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Fundamental Study of Electron Beam Welding of AA6061-T6 Aluminum Alloy for Nuclear Fuel Plate Assembly (I)

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1. Introduction

As one of the most commonly used heat-treatable aluminum alloys, AA6061-T6 aluminum alloy is available in a wide range of structural materials. Typically, it is used in structural members, auto-body sheet and many other applications.[1] Generally, this alloy is easily welded by conventional GTAW (Gas Tungsten Arc Welding), LBW (Laser Beam Welding) and EBW (Electron Beam Welding). However, certain characteristics, such as solidification cracking, porosity, HAZ (Heat-affected Zone) degradation must be considered during welding. Because of high energy density and low heat input, especially LBW and EBW processes posses the advantage of minimizing the fusing zone and HAZ and producing deeper penetration than arc welding processes.[2]

In present study, to apply for the nuclear fuel plate fabrication and assembly, a fundamental EBW experiment using AA6061-T6 aluminum alloy specimens was conducted. Furthermore, to establish the welding process, and satisfy the requirements of the weld quality, EBW apparatus using a electron welding gun and vacuum chamber was developed, and preliminary investigations for optimizing the welding parameters of the specimens using AA6061-T6 aluminum plates were also performed. In this experiment, a feasibility test was carried out by tensile tester, bead-on-plate welding and metallographic examination to comply with the aluminum welding procedure. The EB weld quality of AA6061-T6 aluminum alloy for the fuel plate assembly has been also studied by the mechanical testing and macro-structure examinations.

2. Materials and Results

2.1 Test Materials

All materials used in this experiment are of commercial quality, AA6061-T6 aluminum alloy with 4.5 mm thickness. This chemical composition and mechanical properties are given in Table 1.

2.2 Welding Operation

The welding operation was done at a traveling speed of 600 mm/min. without preheating. The beam current and accelerating voltage were maintained at 70 kV and 40 mA in a vacuum of 10^{-2} Pa.

2.3 Examination Procedure

Test specimens were bead-on-plate welded by EBW. The welding variables were changed in order to find the optimum set of conditions. Before welding, the test specimens were ultrasonically cleaned in ethyl alcohol. Tensile tests were performed at room temperature and three to four specimens were tested for every weld as shown in Fig. 1.[3] The strain rate was 1 mm/min. The macro-structure of welded specimens was investigated by the optical microscopic examination.

Table 1. Chemical composition and mechanical properties of the used aluminum alloy.

(a) Chemical composition (wt. %).

Alloy	Si	Fe	Cu	Mn	Mg	Zn	Cr	Al
AA6061-T6	0.65	0.31	0.27	0.12	1.05	0.01	0.25	bal.

(b) Mechanical properties.

Alloy	0.2% Proof stress (Mpa)	Tensile strength (MPa)	Elongation (%)
AA6061-T6	240	290	8 - 10

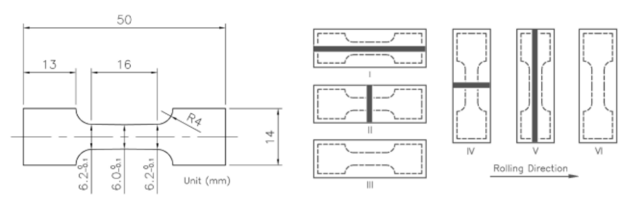
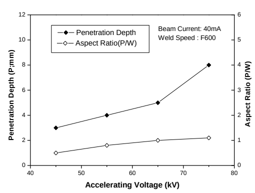


Fig. 1. Dimension of tensile specimen and scheme of test specimens with respect to rolling direction.

2.4 Effect of basic parameters and welding speed

EBW is a welding process that produces coalescence with a concentrated beam, composed of high-velocity electrons impinging on the joint. In practice, the rate of heat input to the weld joint is controlled by four basic parameters, as follows: (1) beam current (2) beam accelerating voltage (3) focal beam spot size (4) welding speed. In this present experiment, in order to investigate the welding parameters which determine penetration depth and bead width during EBW, bead-on-plate welding was carried out using AA6061-T6 aluminum alloy. Fig. 2 and 4 shows the penetration depth and the aspect ratio (depth-to-width) as a function of the accelerating voltage at a beam current 40mA and welding speed F600, respectively. It was found that the effect of aspect ratio which has ability to produce welds with depth-to-width ratio using EBW was negligible. However, the penetration depth was remarkably increased with increasing the accelerating voltage from 45kV to 75kV. Fig. 3 also shows the penetration depth and the aspect ratio as a function of the beam current at accelerating voltage 75kV and welding speed F600. Increasing beam current results in increase of the bead width and the penetration depth respectively and there is no difference between the aspect ratio and increasing the beam current from 25mA to 40mA. Fig. 5 shows the relationship between the welding speed and the penetration depth at a accelerating voltage 70kV and beam current 40mA. It was found that the penetration depth decreased remarkably by increasing the welding speed, while the bead width also decreased.



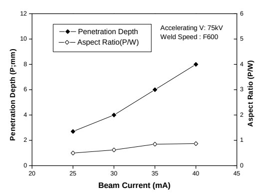


Fig. 2. Accelerating voltages vs. penetration depths.
Fig. 3. Beam currents vs. penetration depths.

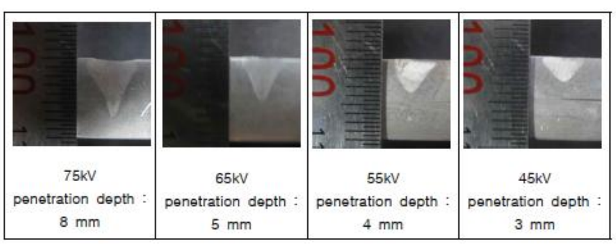


Fig. 4. Macro-cross sections of EB welded specimens.

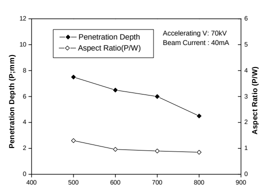
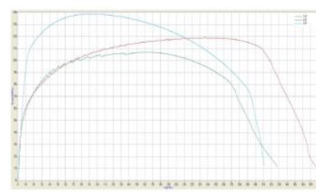


Fig. 5. Welding speeds vs. penetration depths.

2.5 Mechanical properties of EB welded specimens

The mechanical properties such as yield strength, tensile strength, and percentage of elongation of AA6061-T6 aluminum alloy joints were investigated. In each condition, three specimens were tested, and average of the three results is presented in Fig. 6 and 7. No significant difference could be found between the tensile properties of specimens cut along the rolling direction and those transverse to it. The fracture of the transverse welded specimens occurred in the base metal far from the weld. Maximum loading forces of the base metals with the specimen III and specimen IV are 400 kgf and 385 kgf, respectively. Joint efficiency is the ratio between the tensile strength of welded joint and the tensile strength of unwelded base metal. In the two types of the rolling directions, the joint efficiency of longitudinal welded joint is approximately 87% and the joint efficiency of transverse welded joint is also similarly 75%.



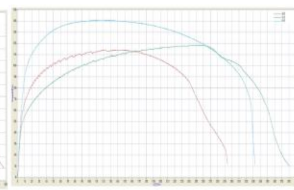


Fig. 6. Stress-strain curves for EB welds and unwelded specimen (I, II, III).
Fig. 7. Stress-strain curves for EB welds and unwelded specimen (IV, V, VI).

3. Conclusion

This study was carried out to determine the suitable welding parameters and to evaluate tensile strength of AA6061-T6 aluminum alloy. In the present experiment, satisfactory EBW of the bead-on-plate test specimens was developed. In comparison with the rolling directions of test specimens, the tensile strengths were no difference between the longitudinal and transverse welds. Based on this fundamental study, fabrication and assembly of the nuclear fuel plates will be provided for the future Kijang research reactor project.

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