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Integrity Assessment of Welds for Curved-type Nuclear Fuel Plate Assembly

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1. Introduction

The fabrication of high-density, low-enriched uranium research reactor fuel using atomized U_3Si_2 powders has been developed for the KaerI High Density Atomized Silicide Fuel Qualification Irradiation project - Generic Test Assembly (KIMQI-GTA). The Korea Atomic Energy Research Institute (KAERI) and the Studie Centrum voor Kernenergie - Centre d'Etude de l'energie Nucleaire have agreed to irradiate the KIMQI-GTA in the BR2 high-performance research reactor in Belgium since 2022. The KIMQI-GTA is composed of nine nuclear fuel plates that are inserted into the slots of side plates and swaged to be structurally combined. The swaging assembly is then welded to end caps on both sides to ensure mechanical integrity. The welds must be defect-free, without any pores, and the proper welding depth is essential to ensure weight stability in the welded area. In this paper, we calculate the minimum weld depth using the ANSIS program, considering the weight of the fuel assembly and assembly components electron beam (EB) welded. We also examine the cross-sectional microstructure of the bead formed after the Al weld process to confirm the soundness and integrity of the welded area.

2. Methods and Results

2.1 KIMQI-GTA assembly

Fig. 1 shows a KIMQI-GTA assembly near the welding zone area. The fuel elements are made of an assembly of plates containing U_3Si_2 fuel meat and shown in orange color. Weld zone, side plate, and end cap showed in gray, green, and blue, respectively.

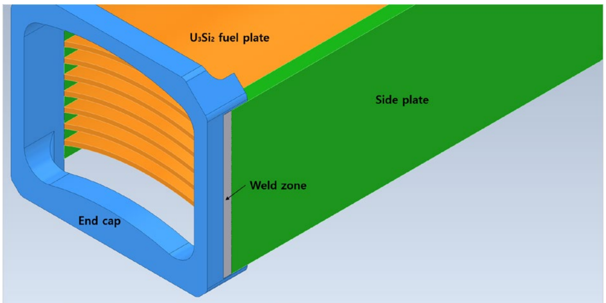

Fig. 1. Weld zone of KIMQI-GTA assembly

2.2 ANSYS simulation

In order to verify the mechanical integrity of the KIMQI-GTA after welding process, the minimum weld depth between two components, side plate and end cap, was calculated according to the following equations (1) and (2).

$$W \leq \sigma A = 2\sigma_a t_{min} \omega \quad \cdots (1)$$

$$t_{min} \geq \frac{W}{2w\sigma_a} \quad \cdots (2)$$

- W : weight of KIMQI − GTA fuel assembly
- ω : weld length
- t_{min} : minimum weld depth
- σ_a : allowable stress(refer to ASME Section Ⅱ Part D table 1 B)

The fuel assembly for the KIMQI-GTA project comprises nine nuclear fuel plates, two side plates, and two end caps, with a conservative weight estimation of 5 kg. Using the equation based on the weld length (ω) of 42.5 mm and the allowable stress value (σ_a) of Al6061-T6 material for weld condition of around 41.37 MPa, the minimum weld depth (t_{min}) was calculated to be approximately 0.014 mm. However, for conservative reasons, it was considered that the minimum weld depth should be 0.1 mm. Subsequently, ANSYS analysis was carried out to evaluate the stress values for different weld depths ranging from 0.2 mm to 2 mm with intervals of 0.2 mm, as illustrated in Fig. 2 and 3. The results demonstrated that the maximum stress acting in the weld zone, even for a weight of 18 kg or more and a weld depth of only 0.1 mm (100 ㎛), was lower than the maximum allowable stress value of the Al 6061-T6 weld. These calculations were performed under the most stringent conditions using the least squares method.

Fig. 2. Ansys simulation result for 0.2mm weld depth

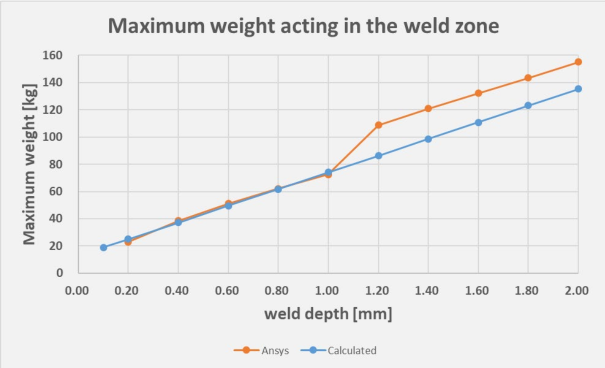

Fig. 3. Maximum weight on the weld area in function of the weld depth

2.3 EB Welding

The weld specimen, having the same dimensions and material as that of the KIMQI-GTA weld components, was prepared as shown in Fig. 4. The electron beam (EB) welding was carried out in accordance with the welding procedure specification (WPS) based on the ASME code section Ⅸ requirements. Before initiating the welding process, a pre-cleaning step was carried out to eliminate the oxide film on the aluminum surface, which may cause defects such as pores in the weld zone. The specimen was then EB welded at a beam current of 18 mA, beam voltage of 60 kV, welding speed of 1200 mm/min, and beam focus current of 1090 mA. Fig. 5 (a) shows the specimen immediately after welding, and the surface of the specimen was machined to approximately 1 mm for liquid penetration testing, as shown in Fig. 5(b). The inspection was conducted using the same procedure as that for the fuel assembly weld inspection. During the examination, no cracks, pits, or holes deeper than 0.5 mm were detected.

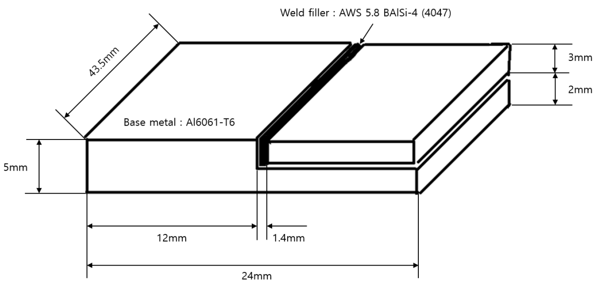

Fig. 4. Specimen size for EB welding test

2.4 Bead cross section

To examine the internal weld defects and weld filler penetration depth, the welded specimen was sectioned and the cross-section of the bead was observed using a microscope. The weld depth was measured from the first defect, and as shown in Fig. 6, it was found that the weld depth was approximately 1mm, which is 10 times greater than the required minimum weld depth of 0.1 mm.

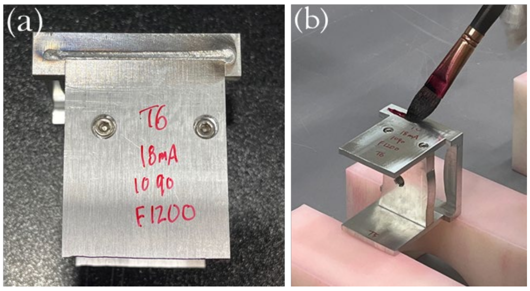

Fig. 5. (a) Welded test specimen and (b) Liquid penetration test for welded test specimen

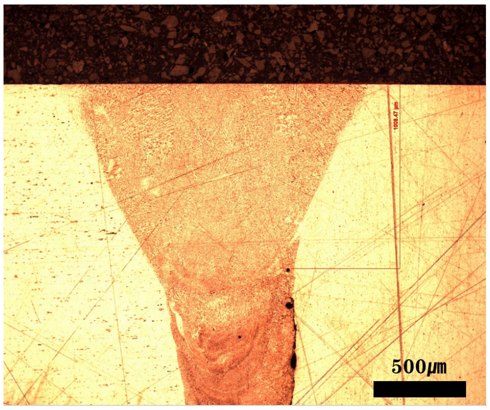

Fig. 6. Cross sectional microscopic image obtained in bead area

Although some pores were present on the bead, it was confirmed that the weld filler and base materials were properly bonded, as the filler penetrated both sides of the base materials, and the heat-affected zone was well-formed in the base metal.

3. Conclusions

To fabricate a curved plate-type nuclear fuel assembly, KAERI developed a WPS in accordance with ASME code section Ⅸ requirements and welded a test coupon composed of the same material and dimensions. Based on the welding parameters established from the test coupon and WPS documents, an EB welding process was performed on a specimen with the same material and dimensions as the nuclear fuel assembly to evaluate the integrity of the weld. As a result, welding conditions satisfying the minimum weld depth could be confirmed and the soundness of the weld was confirmed through macroscopic inspection and ANSYS simulation.

Acknowledgment

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