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New Method for Mitigating the Tensile Residual Stresses induced on the Inside Wall of Butt Welded Pipes

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1. Introduction

Because dissimilar metal welding between ferritic steel and austenitic stainless steel needs not post weld heat treatment (PWHT), the effect of residual stresses induce during the welding should be investigated to assess the reliability of the weld process. It is known that the A82/182 weld metals, which are used for filler metals of the butt welding between the ferritic steel pipe and the stainless steel pipe, are susceptible to PWSCC (Primary Water Stress Corrosion Cracking) in PWR plant. The tensile residual stresses on the inside wall of the pipe, which are induced during the production welding, tend to be the dominant driving force for the PWSCC initiation and crack growth. In order to prevent the PWSCC the tensile residual stresses should be mitigated or removed. Two methods, weld overlay and mechanical stress improvement process (MSIP) have been considered proper tools to reduce the tensile residual stresses and to mitigate the PWSCC susceptibility of the dissimilar metal welded nozzles and pipes[1,2].

In this research, new method for mitigating the tensile residual stresses induced on the inside wall of pipe during the production welding between the ferritic steel pipe and the stainless steel pipe was suggested. This new method may be able to apply to the SA508 /A182/SS316 nozzles of the pressure vessels in PWR to prevent PWSCC susceptibility as another substitute method.

2. Mechanical Stress Improvement Process (MSIP)

The MSIP have been considered proper candidate to mitigate the PWSCC susceptibility. The MSIP is approved and accepted by the NUREG-0313. Figure 1 shows the steps during the MSIP schematically. As shown in Fig. 1, the MSIP works by using a hydraulically operated clamp to slightly contract the pipe on one side of the weldment. The permanent contraction generates a concave contour at the weld location and results in a corresponding reduction in pipe circumference. Once the tool is removed, the weld area remains in axial and hoop compression. During application of MSIP, the inside wall is subjected to monotonically increasing compressive strains[2].

3. New Method using Concentrated Deformation

The conventional MSIP needs high capacity of hydraulic pressure to obtain proper plastic flow around the weld region. To support and to control the high pressure applied on the outside wall of the pipe, a ring should be inserted into the pipe. Because just narrow root region of weld metal of A82/182 is most susceptible PWSCC, the wide plastic zone induced during MSIP may not be sufficiently effective.

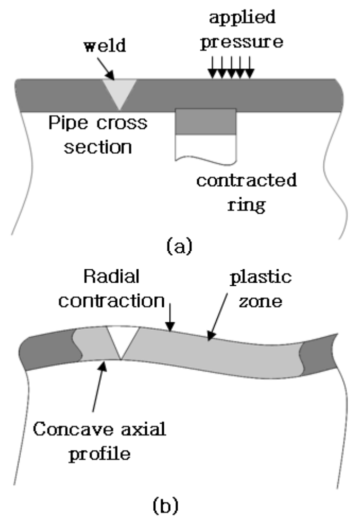

Fig. 1 Schematic drawing of step (a) and (b) for Mechanical Stress Improvement Process (MSIP).

The new method for mitigating the tensile residual stresses and the PWSCC susceptibility on the root region of butt weld was suggested, which may be substitute for the conventional MSIP. Figure 2 shows the steps of newly suggested method process. As shown in step (b), the U-groove, almost 0.5 depth of pipe thickness, in the weld metal was temporally machined along circumferential direction, which can concentrate the plastic flow on the weld region during the pressing. This plastic zone is narrower than that of MSIP. Because the plastic deformation is concentrated at the root region under the U-groove, the support ring is not needed. The temporally machined U-groove is welded using Ni-filler of A182 after plastic deformation. Because the weld metal of the dissimilar metal is Ni-base filler, the additional PWHT is not needed after welding for U-groove. Compare to the conventional MSIP, this suggested method is simple and easy to apply it to the butt welded pipes and nozzles in nuclear power plants.

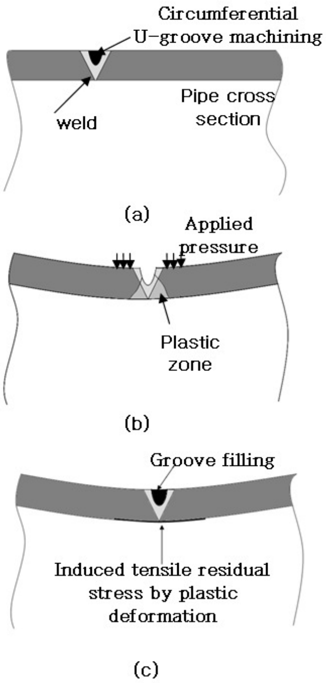

Fig. 2 Suggested new method process for mitigating tensile residual stresses induced on the inside wall of dissimilar metal butt welded pipes.

4. Modeling and Calculation of Residual Stresses

In order to investigate the effect of the new method, the behavior of residual stresses on the inside wall of the butt welded pipes were calculated by using commercial FE program. Axi-symmetric modeling was performed, and uncoupled thermo-mechanical analysis was used to calculate the heat flows and the residual stresses in the butt welded pipes of SA508 steel and stainless steel 304. The pipe thickness is simulated 32mm, and the out diameter is 380mm. The weld ampere of 120A, the arc speed of 2mm/sec, and the 120MPa of applied pressure were used for calculation. Element rebirth technique was used to simulate the deposition of weld beads and the machining of U-groove. Lumping method was chosen to simplify the modeling of the weld process[3].

Figure 3 shows the residual stress distributions around weld region after final state of the suggested method. The reduction of tensile residual stress on the inside wall can be observed. Figure 4 shows the variation of the calculated axial and hoop directional residual stresses at the observed positions on each step. These observed positions are the points of 5mm from the center of root of weld metal to the direction of SA508 steel pipe and stainless steel pipe. As shown in Fig. 4, the tensile residual stresses induced by the initial welding rapidly decrease after the plastic deformation under the U-groove. After welding stage for filling the temporally machined U-groove, the residual stresses do not increase to the state of tensile stress.

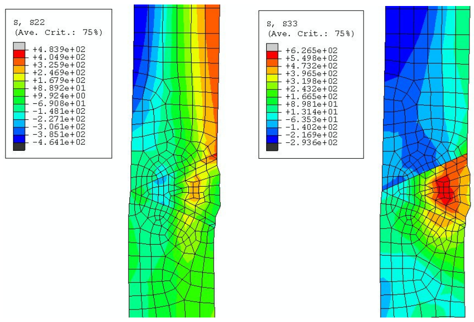

Fig. 3 Calculated final residual stress distribution obtained from modeling of new method process. (a) is the axial residual stress distribution and (b) is the hoop residual stress distribution.

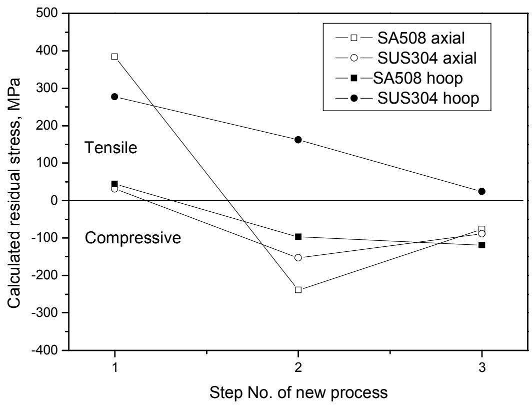

Fig. 4 Variation of calculated residual stresses near root region on each step of the new method (1: initial state, 2: after pressing step, 3: final step).

5. Conclusion

New method for mitigating the tensile residual stresses near the root region of the weld between the ferritic steel pipe and the austenitic stainless steel pipe was suggested. This method may be able to apply to the SA508/A182/SS316 nozzles in PWR plant to prevent PWSCC susceptibility.

REFERENCES

[1] Material Reliability Program: Technical Basis for Preemptive Weld Overlays for alloy 82/182 Butt Welds in PWRs (MRP-169), EPRI Technical Report, 2005, 1012843
[2] United States Patent 4683014
[3] Jeong Kyun Hong, Study of numerical methodologies for multi-pass welding analysis, The Ohio State University Degree Doctor of Philosophy, 1996