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Experimental Investigation on Tensile Test Properties of EB Welded Joints of Aluminum 6061-T6 Alloy for Plate-type Fuel Assembly Fabrication

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1. Introduction

The Electron beam welding (EBW) is a relatively high energy density joining process, developed by Karl Heinz Steigerwald, Germany, in 1958 [1]. This welding technique has proven to be very successful in joining aluminum alloys. It can produce superior mechanical properties when compared to the typical electrical arc welding and laser beam welding processes, and therefore has gained considerable interest in the past decade [2]. Even though the electrical arc welding process is widely used for manufacturing commercial fuel assemblies, it cannot be recommended for fusion welding, which a side plate is connected to end fitting part of a fuel assembly owing to the complexity of the electrode alignment and the excessive heat input during the welding. Therefore, a high-density energy method was chosen as a candidate for this application. To select a more suitable welding technique, the characteristics of the welds made by the EBW process will be compared in terms of their penetrations and tensile strength. In this examination, an effort will be exerted on an improvement of the EBW process for joining a side plate to an end fitting part. Another advantage of the EBW process is that it is a qualified process for aluminum welding in which there is extensive production experience. In this study, experimental test was carried out using a tensile tester, a micro-hardness tester, and metallographic examinations to comply with the aluminum welding technique. The EB welded performance of AA6061-T6 aluminum alloy for the plate-type fuel assembly was also studied based on the mechanical properties and SEM examinations.

2. Experimental method

2.1. Specimen materials

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

2.2. Welding operations

The welding operation was conducted at a traveling speed of 1200mm/min. The beam current and accelerating voltage were maintained at 60kV and 35mA in a vacuum of 10^{-3} Pa.

2.3. Examination procedures

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

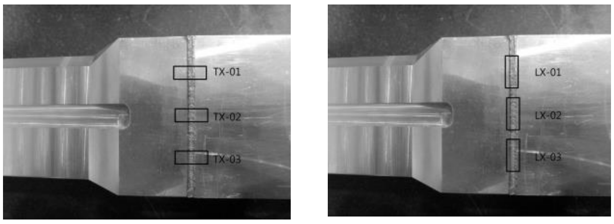
Table 1. Chemical compositions and mechanical properties of the AA6061-T6 aluminum plate

(a) Chemical compositions (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



(Transverse location: II/IV) (Longitudinal location: I/V)

Fig. 1. Schematic of tensile specimens with respect to rolling directions using a full-sized fuel assembly

3. Results and discussion

3.1. Tensile test properties of EB welded specimens

Mechanical properties such as the yield strength, tensile strength, and percentage of elongation of AA6061-T6 aluminum alloy joints were investigated. Under each condition, three specimens were tested, and the average of the three results is presented in Table 2. 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. The ultimate tensile strengths of the base metals with specimens III and IV is 304 MPa, and the ultimate tensile strengths of the weld metals which have middle parts using specimens II/IV and I/V are 226 and 257 MPa, respectively. The joint efficiency is the ratio between the tensile strength of a welded joint and the tensile strength of the base metal. In the two types of rolling directions, the joint efficiency of a longitudinal welded joint is approximately 85%, and the joint efficiency of a transverse welded joint is also similarly 74%. Fig. 2 shows the fractography of the tensile specimens using AWS 4047 filler material. The mode of the fracture consists entirely of dimples with a micro-void coalescence, which indicates that most of the tensile specimens failed in a ductile manner under the pattern of tensile loading.

Table 2. Tensile test properties of EB welds and base metal

Type of specimens	Ultimate tensile strength (MPa)	Elongation (%)	Joint efficiency (%)
Weld metal (autogeneous)	Top 243	12	79.93
	Middle 226	8	74.34
	Bottom 198	7	65.13
Weld metal (AWS4047)	Top 240	8	78.94
	Middle 257	12	84.54
	Bottom 144	11	80.26
Base metal	304	18	-

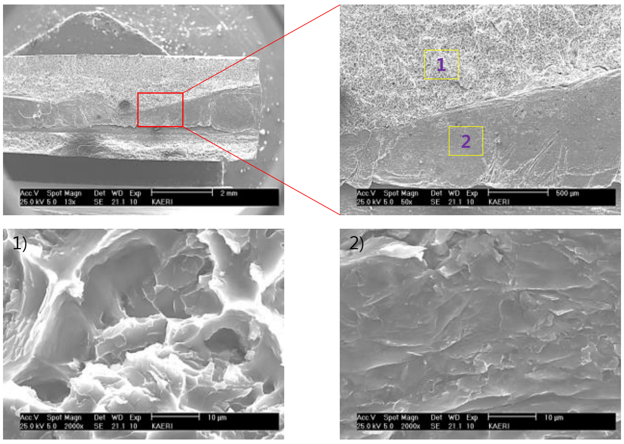
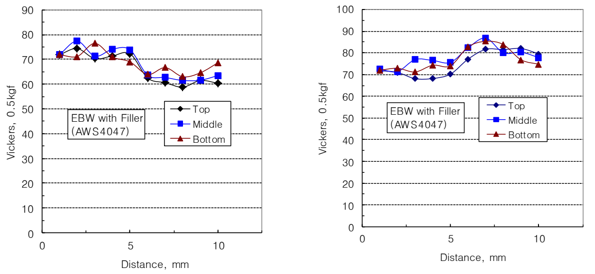


Fig. 2. Fractographs of EB welded zones using fractured tensile specimens

3.2. Micro-hardness test of EB welded specimens

The micro-hardness across the weld sections was measured using a Vickers hardness tester, and the vales are presented in Fig. 3, which shows a comparison of the hardness variations for weld regions that have a square butt joint with AWS 4047 filler material. The hardness distributions of the weld centerline for a square butt welded zone are within the range of 61 to 70 VHN, whereas those for the heat affected zone were in the range of 75 to 87 VHN. This may be due to the welding heat cycle and the usage of AWS 4047 filler material (Al-10%Si). It was found that the hardness variations of the filler addition exhibited a higher hardness compared to the fusion welding joint due to the shear stresses induced by the tool motion, which lead to the generation of a fine grain structure [4]. It seems that further study is necessary to analyze the constituents formed in the weld joints, such as the inter-metallic compounds using electron microprobe analyses and other advanced experimental tools.



(Left side from center of weld line) (Right side from center of weld line)

Fig. 3. Micro-hardness profiles through weld metal, HAZ, and base metal with AWS 4047 filler material

4. Conclusion

This study was carried out to determine suitable welding parameters and to evaluate the tensile strength of an AA6061-T6 aluminum plate. In the present experiment, a satisfactory EBW of the tensile test specimens was developed. In comparison with the rolling directions of the test specimens, the tensile strengths showed no difference between the longitudinal and transverse welds. Based on this fundamental experiment, the fabrication and assembly of U-Mo plate-type nuclear fuels will be provided for the future Ki-jang research reactor project.

REFERENCES

[1] J. Elmer, P. Hochanadel, K. Lachenberg, T. Webber, "Introduction to High Energy Density Electron and Laser Beam Welding," ASM welding handbooks, 11 edition, 2009.

[2] Sung-wook Kim, Sook-hwan Kim, "Effects of the Chemical Composition on the Depth of Weld in EBW of Aluminum Alloys," Journal of KWJS, Vol. 26 No. 5, pp.433-435, 2008.

[3] Welding Handbook, "Welding Processes, part II," American Welding Society, pp.451-502, 2007.

[4] A. K. Lakshminarayanan, V. Balasubramanian, K. Elangovan "Effect of Welding Processes on Tensile Properties of AA6061 Aluminum Alloy Joints," International J. of Advance Manufacturing Technology, pp.286-296, 2009.