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Residual Stress Analysis of Alloy 690 for J-Groove Weldment in Reactor Head Vessel CRDM Penetration Nozzle

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1. Introduction

It is known that PWSCC is the biggest cause of nozzle weld damage on the upper part of the reactor head, which was first generated in Bugey # 3, France in 1991, but it is known to have a large effect on residual stress due to welding. At present, in operation, power plants are being replaced with Inconel 600 to Inconel 690, a material which is more resistant to stress corrosion cracking, for head penetrating nozzle. In general, it is known that PWSCC and residual stress due to welding have a large effect on defects generated in nozzle welds. Residual stress evaluation for this effect evaluation can be classified by experimental method and numerical analysis method.[1][2] This research on the residual stress evaluation by numerical analysis method with a finite element analysis of dissimilar metal welds considering nozzle shape is conducted to evaluate the residual stress of penetration nozzle weldment on J-Groove of the replacement reactor vessel head for Kori No.2 using Inconel 690, which is a proven material for PWSCC.

2. Finite element analysis

2.1 Selection of research subjects

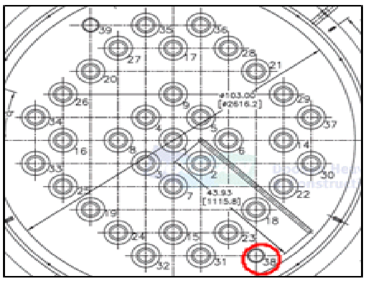
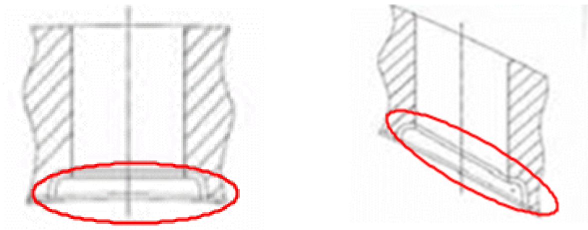


Fig. 1. Kori #2. replacement reactor vessel head penetration nozzle configuration layout[3]

The replacement reactor vessel head CRDM consists of 35 penetration nozzles as shown in Fig. 1. Of these, No.38 nozzle is the outermost nozzle located farthest from the center of the reactor head.



No.1 Nozzle No.38 Nozzle

Fig. 2. Penetration nozzle weld layout of Kori #2. Replacement reactor vessel head J-Groove [3]

As shown in Fig. 2, the geometrical asymmetry of the J-Groove weld increases as the CRDM penetration nozzle moves from the No.1 central nozzle to the outer edge, and the influence on structural integrity of nozzle by the residual stress weld increases. In addition, the total area of the welds increases due to the increase of the cross-sectional area and the length of the weld path, and the fact that the welding amount is large is a condition where many residual stresses are generated. Therefore, this research can represent the effect analysis by the residual stress evaluation of the penetration nozzle weld, because No.38 nozzle of 35 penetration nozzles is expected to have the greatest influence of residual stress, which is considered as the worst case.

2.2 Finite Element Analysis

The residual stress is largely divided into experimental method and numerical method, and in this study, a numerical method was performed using the SYSWELD program[4],[5], which is often used for local stress analysis of welds. The welding conditions that occur immediately after welding and the field operating conditions are largely applied to the finite element method model, and the final modeling was completed by reflecting other welding conditions and mechanical / thermal boundary conditions.

2.3 Analysis of Variables on Residual Stress

Generally, stress due to shrinkage during welding can be divided into tensile stress and compressive stress and the generated stress was divided into axial direction and circumferential direction according to the nozzle weld direction. The change of the residual stress according to the inner and outer diameters of the penetration nozzle and the positions of the axial and circumferential angles (0°, 90°, 180°, 270°) were analyzed. In order to analyze the residual stress of the welding part in the direction of the nozzle length, a range of ± 2 inches (about 150 mm) was defined. [5]

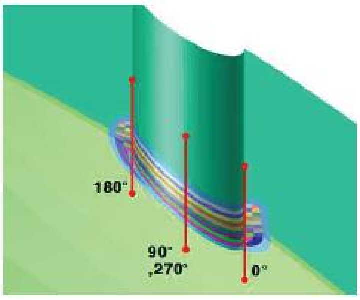


Fig. 3. Residual Stress Measurement Site of PenetrationNozzle Weldment(No. 38)

2.4 Finite element method boundary condition

As mentioned above, the boundary conditions of the finite element method are four boundary conditions, ie, mechanical boundary condition(Fig.4,5), thermal boundary condition(T= 20°C, h= 25W/m^2°C), welding condition, and two cases for residual stress analysis (post weld condition, operating condition). [5] Welding conditions were the same as WPS applied to the J-Groove weld of the reactor vessel head. Figure 4 shows the 3D shape reflecting the weld bead of nozzle No. 38 of the penetration nozzle selected for the study. Figure 5 shows the 3D shape of the mechanical boundary condition reflecting the X, Y, Z axis fixation and symmetry conditions.

Weld Type	Auto GTAW
Arc Parameter	150~220A x 9~12V
Weld Velocity	60~90 mm/min
Total Pass	16~18 pass
Heat Input	18KJ/cm

Table 1. Kori #2. reactor vessel head J-Groove penetration nozzle WPS[6]

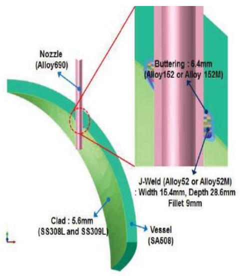


Fig. 4. Penetration No.38 Nozzle Weld Bead Reflected 3-D Shape[4]

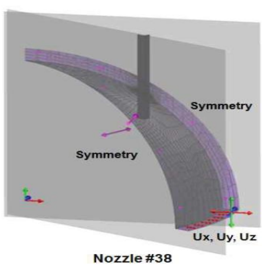


Fig. 5. Mechanical Boundary Condition[4]

3. Residual Stress Analysis Result

3.1 90° residual stress distribution of axial inner and outer diameter

Fig. 6 and Fig. 7 show that the tensile stress (+) and compressive stress (-) are almost symmetrically generated in the ID, similar to 0 °, as a result of residual stress analysis in the axial direction, and OD shows a tendency similar to 0 °, but a relatively large tensile stress value is generated. From the results after welding and operating conditions, it can be seen that the stress at the position where the maximum tensile stress is generated is reduced by almost 100 MPa or more.

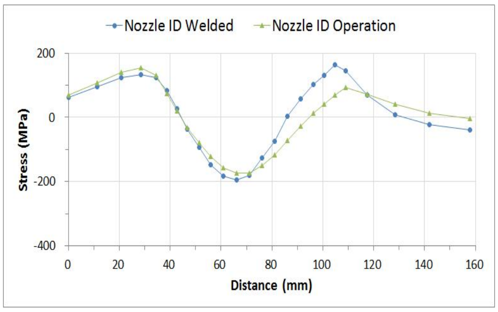


Fig. 6. Axial residual stress measurement analysis graph (ID, 90°)[5]

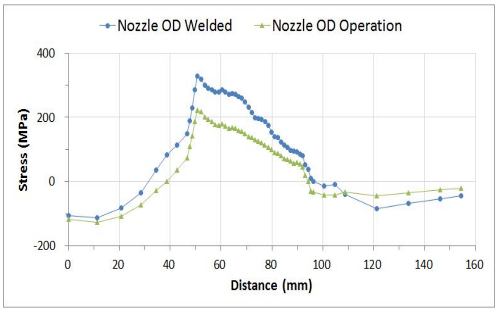


Fig. 7. Axial residual stress measurement analysis graph (OD, 90°)[5]

3.2 270° residual stress distribution of axial inner and outer diameter

Fig. 8 and Fig. 9 show that the tensile stress (+) and compressive stress (-) are symmetrically generated in the ID, similar to the positions of 0 °, 90 °, and 180 ° in the residual stress analysis results, and in the OD, it tends to be similar to 90 ° and 180 °. In addition, as in the case of 90 ° and 180 °, it can be seen that almost 100 MPa stress is decreased at the position where the maximum tensile stress is generated after welding and operating conditions.

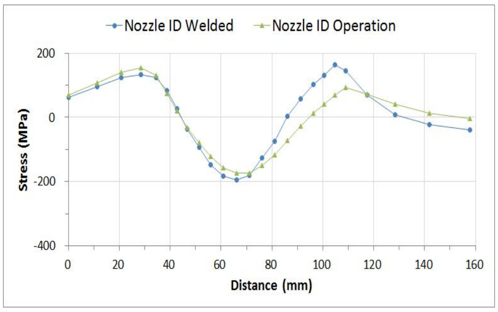


Fig. 8. Axial residual stress measurement analysis graph (ID, 270°)[5]

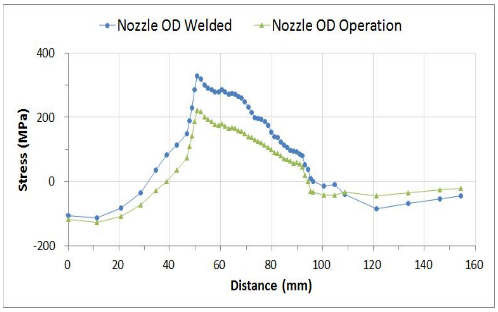


Fig. 9. Axial residual stress measurement analysis graph (OD, 270°)[5]

3.3 90° residual stress distribution of Circumferential inner and outer diameter

As a result of the analysis of the residual stresses shown in Fig. 10 and Fig. 11, a symmetrical tensile stress (+)distribution appears in the ID, different from that at 0 °position, and in the OD, the tendency is similar to that at 0 °position, and the tensile stress value at the center position is about 400Mpa.

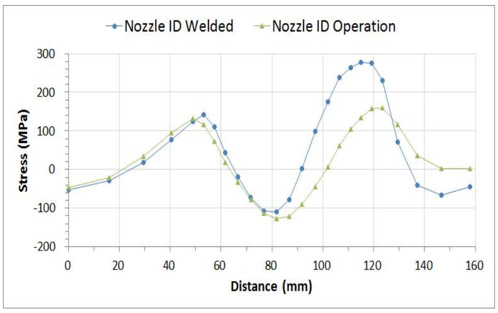


Fig. 10. Circumferential residual stress measurement analysis graph(ID, 90°)[5]

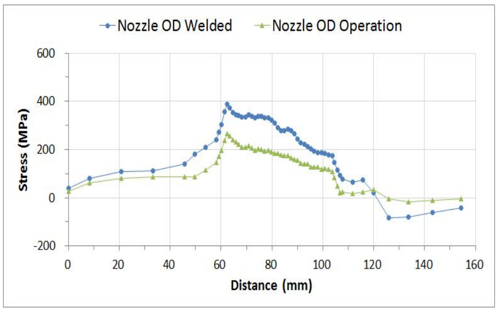


Fig. 11. Circumferential residual stress measurement analysis graph(OD, 90°)[5]

3.4 270° residual stress distribution of Circumferential inner and outer diameter

As a result of the analysis of the residual stresses shown in Fig. 12 and Fig. 13, a symmetrical tensile stress (+)distribution appears in the ID, different from that at 0 °position, and in the OD, the tendency is similar to those at 0°, 90°, 180° positions, and the tensile stress value at the center position is about 400Mpa.

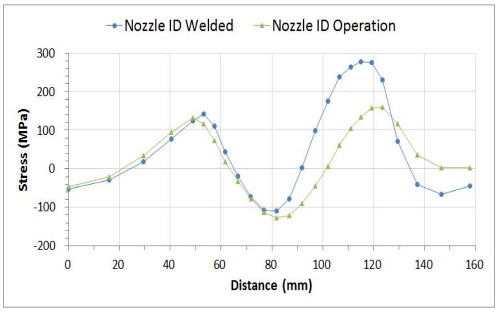


Fig. 12. Circumferential residual stress measurement analysis graph(ID, 270°)[5]

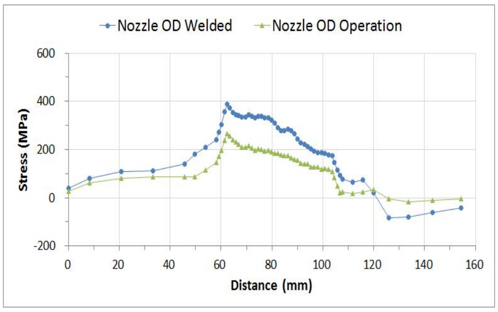


Fig. 13. Circumferential residual stress measurement analysis graph(OD, 270°)[5]

4. Conclusion

In this study, the results of the residual stress measurement are summarized as follows. It can be seen that the influence of the tensile stress largely affects the circumferential direction more than the axial direction, and it can be seen that the tensile stress value at the outer diameter is higher than the inner diameter at most. In the case of cracks occurring in the field, the probability of occurrence in the circumferential direction is larger than that in the axial direction, and the defects are firstly generated in the outer diameter. In addition, the results of the residual stress at the room temperature after welding and the residual stress results under the operating condition are compared with each other. As a result, the residual stress results are more stable in the operating condition as a whole. The results of this study show that it is possible to predict the more accurate residual stress of the reactor vessel head penetration nozzle using alloy 690.

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