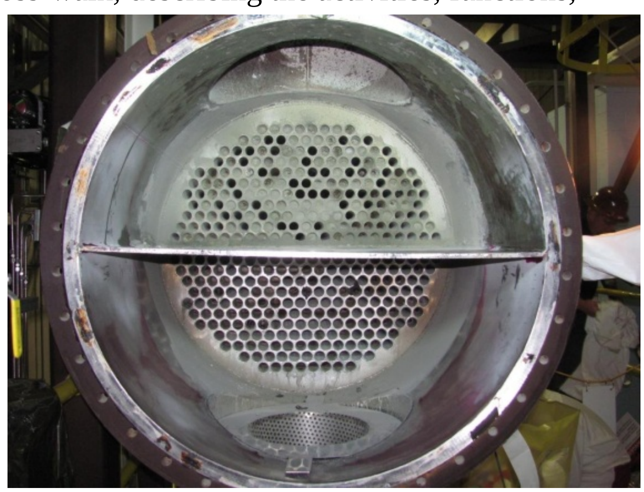

Figure 4. View into the open end of the vessel showing the pass partition plate and tubes.

CAUSE OF FAILURE

No formal failure analysis was performed; however, based on vessel design, principles of materials performance, visual and nondestructive examination, the likely cause of failure was identified as material fatigue and is discussed as follows:

Figure 4 shows the 3/8-in thick, Alloy 625 pass partition plate welded to the 3/16-in thick shell

ID (two sides) and to the tube sheet. The remaining side butts against the Channel Blind, but is not secured or supported, leaving it free to flex when loaded by the incoming 6,000 gpm brine flow through the inlet nozzle. Failure (cracking) occurred in the plate-to-shell welds and in the partition plate as shown in Figure 2. Cracking extended along the toe of the welds, into the plate, veered out into the plate and then back into the weld. UT examination (along with subsequent visual inspection of the shell ID) indicated that neither general nor localized corrosion processes were active. No physical deformation (material strain) was observed at the area where cracking was observed.

Material fatigue, resulting from cyclical loading, appears to have been the cause of cracking. Impingement of the brine flow against the plate is believed to have set up flow induced vibration and cyclical stress, especially at the "free" end. Fatigue cracks tend to initiate at stress risers, which would include the notch at the root of the fillet weld (inherent in the joint design) and the undercut at the toe of the weld. The cracks observed are associated with these features and are consistent with classic fatigue crack travel and propagation. As noted a formal failure analysis was not performed; however, given the nature of the failure, appearance of the cracking, location of the cracking, absence of localized corrosion and an understanding of materials performance, it is believed the most likely cause of failure was fatigue.

PERFORMING THE WELD REPAIR

Preparing for the Repair

Appropriate work packages were prepared delineating scope and roles and responsibilities between the ETF facility and Fluor R-Stamp programs as well delineating the hold/witness points for the Authorized Inspector and Fluor personnel. Material and tool control, Welder and welding procedure qualifications, NDE and Examiner qualifications along with controlling and documenting the work were performed in accordance with the Fluor program. CHPRC provided facility management, operations and engineering support, as well as safety/industrial hygiene, and radiological protection services. It is noted that the Welders, who performed the repair, had existing qualifications under the Hanford Site Welding program; however, because of the R-Stamp requirements, they were required to re-qualify under the Fluor Welding Program. The NDE program and personnel, provided by another teaming partner AREVA, were reviewed and approved by Fluor's NDE Level III.

Performing the Weld Repair

Given the initial examination, along with the failure evaluation discussed above, it was believed that cracking was limited to the shell / plate weldment area along both sides of the plate for a distance of about nine inches. Because cracking could have propagated immediately behind the plate edge, it was decided to remove a portion of the pass partition plate. Several additional reasons justified plate removal, as follows:

- With regard to the through wall leak defect, weld repair required access to the backside of the repaired area to assure complete removal of the defect, be able to clean the area and to provide gas shielding during welding.
- Visual access to this area could potentially help understand and explain the cause of failure, e.g., were there signs that crevice corrosion was active at the plate/shell interface?
- Attempting to weld repair the pass partition plate in place could present a challenge with regard to shell and plate distortion. Some of the plate cracking was through-wall and the process of grinding out, chasing the cracking, prepping for the weld repair and re-welding the 3/8-in plate, in place, could lead to significant distortion of the 3/16-in shell.

Once the area of interest was cleaned, prior to plate removal, a thorough examination by VT and PT was performed to determine the extent of cracking along the area where the pass partition plate was attached. The results of the PT examination disclosed several cracks in the pass partition plate attachment welds, in addition to the obvious cracks along the plate edges.

A section of the plate, measuring approximately 9-inches deep by 35-inches wide, was removed using a plasma arc cutting torch. The cut line on the plate running parallel to the shell axis was placed approximately 3/4 of an inch inward from the shell – see Figure 5. This was done to avoid any potential impact (wall thinning) on the shell thickness. The remaining piece of plate and the two attachment fillet welds were completely removed by grinding. The shell ID surface was now fully accessible for evaluation and was examined (on both sides of the shell) by VT and PT to establish the extent of cracking – see Figure 6. Visual examination revealed no indications of corrosion at the plate / shell interface. Liquid penetrant examination disclosed numerous linear indications on both the exterior and interior shell surfaces where the plate was attached to the shell.

Figure 5. Section of pass partition plate removed – leaving a 3/4-in piece along the shell.

Defects identified by PT examination were weld repaired using the Fluor-certified R-Stamp program. Repair consisted of removing the defects by grinding and defect removal was confirmed by PT. Once confirmed, the excavated area was prepared (with a groove sufficient to

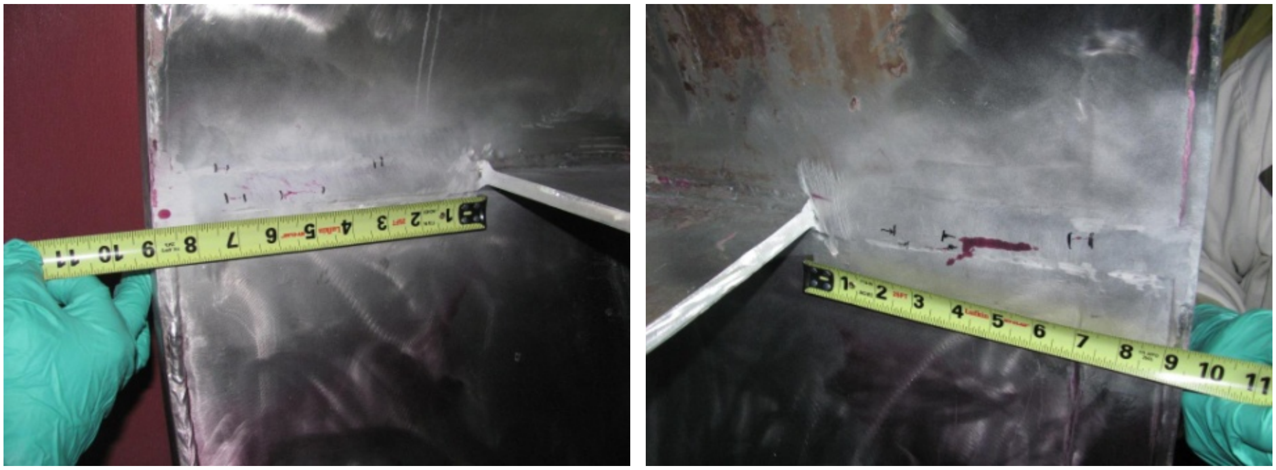

Figure 6. Shell ID after pass partition plate removal.

Accommodate a stringer bead(s)) and welded using the Gas Tungsten Arc Welding (GTAW) process. Care was exercised to ensure the shell was restored to its original thickness. Through-wall defects were welded from both the interior and exterior sides of the shell.

On several occasions, PT of the repaired areas disclosed indications adjacent to the repair; indications that were not identified by PT prior to weld repair. It is believed the new indications were "incipient", and along with the other identified cracking, the result of fatigue loading. These "new" cracks opened up, sufficient to be disclosed by PT, as a result of shrinkage stress caused from repair welding. All defects were removed, verified by PT, weld repaired and PT examined for acceptance.

When both east and west sides of the shell were determined to be free of defects, UT examination was performed to verify minimum wall thickness requirements were satisfied.

Repair at Weld Burn-Through Area

It was noted above that a linear region of affected base material (approximately 7 inches in length), running in a circumferential direction near the end of the shell, was visually identified – see Figure 3. The condition is believed to have been caused by weld metal burn through during initial vessel fabrication - this area lined up directly behind the fillet weld attaching the OD flange to the shell. This area was prepared by grinding (light blending) and welded by depositing a stringer bead(s) sufficient to restore the shell to its original specified thickness.

REPAIRED VESSEL TESTING

All repaired areas, including the "burn-through" area, were leak tested with a vacuum box using the bubble formation technique in accordance with ASME B&PVC Section V. NBIC/ANSI NB23 permitted use of this alternative leak test method in lieu of the code of record test –

hydrostatic leak test. Due to the configuration of the heat exchanger, performing a hydrostatic test would have been difficult.

RE-INSTALLATION OF THE PASS PARTITION PLATE

With weld repairs complete, including acceptable VT and PT inspections of the repaired areas, a section of new Inconel plate was installed to restore the pass partition plate to its original dimensions. The new plate was machined with a K-bevel for full-penetration welding to the remaining piece of installed plate and the two sides, attaching to the shell, were given a square end prep to accommodate the two fillet welds. The new plate piece was installed and inspected by VT and PT – see Figure 7.

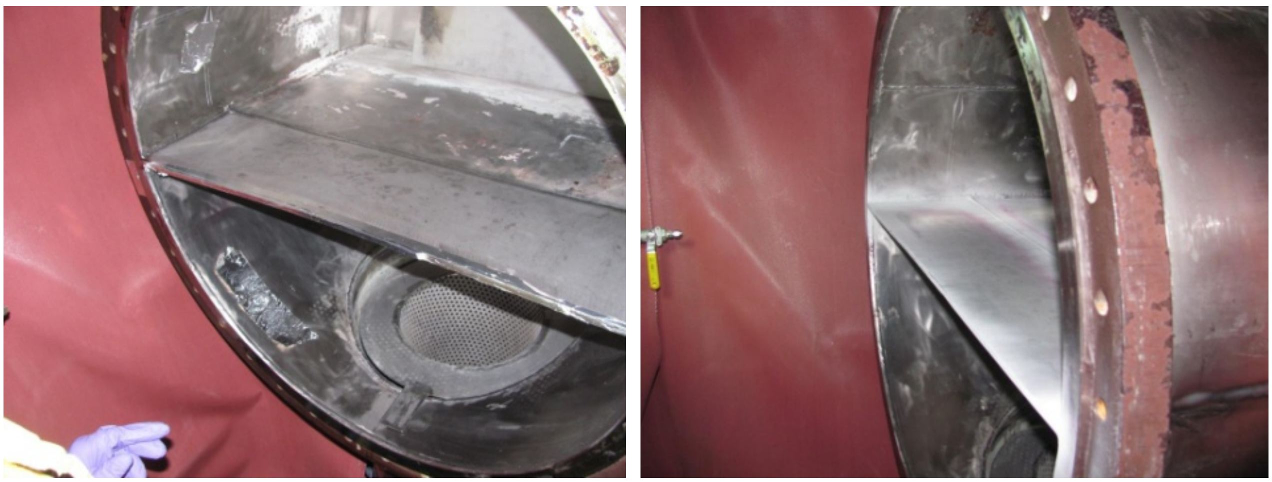

Figure 7. New piece of Inconel plate installed and inspected.

SUMMARY / CONCLUSION

Summary

To summarize, the actual repair activities took approximately two months and consisted of the following:

- Removal of a portion of the pass partition, including attaching fillet welds,
- NDE (VT and PT) to determine extent of cracking on the shell, both sides,
- Removal of cracks utilizing grinding wheels, with verification of removal by VT and PT,
- Welding of defect removal cavities and the burn-through area,
- Final NDE (VT and PT of weld repaired areas) and UT to verify required shell minimum thickness levels,

- Fabrication, fit-up and welding and NDE of the replacement piece of pass partition plate,
- Final bubble (vacuum box) leak testing, and
- Weld of repair stamp onto vessel.

Conclusion

The ETF Heat Exchanger repair was successfully completed without personnel injury or radiological contamination. The work was performed in accordance with the NBIC code for the repair of an ASME B&PV Section VIII Code Vessel. Personnel from multiple organizations worked together to complete a complex task - complex with regard to code and facility requirement integration, and the constraints of performing the work in a radiologically controlled zone. There was no precedent for this type of activity at Hanford Site.