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

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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 microstructure examinations.

2. Materials and Results

2.1 Test Materials

All materials used in this experiment are of commercial quality, AA6061-T6 aluminum alloy with 6 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 40 kV and 50 mA in a vacuum of 10^{-2} Pa.

2.3 Examination Procedure

Square butt joint configuration as shown in Fig. 1 was prepared to fabricate EBW. The welding variables were selected in order to find the optimum set of conditions. Before EB welding, the weld specimens were ultrasonically cleaned in ethyl alcohol. Tensile tests were performed at room temperature and three to five specimens were tested for every weld as shown in Fig. 2.[3] The strain rate was 1 mm/min. The microstructure of EB welded specimen was observed by optical microscopic method.

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

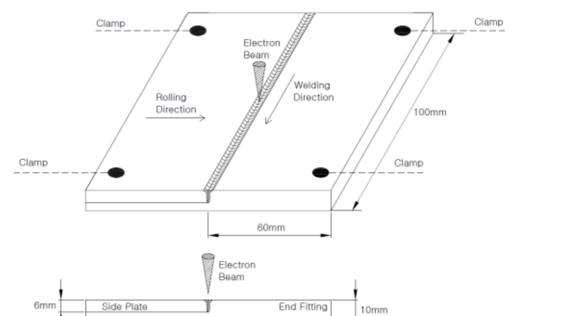


Fig. 1 Dimensions of weld joint configuration.

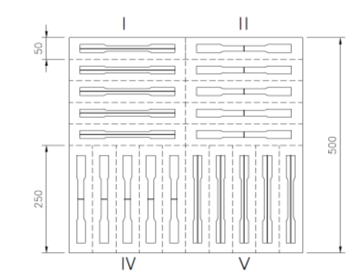
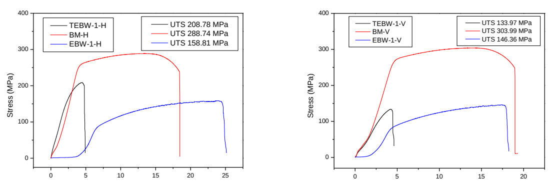


Fig. 2 Schemes of test specimens with respect to rolling direction.

2.4 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. 3. 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 weld metal adjacent to the centerline. Maximum tensile strengths of the base metals with the specimen III and specimen IV are 289 MPa and 304 MPa, respectively. Joint efficiency is the ratio between the tensile strength of welded joint and the tensile strength of un-welded base metal. In the two types of the rolling directions, the joint efficiency of longitudinal welded joint is approximately 66% and the joint efficiency of transverse welded joint is also similarly 43%.



(Longitudinal joint) (Transverse joint)

Fig. 3 Stress-strain curves for EB welded specimens.

2.5 Micro-hardness and microstructure examinations

Fig. 4 and Fig. 5 show the hardness variations and across the base metal, HAZ, and a weld metal of the square butt joint and U-groove joint using filler wire (ER4047). The hardness values of the base metal, HAZ, and the weld metal are 68-77 Hv, 61-75 Hv, and 58-86 Hv, respectively. The hardness values of the weld metal obtained in weld specimens using filler wire are slightly higher than compared with the butt welded specimens, as shown in Fig. 4 and Fig. 5. It seems that the difference in the hardness values between the weld metals of the autogenous method and filler additions by EBW is due to the formation of hard phases based on the aluminum alloy binary diagram. Fig. 6 shows the microstructures of the butt joint using welded specimen without filler wire.

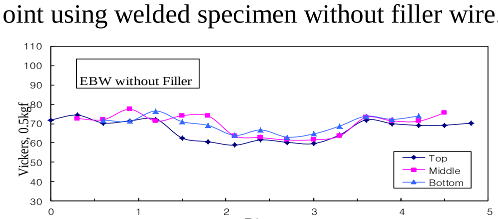


Fig. 4 Hardness profiles through weld metal, HAZ, and base metal of EBW without filler wire.

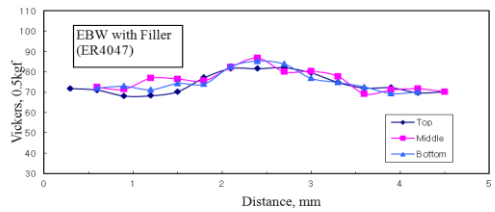
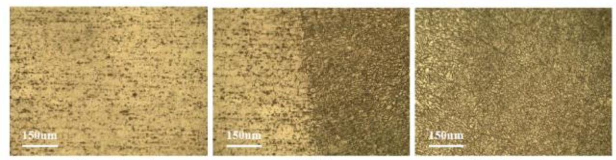


Fig. 5 Hardness profiles through weld metal, HAZ, and base metal of EBW with filler wire.



(Base Metal) (HAZ) (Weld Metal)

Fig. 6 Microstructures of the square butt welded specimen
(Keller's reagent; 95mL water, 2.5mL HNO_3, 1.5mL HCL, 1.0mL HF)

3. Conclusion

This study was carried out to determine the suitable welding process and to investigate tensile strength of AA6061-T6 aluminum alloy. In the present experiment, satisfactory EBW of the square butt weld 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.

Acknowledgements

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