Electron Beam Welding Process for the End Plug joining of HANARO Fuel Rod

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1. Introduction

It is important to maintain the airtightness between the clad and end plug in the welding process for end plug joining of HANARO fuel rod. Because the thermal conductivity of Al 1060 for clad material is high and the section for welding is small in thickness and diameter, it is necessary to introduce the precision weld technique with higher energy concentration and small HAZ. Electron Beam welding process uses electron beam emitted and strongly focused from the filament heated by the electricity. Therefore, it is possible that small bead width, deep penetration depth, and low heat caused-distortion.

In this study the electron beam welding process for end plug joining of HANARO fuel rod has been described and the method for reducing bubbles in gaps between the clad and end plug has also been studied.

2. Establishing and Application of Welding Process Condition

2.1 Characterization of Al 1060 Bead Welded by Electron Beam Process

Penetration depth of weld and the width of bead increase with the accelerating voltage increase. The rate of increase in penetration depth increases with higher beam current, and the rate of increase in width of bead decreases with higher accelerating voltage.

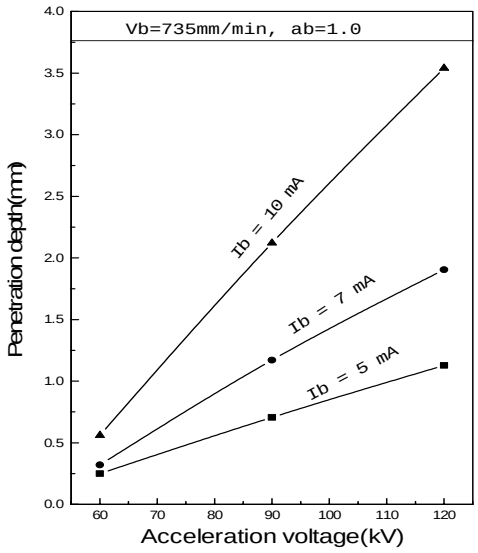

Figure 1. Relation between acceleration voltage and penetration depth

Besides, penetration depth and the width of bead decrease with welding speed increase .

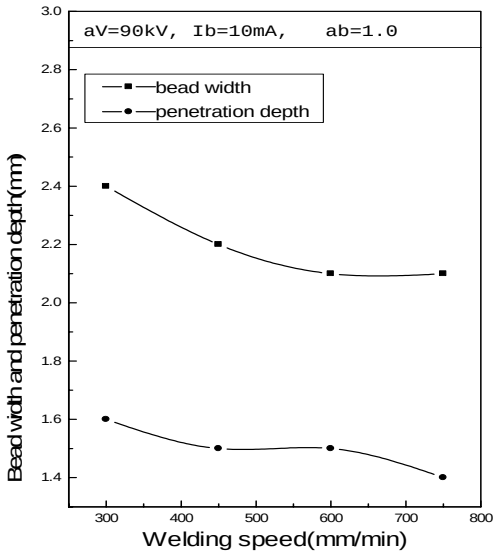

Figure 2. Relation between welding speed and bead cross-section

In the case of increasing penetration depth with higher accelerating voltage, spiking in the root of beads and small bubbles can occur because of the fluctuation in welding pool [1,2]. In order to obtain the suitable bead for design and dimension of end plug in HANARO fuel rod, it is necessary to optimize acceleration voltage, beam current and welding speed.

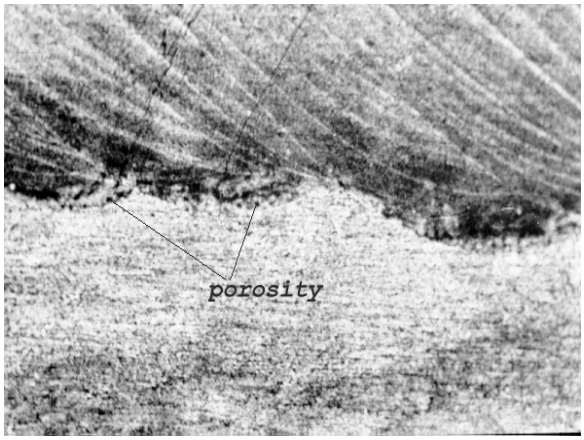

Figure 3. Porosity at root of Al1060 plate weld by electron beam welding (120kV,7mA)

2.2 Design of Welding Machine

Figure 3 shows the electron beam welding machine for end plug welding of HANARO fuel rod. The capacity of the electron gun was 60 kV and 100 mA. The chamber was a 600 mm cube and the extension tubes could be attached in the front side and back side of the chamber. The work table and rotary fixture controlled by CNC (Computer Numeric Control) were installed in the chamber in order to shift and rotate the work piece.

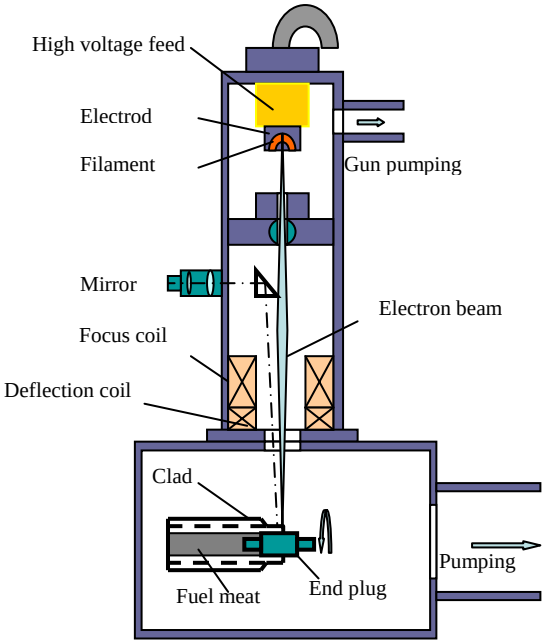

Figure 4. Schematic diagram of the welding machine for joining of the end plug

2.3 Optimizing of Welding Condition

After an extensive examination of various welding condition of the electron beam welding machine, the optimized welding condition were fixed; the acceleration voltage was 60 kV, beam current was 8.5-9.0 mA, welding speed was 730-800 mm/min and beam gun position was 0.2-0.3 mm apart from the welding shoulder. Figure 5 shows the cross-section of the bead welded suitably.

In order to verify the fracture strength, the burst test of 5 samples prepared by the optimized condition was carried out using Ar gas. All samples fractured not in the welded part but in the clad. The average fracture strength was 77 MPa. The result showed the welded part prepared by optimized condition was suitable for the application.

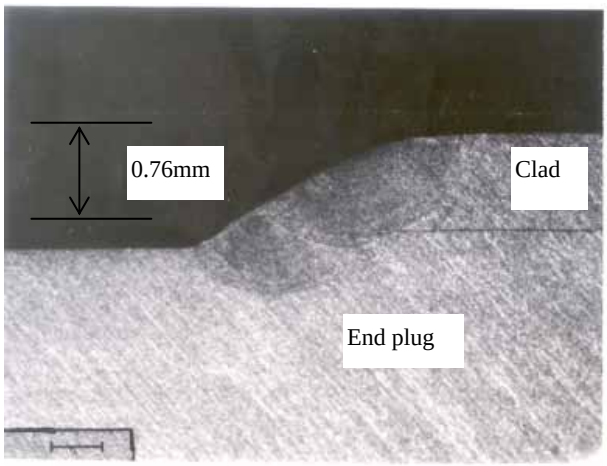

Figure 5. The cross section of the sound bead on end plug and clad welded at optimized condition (60kV, 8.5mA, 740mm/min)

2.4 Problem of Welding Defect Occurrence

The welded parts of end plug in HANARO fuel are likely to have weld defects by weld bubbles and heat caused-distortion, because of lap joint structure of fuel rod, high thermal conductivity of the material, a long borderline between the clad and fuel meat. For reducing the bubbles at the welded part, it was necessary to maintain cleanliness in the fabrication process of fuel meat. The using of alcohol instead of using mineral lubricant offered the clear surface in fabricating process of end plug and peeling process, and reduced the welding bubbles by out gassing. It was also observed that the heat sink enhanced the weldability of clad and end plug by minimizing heat caused-distortion.

3. Conclusion

The welding process condition was optimized in the electron beam welding machine for the welding of end plug joining of HARARO fuel rod. For the suitable penetration depth of weld and the width of bead, the acceleration voltage was 60 kV, beam current was 8.5-9.0 mA, and welding speed was 730-800 mm/min respectively. In order to reduce the weld defects without changing design of the part, it was required that the cleanliness of fabrication process and the use of the heat sink.

REFERENCES

[1] Yoshiaki ARATA, . Michio Tomie, Nobuyuki ABE, and Xiang –Yu Yao, Observation of Molten Metal Flow during EB Welding

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