Examination of Overlay Pipe Weldments Removed from the Hatch-2 Reactor

J.Y. Park, D.S. Kupperman, W.J. Shack

Argonne National Laboratory, Materials Science and Technology Division, 9700 South Cass Ave.,
Argonne, Illinois 60439, U.S.A.

Abstract

Laboratory ultrasonic examination (UT), dye penetrant examination (PT), metallography, and sensitization measurements were performed on Type 304 stainless steel overlay pipe weldments from the Hatch-2 BWR to determine the effectiveness of UT through overlays and the effects of the overlays on crack propagation in the weldments. Little correlation was observed between the results of earlier in-service ultrasonic inspection and the results of PT and destructive examination. Considerable difficulty was encountered in correctly detecting the presence of cracks by UT in the laboratory. Blunting of the crack tip by the weld overlay was observed, but there was no evidence of tearing or throughwall extension of the crack beyond the blunted region.

1. Introduction

Laboratory ultrasonic examination (UT), dye penetrant examination (PT), metallographic examination, and sensitization measurements were performed on two 12-in.-diameter Type 304 stainless steel pipe-to-elbow weldments, designated 2B31-1RC-12BR-C2 and -C3, from the primary coolant recirculation piping of the Hatch-2 boiling water reactor (BWR). Overlays had been applied to these weldments after an ultrasonic in-service inspection (ISI) revealed intermittent crack indications at numerous locations around the inner circumference on the pipe side for both weldments. The crack depths were estimated to be 28% throughwall for weldment C2 and 30% for weldment C3. After the overlays were applied, the weldments remained in service for about one year; they were removed when the recirculation piping in Hatch-2 was replaced.

2. Ultrasonic and Dye Penetrant Examinations

Before shipment to ANL, the weldments were electrochemically polished at Quadrex Inc. (Oak Ridge, Tenn.) to remove corrosion film and reduce radiation levels. After the weldments arrived at ANL, Magnaflux dye penetrant was applied to the inner surface. No PT indications were found on weldment C3, even in several sections that were subjected to three-point bending in order to open tight cracks that might be present. Twenty PT indications were observed on weldment C2 (15 on the elbow side and 5 on the pipe side). The PT results for C2 are summarized in Table I. The indications were of a variety of types (axial, circumferential, skewed

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or point), and most of them were located within 8 mm of the weld fusion lines (WFLs). There were no undercuts at the WFLs that produced PT indications in either weldment. Figure 1 shows a photograph of the PT indications ob- served at circumferential positions 79 and 81 cm from the origin (see Table I) on the elbow side of weldment C2.

Blind and partially blind UT was carried out on both weldments. Very few correct calls were made, and when cracks were correctly called the success was degraded by considerable overcalling (particularly in the weldment without cracks). It was possible, however, to find at least one ultrasonic signal associated with cracking in the vicinity of the strongest PT indication (29 EL). Ultrasonic echos from cracks had signal to noise (S/N) ratios as high as 15 dB, but signals from areas free of cracks had S/N ratios up to 17 dB.

The analysis of the results indicates, in general, that UT of pipes with weld overlays is not, at present, an effective means to detect intergranular stress corrosion cracking near welds in stainless steel piping. This is a result of the distortion of the ultrasonic beam as it passes through the coarse-grain structure of the overlay, the difficulty in coupling the sound through the rough surface of the overlay, and the problem of considerable ultrasonic noise due to the weld geometry. Comparison of the UT results with the results of the PT and the metallographic sectioning indicates that the detection of cracks through the overlay by UT is difficult and at present unreliable.

3. Metallographic Examination

After PT and UT examination, the weldments were sectioned by sawcutting at a number of selected locations in the axial and circumferential directions. The ferrite contents of the original weld and overlay were determined to be 9 and 12%, respectively. The cross sections were metallographically polished and examined for cracks, defects, or any other features that might produce UT or PT indications. The metallographic results for weldment C3 were consistent with the PT results; i.e., no cracks or defects were found. The results for weldment C2 are summarized in Table I. Figure 2 shows an axial section of weldment C2 at the 85-cm position. The weld overlay is about 7 mm thick. The counterbore on the inner surface of the weldment is about 40-45 mm wide and 2-3 mm deep. There was no evidence anywhere on the entire inner surface of the weldments that the counterbore was the cause of the cracking, although some details of the features on the inner surface may have been removed by electrochemical polishing at Quadrex.

The sectioning (Table I) showed that the circumferential and point indications (22, 29, 33, and 65 EL and 95 PP) were associated with circumferential intergranular cracks, one axial indication (81 EL) was associated with an axial intergranular crack, and one skewed indication (3 EL) was associated with a skewed intergranular crack. It also confirmed that the circumferential cracks 22, 29, and 33 EL were not linked. Figure 3 shows a cross section of the circumferential crack 29 EL. The crack has not propagated into the weld metal. Branching of the crack near the crack tip has occurred.

A cross section of axial crack 81 EL is shown in Fig. 4. Within the wall, the crack is much longer (17 mm) than suggested by the PT indication (2 mm long) at the inner surface. The crack profile, as determined by metallography (Fig. 5), is somewhat unusual in shape (Park and Kupperman [1]; Cheng [2]). It is possible that the crack is growing axially in the HAZ associated with the overlay, but this is uncertain because the extent of the HAZ associated with the original weld is unknown. Also, the crack tip near the original outer surface was blunted as shown in Figs. 4 and 6. Blunting of crack tips by application of a weld overlay has been predicted by finite-element analyses (Maiya and Shack [3]) and would be expected to inhibit further throughwall crack growth. There was no evidence of tearing or extension of the crack beyond the blunted region. In no case did cracks propagate more than a distance of roughly a grain diameter into the original weld metal (Fig. 7).

Metallographic sections were also made at a number of positions (43, 50, 63, 65, 83, and 85 cm) in weldment C2 that produced strong UT signals but showed no PT indications. No cracks or other discernible metallographic features (weld defects, inclusions, etc.) or geometrical irregularities were observed.

The degree of sensitization produced by the combination of the original weld and the overlay was evaluated by the ASTM A262-A procedure [4]. Dual and ditch etch structures were observed in the HAZ. The observed cracks were located within the HAZ of the original weld, except for one crack (65 EL) that extended into the region of the step etch structure (Fig. 8) and perhaps for the one axial crack noted above (81 EL) that showed fairly extensive axial growth. The throughwall EPR measurements at an axial location well removed from the original weld are shown in Fig. 9 for a specimen from weldment C2 at the 82 to 83-cm position. The HAZ of the overlay does not extend more than 5 mm into the pipe wall from the overlay WFL on the original outer surface. However, the maximum EPR values on both the pipe and elbow sides exceed the proposed critical value of 2 C/cm^2 (Clarke [5]). The maximum EPR value occurred at 2-3 mm from the WFL for both sides of the weldment. Larger EPR values were observed on the pipe side as compared to the elbow side.

4. Conclusions

1. Intergranular cracks were observed in both sides of weldment C2. They appear to be stress corrosion cracks similar to those observed in sensitized Type 304 SS components of other BWRs.

2. No cracks were observed in weldment C3.

3. The correlation between PT indications and cracking is excellent, although the extent of cracking inside the pipe wall can be more severe than the PT indication at the inner surface would suggest.

4. Considerable difficulty was encountered in correctly detecting the presence of cracks by UT in the laboratory.

5. One of the cracks may have been growing axially in the HAZ associated with the weld overlay, but this is uncertain because the extent of the HAZ associated with the original weld is unknown.

6. Blunting of the crack tip by the weld overlay was observed, but there was no evidence of tearing or throughwall extension of the crack beyond the blunted region.

7. There was no evidence that the counterbore of the inner surface at the weldment caused the cracking.

References

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2. CHENG, C. F., "Failure Analyses for Cracked Type 304 Stainless Steel Piping in the 4-in. Recirculation Bypass Lines of the Dresden-II and Quad Cities-II BWR Systems," Unpublished report prepared for Commonwealth Edison Co. (December, 1974).
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4. "Standard Recommended Practice for Detecting Susceptibility to Intergranular Attack in Stainless Steels," ASTM Standard G815-1970, Designation A262-70.
5. CLARKE, W. L., "The EPR Method for the Detection of Sensitization in Stainless Steels," General Electric Co. Report NUREG/CR-1095, GEAP-24888 R-5 (April, 1981).

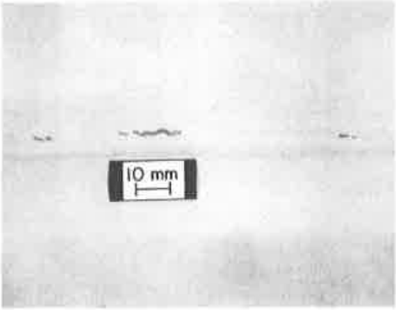
Table I. Results of Dye Penetrant Examination and Metallographic Sectioning of Weldment C2

Position[a] (cm)	PT Indications		Cracks Detected by Metallography	
	Type[b]	Size (mm)	Depth (mm)	% Penetration[c]
3 EL	S	6	11	44
10 PP	A	3		
11 PP	A	2		
22 EL	C	8	4	17
29 EL	C	16	5	22
33 EL	C	8	13	57
65 EL	P	–	>5	
76 EL	P	–		
77 EL	A	2		
78 EL	C	3		
78 EL	S	4		
79 EL	A	2		
81 EL	A	2	13	57
87 EL	S	3		
91 EL	C	2		
92 EL	P	–		
93 PP	C	3		
93 EL	C	2		
95 PP	P	–	2	9
95 PP	P	–		

[a] The position of indications is described in terms of circumferential distance on the outer surface, measured from the origin in a clockwise direction as seen by an observer looking in the coolant flow direction. The origin was chosen as the extrados of the elbow. EL = elbow side; PP = pipe side.

[b] S = skewed; A = axial; C = circumferential; P = point.

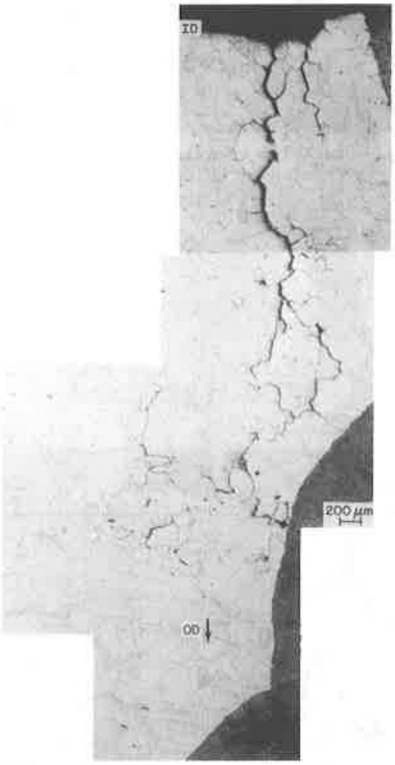
[c] Based on the total thickness, including the overlay.



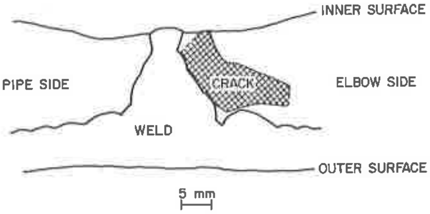
1. Three PT Indications at Inner Surface of Weldment C2 (Elbow Side).

2. Axial Section of Weldment C2 at 85-cm Position.

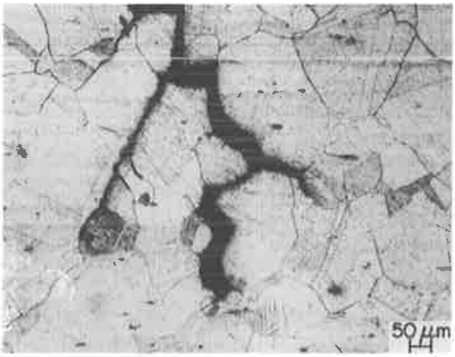
4. Axial Intergranular Crack at 81-cm Position of Weldment C2.



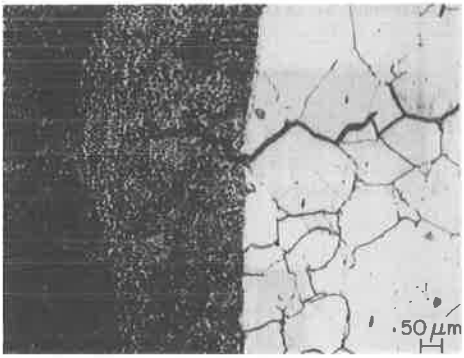
3. Circumferential Intergranular Crack at 29-cm Position of Weldment C2.



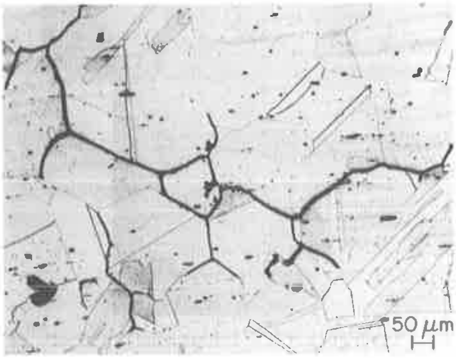
5. Mapping of Axial Crack at 81-cm Position of Weldment C2.



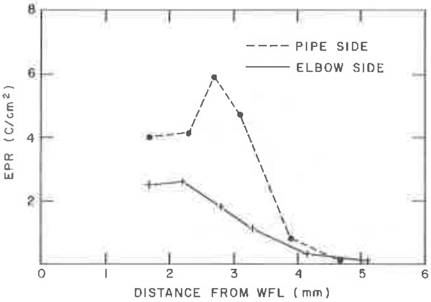
6. Crack Tip of Axial Crack at 81-cm Position of Weldment C2.



7. Propagation of Same Crack Shown in Fig. 6 into Weld Metal.



8. Extension of Intergranular Crack into Region of Step Etch Structure.



9. Throughwall EPR Measurements at 82 to 83-cm Position of Weldment C2, at Sites Well Removed from Original Weld. Measurements were made at various distances from the overlay WFL.