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Seal welding repair technology for J-Groove welds of the reactor vessel upper head

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ABSTRACT

Primary water stress corrosion cracking(PWSCC) of Alloy 600 material in reactor vessel upper heads has lead to leakage since early 2000 around the world. Recently outside surface flaws of penetration nozzles were detected in Korea during 2012 outage. To prevent from those flaws, seal welding repair(SWR) technology has been developed. The concept of SWR is that Alloy 82/182 material is isolated from primary water by weld onlay with Alloy 52M which has a higher resistance of PWSCC. Three machines that are an electrical discharge machine, a seal welding machine and a funnel welding machine have been developed to apply sealing welding to J- Groove welds of reactor vessel upper heads. Those processes have been also developed. Engineering evaluations are performed with postulated flaws based on the results of the stress generated by both welding and transients.

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 was founded and repaired with embedded flaw repair(EFR) welding method by Westinghouse [4]. The repair technique for Alloy 600 partial penetration welds and its nozzles with the increase in PWSCC generation is certainly necessary. Therefore, in this study, the developed seal welding equipment, results of experiments and engineering evaluations for the preemptive repair (EFR) with Alloy 600 J-Groove welds of reactor vessel upper head penetration nozzles introduce in brief.

Development of seal welding technology for CEDM nozzles

Seal welding method

Seal welding technology is a preventive maintenance technique that suppresses PWSSCC initiation and growth by isolating Alloy 82/182 welds from primary water that are vulnerable to PWSCC using Alloy 52M filler which is high resistance material of PWSCC. Figure 1 shows a reactor vessel upper head. The reactor vessel head and CEDM Nozzles are welded. CEDM nozzles and guided funnel are connected by threads and a plug weld. Materials of CEDM nozzle are Alloy 690 but materials of J-groove welds are Alloy 600. Therefore, J-groove welds are likely to cause PWSCC. Figure 2 shows design of seal welding.

To prevent PWSCC at J- groove welds, seal welding is carried out with minimum thickness of 4 mm and minimum 3 layers. This technology has been applied and proven since 1992 in United States.

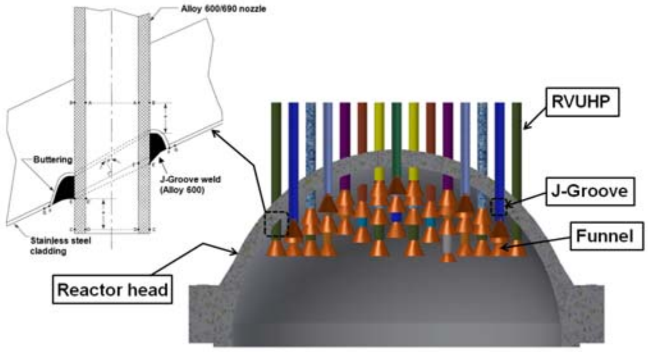


Figure 1. reactor vessel upper head(CE type) and shape characteristics of original Alloy 600 J-Groove welds

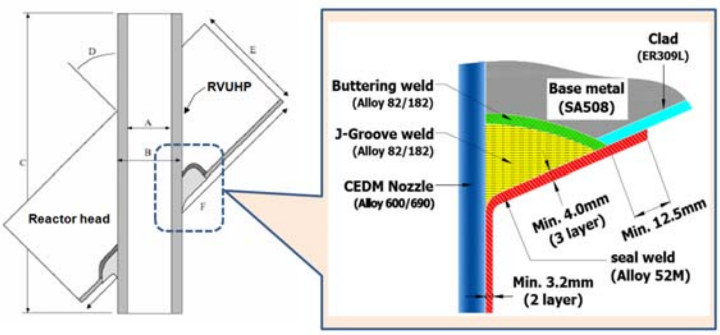


Figure 2. EFR welding design for Alloy 600 J-Groove welds

Development of an electrical discharge machine

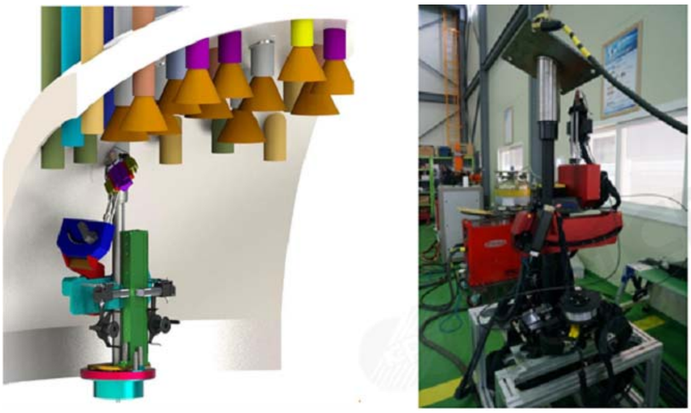
In order to install the welding machine and secure work space, Guided funnel must be removed first EDM machine has been developed to quick installation and alignment shown in figure 3 (a) because there is high radiation area under the reactor upper head. It takes about an hour to completely cut the guided funnel shown in figure 3 (b). weight of EDM machine is about 10 kg, it is enough for one engineer to handle

(a) EDM machine (b) specimen

Figure 3. EDM machine and specimen

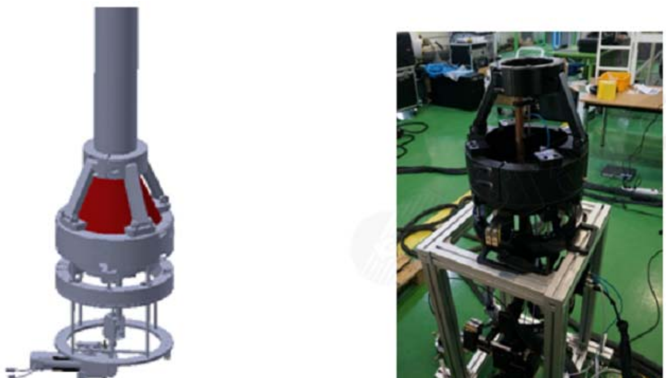
Development of welding machines

Seal welding machine employs GTAW machine welding and two filler wire nozzles. Seal welding machine is installed very quickly and alignment is unnecessary because this is fixed inside of CEDM nozzles. The space of J-groove welds is very narrow and in the hemispherical shape, welding arc is unstable. In order to prevent this problem and to control the welding accurately, seal welding machine consists of 6 axes and welding torch maintains the optimum angle depend on the position shown in figure 4. After performing seal welding at J-groove, guided funnel must be installed on CEDM nozzles again. Welding machine is fixed at outer diameter of CEDM nozzles, minimizing the time for installing and aligning the welding machine shown in figure 5.



(a) Concept image (b) seal welding machine

Figure 4. seal welding machine



(a) Concept image (b) funnel welding machine

Figure 4. funnel welding machine

Development of welding process

BOP(bead on plate) welding experiments to obtain the available process conditions prior to CEDM Mock-up test were conducted, as shown in Table 1. 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. . 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

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

BOP welding experiments for three welding parts were conducted to change current(A), voltage(V), welding speed(IPM), wire feeding speed(IPM), etc. Figure 5 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 6 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 7 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.

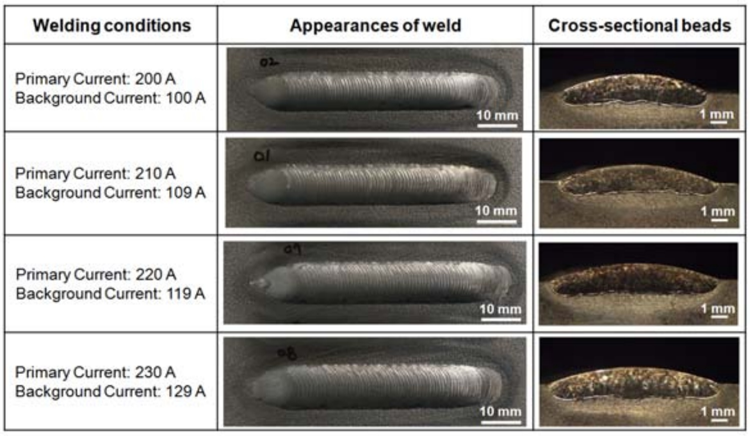


Figure. 5. Top appearances and cross-sectional beads obtained during welding of SA240 T304L and ERNiCrFe-7A

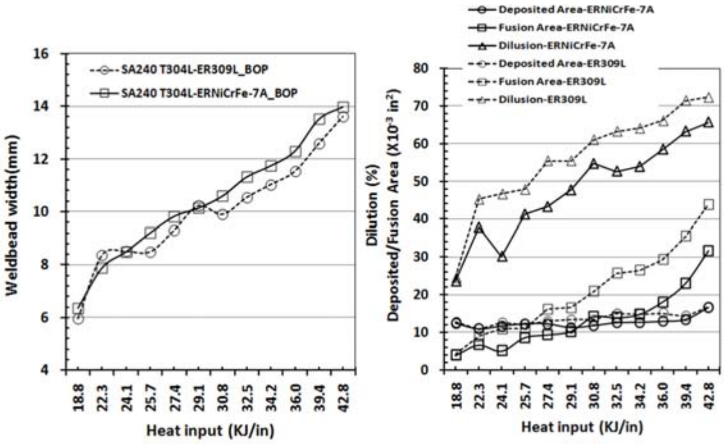


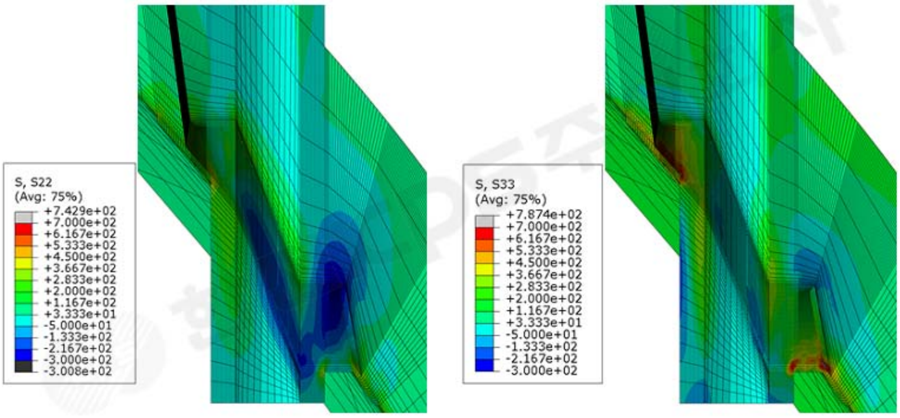
Figure.6. Comparison on welding results obtained at welding of base metal (SA240 T304L) and different filler wires

Welding conditions	Appearances of weld bead	Cross-sectional beads
Primary Current: 200 A Background Current: 100 A 10 mm		 2 mm
Primary Current: 210 A Background Current: 109 A 10 mm		 2 mm
Primary Current: 220 A Background Current: 119 A 10 mm		 2 mm
Primary Current: 230 A Background Current: 129 A 10 mm		 2 mm

Figure.7. Top appearances and cross-sectional beads obtained during overlay welding of Alloy 600 and ERNiCrFe-7A

Flaw evaluation

Welding residual stress analysis is performed according to welding and operation condition. Figure 8 shows stress distribution. Flaw evaluation is also performed at reactor vessel head and seal welding. At present, non-destructive inspection technology is not able to fully inspect the J-groove welds. So all J groove welds area is assumed to be flaws. Figure 9 shows the results of LEFM evaluation at the reactor vessel upper head. Figure 10 shows the results of fatigue growth evaluation at the reactor vessel upper head. The integrity of reactor vessel upper head and seal welds is evaluated to be maintained



(a) Hoop stress (b) axial stress

Figure 8. stress distribution after seal welding

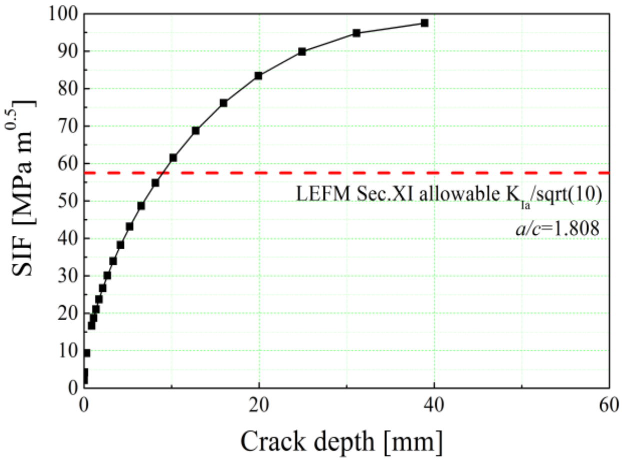


Figure 9. the results of LEFM evaluation at J-groove welds

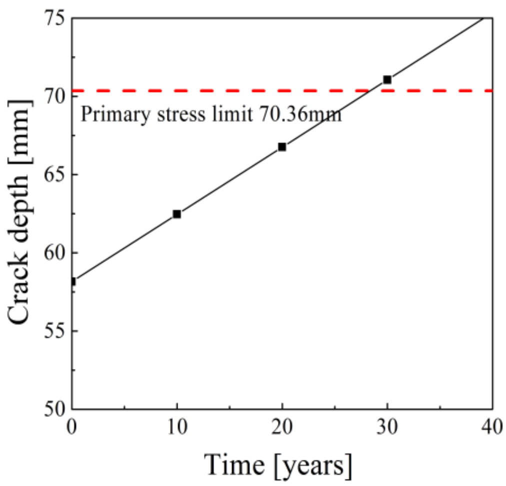


Figure 10. the results of fatigue growth evaluation at J-groove welds

Conclusion

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 developed EFR welding equipment was certified 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 revealed 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. . The integrity of reactor vessel upper head and seal welds is evaluated to be maintained. Consequently, it was noted that EFR seal welding technique developed for the repair with original Alloy 600 J-Groove welds of RVUHP was available in field application

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