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WELDING RESIDUAL STRESS ANALYSIS AND MEASUREMENT IN REPAIRED WELDMENT

L.H. Wang, S.W. Lin, M.W. Lin and H.J. Yen

Materials Research Laboratories, Industrial Technology Research Institute, Taiwan, R.O.C.

ABSTRACT

Two types of weld repair were encountered in the recirculation piping replacement work of Chin-shan nuclear power plant. To determine the effects of these weld repairs on weldment's residual stress, two mockups simulating root and groove repair were prepared and both of analytical and experimental techniques were used to estimate the level of the residual stress.

The results showed that groove repairs create higher tensile residual stress than the as-welded case, especially for the axial stress. However, there is no significant difference in residual stresses between the root repair and as-welded values. Finally, the study suggests that the non-destructive examination after the root welding should be thoroughly enforced for detecting defects earlier to reduce the risk of weld repair.

INTRODUCTION

The recirculation piping of Chin-shan nuclear power plant were replaced within 1988 and 1989 due to stress corrosion cracks. In the recirculation piping replacement work, two types of weld repair were applied. One type of repair was performed on the nozzle-to-safe end weld (weld F1) and the other on the pipe-to-safe end butt weld (weld F2). The weld F1 was shown by radiography to have root edge undercut after completion of the root weld. It was decided to make a partial-circumferential through-wall excavation to remove the indication and perform open-butt reweld. For the weld F2, the welding defect was detected by radiography after completion of the groove weld. It was necessary to excavate the indicative area and weld-out the repair area.

Since there is grave concern on the effect of the residual stresses associated with these repairs, two mockups simulating root and groove repair were prepared to determine the effects of these weld repairs on weldment's residual stresses. Both of analytical and experimental techniques were used to estimate the level of the residual stress. This paper will summarize these results and compare the differences.

MOCKUP FABRICATION

Figure 1 presents typical configuration of nozzle-to-safe end (weld F1) and pipe-to-safe end (weld F2) welds. To duplicate the aforementioned weldments, Materials Research Laboratories requested NUTECH International, Inc. (NUTECH) to prepare two mockup welding coupons.[1] All the welding procedures and the weld metals utilized in the field were used in the mockup fabrication plan.

The fabrication of the nozzle-to-safe end (weld F1) mockup was accomplished in three stages as follows,
1. nozzle machining/ buttering/ cladding
2. pipe overlay(simulated safe end)/ machining/ buttering
3. nozzle-to-safe end welding

To simulate a through-wall root defect, approximate 4 inch of root pass was removed. After the dye penetrant checking of the excavation area, the root pass repair welding was made using manual Gas Tungsten Arc Welding (GTAW) process. This butt-weld's detail is shown in the figure 2.

An excavation, length of 6 inch and depth of quarter inch, was prepared on an existing type 316NG pipe-to-type 316NG pipe weldment as shown in figure 3 to simulate the weld defect on the pipe-to-safe end weld (weld F2). Dye penetrant examination was then applied on the excavation and the repair area was welded out using manual GTAW process. Welding was completed by applying seven layers of filler materials. The results of final radiographic testing of this weld were found to be acceptable.

EXPERIMENTAL & ANALYTICAL WORKS

The blind hole drilling method was used to measure the residual stresses of the weld F1. Since its welding configuration was fairly complicated, the analytical method was not adopted. The weld coupon was cut into two semicircular pieces. They were identified as weld F1-R for repaired weldment and F1-AW for as-welded weldment. Then the areas to be measured in the circumferential weld roots of each pieces were smoothed out by emery wheel and paper. The surfaces of each pieces were prepared for the attachment of strain gauges. The strain gauge rosette used was the three element type EA-09-062RE-120. This operation was performed to avoid changing the inside surface after the weld was completed. All the measuring procedures followed the ASTM Standard E837-85.[2]

Both of the analytical and measuring techniques were applied to estimate the residual stress of the weld F2. The analytical work was completed by using WELD-III Finite Element Computational Model. This procedure for calculating welding residual stress consists of two steps, a heat transfer analysis and a thermal stress analysis. Temperature distributions can be obtained from inputs of welding current and voltage through heat transfer analysis. Results from the heat transfer analysis in the form of temperature distributions are inputted for the thermal stress analysis which solves the residual stress. The two dimensional iso-parameter axisymmetrical 4-node element was used in this model. Figure 4 shows the finite element model.

As mentioned in the mockup preparation, the repair (excavation) was performed after completion of the butt weld of two pipe spools. A stress field has been established before excavation. This stress distribution of the typical butt weld was calculated using the welding parameters shown on Table 1. The excavation process was simulated by considering excavation as a liquid pool of melt metal at 2100°F, where no mechanical stress is present. The thermal stresses induced by groove repair were then calculated in the same way as the butt weld analysis. The welding parameters of this repair weld is shown on Table 2.

The residual stress of weld F2 was also measured by using sectioning method (or back computation method).[3] The measurement coupon with strain gauge rosette was parted out from the welded pipe, then the coupon was split and sliced by Electro-Discharge-Machining (EDM), within the process which the residual strain was gradually released. The strain gauges were glued to the measurement surface in advance in order to record the released strain in each slicing step. As the rule of equilibrium of stresses, the residual stress distribution can be back computed from the recorded released strains.

RESULTS & DISCUSSIONS

Figure 5 shows a comparison of the as-welded and root repair residual stress in weld F1 where a root repair was made. The stresses in the repair area are as they were in the as-welded condition at the weld center line. The root pass repair had little effect on the residual stress. However, either the hoop stresses or the axial stresses of repair area and as-welded area were found to be compressive. This is contrary to the belief that tensile stresses are generally expected in the inner surface, especially in the axial direction. The main cause may be due to the overlay process applied around the pipe so that the stress state was changed. The weld overlay has been adopted as a IGSCC mitigation by creating a compressive stress field in the inner surface that prevents IGSCC propagation.[4]

A root repair is performed at an early point in the weld and the repair area would experience the same degree of shrinkage as an unrepaired weld. Therefore, a root repair area would be expected to have residual stress similar to the as-welded values.

Figure 6 illustrates the analytical results of groove repair F2 weldment by finite element analysis. It shows that groove repairs create higher tensile residual stress than the as-welded case in the axial direction. However, no significant difference was found in the hoop stresses. In order to confirm the analytical stress evaluations, the experimental technique was also applied. Figure 7 shows the stress distribution through the wall thickness which was measured by sectioning method. The stress transition point in this figure fully corresponds with the depth where the groove repair started. This result indicated that the measurement technique is reliable. Figure 8 presents the stress distribution perpendicular to the weld center line. The measurement result was only obtained for repair weldment. The data for as-welded weldment was inaccurate due to strain gauge failure. Nevertheless, the experimental data generally confirmed the analytical stress evaluation since the stress distribution in the measurement results showed the same trend as in the analytical results for the repair weldment.

CONCLUSIONS

If a root defect is found at early time, it can be repaired without greatly increasing the residual stresses in the repair area. If a mid-groove defect is found and repaired after the weld is completed, it will result in higher tensile residual stress. Therefore, this study suggests that the non-destructive examination after the root and first few fill passes should be thoroughly enforced for detecting defects earlier to reduce the risk of weld repair.

ACKNOWLEDGMENT

Support of this research through a grant from Taiwan Power Company is gratefully acknowledged.

REFERENCES

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3. W.J. Shack et al, "Measurement of Residual Stress in Type 304 Stainless Steel Piping Butt Weldments", Argonne National Lab., EPRI Report NP-1413, 1980

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Table 1. Welding Parameters of Butt Weld F2

LAYER NO.	PASS NUMBER	CURRENT (A)	VOLTAGE (V)	TRAVELLING SPEED(cm/min)	INTERPASS TEMP.(℃)	WATTAGE (W)
1	1	90	9.3	9	19	585.9
2	1	"	8.8	"	51	554.4
3	1	"	9.0	"	80	567.0
4	1	"	"	"	98	598.5
5	1	"	"	"	56	"
6	2	95	"	"	79	"
7	2	"	"	"	88	"
8	2	"	"	"	63	"
9	2	100	"	"	92	630.0
10	3	"	"	"	65	"

Table 2. Welding Parameters of Weld F2 Groove Repair

LAYER NO.	PASS NUMBER	CURRENT (A)	VOLTAGE (V)	TRAVELLING SPEED(cm/min)	INTERPASS TEMP.(℉)	WATTAGE (W)
1	1	100	9-12	3.0	350	735.0
2	1	125	10-13	"	"	1006.3
3	2	130	"	2.5	"	1046.5
4	1	"	"	"	"	"
5	3	"	"	2.0	"	"
6	3	"	"	"	"	"
7	3	140	11-13	"	"	1176.0

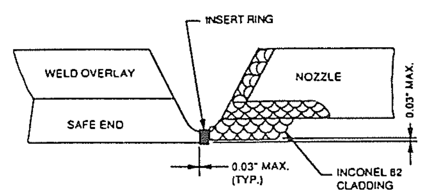

Figure 2. Detail of Weld F1 (Nozzle-to-Safe End Weld, Root Repair)

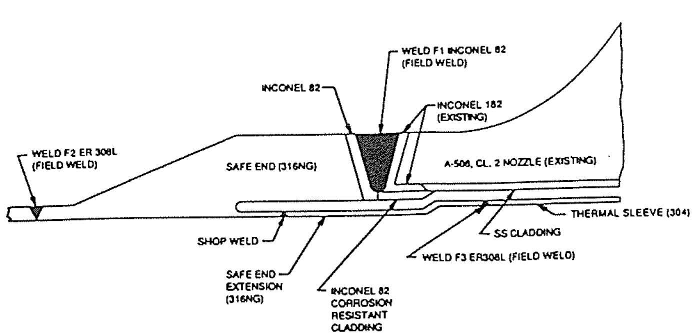

Figure 1. Configuration of Nozzle-to-Safe End and Pipe-to-Safe End Welds

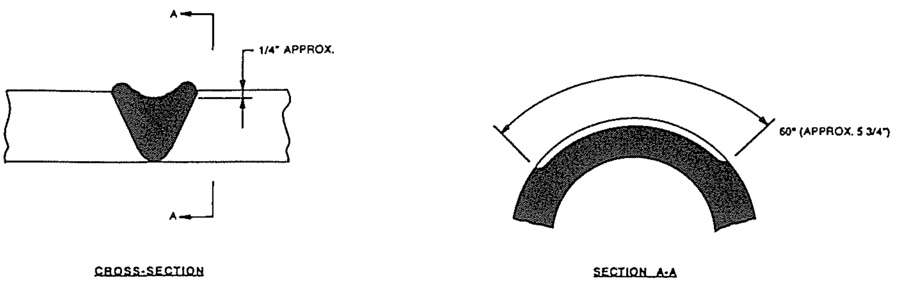

Figure 3. Detail of Weld F2 (Pipe-to-safe End Weld, Groove Repair)

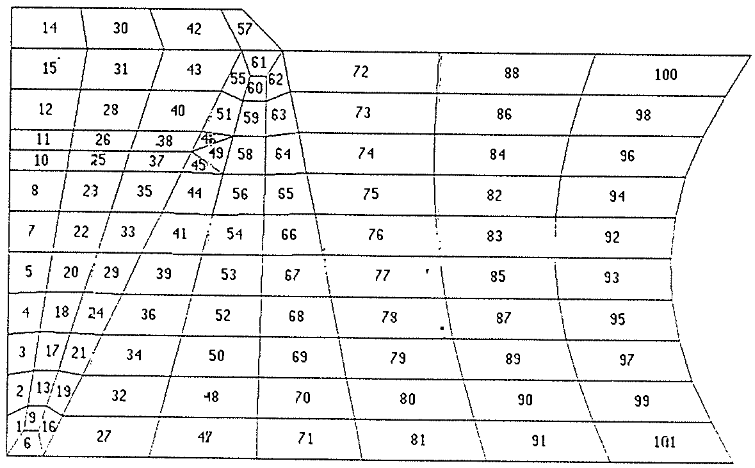

Figure 4. FEM Model For Weld F2

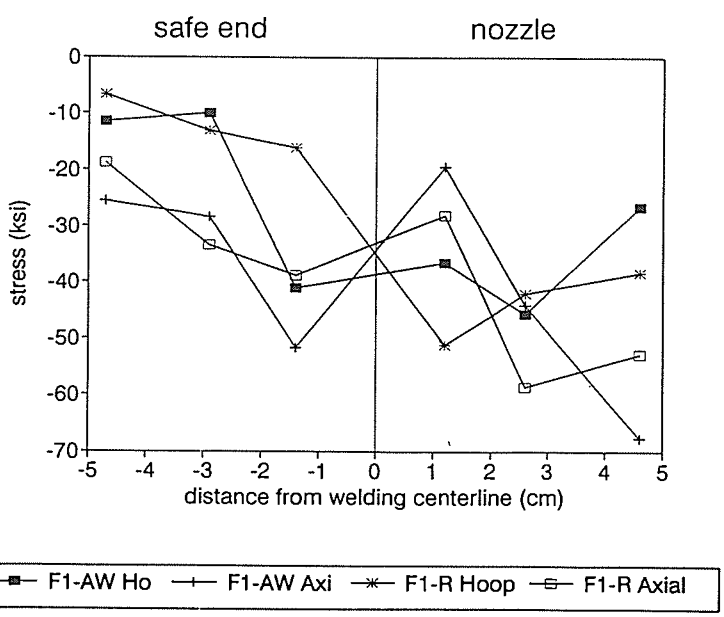

Figure 5. F1 Weld Residual Stress Comparison of As-Welded and Root Repaired Conditions

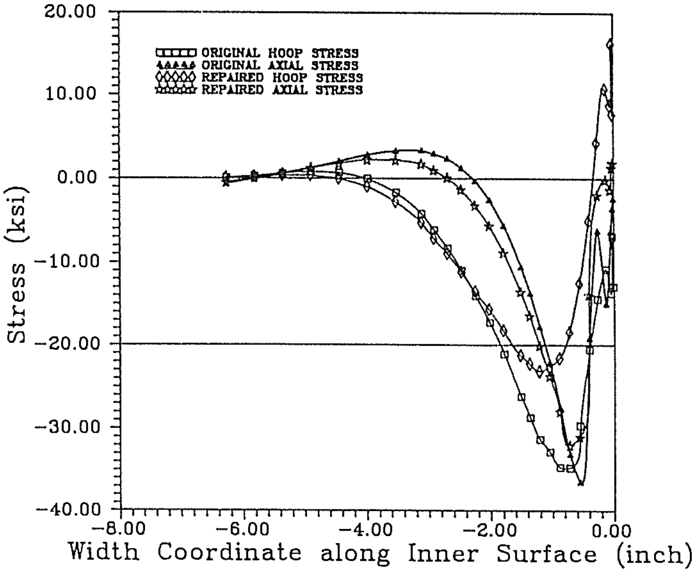

Figure 6. F2 Weld Residual Stress Distribution by FEM Analysis

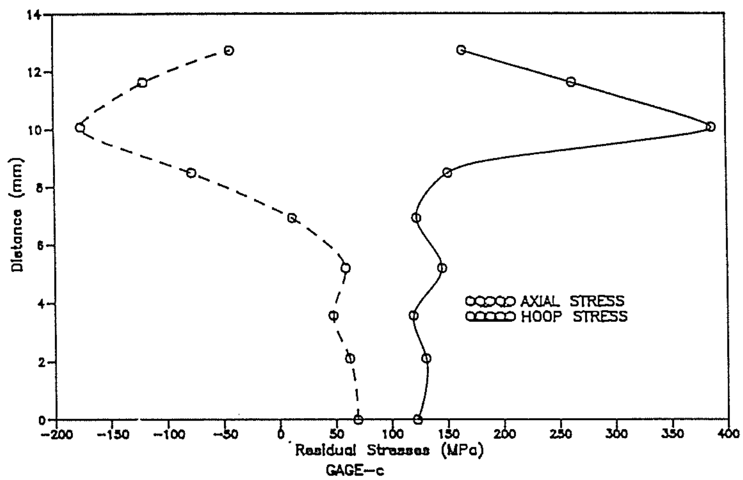

Figure 7. F2 Groove Repair Weldment's Residual Stresses through Wall Thickness, Measured by Sectioning Method

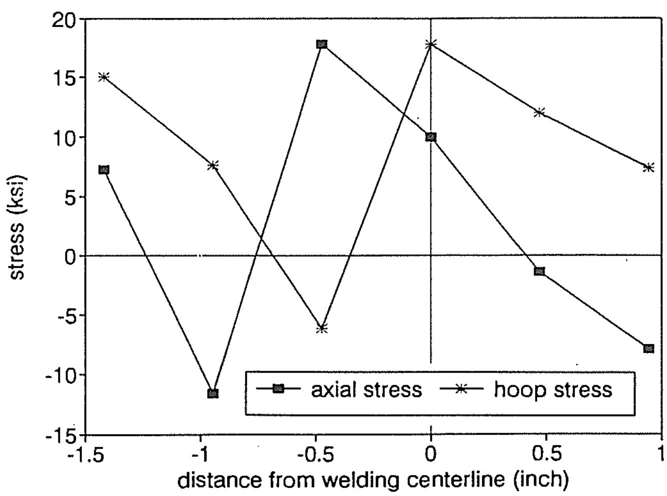

Figure 8. F2 Groove Repair Weldment's Residual Stress Measured by Sectioning Method