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An Evaluation on the Residual Stresses Induced by EFR Welding of CEDM Nozzle

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1. Introduction

The Primary Water Stress Corrosion Cracking (PWSCC) has become a problem that generated inside and outside in the reactor Control Element Drive Mechanism (CEDM).

The PWSCC of Dissimilar Metal Zone of reactor can degrade the integrity of the main device in nuclear power plant, and according to the power plant stopped for inspection, it can cause an enormous amount of lost sales when the crack is occurred.

Various methods have been developed to reduce residual stress to prevent the PWSCC like Weld Overlay (WOL), Mechanical Stress Improvement Process (MSIP), Laser Peening, Inlay Weld, etc.

Among them, WOL is the most commonly used welding method in nuclear power plant. When performing a WOL, structure rigidity will be increase, and residual stress of welding zone will be changed into compressive stress from the tensile stress. This has the advantage that improved resistance to PWSCC.

The most commonly used material in nuclear power plant is Inconel 600. Inconel 600 consist of a Ni-Cr-Fe and it has 14~17% of Cr content, 10% of Fe content and susceptible to PWSCC. The more Cr content is more stronger against PWSCC. Inconel 690 which has 2 times more Cr content than Inconel 600 has very strong resistance to PWSCC than Inconel 600.

Embedded Flaw Repair (EFR) has been developed in Westinghouse by 1994. The welding metal with high corrosion resistance is embedded on the surface of component, and could protect cracking part from the PWSCC. It is permanent repair method that isolates the flaw from the environment, eliminating further crack propagation due to PWSCC. EFR method is that at least three layers of Alloy 52/52M material are deposited covering the entire wetted surface of the attachment J-groove weld. Figure1 shows the procedure of EFR welding.

In this paper, carried out the welding analysis to use the SYSWELD as welding interpretation code based on the reactor upper head nozzle.

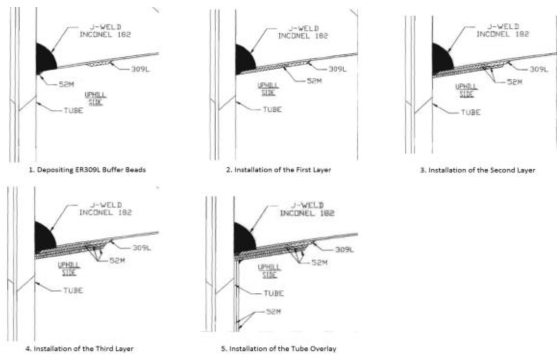

Figure 1 Welding Process of EFR

2. EFR FEA Methods and Procedures

The research of EFR weld zone residual stress was used the Visual Environment of SYSWELD which is the welding interpretation code. FEA analysis procedures for the EFR welding and welding process shows as in figure 2.

For FE modeling, apply the plant's reactor size in figure 3 for developing as a module of the Visual Mesh of SYSWELD.

In order to get welding heat source that is needed for Dissimilar Metal Weld (DMW), Similar Metal Weld, (SMW), Welding Overlay (WOL) using Gas Tungsten Arc Welding (GTAW) from "Bead On Plate" through Visual Weld of SYSWELD.

Finally, used to perform Visual Weld of SYSWELD to analysis about the J-Groove Welding, 4 Cycle normal plant operation, EFR Welding, 4 Cycle normal plant operation for FEA. And assigned 15.51Mpa, 318.8℃ as normal plant operation condition. For Post Processing treatment, used Visual Viewer of SYSWELD.

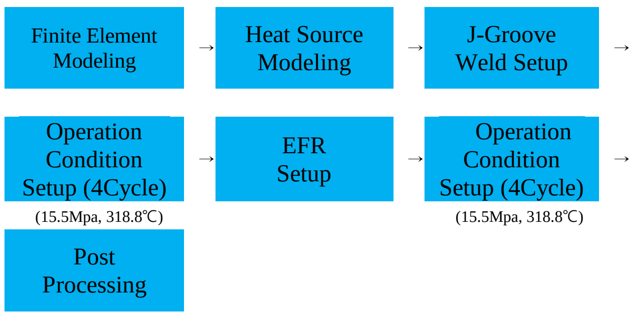

Figure 2 Process of EFR FEA

2.1 Finite Element Analysis (FEA) Modeling

In this paper, shape and size of EFR welding zone are the same as in Number 1 of figure 3. Also EFR WOL welding zone model for FE modeling are the same as in figure 4.

In FE modeling, it was modeled by the application of the triangle and rectangle as 0.5mm size. 2D element number had 17,588, 1D element number had 3,422 for heat transfer calculation and total node number had 17,933.

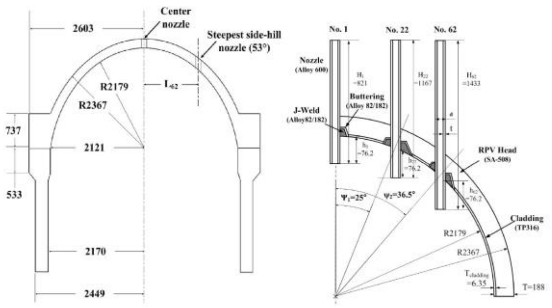

Figure 3 RPV upper head geometry details (mm)

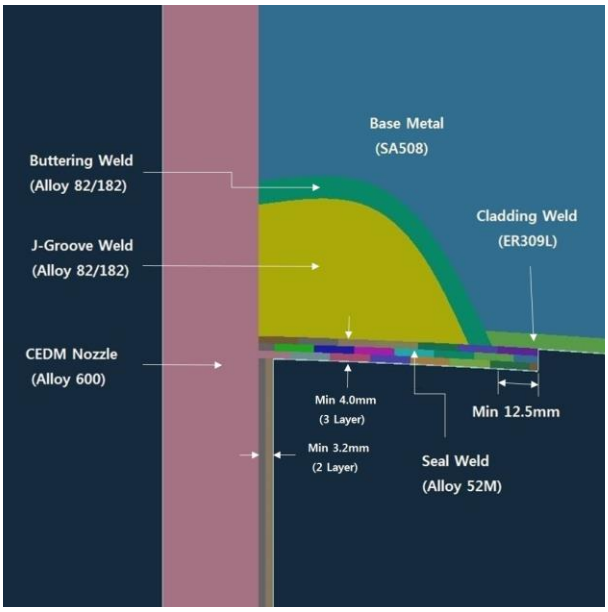

Figure 4 EFR WOL Welding Zone

2.2 Material Property

Table 1 shows to represent the applied materials for analysis.

Provided by SYSWELD Material Database to apply under the assumption of similar materials due to difficulty in securing the material properties with temperature.

Table 1 CEDM Nozzle Material and Analysis Material

Part	Material	Assumptions Material in Analysis
CEDM Nozzle	Alloy 82/182	Alloy 82/182
Cladding	ER309L	316L
Buttering	Alloy 82/182	Alloy 82/182
J-Groove	Alloy 82/182	Alloy 82/182
Base Metal	SA508	A508
EFR	Alloy 52/152	Alloy 52/152

2.3 Welding Variable

Two times weld analysis is performed in EFR FEA which J-Groove welding zone and EFR welding zone.

Welding Procedure Specification (WPS) and Procedure Qualification Record (PQR) which actually in use for nuclear plant was adopted for FEA analysis of J-Groove welding zone and EFR welding zone. Table 2 shows the welding variable from WPS and PQR.

It was supposed J-Groove welding zone for 50% weld efficiency, EFR welding zone for 70% weld efficiency in this paper. And extracted each heat source model and heat source cycle for adapting to the welding zone heat input.

Table 2 Welding Variable from WPS and PQR

Part	J-Groove	EFR
Weld Process Type	GTAW (Machined)	GTAW (Machined)
Heat input (J/mm)	2945	944.4
Efficiency (%)	50	80
Welding Velocity (mm/s)	1.27	1.905
Interpass Temperature	149	150
Filler Metal	ERNiCrFe-7A	ERNiCrFe-7A

3. Result Analysis

3.1 Residual Stress Distribution Analysis

3.1.1 Axial Stress Distribution

The measured area was expressed as point1~4.

Figure 6 shows the axial stress after J-Groove welding such as the point indicated in figure 5.

Major region of occurred PWSCC in reactor head are between point2 and point3. The axial stress after J-Groove welding and 4 Cycle operation shows the 104Mpa compressive stress at point1. 55Mpa compressive stress was occurred at point2 which beginning part of J-Groove welding. Compressive stress was changed to tensile stress, the tensile stress is gradually increased when going to the lower end of the tube. The maximum tensile stress of 444Mpa shown at point3. Tensile stress was decreased at point3 from the lower end of the tube, finally 27Mpa compressive stress was occurred at point4.

The axial stress after EFR and 4 Cycle operation shows the 93Mpa compressive stress at point1. 85Mpa compressive stress was occurred at point2 such as main part of caused PWSCC. Compressive stress was changed to tensile stress, the tensile stress is gradually increased when is going to the middle of J-Groove welding. Finally 428Mpa tensile stress was occurred at point3. 241Mpa tensile stress was occurred at point4 when is going to the lower end of the tube.

3.1.2 Hoop Stress Distribution

The Hoop stress distribution by J-Groove are the same as in figure 7. In J-Groove case, 472Mpa tensile stress was occurred at point1 and is increasing. There are maximum tensile stress at between point2 and point3. Since tensile stress started to reduce, 158Mpa was occurred at point4 which is the lower end of the tube.

In case of EFR, 401Mpa tensile stress was occurred at point1. This value is lower than after the J-Groove welding. And 367Mpa at point2, 849Mpa at point3 was occurred that is higher values than after J-Groove welding. Finally, 420Mpa tensile stress was occurred at point4.

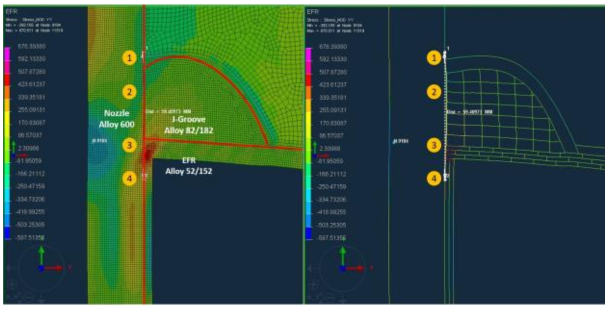

Figure 5 FEA Model

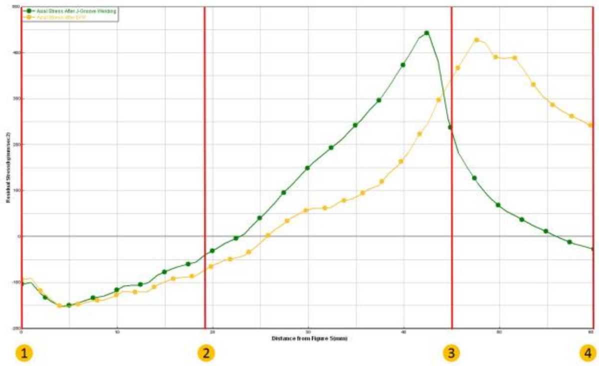

Figure 6 Axial Stress

5. Conclusions

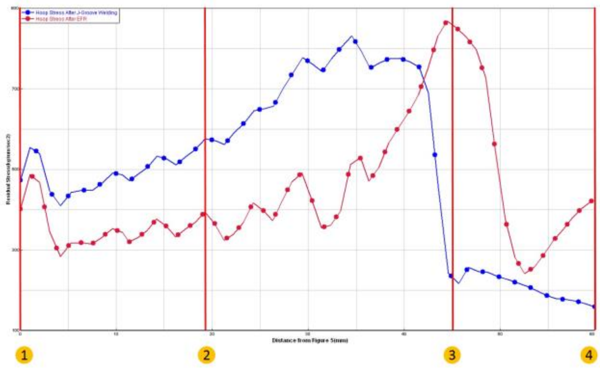

Figure 7 Hoop Stress

In this paper, evaluated the residual stress in CEDM nozzle by EFR through the SYSWELD which is the welding interpretation code.

The conclusion are same as below.

1) When comparing with Hoop Stress and Axial Stress by J-Groove and EFR, after welding residual stress by EFR is lower than after J-Groove.

2) After EFR, it was confirmed that the tensile stress is reduced after increasing over the point3. This is considered because it is subjected to continuous heat in point3 while EFR welding. To relieve the tensile stress remaining in the part, the mechanical surface hardening procedures are required such as peening.

3) Residual stress by EFR showed a relatively lower value compared to the existing welding. For validation of the results, future experimental method will be additionally performed.

6. Acknowledgement

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