Analytical parameter study for residual stress improvement on RV nozzle butt welds by MeSIA®

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1. Introduction

Primary Water Corrosion Cracking(PWSCC) is worldwide issue recently. Some nuclear power plants in Korea had also the leakage at steam generator drain line due to PWSCC. So the regulatory institution and utility have a lot of concerns for material aging. Several kinds of technologies have been developed to mitigate or repair DMW locations with alloy 600 in foreign countries. But few technologies have been developing in Korea. Those technologies couldn't cover all DMW locations because there are a number of DMW locations with various surrounding condition in power plants. Weld overlay has been being applied at pressurizer nozzles having the highest possibility occurring PWSCC owing to high temperature. The next major concern of DMW locations would be RV nozzles. So a mitigation technology, MeSIA®(Mechanical Stress Improvement Apparatus), changing residual tension stress to residual compressive stress in the weldment and heat-affected zone at the inner region of the RV nozzle wall is being developed. The concept of this technology is to eliminate tensile stress which is one of three conditions contributing PWSCC[1]. This study will be complete in 2012 when mock-up test is complete. Therefore, the information shown in this paper is subject to adding data.

This paper addresses the results of finite element analysis performing parameter study to generate optimum residual compressive stresses

2. The results of parameter study

MeSIA® makes pressure on outside of pipe to generate plastic deformation. To have optimum residual compressive stress in inner wall of welds, there are three of major parameters which are the position of MeSIA®, loading width and load values. Parameter study was performed by FEA with the results of welding residual stresses FEA, material properties and geometry of RV nozzles at Kori unit 1 were used. Elastic-perfectly plastic model was used for plasticity analysis. In this section, the results of parameter study are shown

2.1 Welding residual stress analysis

The residual stresses generated by the welding process are a major factor in PWSCC. Welding residual stresses FEA, the same methodology of structural weld overlay applied for presurizer nozzles at Kori unit 1, was used to predict residual stress distribution[2].

Repair welding with 50% thickness of pipe wall was assumed for much more conservative analysis. The figure 1 is the results of analysis. Left graph is stress distributions at inner wall of DMW piping butts welds in axial and hoop directions. Inner wall of buttering near DMW has bigger tension stress in axial direction. In case of hoop direction, bigger tension stresses are generated at inner wall of DMW. Right graph shows stress distribution at center line of DMW between inner wall and outer. Tension stresses are generated at inner wall in both axial and hoop directions.

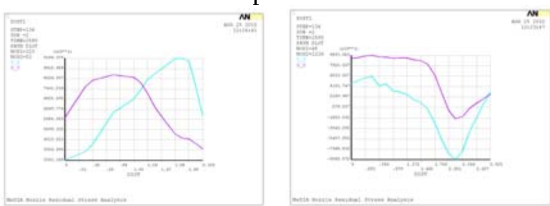

Figure 1. Stress distributions on DMW locations

2.2 Loading value

The purpose of MeSIA® is to generate less than -10 ksi of residual compressive stress at inner wall of DMW. To determine required pressure, Radial displacement in range of 0.12in ~ 0.2in was made according to both loading width and distance. The bigger radial displacement was given, the bigger compressive stresses were generated in axial and hoop directions as showed in figure2 and 3.

Loading width of figure 2 and 3 is 2.9in. The trend is similar with all other loading widths.

2.3 The position of installing MeSIA®

The parameter of the MeSIA® position in range of 1.5in ~ 2.2in was performed from DMW center line to the edge of MeSIA® which is "A" in figure 6. Axial compressive stresses were decreased according to further distance. But hoop compressive stresses were increased up to 1.9in of distance except 0.2in of radial displacement which made axial and hoop compressive stresses bigger according to further distance

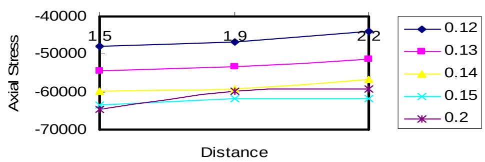

Figure 2. Axial Stress related to loading and position with 2.9in width

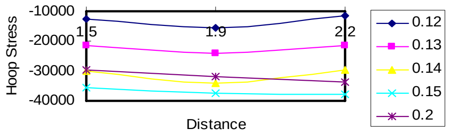

Figure 3. Hoop Stress related to loading and position with 2.9in width

2.3 Loading width

The parameter of the loading width in range of 1in ~ 3in which is "B" in figure 6 was performed. Figure 4 shows that axial compressive stresses were increased until 2.9in of loading width. 1in of loading width didn't make enough hoop compressive stresses. Radial displacement of figure 4 and 5 is 0.13in. The trend of all other radial displacement is also similar

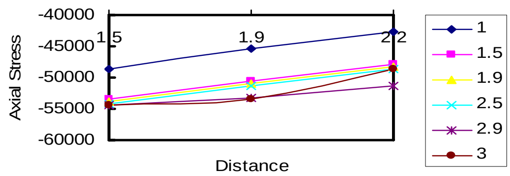

Figure 4. Axial Stress related to loading width with 0.13 displacement

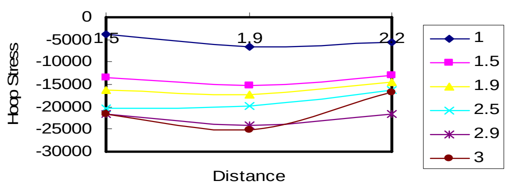

Figure 5. Hoop Stress related to loading width with 0.13 displacement

3. Conclusions

The purpose of parameter study is to generate optimum compressive stress through pressure that is as small as possible. The relation of those parameters has clear trend. Representative parameter combinations show table 1.

Table 1. Representative parameter combinations

Case	Distance [A]	Width [B]	Pressure	Stress	Radial contraction
1	1.9	2.9	0.12 234Mpa	-323.4MPa -106.4MPa	0.417%
2	1.9	2.9	0.13 238Mpa	-367.3MPa -167.0MPa	0.471%
3	1.9	2.9	0.14 242Mpa	-407.6MPa -235.7MPa	0.524%

As shown in stress of table 1, upper value is axial stress and bottom one is hoop stress in inner of DMW wall. Permanent contraction rate of radial safe end where MeSIA® is installed is shown in radial contraction. In pressure, upper value is radial displacement for loads and bottom one is the required pressure to have this displacement.

With consideration of various conditions, Case 2 would be the optimum parameter combination with those FEA results. Left picture in figure 6 shows condition of welding residual stress. And right picture shows stress distribution after applying MeSIA® in axial direction with case 2 parameters.

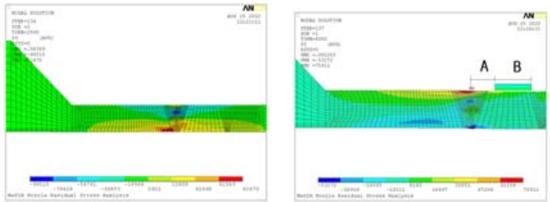

Figure 6. Axial Stress Distribution

Even though a lot of residual tension stresses are generated by repair welding, enough residual compressive stresses are generated by MeSIA®. In figure 7, left graph shows stress conditions in inner wall between buttering and the end of DMW. Right graph shows stress conditions at center line of DMW between inner wall and outer. Compressive stresses are generated in 30% of thickness wall.

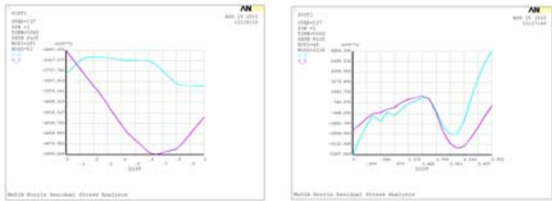

Figure 7. Axial and hoop Stress with optimum parameters

Figure 8 shows 6in of MeSIA® performing Mock-up test with strain gauges. Mock up test with 29in MeSIA ® will be performed based on those parameters when manufacture of MeSIA® is done. And FEA results will be validated by comparing the results of mock up test.

Figure 8. 6in Mock-up test picture

REFERENCES

[1] Materials Reliability Program : Mechanical Stress Improvement Process(MSIP) Implementation and performance Experience for PWR Application(MRP-121), EPRI, Palo Alto, CA:2004

[2] Materials Reliability Program : Validation of Welding Residual Stress Models for PWR Piping Dissimilar Metal Welds(MRP-271), EPRI, Palo Alto, CA:2009. 1019087