ABSTRACT

Background: During a JAPEIC (Japan Power Engineering and Inspection Corporation) "WOL qualification test" in 2003, UT capability on weld-overlaid piping was successfully demonstrated with a mockup test sample that contained simulated weld defects and fatigue flaws. However, there were some concerns on UT accuracy raised by Japanese BWR industry that some deep SCC flaw of which flaw tip was located in the butt weld of the original piping was more difficult to accurately measure compared with the other SCC flaws of which flaw tip is located in the HAZ (heat affected zone) area. In order to respond to this concern, Japan BWR utilities and vendors fabricated the WOL test piece that contained SCC flaws of which flaw tip is located in the HAZ and butt weld of the original piping and performed UT depth sizing for accuracy confirmation.

Joint Study Outline:
1. Test sample fabrication
   - Test Piece: SUS316L, 600A piping, 38.9mm thickness
   - (2) SCC flaw: Magnesium Chloride + Bending
   - (3) Flaw tip: In the upper 25% of the original piping (including butt weld)
2. Pre-WOL UT: Phased Array, Longitudinal angle beam (Tip diffraction)
3. WOL: Minimum 22.9mm thickness (Required)
4. Post-WOL UT: Phased Array, Longitudinal angle beam (Tip diffraction)
5. Flaw depth measurement: Sliced and measured from OD surface to the tip.

Post-WOL UT Result:
All vendors that participated to this program performed phased array UT for a total of 36 depth measurements from SCC flaws on the WOL test piece. As shown in Table 1, UT capability on Weld Overlaid piping was successfully demonstrated.

Joint Study Summary:
1) All vendors used phased array UT technique and successfully measured SCC flaw depth located in the inspection volume (upper 25% of the original piping including the butt weld of the original piping).
2) RMSE was less than 3.2 mm.
3) Some SCC flaws of which flaw tip was located in the butt weld of the original piping were not successfully measured without using phased array technique.

Executive Summary

This study was jointly performed by the following BWR owner’s group and corporations for the purpose to demonstrate UT sizing accuracy for SCC flaws in WOL piping. The joint study result showed that all corporations successfully demonstrated SCC flaw depth sizing capability in the WOL inspection volume by using a phased array technique.

This report consists of the following outlines.
1. WOL Outline
2. Background and Study Purpose
3. Joint Study Details
4. Joint Study Conclusion
1. WOL Outline

WOL is a piping repair method that applies several layers of weld metal on the OD surface of the piping when service induced flaws (e.g. SCC flaws) were found at a weld joint of the piping. Figure 1 shows the image of WOL piping.

Figure 2 shows the sectional view of the red-circled area in Figure 1. The shadowed area shows the UT inspection volume. It is WOL part and upper 25% of the original piping in thickness and 13mm both sides of the weld preparation edges in width.

2. Background and Study Purpose

During a JAPEIC (Japan Power Engineering and Inspection Corporation) “WOL qualification test” in 2003, UT capability on weld-overlaid piping was successfully demonstrated with a mockup test sample that contained simulated weld defects and fatigue flaws. However, there were some concerns on UT accuracy raised by Japanese BWR industry that some SCC flaws of which flaw tip was located in the butt weld of the original piping was more difficult to accurately measure the flaw depth compared with the other SCC flaws of which flaw tip is located in the HAZ (heat affected zone) area. In order to respond to this concern, this joint study team fabricated the WOL test piece that contained SCC flaws of which flaw tip is located in the HAZ and butt weld of the original piping and performed UT depth sizing for accuracy confirmation.

3. Joint Study Details

The program was consisted of the following steps.
(1) Test Piece fabrication (SCC Fabrication + WOL design)
(2) Pre-WOL UT
(3) WOL application on the test piece
(4) Post-WOL UT
(5) Destructive testing for the true flaw depth
(6) UT accuracy analysis

In this report, (1) Test piece fabrication (SCC fabrication + WOL design), (4) Post-WOL UT and (6) UT accuracy analysis were discussed in details.

(1) Test Piece Fabrication (SCC Fabrication + WOL design)

Design Conditions on the test piece fabrication were as shown below.

① Piping Material was stainless steel 316L, 600A diameter, and 38.9mm thickness
② SCC depth was in the upper 25% range of the original piping.
③ The test piece contained 6 different SCC flaws
④ WOL design thickness was minimum 22.9mm.
⑤ Calibration Reflector (side drilled hole) was located in the test piece in the upper 27.5% of the original piping, which is slightly outside the UT inspection volume.

Photo 1 shows the test piece pictures prior (left) and after (right) the WOL application.

Post-WOL UT

In order to obtain adequate number of samples, each SCC flaw was basically* measured at two different 20mm ranges for the peak flaw depth in the range. There were 6 SCC flaws in the test piece, and the total sizing sample number was 12.3 corporations (Toshiba/IHI, Hitachi-GE, and GE-Hitachi) performed sizing, therefore the total of 36 sizing samples. The Figure 3 shows the SCC flaw and sizing range image. Please note that the flaw depth was measured as a remaining ligament in this study, measured from the OD surface to the flaw tip location.

*: See Table 2 in UT accuracy analysis section for details.
All 3 Corporations performed sizing UT with phased array technique as shown in Table 1. All examiners who performed sizing in this joint study had some flaw sizing experience in the past.

![Figure 3 - UT sizing location Image](image)

<table>
<thead>
<tr>
<th>Scan Method</th>
<th>A corporation</th>
<th>B corporation</th>
<th>C corporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>2 MHz</td>
<td>2.25~5 MHz</td>
<td>1.5~2.25 MHz</td>
</tr>
<tr>
<td>Ch. number</td>
<td>24~48ch</td>
<td>64ch</td>
<td>32ch×2</td>
</tr>
<tr>
<td>medium</td>
<td>Glycerin</td>
<td>Glycerin</td>
<td>Water</td>
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</table>

Table 1 - Post-WOL Phased Array UT Method

Figure 4 shows examples of B-scan images obtained by Phased Array UT. In the B-scan images, flaw tip signal is pointed by an arrow. The flaw tip signals have higher amplitude than the background level as shown by a darker blue.

(a) AF-20 B-scan image shows that the flaw tip is located in the original butt weld, and (b) AF-27 B-scan image shows that the flaw tip is located in the heat affected zone.
Table 2 shows the comparison data between the UT sizing data and true flaw depth data measured by the destructive testing.

In case of AF-27 for example, the flaw depth measured by the destructive testing is 40mm depth at X=120mm. “A” Corporation measured the flaw depth as 39.7mm at X=124mm by UT, and the difference between the actual and UT measured was 0.3mm. It was 2.4mm difference for “B” Corporation case, and 0.4mm difference for “C” Corporation case.

UT accuracy analysis

Figure 5 shows the UT measured flaw depth data and true flaw depth (as shown by a straight line) measured by a destructive testing on a same graph. The X-axis shows true flaw depth and the Y-axis shows UT measured value. If UT measured values were exactly the same as the true depth, all the data would be shown on the centerline.

As shown in this graph, the UT data were well aligned with the centerline.

From the data analysis, the followings statistical data were observed.

- Total sample number is 36.
- (12 measurement locations by the 3 corporations.)
- Root Means Square Error, RMSE was 1.98mm.
- Error average was 0.98mm,
- Standard deviation was 1.72 mm,
- Coefficient of correlation was 0.90.
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Flaw Properties</th>
<th>Location</th>
<th>Post-Wol UT</th>
<th>Destructive</th>
<th>Difference</th>
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<tr>
<td>AF25</td>
<td>In Base Material</td>
<td>X=110</td>
<td>120 120 38.9 36.4</td>
<td>120 38.8 - 0.1</td>
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<tr>
<td></td>
<td></td>
<td>~130mm</td>
<td>124 38.6</td>
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<td></td>
<td></td>
<td>X=130</td>
<td>140 140 39.1 36.4</td>
<td>140 39.1 0.0</td>
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<td></td>
<td></td>
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<td>143 38.0</td>
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<td>AF20</td>
<td>In Weld Material</td>
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<tr>
<td></td>
<td></td>
<td>~195mm</td>
<td>185 43.5 43.4</td>
<td>185 44.7 1.2</td>
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<td></td>
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<td>208 43.8</td>
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<td></td>
<td></td>
<td>~220mm</td>
<td>210 43.0 40.2</td>
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<td>76 43.6</td>
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<td></td>
<td></td>
<td>~90mm</td>
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<td></td>
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<td>90 38.8 37.3 39.3</td>
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<td></td>
<td></td>
<td>X=110</td>
<td>120 39.7 37.6 39.6</td>
<td>120 40.0 0.3</td>
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<td></td>
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<td>~130mm</td>
<td>124 123</td>
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<tr>
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<td></td>
<td></td>
<td>X=140</td>
<td>150 39.7 38.9 38.5</td>
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<td>206</td>
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</tbody>
</table>

※Data count for UT beam skew in the WOL area
4. Joint Study Conclusion

- Using phased array technique, all corporations successfully demonstrated SCC flaw depth sizing capability in the WOL inspection volume.
- RMSE was 1.98mm, which is within the ASME Sec XI Appendix VIII sizing acceptance criteria of 3.2 mm.
- All sizing was performed by the sizing experienced examiners with Phased Array technique.
- In this study, it was found that UT beam skew was observed in the WOL as well.

Therefore, the purpose of this joint study for demonstrating the UT accuracy for the SCC flaws sizing was successfully met.

We appreciate all the people contributed to this joint study and also the Secretariats of 7th international conference on NDE who provided an opportunity to publish the study result.