Numerical analyses of weld overlay and shot peening for comparing weld residual stress mitigation

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1. Introduction

Nickel-based alloys such as 82/182 which compose typical PZR(Pressurizer) nozzles have been widely used in nuclear power plants. However, they are sensitive to PWSCC(Primary Water Stress Corrosion Cracking) and WRS(Weld Residual Stress) is one of the main factors[1-4]. In this study, variations of stresses through weld overlay and shot peening to the PZR nozzle were calculated by FEA(Finite Element Analysis) and their results were compared.

2. Analysis methods and conditions

2.1 Weld overlay

Fig. 1 represents the photograph and FE model of the PZR nozzle mock-up. The temperature dependent thermal and mechanical properties which were used in this analysis were obtained from previous studies[1-3]. In case of alloy 82/182, alloy 52M is mainly used for weld overlay. However, it was assumed that alloy 52/152 was substituted based on previous studies[2, 3]. The analysis was proceeded in the order of heat transfer and thermal stress by using temperature method (T_m+10 ˚C)[4]. The heat sink temperature was 20 ˚C and heat transfer coefficient was 0.0284 mW/mm^2°C. Also, boundary condition was the same as the actual welding process and the annealing effect was considered with the isotropic hardening model.

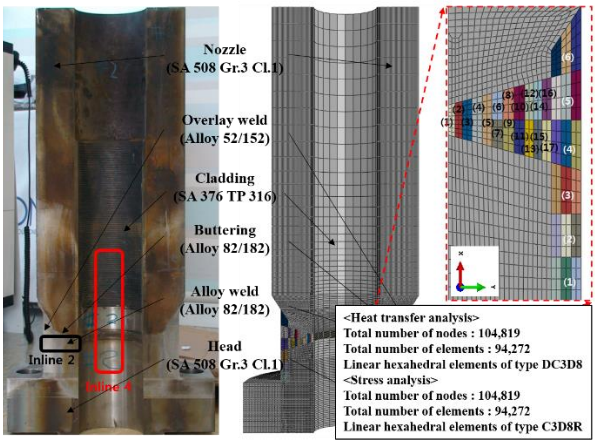

Fig. 1. The photograph and FE model of PZR nozzle mock-up[5].

2.2 Shot peening

Fig. 2 shows FE model of PZR nozzle and SPH(Smoothed Particle Hydrodynamics) model of shot ball. SPH model was applied to simulate multiple collisions of the shot ball effectively. SPH is effective in simulating large deformation phenomena and behaviors such as debris and dispersion due to the high-speed collisions. This is a mesh-free method that can express the behavior of particles related to density, mass and volume with surrounding particles by constructing the object to be analyzed as a set of particles[6]. Meanwhile, EOS(Equation of State) is required to simulate the behavior through the relationship with the object of the actual shot ball and the surrounding air after the impact[7, 8]. For this matter, Grüneisen EOS was applied based on previous research[8]. Meanwhile, shot peening causes a high and even distribution of compressive stress according to the coverage which was calculated by the area pressed by the shot ball per unit area. In this study, shot ball was simulated to be sprayed as 45 m/s with the coverage of 120 % based on previous study. Also, shot ball was cast iron having density of 7,207 kg/m^3 with average diameter of 0.8 mm[9].

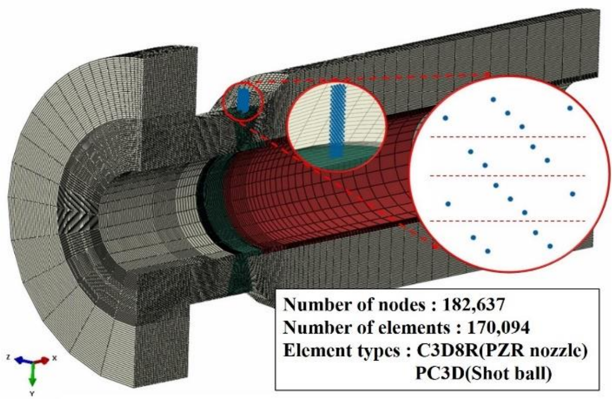

Fig. 2. SPH and FE model for the shot peening simulation.

3. Analyses results

3.1 Weld overlay

The WRS measurement results obtained by IIT(Instrumentation Indentation Test) on the inline 4 and the FEA results before and after weld overlay were compared in Fig. 3[5]. The square symbols indicate IIT results, circle and triangle symbols are FEA results before and after the weld overlay. Solid and open symbols mean hoop and axial stress. The IIT results show that there were not a large difference between the stress components and those were distributed between hoop and axial stress of FEA results. Meanwhile, overall hoop and axial stresses were mitigated through the weld overlay. Especially, hoop stress at the HAZ(Heat Affected Zone) and weld part moved to the compressive area. It was also confirmed that the axial stress was relaxed even though it was a tensile region.

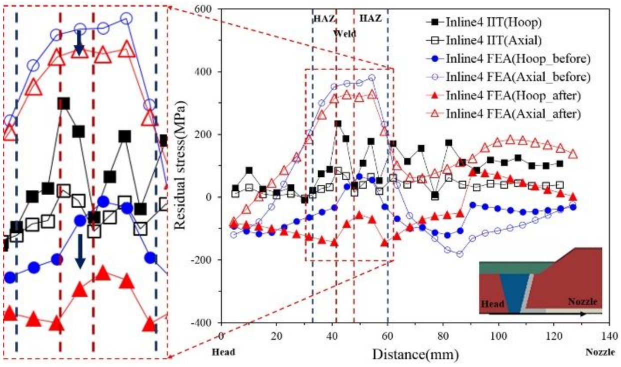

Fig. 3. WRS measurement and analysis results on the Inline4 according to the weld overlay[5].

3.2 Shot peening

The WRS distribution before and after shot peening on the inline 4 is shown in Fig. 4. The circle and diamond symbols mean the before and after shot peening. The solid and open symbols mean hoop and axial stress. The overall stress variation before and after the peening process was almost similar. In case of axial stress, stresses decreased in HAZ and weld part. The hoop stress was not significantly different from before the mitigation treatment, but was slightly reduced in some HAZ and weld part.

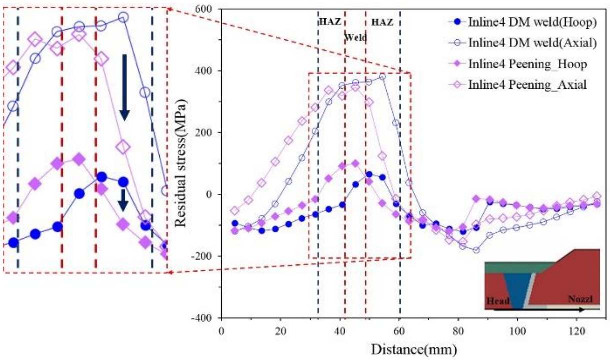

Fig. 4. WRS measurement and analysis results on the Inline4 according to the shot peening.

3.3 Comparison of weld overlay and shot peening

WRS variations due to the weld overlay and shot peening on the inline 4 were compared in Fig. 5. Although it was confirmed that the axial stress was reduced locally in some HAZ part, effect of shot peening of both stress components was not significant. On the other hand, although there was some local relaxation due to the shot peening, the effects of weld overlay had large effect on both stress components generally.

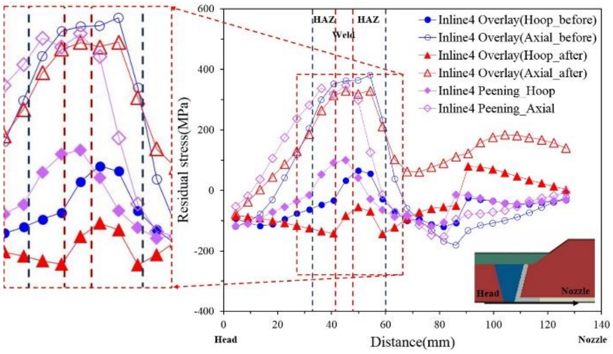

Fig. 5. Comparison of WRS relaxation on the Inline4 with weld overlay and shot peening.

4. Conclusions

In this paper, weld overlay and shot peening were selected as a part of PWSCC mitigation strategy and comparative analyses to a typical PZR nozzle were performed.

(1) The measurement and analysis results showed that WRS components were reduced by the weld overlay.
(2) The stress variation due to the shot peening was partially reversed but reduced in some HAZ and weld parts.
(3) As a results of comparing the two mitigation processes, overall WRS was more reduced by the weld overlay.

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