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Investigation of Welding Condition for the HANARO Fuel Rod Weld Zone

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ABSTRACT

The Korea Atomic Energy Research Institute (KAERI) is producing U_3Si nuclear fuels used for the drive fuel for the HANARO research reactor at KAERI. The end plugs are inserted at both ends of a HANARO fuel rod, and the cladding must be sealed perfectly by welding to prevent leakage of radioactive material. The materials of the fuel cladding and end plug are pure aluminum as AA 1060 and the cladding is 0.76mm in thickness. For this kind of welding, vacuum atmosphere and high energy concentration are needed. The electron beam welding (EB welding) satisfies this condition and it is important to find the optimum welding condition. With improper welding lack of fusion or defect such as blow holes may occur. In this study, we investigated the depth of penetration according to the beam current and observed the defects using real time X-ray radiography, and found the optimum condition for the end plug welding.

1. Introduction

For the fabrication of HANARO nuclear fuel, joining the end plug and cladding is important to prevent leakage of radioactive materials. The material of the end plug and cladding is pure aluminum, and the thickness of the cladding is 0.76 mm. The thermal conductivity of aluminum is high and the welding section is small. Under this condition, a precise and high energy concentrated welding technic is required. The EB welding emits a high amount of focused electron energy to the weld material. This provides a deep penetration and little thermal distortion [1, 2]. In addition, the EB welding condition is easy to control by changing the beam current, acceleration voltage, and speed. In this study, to obtain an optimum weld condition for the end plug welding, we change the beam current among the many parameters and inspect the welded zone. Through non-destructive test, we inspect the fuel rod using real-time X-ray radiography to detect blow holes in the welded zone. After that, we examine the cross section of the welded zone to measure the penetration depth and bead width as a destructive test.

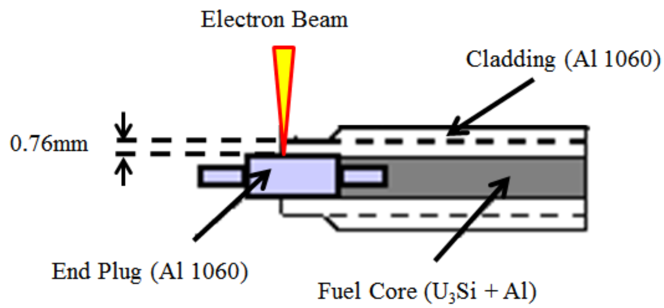

Fig.1 Schematic diagram of the HANARO fuel rod welding

2. Experimental method

Fig.2 shows the schematic diagram of EB welding. Electrons from a cathode are attracted by a positive anode. The speed of the electrons depends on the voltage difference between the cathode and anode. This is called the acceleration voltage. Wehnelt is the third electrode and acts like a gate of the electron beam gun. A highly concentrated electron beam passes through the focus coil and deflection coil and impacts the part to be welded. This can results in a better output in a high vacuum environment because electron beam loses its energy when colliding with molecules in the air. [3, 4].

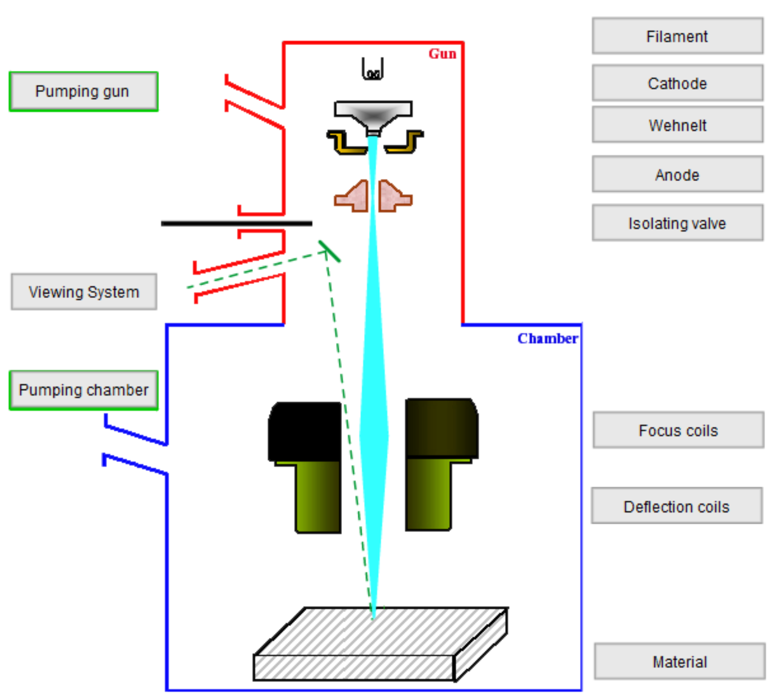

Fig.2 Schematic diagram of EB welding

The welding machine for this experiment was manufactured by TECHMETA. The acceleration voltage is set to 30 kV, and the beam current was increased from 18 mA to 23 mA by 1 mA steps. The welding speed and vacuum level were also fixed at 2,470 mm/min and 3.0×10^{-3} torr., respectively.

Fig.3 Electron beam welding machine for HANARO fuel

The welded zone of the fuel is inspected by real-time X-ray radiography. The inspection conditions of the machine are 55 kV, 0.074 mA. The RTR can be used to measure the bead width and detects such as blow holes of the whole welded zone while the fuel rod is rotating.

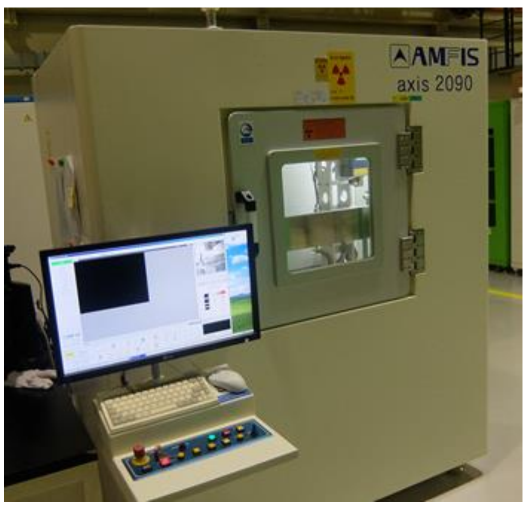

Fig.4 Real time X-ray radiography

The cross-section of each specimen is polished and etched using NaOH, and observed using a 20 x magnification with an optical projector.

3. Results

After the specimens were welded using an 18 mA to 23 mA beam current, the welded zones were observed using an optical projector. The bead width, penetration depth and the number of blow holes of each specimen were measured. The results are shown in Table 1. Fig. 5 shows each measurement position on the welded zone.

No.	Bead width (mm)	Penetration depth (mm)	Blow hole (count)	Beam current (mA)
1	0.710	0.258	5	18
2	0.628	0.278		
3	0.706	0.382	1	
4	0.252	0.453		
5	0.686	0.344	0	19
6	0.617	0.291		
7	0.618	0.440	2	
8	0.636	0.475		
9	0.641	0.560	3	20
10	0.653	0.413		
11	0.612	0.523	3	
12	0.695	0.473		
13	0.614	0.869	3	21
14	0.594	0.662		
15	0.555	0.645	2	
16	0.638	0.751		
17	0.629	0.748	5	22
18	0.632	0.784		
19	0.614	1.075	5	
20	0.707	0.770		
21	0.531	0.683	5	23
22	0.697	1.239		
23	0.690	1.136	5	
24	0.600	1.237		

Table 1. Number of blow holes in the welded zone, bead width and penetration depth

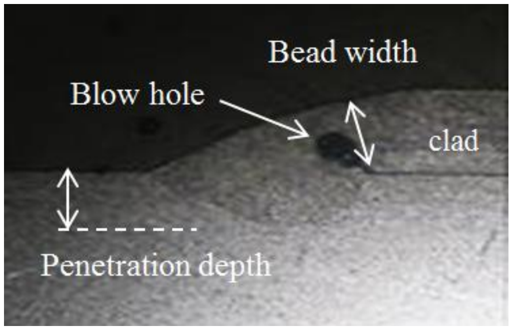

Fig.5 Definition for measurement position

The standard of the bead width according to the specifications of HANARO fuel is at least 0.33 mm and the acceptable number of blow holes is fewer than 5 counts around the welded zone [5]. Even when the beam current is increased, the bead width is measured to be between 0.5 and 0.8 mm. Only the No. 4 specimen has a blow hole in the cross section, and it may not require the welding criteria (Fig.6). In the case of the blow holes, we can find 5 in the 18, 22, 23 mA specimens and therefore, these beam currents is not suitable for end plug welding. The penetration depth deepens with an increase in the beam current (Fig. 7). According to this experiment, welding with a beam current from 19 mA to 21 mA satisfies the welding criteria.

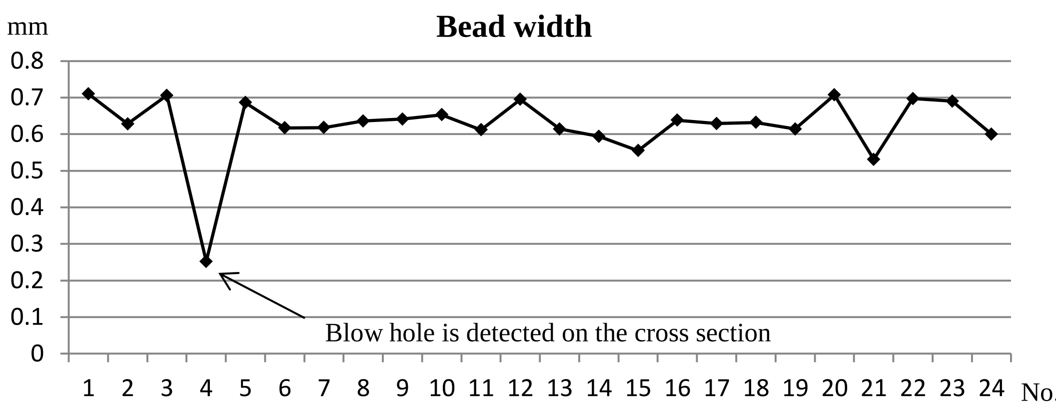

Fig.6 Bead width according to beam current

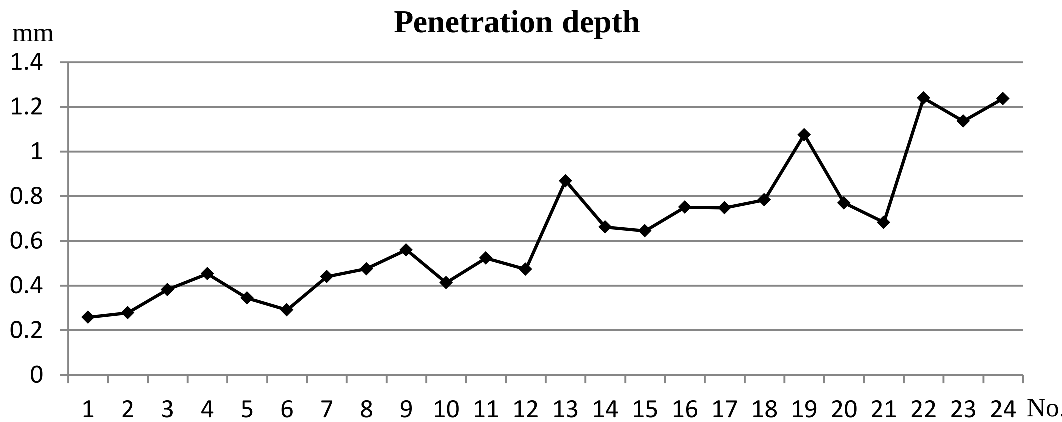

Fig.7 Penetration depth according to beam current

Photos of the cross section for each beam current are shown in Fig. 8. Fig. 9 shows X-ray radiography for specimen No. 4. A large blow hole is detected in the welded zone.

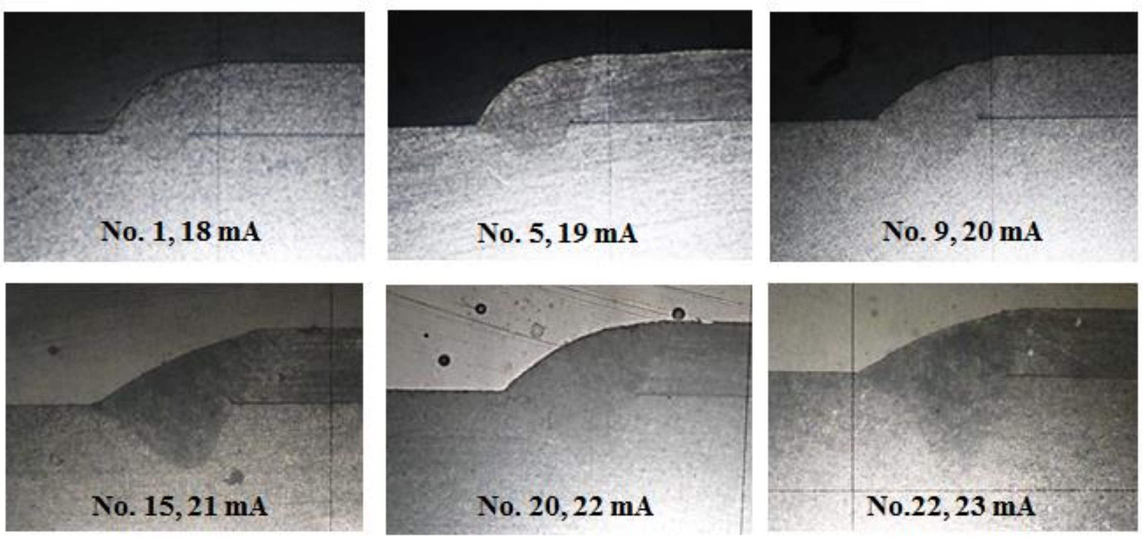

Fig.8 Cross sections of specimens with each beam current

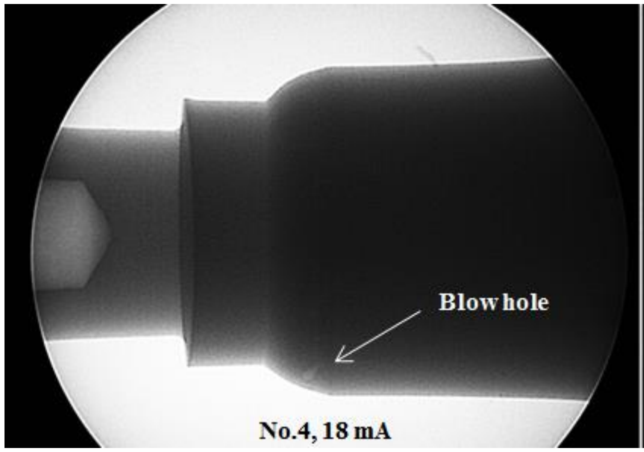

Fig. 9 X-ray radiography image of specimen No.4

4. Conclusion

In this study, we investigated the width of a welded bead, the penetration depth, and the number of blow holes according to an increasing beam current and compared the result with HANARO fuel welding specification. As a result, the optimum beam current for the HANARO fuel end plug welding is between19 mA to 21 mA.

5. Reference

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