Development of Preemptive Repair Technology for Alloy 600 J-Groove Welds of Reactor Vessel Upper Head CEDM Nozzles

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1. Introduction

Reactor vessel upper head(RVUH) and CEDM(Control Element Drive Mechanism) nozzles are retaining pressure by J-Groove partial penetration welds with Alloy 600(Alloy 82/182) material [1]. In 1991, however, boric acid leakage in reactor vessel upper head nozzles of France Bugey NPP(Nuclear Power Plant) Unit3 was found initially, and the reason was confirmed due to PWSCC(Primary Water Stress Corrosion Cracking) generated in Alloy 600 partial penetration welds and nozzles. After 2000, PWSCC in numerous NPPs around the world has been generated [2,3], and recently, PWSCC in several CEDM nozzles of domestic NPP Hanbit Unit 3&4 was founded and repaired with embedded flaw repair(EFR) welding method by Westinghouse [4]. In this study, development status of EFR equipment and basic experimental results for preventive PWSCC of RVUH CEDM nozzles will be introduced.

2. Equipment and experimental methods

Figure 1 represents a design of RVUH and shape characteristics of J-Groove welds between reactor vessel upper head and CEDM nozzles. Figure 2 indicates a conceptual design for EFR seal welding of original Alloy 600 J-Groove welds and OD penetration. This technique is to conduct seal welding to Alloy 690(Alloy 52M) filler wire with high PWSCC resistance instead of original Alloy 600 partial penetration welds and nozzles, as shown in Figure 2. In this study, 6-axis EFR seal welding equipment, which can perform overlay welding to track automatically J-Groove welds with a different three dimensional curved surface regardless of locations of CEDM nozzles, and OD penetration welding head were developed, respectively. Figure 3 shows a design concept of welding equipment and the manufactured prototype for EFR welding with original J-Groove welds of CEDM nozzles. Next, BOP(bead on plate) welding experiments to obtain the available process conditions prior to CEDM Mock-up test were conducted, as shown in Table I.

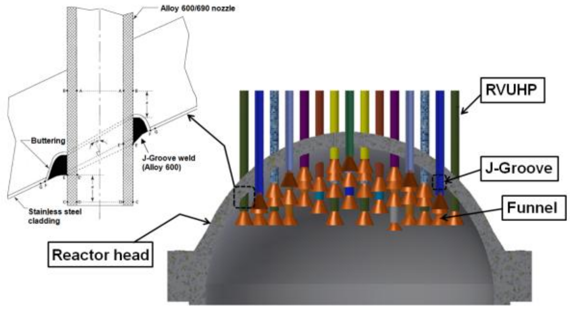

Fig. 1. Configuration of RVUH(CE type)

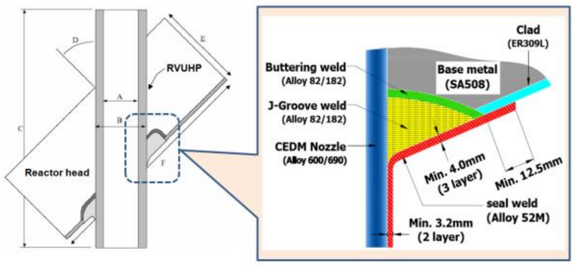

Fig. 2. EFR welding concept for CEDM nozzle

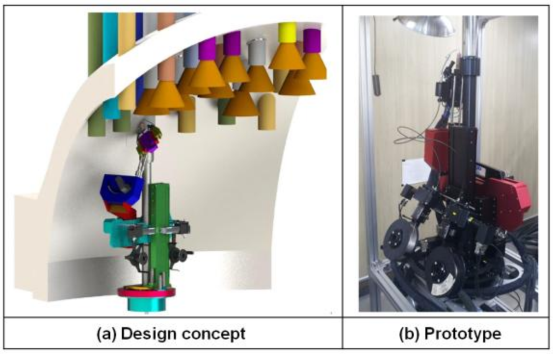

Fig. 3. Prototype for EFR welding

The welding machine was Max. 500A GTAW. Base metals and filler wire materials were SA240 T304L, Alloy 600 and ER309L, ERNiCrFe-7A, respectively. Based on EFR welding design of Figure 2, BOP welding experiments for Clad and J-Weld parts were conducted with range of heat input within 18.8～42.8 KJ/in, and only OD penetration part, the experiments at the vertical welding position(Downhill) were performed with range of low heat input within 20.9～30.2 KJ/in.

Table I: Welding conditions for BOP experiments

Weld parts	Base metals	Filler wires	Heat input (KJ/in)
Clad	SA240 T304L Alloy 600	ER309L ERNiCrFe-7A	18.8～42.8 Horizontal
J-Weld	Alloy 600		
OD	Alloy 600	ERNiCrFe-7A	20.9～32.2 Vertical

Also, three passes overlay welding experiments with 50% overlap were carried out.

In order to estimate weldability of BOP and overlay welding experiments, the appearances on the weld surface and cross-sectional weld beads were evaluated to confirm the existence of defects, weld bead width, penetration depth, deposited height and dilution.

3. Experimental results

BOP welding experiments for three welding parts were conducted to change current(A), voltage(V), welding speed(IPM), wire feeding speed(IPM), etc. Figure 4 shows top appearances of welds and cross-sectional beads obtained at current of 200A～230A, voltage of 10V, welding speed of 3.5IPM, wire feeding speed of 45IPM. All weld beads with no defects, such as spatters, undercut and cracks at the welding conditions were obtained. Figure 5 indicates welding results measured during welding with two different filler wires on the SA240 T304L base metal. Weld bead width with the increase in heat input of 18.8～42.8 KJ/in increased linearly to about 6～14 mm. Weld bead width of the filler wire with ERNiCrFe-7A had a little longer compared with that of ER309L. The dilution increased with the increase in heat input. And in case of allogeneic material, the dilution measured at the same heat input seemed a higher range than dissimilar material. Figure 6 represents top appearances of welds and cross-sectional beads obtained during overlay welding of Alloy 600 and ERNiCrFe-7A. It was confirmed that a good overlay welding with no defects, such as lack of fusion and cracks at the specific welding conditions could be accomplished.

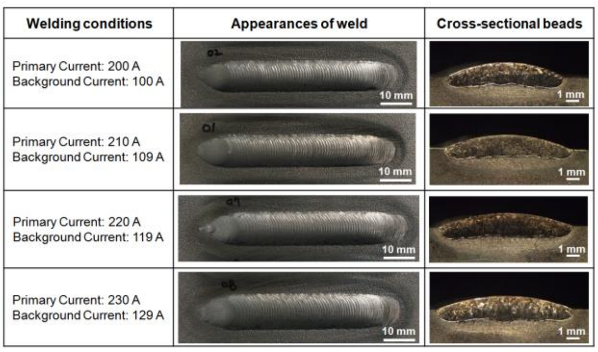

Fig. 4. Top appearances and cross-sectional beads obtained after welding of SA240 T304L and ERNiCrFe-7A

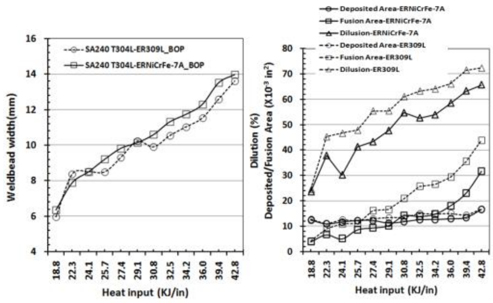

Fig. 5. Comparison on welding results obtained at welding of base metal (SA240 T304L) and different filler wires

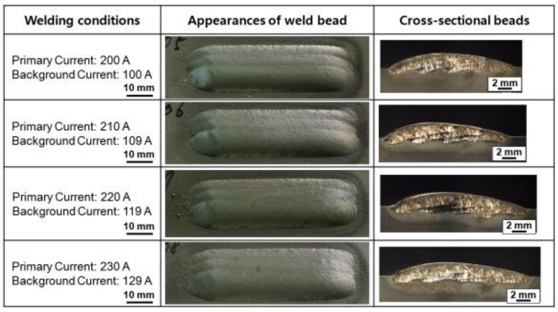

Fig. 6. Top appearances and cross-sectional beads obtained after overlay welding of Alloy 600 and ERNiCrFe-7A

4. Conclusions

The development of EFR seal welding equipment and welding process for the preemptive repair with original Alloy 600 J-Groove welds of RVUHP was conducted. The EFR welding equipment was tested to be possible seal welding to track J-Groove welds with three dimensional curved surfaces and OD penetration with vertical welding position. Through several BOP and overlay welding experiments, it was verified that good weld beads with no defects, such as cracks, spatter, undercut at the stable welding conditions with heat input of 27.4～32.5 KJ/in were well produced. Consequently, it is expected that the EFR seal welding technique will be applicable on the site.

REFERENCES

[1] Davis-Besse reactor pressure vessel head degradation: Overview, NUREG/BR-0353, Rev.1, US Nuclear Regulatory Commission, 2008

[2] K. Ahluwalia and C. King, Review of stress corrosion cracking of Alloys 182 and 82 in PWR primary water service, MRP-220, Electric Power Research Institute, 2007

[3] C. King, Alloy 600 nozzle Repair and mitigation historical applications, MRP-76, Electric Power Research Institute, 2002.

[4] Technical basis for the embedded flaw process for repair of reactor vessel head penetrations, WCAP-15987-P Rev.2-P-A, Westinghouse, 2013.