Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

Assessment of Alloy 690/152 cylindrical weld specimen

Sang Hwan Lee [a], Da Hye Kim [a], Yoon-Suk Chang [a*], Sung-Woo Kim [b] and Seong-Sik Hwang [b]
[a] *Department of Nuclear Engineering, Kyung Hee University, Yongin, Korea*
[b] *Korea Atomic Energy Research Institute, Daejeon, Korea*
[*] *Corresponding author: yschang@khu.ac.kr*

1. Introduction

High tensile weld residual stress in conjunction with aggressive environments and susceptible material may lead to nuclear component failures by PWSCC(Primary Water Stress Corrosion Cracking). In practice, severe defects have been reported world widely at dissimilar metal welds of pipe, reactor head penetration, pressurizer nozzle and so on[1]. As one of options to prevent these unanticipated failures due to PWSCC, recently, the susceptible materials such as Alloy 600 and 82/182 are being changed into Alloy 690 and 52/152. In this research, numerical simulation is carried out to examine residual stress of weld specimen made of Alloy 690/152. Parametric FE(Finite Element) analyses are performed to decide optimum simulation conditions and then applied to determine the weld residual stress distributions of the specimen.

2. Analysis Condition

2.1 Information of weld specimen

Fig. 1 shows the geometry and welding passes of the specimen with a hole. Its outside diameter is 12.4cm, inside diameter is 5.6cm and thickness is 8.2cm respectively. The base material is Alloy 690 and weld material is Alloy 152. Four parts are welded and each welding pass numbers are different from 30 to 50.

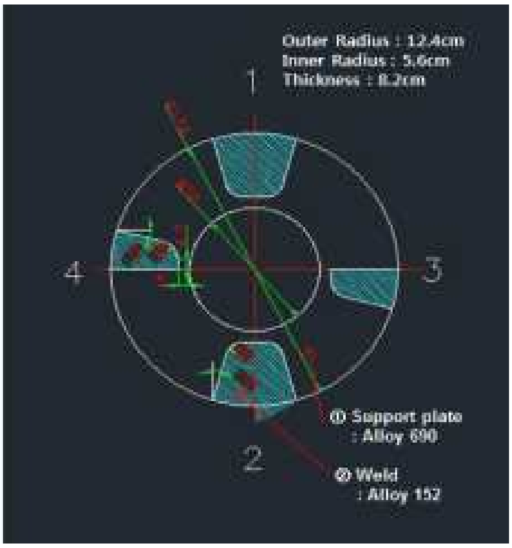

Fig. 1 Geometry and welding passes of specimen[2]

2.2 Analysis method

FE model of the specimen was generated with 6,652 nodes and 6,519 elements by employing 4-node element (element type DC2D4 for heat transfer and CPE4 for stress analyses in ABAQUS element library).

As reported in many previous studies, residual stresses were caused by mismatched properties of dissimilar metal welds and local melting induced non-uniform temperature gradients. In the present FE analysis, in order to simulate the actual welding process, welding beads were sequentially generated by selecting <MODEL CHANGE> option in ABAQUS. Also, bead simplification was adopted for effective computing based on the LPM(Lumped Pass Method)[3].

Regarding the heat transfer analysis, an accumulation temperature of weld material was set to 1900 ℃ that is higher than the liquidus temperature[4]. As boundary conditions, a sink temperature of $T = 25$ ℃ and a natural convection with heat loss coefficient of $h = 10\mathrm{W/m^2}$ ℃ were considered.

With regard to the thermal stress analysis, mechanisms of melting and recrystallization of the weld were incorporated by specifying an annealing temperature in use of <ANNEAL TEMPERATURE> option. In addition, PWHT(Post Weld Heat Mechanism) and pre buttering welding were not considered to get conservative weld residual stress.

3. Analysis Results

3.1 Parametric analysis

In order to examine effects of welding variables, parametric analyses were carried out by changing welding processes, cooling conditions and boundary conditions as follows:

Welding process

Two cases were investigated; one is cutting all the welding parts in advance and filling-in beads sequentially (Case 1). The other is repeating each welding and filling-in bead process (Case 2). As shown in Fig. 2, the resulting residual stress distributions were similar while some differences were observed. This means that the effect welding process is not significant. So, the Case 2 was selected as optimum because it was defined in the WPS(Welding Procedure Specification).

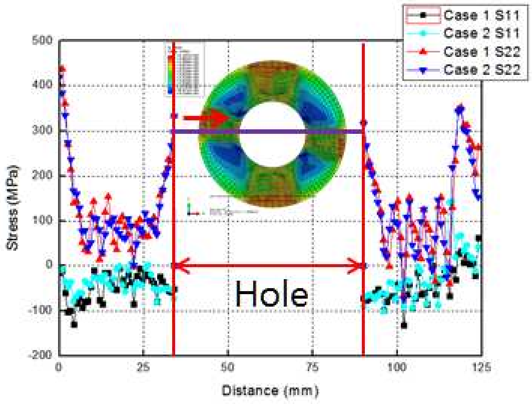

Fig. 2 Comparison of stress distributions under different welding processes

Cooling process

Two cases were investigated; one is a forced cooling at 25℃ (Case 1) and the other is a 30 minutes natural cooling for each bead (Case 2). As shown in Fig. 3, the resulting residual stress distributions were different remarkably. So, the Case 2 was selected as optimum because it was defined in the WPS.

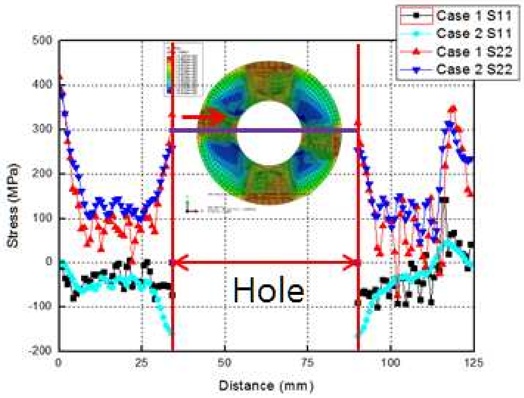

Fig. 3 Comparison of stress distributions under different cooling conditions

Boundary condition

Two cases were investigated because the dead weight of the specimen was not considered in FE analyses; one is outer edges, between four welding parts, locally fixed condition (Case 1). The other is inner radius locations fully fixed condition (Case 2). As shown in Fig. 4, the resulting residual stress distributions in and near the welds were similar while some differences were observed in the base metals. So, the Case 1 was selected as optimum because it is more realistic.

3.2 Analysis results by using the optimized conditions

Based on the optimum conditions (Case 2 of the welding process, Case 2 of the cooling condition and Case 1 of the boundary condition), a main analysis were carried out.

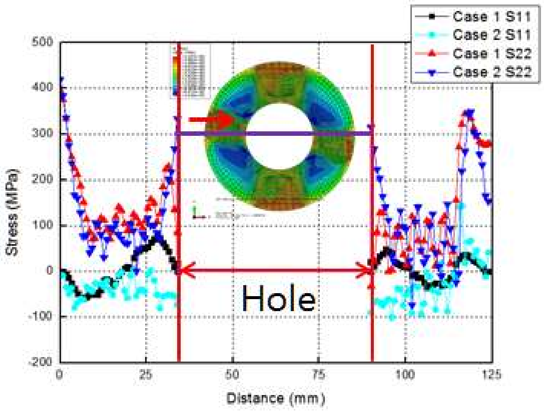

Fig. 4 Comparison of stress distributions under different boundary conditions

As shown in Fig. 5, stress distribution of the specimen was symmetric along x- and y-directions. Also, the resulting maximum von Mises stress was calculated as 507MPa.

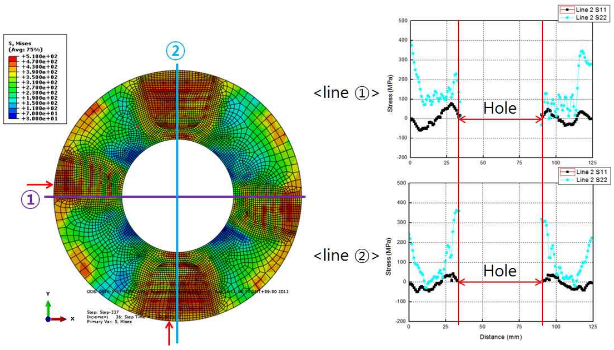

Fig. 5 Stress distributions of weld specimen

4. Conclusions

In the present research, numerical simulation was carried out to examine residual stress of weld specimen made of Alloy 690/152. Stress distributions according to different welding processes, cooling processes and boundary conditions were compared, from which an optimum analysis condition was derived. Finally, the weld residual stress distribution was calculated and will be used to determine realistic load-carrying capacity through subsequent experiments.

REFERENCES

[1] Anderson, M.T., Rudland, D., Zhang, T. and Wilkowski, G., 2008, "Final Report - Inspection Limit Confirmation for Upper Head Penetration Nozzle Cracking," U.S. Department of Energy, pp.1~22.

[2] Internal communication with KAERI, 2013.

[3] Rudland, D., Chen, Y., Zhang, T., Wilkowski, G., Broussard, J. and White, G., 2007, "Comparison of Welding Residual Stress Solutions for Control Rod Drive Mechanism Nozzles," Trans. of ASME PVP conference, PVP2007-26045.

[4] Kim, D.H., Chang, Y.S., Hwang, S.S. and Kim, S.W., 2013, "Residual Stress Analysis of Alloy 690 Dissimilar Metal Welds," The KSME Spring Annual Conference, Vol.13, pp.209~210.