UNIFIED WELDING RESIDUAL STRESS PROFILE FOR DISSIMILAR METAL WELD IN PWR NOZZLE

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1. Summary
Recently, welding residual stresses in dissimilar metal weld in nuclear power plant nozzle have been estimated through experiment measurements and FE analyses[1-5]. However, those results are limited to specific nozzle considered in each work. In this work, simplified nozzle component has been proposed, which enable systematic analyses for various geometries. As a result, unified welding residual stress profile, which is generally adequate for various nozzle shape, has been provided for dissimilar metal weld in nozzle component.

2. Background
Many studies on welding residual stresses in austenitic pipe butt weld in BWR are conducted for decades, hence residual stress profiles in the closed form have been proposed in many literatures or codes, i.e. R6[6], API579[7] and ASME[8]. On the other hand, welding residual stress profiles in dissimilar metal weld in PWR has not been provided in closed form due to complex shape of nozzle component. In this study, simplified model for nozzle component are proposed based on the some characteristics observed in nozzle component.

3. Methods
Welding residual stress analysis was conducted using commercial finite element analysis code, ABAQUS[9]. Un-coupled thermal and stress analyses were adopted. Therefore, time dependent temperature histories from thermal analysis were used as input data for stress analysis. Axisymmetric model was employed and relevant welding parameters were calculated according to welding procedure specification. In stress analysis, plastic strain was annealed at melting temperature and non-linear kinematic hardening model was used to consider Bauchinger effect.

Temperature dependent material properties including Young’s modulus, yield strength, specific heat and other relevant properties were obtained through existing literature, database by manufacturer and design code[10].

Fig.1(a) shows schematic diagram for surge nozzle used in Korean nuclear power plant and Fig. 1(b) depicts proposed idealized nozzle corresponding to Fig. 1(a). The welding residual stress for idealized nozzle is almost similar to those for corresponding real nozzle. For systematic analyses, three values of thickness, $t_{SE}=20, 40, 80$ mm, and three values of radius to thickness ratios, $r_t/t_{SE}=1, 3, 5$, were considered, respectively. And for the length of safe end, $w_{SE}, w_{SE}=0.5, 1.0, 2.0$ and 4.0 are considered, which is expected to cover all the real nozzle shape.
4. Results

Fig. 2 shows residual stress distribution for the nozzle of $t=40$ mm and $r/r_{SE}=5$. The residual stresses are extracted along the center line within the dissimilar metal weld. In the figure, symbols denote FE results and line are existing closed-form residual stress profile for austenitic pipe butt weld in R6 code. All the residual stresses were normalized with relevant values, i.e., 0.2% proof stress of parent material, $\sigma_{yp}$, for axial residual stresses and 0.2% proof stress of weld material, $\sigma_{yw}$, for hoop stresses, respectively. As can be seen, FE results shows overall good agreement with existing solution for austenitic pipe butt weld in R6 if relevant normalizing stresses, $\sigma_{yp}$ and $\sigma_{yp}$, are employed.

5. Conclusions

In this paper, welding residual stress analyses for dissimilar metal weld of PWR nozzle are conducted. For systematic studies on the effect of nozzle geometry on welding residual stress
profiles, idealized nozzle is proposed based on the investigation of the nozzles used in the site. As results, welding residual stresses for various nozzle shape are provided, which is properly expressed with existing solution for austenitic pipe butt weld in R6 if relevant normalizing stresses are employed. For relevant normalizing stresses, 0.2% proof stress of parent material is used for axial residual stresses and 0.2% proof stress of weld material is used for hoop residual stresses, respectively.

5. References