NDT WITH THE STRUCTURAL WELD OVERLAY PROGRAM:
RECENT FIELD EXPERIENCE AND LESSONS LEARNED

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ABSTRACT

Structural weld overlay (SWOL) has become a predominant mitigation technique within the Alloy 600 program. For the pressurizer nozzles, MRP-139 requires volumetric examination by year end 2007. Many nozzles are un-inspectable due to geometry and material limitations that preclude interrogation of the required examination volume. SWOL therefore is the mitigation technique which overcomes these limitations. SWOL of the pressurizer nozzles has been a challenge for all the vendors. Alloy 52 has proven to be difficult to weld under field conditions. The NDT technique chosen to demonstrate the integrity of the overlay needs to be adapted to the specific repair process and nozzle geometry. The purpose of this paper will be to present Westinghouse’s integrated approach for SWOL with the focus on the NDT aspects. Topics will include main repair process steps, NDT qualification, recent field experience and lessons learned.
INTRODUCTION

Primary Water Stress Corrosion Cracking (PWSCC) of Alloy 82/182 weld metal and Alloy 600 material has occurred in pressurized water reactor (PWR) plants since the mid-1980s. However, its impact became significantly more evident in 2000 when a through-wall leak was discovered in a reactor vessel hot leg nozzle dissimilar metal weld at the V. C. Summer plant in the USA. This crack was axially oriented similar to previous cracking experiences. However, a shallow circumferential crack was also discovered. Now with additional circumferential flaw indications in such materials being discovered by in-service inspection programs, and the relatively long service times on these materials, structural integrity concerns have been raised.

To address some of these concerns the Material Reliability Program (MRP) project in the USA developed approaches for inspection, re-inspection, mitigation and flaw evaluation that is documented in the report, MRP-139: Primary System Piping Butt Weld Inspection and Evaluation Guideline [1]. Smaller higher temperature components, like the pressurizer nozzle welds, were targeted for the earliest inspections. If adequate volumetric inspections cannot be performed then mitigation actions are mandated.

INSPECTIONS

The volumetric inspections (ultrasonics) are required to be performed using techniques demonstrated in accordance with the ASME Code Section XI, Appendix VIII. In individual plant surveys, it has become evident that most of the targeted pressurizer nozzle welds are un-inspectable due to insufficient OD surface conditions; where un-inspectable is regarded as <90% examination volume coverage particularly for ID-initiated circumferentially oriented flaws. Examination volume credit can only be obtained if all the demonstrated UT beam angles cover the same examination volume. For circumferential flaws, the beam angles typically include 45° and 60° for a component wall thickness ≥ 13 mm [2]. The higher beam angle requires the greatest axial extent on the OD surface for coverage and because of limited access results in a significant lack of coverage. An example of this coverage is shown in Figure 1 for a representative pressurizer nozzle weld configuration. The 60° probe results in < 25% coverage for circumferential flaws within the examination volume.

Figure 1: Example of Examination Coverage for Circumferential Flaws in a Representative Pressurizer Weld Configuration - 45° Probe > 90%, 60° Probe < 25% (Examination volume is highlighted)
3 MITIGATION

The lack of >90% examination coverage on pressurizer nozzle welds has led to methods to mitigate against the occurrence of PWSCC or the significance of PWSCC. While a variety of mitigation strategies exist, the approach of choice for pressurizer nozzle welds is structural weld overlay (SWOL).

SWOL is the addition of weld reinforcement material on the outside surface of the pipe to a sufficient thickness and extent to create a new structural barrier. Figure 2 shows two types of SWOL designs. The one SWOL design minimizes the amount of weld reinforcement material applied thus reducing the application time.

![Figure 2: SWOL Designs](image)

The weld reinforcement material is Alloy 52 (an austenitic nickel alloy containing a minimum of 28% chromium), which is considered to be resistant to PWSCC. Another beneficial aspect of the SWOL process is the creation of compressive residual stresses at the ID surface which serve to inhibit the initiation and propagation of new PWSCC occurrences.

4 SWOL DESIGN

The design of a SWOL is based on the as-built configuration of each component. The two primary objectives of the SWOL design are to satisfy minimum structural requirements and to allow for future ultrasonic examinations of any underlying welds and adjacent base material. The latter objective is to eliminate past inspection issues.

For the minimum SWOL thickness determination, a 100% through-wall flaw extending the entire circumference of the original pipe is assumed. The minimum axial length and end slope of the SWOL is dependent on sufficient load redistribution from the pipe into the deposited weld metal and back to the pipe without violating applicable ASME Code Section III stress limits [3].

Future ultrasonic examinations must be able to examine the underlying weld(s) for service-induced cracking. Once a SWOL has been applied, the defined examination volume
for an underlying weld is to extend axially 13mm on each side of the weld toe, in depth from the OD surface of the SWOL to the outer 25% of the original pipe thickness, and circumferentially 360-degrees around the pipe [3]. This examination volume must be examined in four directions – two axial and two circumferential. The objective is 100% examination coverage in each of the four directions. These criteria have typically mandated an extension in the axial extent of the SWOL and an added SWOL thickness, both of which are beyond the design conditions. The added SWOL thickness is to obtain an OD surface profile that allows for adequate coupling of the ultrasonic test probes. The added length of the SWOL typically encompasses the next weld along the piping run as well as the axial extent required to inspect this weld.

5 SWOL IMPLEMENTATION PROCESS

Field application of the SWOL process is a combined effort of welding, contouring, and inspection teams. The welding team is tasked with fabricating a SWOL in accordance with detailed design drawings using Alloy 52 material. This material has proven to be difficult to weld under field conditions particularly on original piping materials with high sulphur content; Alloy 52 is highly susceptible to sulphur-induced cracking in the initial layer. Outage schedules dictate that parallel welding operations be implemented. Figure 3 shows a five welding machine set-up on a pressurizer mock-up.

![Figure 3: Five Parallel SWOL Welding Setups on a Pressurizer Mock-up](image)

The contouring team ensures that the final surface of the SWOL satisfies the requirements of the qualified final acceptance inspection procedure. The criteria include a general overall surface roughness and smoothness.

The inspection team is challenged with: obtaining key substrate information on weld locations that impact future inspections; ultrasonically measuring the SWOL thickness; ensuring that the final surface condition and profile is adequate for the required ultrasonic examinations; and performing final acceptance NDT of the SWOL and underlying welds. Figure 4 shows a finished SWOL on pressurizer 4” (102 mm) spray nozzle.
6 FINAL ACCEPTANCE NDT OF SWOL

Once the inspection team is satisfied with the final contour, the OD surface of the SWOL is inspected using the liquid penetrant examination method. This surface examination is followed up with a two-part ultrasonic examination. Because of the small pipe sizes and complex geometries of the pressurizer SWOL configurations, these ultrasonic examinations are conducted manually using demonstrated inspection procedures and qualified inspection personnel. Both the inspection procedure and personnel have been qualified in accordance with the ASME Code Section XI, Appendix VIII, Supplement 11 as implemented by the Performance Demonstration Initiative (PDI).

The first ultrasonic examination is designed to determine the integrity of the SWOL itself. Of interest are flaws such as lack of bond, lack of fusion and cracks. The general examination approach is the use of a 0° TRL (transmit-receive, longitudinal) probe for lack of bond and multiple TRL angle beam probes for inter-bead lack of fusion and cracks. The angle beam TRL probes are focussed at various depth zones in the SWOL for both axial and circumferential scans. Probe selection is a function of SWOL thickness, required focal depth range, probe contouring and beam impingement angle at the lower extent of the examination volume. Examination sensitivity is established using material noise levels [4].

An example of the examination process for inspecting the SWOL is shown in Figure 5 for the axial angle beam and straight beam probes; both axial directions are scanned. The required circumferential beam angles are similar however the actual beam angles are contingent on the impingement angles in the examination volume. The number of probes required varies for each SWOL however it typically ranges from 7 – 10. Four directional scanning is conducted [4].
The second ultrasonic examination is to ensure that no new cracks or existing cracks have extended into the upper 25% of the original weld and adjacent base metal as a baseline for future in-service inspections. TRL angle beam probes are used for this examination. Probe selection is a function of the same parameters for the SWOL examination but with the addition of examination volume thickness. An example of the examination process for inspecting the underlying welds is shown in Figure 6 for the axial angle beam probes; both axial directions are scanned. The required circumferential beam angles are similar however the actual beam angles are contingent on the impingement angles in the examination volume. The number of probes required varies for each SWOL underlying weld however it typically ranges from 2 – 4. Four directional scanning is conducted. Examination sensitivity is established using material noise levels [4].
FIELD EXPERIENCE

Since 2005 fifty-five (55) structural weld overlays have been installed. Two of these were installed prior to Fall 2006 on an emergent basis due to in-service inspection findings. Twenty-three (23) SWOLs were installed in Fall 2006 for which seven (7) required repair. These repairs were based on the results of the final acceptance UT. The flaws have been attributed to a combination of welding process and human performance issues. In Spring 2007, thirty (30) SWOLs were installed with only one requiring repair. The final acceptance UT detected the unacceptable condition. This particular repair is attributed to a human performance error that has been the subject of specific corrective measures that will be instituted in future SWOL work.

In both the Fall 2006 and Spring 2007 SWOL campaigns, the final acceptance UT has been quite effective in detecting conditions which fall outside the bounds of established acceptance criteria [5]. The number of repair areas in the Fall 2006 resulted in considerable time being spent sizing and recording flaw indications. Personnel dose increased as well. However in the Spring 2007 campaigns (5 plants), where the number of flaw indications were significantly reduced, the time and dose statistics were substantially better for the manual UT techniques. Table 1 provides these statistics. It is noted that the number of probes necessary for these inspections ranges from 7 – 14.

<table>
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<tr>
<th>Table 1: Average Inspection Time and Average Dose for the Final Acceptance UT for Spring 2007 SWOL Campaigns (Manual UT)</th>
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<tr>
<td><strong>Nozzle</strong></td>
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<td>4” Nozzle</td>
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<td>6” Nozzle</td>
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<td>12-16” Nozzle</td>
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LESSONS LEARNED

The large number of repairs in the Fall 2006 SWOL campaigns mandated that the welding and human performance issues be corrected. A concerted effort was initiated in late 2006 to early 2007 to make these adjustments in preparation for the Spring 2007 efforts. An extensive series of design of experiments (DOE) were conducted to optimize the welding parameters used for the initial 1st layer of overlay and to alleviate sulphur-induced cracking.

More intensive welder training and testing was conducted that was intended to improve each welder’s understanding of the SWOL process and to gain a quantifiable measurement of each welder’s skills. The result was much higher quality production welds and an enhanced team approach to production.

Communication between the welding, contouring and inspection teams was more pronounced and effective resulting in a better understanding by all parties of the primary objective of making the SWOL inspectable for future in-service inspections.

Lastly, flawless welds allowed for a more efficient UT inspection process that decreases the time of inspection and the accumulated personnel dose.

These improvements resulted in a 97% first time weld quality rate in the Spring 2007 campaigns.

For future improvements, the focus is on dose and schedule improvement, continuing welder mentoring and training, and improving the weld deposit cleanliness.
9 CONCLUDING REMARKS

SWOL is a proven mitigation action against PWSCC for pressurizer nozzle welds. This mitigation is required because adequate ultrasonic examination cannot be performed on the original Alloy 82/182 welds. With proper design, the SWOL can satisfy the structural requirements for the piping and allow for proper in-service inspection in the future. Continued improvements in the implementation process must be implemented to address quality, personnel dose and schedule constraints.

REFERENCES


[2] ‘PDI Generic Procedure for the Ultrasonic Examination of Dissimilar Metal Welds, PDI-UT-10”, Performance Demonstration Initiative (PDI), Revision C.

[3] “Case N-740: Dissimilar Metal Weld Overlay for Repair of Class 1, 2 and 3 Items, Section XI, Division 1”, ASME Boiler and Pressure Vessel Code, Section XI.

[4] “PDI Generic Procedure for the Ultrasonic Examination of Weld Overlaid Similar and Dissimilar Metal Welds, PDI-UT-8”, Performance Demonstration Initiative (PDI), Revision F.