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Residual Stress Evaluation of Weld Inlay Process on Reactor Vessel Nozzles

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1. Introduction

The commercial nuclear power plants around the world have been performing mitigation and repairs to deal with primary water corrosion cracking in nickel based dissimilar metal welds which are Alloy 600 materials in pressurized water reactors. Weld overlay, weld inlay and stress improvement are mitigation technologies for butt joints. Weld overlay is done on pressurizer nozzles which are the highest potential locations occurring PWSCC due to high temperature in Korea. Reactor vessel nozzles are other big safety concerns for butt joints. Weld overlay and stress improvement should be so difficult to apply to those locations because space is too limited. Weld inlay should be one of the solutions. KEPCO KPS has developed laser welding system and process for reactor nozzles. Welding residual stress analysis is necessary for flaw evaluation. United States nuclear regulatory commission has calculated GTAW(Gas Tungsten Arc Welding) residual stress using ABAQUS[1].

To confirm effectiveness of weld inlay process, welding residual stress analysis was performed. and difference between GTAW and LASER welding process was compared

2. Methods and Results

2.1 Finite element analysis model

Welding residual stress analysis was performed by ANSYS and ABAQUS to compare with the results[2,3]. Both packages uses linear element for thermal and structural analysis because this analysis is highly nonlinear. So MRP 317 recommends using linear elements[4]. Fig 1 shows mesh shape which is a tetragon. Nonlinear elastic plastic two dimensional axisymmetric model is used. The analysis process is similar with real manufacturing and installing process such as dissimilar metal welding, similar metal welding, hydraulic test, heat up and cool down 4 cycles, weld inlay machining, weld inlay welding, finishing machining, heat up and cool down 4 cycles.

Fig. 1. FEA model.

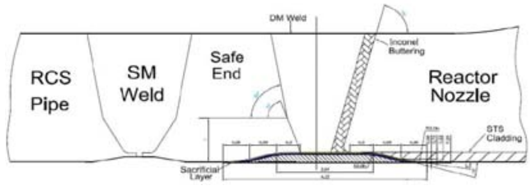


Fig. 2. Weld inlay shape.

Temperature dependant thermal and mechanical properties were used based on ASME Sec Ⅱ[5].

Fig 2 shows joint shapes. Weld inlay is designed based on ASME code case 766[6]. GTAW process was used on two butt joints and LASER welding process was used on weld inlay. Table 1 shows heat input per bead volumes.

Table 1: heat inputs(BTU/in^3)

Item	DMW	SMW	Weld inlay
Heat input	307.45	175.05	1566.61

Temperature dependant heat transfer coefficient applied to outside and inside of the model whose range is 2.45~76.38 BTU/hr-ft^2-F[7].

Horizontal degree of freedom is fixed on nozzle side and coupling condition is used on the end of pipe applied to end cap pressure. Isotropic strain hardening model is used to have conservative results[1].

2.2 Validation of FEA model

To verify the FEA model, the results of FEA and experiment were compared. Experiment data measuring temperature with K type thermocouples is from MRP-271 with GTAW whose parameters are 275 current, 11.5 voltage, 6.0 in/min travel speed[8]. 2D plain strain model was used. Fig 3 shows comparison with measured temperature and calculated temperature on bottom of bead at the moment of welding torch moving. Temperature profile is similar to both of them.

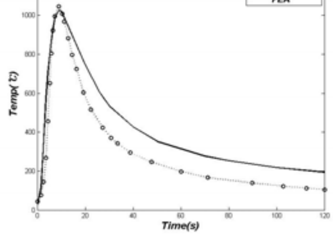
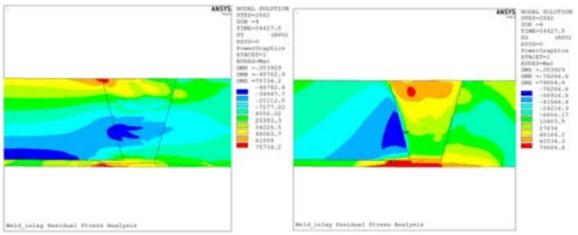


Fig. 3. Validation of FEA model.

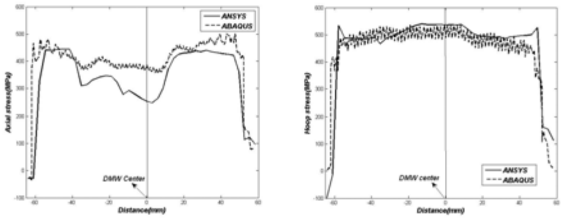
2.3 FEA results

Fig 4 shows stress contours around reactor nozzles. And Fig 5 shows axial and hoop stress on inside surface at near DMW center line. Magnitude of axial and hoop stress is similar. Fig 6 shows axial and hoop stress along the thickness diction. Stress trend and stress magnitude are similar with the results of ANSYS and ABAQUS. Residual tensile stresses of 400~500 MPa are generated on inside surface. And residual compressive stresses are generated at 10~20% of thickness from inside surface.



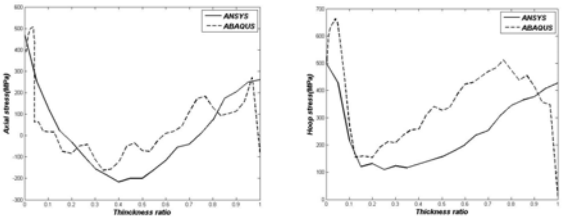
(a)Axial stress (b)Hoop stress

Fig. 4. Stress contours around weld inlay.



(a)Axial stress (b)Hoop stress

Fig. 5. Stress on the inside surface of nozzle.



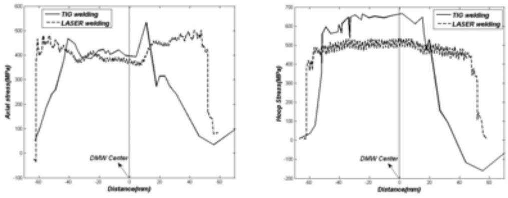
(a)Axial stress (b)Hoop stress

Fig. 6. Stress on thickness direction at DMW center.

2.4 Comparison with GTAW and LASER welding

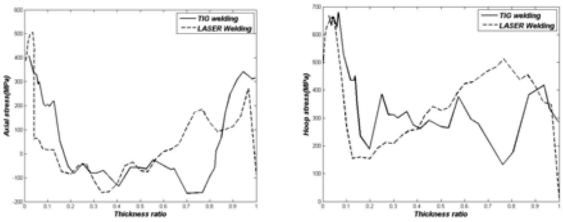
Weld inlay evaluation is performed by NRC with GTAW process[1]. When comparing with the results of NRC and this study, Fig 7 shows stress on the inside surface and Fig 8 shows stress along the thickness direction. Magnitude of axial stress on surface is similar but in case of hoop stress, GTAW is higher that LASER. Fig 8 shows stress at thickness direction. Magnitude and trends of stress are similar.

LASER welding is high energy density making locally temperature high and making it possible that HAZ is much smaller than GTAW process. So magnitude of stress between LASER welding area and HAZ is hugely different.



(a)Axial stress (b)Hoop stress

Fig. 7. Comparison with GTAW and LASER on inside surface.



(a)Axial stress (b)Hoop stress

Fig. 8. Comparison with GTAW and LASER on thickness.

3. Conclusions

Evaluation of weld inlay process using ANSYS and ABAQUS is performed. All of the both results are similar. The residual stress generated after weld inlay was on range of 450~500 MPa. Welding residual stresses are differently generated by GTAW and LASER welding. But regardless of welding process type, residual tensile stress is generated on inside surface. Therefore, when weld inlay applies to nozzles, the way of reducing residual tensile stress must be found to prevent form initiating any kind of cracks.

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