A Study on the Evaluation Technology of Welds Integrity in Nuclear Power Plants

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The final goal of this study is to develop the core technologies applicable to the design, operation and maintenance of welds in nuclear structures. This study includes predicting microstructure changes and residual stress for welded parts of nuclear power plant components. Furthermore, researches are performed on evaluating fatigue, corrosion, and hydrogen induced cracking and finally constructs systematically integrated evaluation system for structural integrity of nuclear welded structures.
In this study, metallurgical and mechanical approaches have been effectively coordinated considering real welding phenomena in the fields of welds properties such as microstructure, composition and residual stress, and in the fields of damage evaluations such as fatigue, corrosion, fatigue crack propagation, and stress corrosion cracking. Evaluation techniques tried in this study can be much economical and effective in that it uses theoretical/semi-empirical but includes many additional parameters that can be introduced in real phenomena such as phase transformation, strength mismatch and residual stress. It is clear that residual stress makes great contribution to fatigue and stress corrosion cracking. Therefore the mitigation techniques have been approached by reducing the residual stress of selected parts resulting in successful conclusions.

Keywords *: nuclear power plants, welds, residual stress, fatigue, stress corrosion cracking*

1. Introduction

In Korean nuclear power plants, welds are designed and inspected based on ASME B&PV Code Sec.II, III, XI[2)~4)] and AWS Code[5)] etc.. Even though materials selection, welds evaluation, post heat treatment, quality management and in-service inspections are carrying in the stage of design, construction, operation and maintenance, the evaluation technology of welds integrity has not been completely established and many problems have been occurred in welds. Especially, many prior researches in Korea have been separately carried out based on each fields of study, metallurgical and mechanical approaches have not been effectively coordinated considering real welding phenomena in the fields of welds properties such as microstructure, composition and residual stress, and in the fields of damage evaluations such as fatigue, corrosion, fatigue crack propagation, and stress corrosion cracking.

The final goal of this study is to develop the core technologies applicable to the design, operation and maintenance of welds in nuclear structures. This study includes predicting microstructure changes and residual stress for welded parts of nuclear power plant components. Furthermore, researches are performed on evaluating fatigue, corrosion, and hydrogen induced cracking and finally constructs systematically integrated evaluation system for structural integrity of nuclear welded structures.

2. Scope of the work

In the field of fatigue evaluation technologies, the life predictions of fatigue crack initiation and fatigue crack growth have been studied. These works include the selection of a significant welded component for evaluation, determination of materials properties including fatigue crack growth characteristics of welded parts. Thermal analysis, microstructure prediction and stress analysis have been performed. Prediction technologies have been developed for fatigue initiation rate and fatigue crack growth rate. Evaluation results have been verified by comparing with experimental results. Methods have been studied for mitigation of fatigue and fatigue crack growth.

In the field of corrosion evaluation technologies, local corrosion and stress corrosion cracking in the welded component have been considered. Target welded com-

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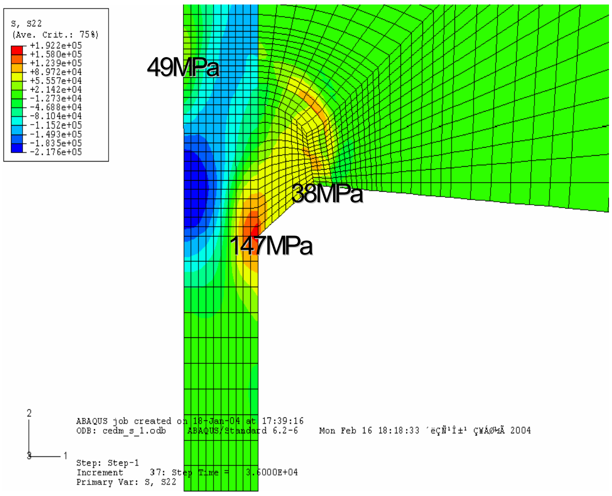
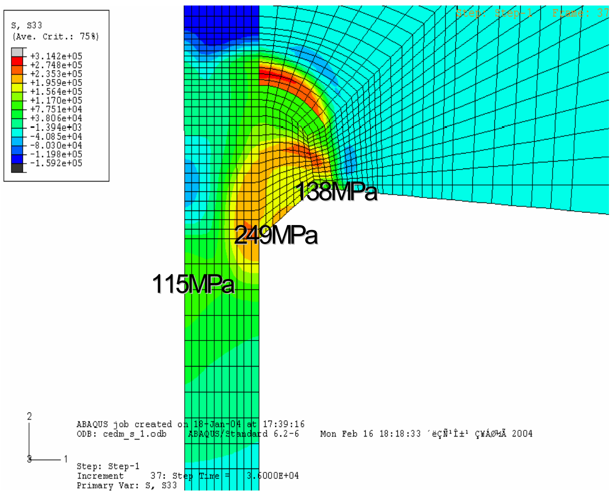


(a)



(b)

Fig. 1. Total stress distribution of dissimilar weld in the CRDM nozzle that include residual stress and operational load((a) axial stress (b) hoop stress).

ponents have been selected for evaluation. Materials properties have been determined including characteristics of local corrosion and stress corrosion cracking of welded parts. Various analyses have been performed including thermal analysis, microstructure prediction, stress analysis and crack analysis. Prediction technologies have been developed for local corrosion rate and stress corrosion crack growth rate. These evaluation techniques have been verified by comparing with experimental results. Methods have been developed for mitigation/prevention of local corrosion and stress corrosion cracking.

In the field of hydrogen induced cracking, plate welds and pipe welds have been studied. For this work, target welded plate and pipe have been selected for evaluation. Materials properties have been determined including hydrogen induced cracking characteristics of welded parts. The analyses performed include microstructure prediction, residual stress analysis and hydrogen diffusion analysis. The analysis method of hydrogen induced cracking has been developed and verified by experiments. The mitigation method of hydrogen induced cracking has been derived.

3. Results and disscussion

For the evaluation of fatigue crack initiation and crack growth rate, the welds of pressurizer spray nozzle were selected. Important physical properties were analyzed such as thermal/physical/mechanical material properties and fatigue characteristics (S-N curve and △K-da/dN). FEM analyses have been performed for finding thermal distribution, location of local brittle zone and residual stress distribution during welding. Fatigue analysis methodologies have been established on the basis of ASME B&PV Code Section III and fatigue evaluation procedures have been set up which diminish conservatism. FEAM computation code on 3-dimensional crack has been introduced and engineering J integral has been considered for strength mismatch. New structural stress/fracture mechanics have been developed based on fatigue analysis techniques which remove conservatism by eliminating uncertainty of analysis. Residual stress relaxation mechanism was analyzed during crack growth. Fatigue crack growth has been predicted using new structural stress/fracture mechanics based on the approach that considers microstructure and residual stress. Analyses have been verified by experiments on the edge crack weld specimen. Tensile residual stress could be relaxed or compressive stress could be induced by MSIP(mechanical stress improvement process).

For the evaluation of local corrosion(pitting) initiation and growth rate, the weld of a seawater supply pump flange has been selected. Its microstructure, hardness and polarization curve has been analyzed. Some physical properties have been analyzed such as thermal distribution during welding, grain size and phase fraction. Current Corrosion rate inside the pit has been predicted by quantifying current, potential and local corrosion region. Post weld heat treatment condition has been quantifying that could result in decrease of corrosion rate. Base on this technique, stress corrosion crack growth rate has been evaluated for the selected DRDM penetration nozzle dissimilar weld metals. Important parameters have been obtained from grain size analysis, polarization curves, re-passivation curves, and impedence spectroscopic curves as well as thermal/physical/mechanical material properties. Several equations(K-da/dt) have been analyzed for applying

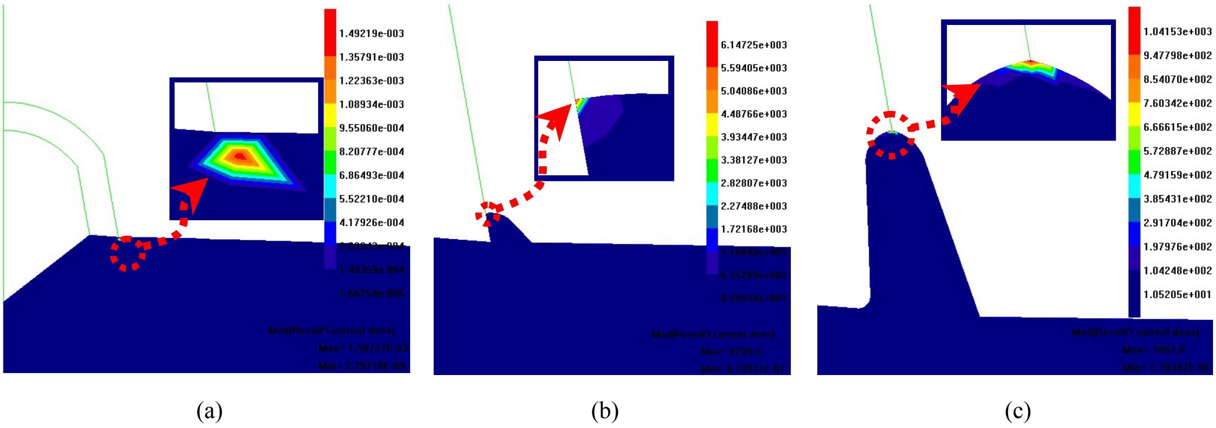


Fig. 2. Corrosion current density distribution of dissimilar metals in the CRDM nozzle((a) crack initiation stage, (b)(c) propagation stage)

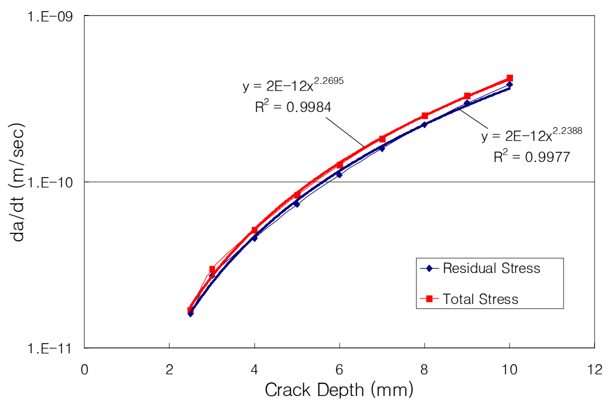


Fig. 3. PWSCC crack propagation rate accompanying with crack growth of the dissimilar metal in the CRDM nozzle

to evaluation for stress corrosion crack growth rate. Temperature and residual stress distributions during welding have been visualized. It could be predicted where the stress corrosion crack located and how much current densities formed in the crack tips. For the crack growth, deformation/oxidation model has been introduced. Analysis results have been verified by the experiment using U-bend weld specimen with center notch. SCC crack growth could be mitigated by applying MSIP resulting in relaxing tensile residual stress.

In order to develop the mitigation method of hydrogen induced crack, plate form weld and pipe form weld have been selected in the SA508 grade 1a low alloy steel. Parameters have been analyzed such as thermal/physical/mechanical material properties and characteristics of high strength low alloy hydrogen induced cracking. It was determined that thermal distribution, final microstructure phase fraction, residual stress, and hydrogen concentration. 2 parameter method(critical principle stress - critical hydrogen contents) has been introduced. Electro-transport treatment is capable of eliminating diffusible hydrogen in the plate formed weld by 53% with applying 400A direct current for 40 minutes. Electrochemical treatment is capable of eliminating diffusible hydrogen in the pipe formed weld by 6% with applying 630 mV for 1 hour. The latter method is superior to former one in efficiency.

4. Conclusions

In this study, metallurgical and mechanical approaches have been effectively coordinated considering real welding phenomena in the fields of welds properties such as microstructure, composition and residual stress, and in the fields of damage evaluations such as fatigue, corrosion, fatigue crack propagation, and stress corrosion cracking. Evaluation techniques tried in this study can be much economical and effective in that it uses theoretical/semi-empirical but includes many additional parameters that can be introduced in real phenomena such as phase transformation, strength mismatch and residual stress.

It is clear that residual stress makes great contribution to fatigue and stress corrosion cracking. Therefore the mitigation techniques have been approached by reducing the residual stress of selected parts resulting in successful conclusions.

It is expected that this study contributes to the engineering improvement for the weld integrity in the view of effectiveness and application.

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