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Evaluation of the Weld-line defects of a nuclear fuel rod end plug weld by RPW process

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1. Introduction

The nuclear fuel rod functions as pressure vessel that prevents the leakage of radioactive fission products. Therefore it is necessary to secure the welding soundness of nuclear fuel rod welding zone. The welding methods applied to the nuclear fuel assembly at KEPCO NF are GTAW, RPW, LBW, EBW and spot welding. RPW process applied to the PWR nuclear fuel rod, is highly productive and enables welding quality to keep constant [1-2]. As for the resistance welding, the weld reinforcement is as the result of plastic deformation by the welding heat generated by specific resistance and contact resistance of tubes and end plugs. There is a high possibility of leakage of the fission products in the weld zone between tubes and end plugs, because internal pressure increases owing to the generated fission products. Stress Corrosion Cracking (SCC) could be caused by the weld-line defects on the weld interface and the change of micro-structure in the long-time nuclear reactor environment. Until recently, the weld-line defects are known as a non-bonding in the domestic. Generally, resistance welding is known as solid state process, but considering a contact line, resistance pressure welding process is partially a fusion welding.

For this study, we observed a temperature of weld area by using the infrared thermal technology, and evaluated a weld-line defects of the nuclear fuel rod end plug weld area by OM, SEM, EDS.

2. Experimental Methods

2.1 Material and welding

Materials used in this study are ZIRLO tube and Zircaloy-4 End plugs, and chemical composition is shown in Table.1. We used materials being currently used for manufacturing nuclear fuel rods in the site as the experimental materials. In the case of welding machine, we used the weld machine installed in the site.

Table 1: Chemical composition of ZIRLO and Zrrcaloy-4

	Sn	Fe	Cr	Ni	Fe +Cr	Nb	O
Zircaloy-4	1.20 -1.45	0.18 -0.24	0.07 -0.13	<0.0 07	0.28 -0.37	…	0.10 -0.15
ZIRLO	0.9 -1.3	0.8 -1.4	…	…	…	0.8 -1.4	0.1 -0.16

2.2 Weld Zone Temperature Measurement by Thermal IR Image

We measured the weld zone temperature during welding using a thermo-graphic camera to improve the accuracy of weld zone temperature measurement in the noncontact way. The thermal image measurement method is divided into two main methods, passive and active. In the case of welding nuclear fuel rod tube and end plugs, because resistance heat is released depending on heat input by welding current and welding force during welding, we measured the temperature using the passive method which is appropriate for this case. We used a FLIR Silver 480M for measuring the temperature of weld area.

2.3 OM, SEM, EDS

After welding, we performed the cross section test in accordance with the quality standard of nuclear fuel rod. We checked the weld zone cross section after polishing the cross section in the longitudinal direction of the fuel rod. When a non-bonding welding defect occurred on the welding line, we determined whether or not it is non-bonding after magnifying it with high magnification by SEM analysis and checked qualitative chemical composition by EDS.

3. Results and Discussions

3.1 Weld areas temperature

RPW is regarded as solid phase welding, different from GATW and LBW. Therefore it is not easy to account for non-bonding that occurs in weld line. We attempted to measure the welding temperature by the thermal IR camera of non-contact way to identify whether or not welding temperature rises in up to melting temperature 1,800℃ in ZIRLO and Zircaloy-4. To calculate the exact temperature values, we measured the temperature of the reference standard specimen using induction heating and then the emissivity was determined. We used a STS 304 tube to determine the emissivity. The correct temperature was measured by using a glass plate during RPW process. The measured emissivity was 0.84. The temperature rose over melting point of 1,800℃ regardless of the value of the weld current as shown in Fig. 1. As for this result, we confirmed that RPW process is a kind of fusion weld between tube and end plug instantaneously.

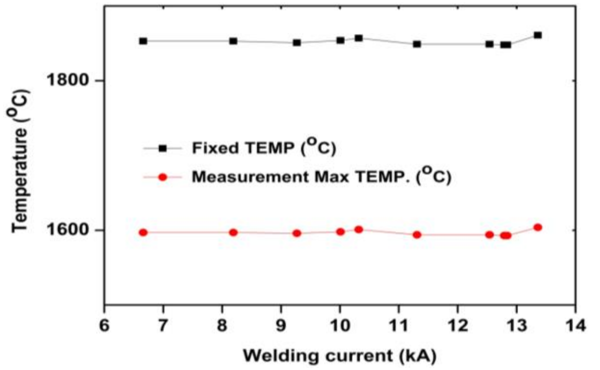

Figure 1. Temperature image of the welding zone during RPW

3.2 SEM and EDS analysis in the weld zone

After the burst test of welding specimens, there were black dots on the cross-section of specimen shown in Fig.2. They have been evaluated as defects in the weld zone because of regarding it as non-bonding. But in general, these black dots were known as porosity or precipitate made by oxide or carbide. The black area of fusion line was magnified by SEM to identify it. The EDS analysis of the black area was performed to identify the compound of this area.

Figure 2. Weld line defect of the fusion line in the fuel rod weld zone

The black area was magnified 10,000 times by SEM as shown Fig.3. The black area was confirmed not non-bonding but precipitate covered on weld zone. Several cracks were founded in the middle of precipitate. Welding specimen cracks did not show the burst test failure in the weld zone. Cracks in the weld zone did not have an effect on the burst test, but it could exert influence on a bad effect such as stress corrosion in nuclear reactor. The welding quality standard clearly has to be set not to contain precipitates depending on the welding heat input. Furthermore, the EDS analysis was performed to identify the cause of the fusion line defect as shown in Fig.3 (b). Table 2 shows the results of the EDS analysis in the fusion line defect. As a result of taking a picture of defects depending on the difference of illumination intensity according to ingredients out of the SEM imaging methods, dark area appeared to be black owing to carbon. When we checked the position No. 8 and 10 in Fig.4 analysed with EDS, it was found that carbon content was higher than Zr content, and carbon content in the position No. 11 was also high. Therefore, the reason why the crack occurred in the weld zone was considered the precipitation of zirconium carbide made by carbon.

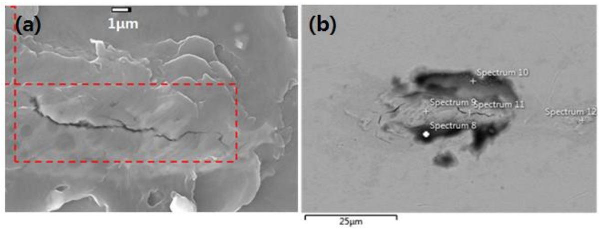

Figure 3. Crack of the weldline defect in fuel rod weld zone (a) x10,000 SEM image (b) Positions of EDS analysis

Table 2: Results of the EDS analysis in the fusion line defect

Position	8	9	10	11	12
Element	wt%				
C	71.04	14.02	58.25	26.64	20.35
O	3.17	3.25	-	3.91	4.4
Na	-	-	0.26	0.15	-
K	-	-	0.35	-	-
Ca	-	-	-	0.44	-
Cr	-	1.03	-	0.52	0.11
Fe	-	10.46	-	3.61	0.18
Zr	25.56	70.73	40.65	63.23	0.85
Sn	-	0.51	0.49	-	0.16
Nb	0.23	-	-	1.5	-
Total:	100	100	100	100	100

4. Conclusion

We measured the welding temperature of RPW treated as the solid phase by using the thermal infrared image method. The temperature of the weld zone was higher than melting temperature 1,800℃. Welding was basically performed by melting. We confirmed that this temperature was close to the melting temperature of the basic materials of fuel rods. After performing SEM and EDS analysis on discontinuous black spots in the weld line regarded as non-bonding defect, we concluded that the black spots caused by the carbide precipitation of Zr during welding.

5. Acknowledgments

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