Fabrication of AA6061-T6 Plate Type Fuel Assembly Using Electron Beam Welding Process

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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.[2] 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 possess the advantage of minimizing the fusing zone and HAZ and producing deeper penetration than arc welding processes.

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 an 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. The EB weld quality of AA6061-T6 aluminum alloy for the fuel plate assembly has been also studied by the shrinkage measurement and weld inspection using computed tomography.

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 60 kV and 35 mA in a vacuum of 10^{-2} Pa.

2.3 Examination Procedure

Test specimens using a dummy assembly as shown in Fig. 1 were 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. 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

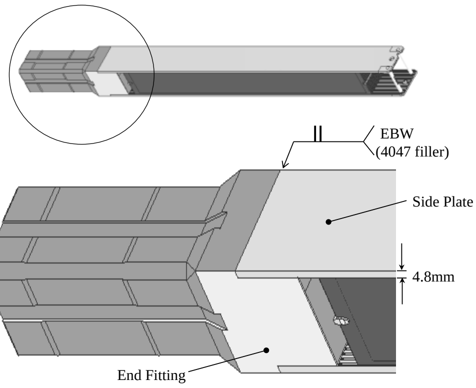
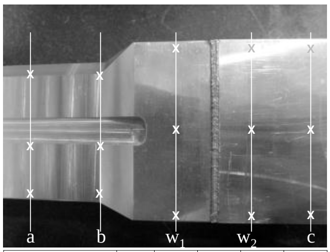


Fig. 1. Schematics of weld configuration using the plate-type fuel assembly.

2.4 Effect of weld distortion and weld parameters

The weld distortion occurred in fabricated fuel assembly is basically caused by three fundamental dimensional changes that find during electron beam welding process: (1) transverse shrinkage that occurs perpendicular to the weld line, (2) longitudinal shrinkage that occurs parallel to the weld line, and (3) an angular change that consists of rotation around the weld line.[3] In this experiment longitudinal shrinkage that occurs in butt joint which has the side plate and end fitting part, in actual sample assembly is usually applicable and Fig. 2 shows the results of longitudinal shrinkage after welding. The weld distortion is affected by electron beam parameters and welding speed during welding process. Fig. 3 shows the effect of beam current on longitudinal shrinkage using the plate-type fuel assembly. As the beam current increases, the shrinkages of w_1 and w_2 slightly increase and the penetration depth of the welded zone also increases. Regarding the effect of welding speed on longitudinal shrinkage, the values of differences between the pre-welding and post-welding decrease as the welding speed is increasing as shown in Fig. 4.



Local positions of weld sample (A-1/2/3)		a	b	w_1	w_2	c
Before welding (BW)	A-1	-0.02	0	0.03	-0.04	0
	A-2	-0.02	-0.01	0.06	0.05	-0.01
	A-3	0	-0.01	-0.04	0	0
After welding (AW, 35mA F1200)	A-1	-0.03	0.02	0.01	-0.02	-0.01
	A-2	-0.05	0.03	-0.02	0.03	-0.02
	A-3	-0.01	-0.02	-0.07	-0.05	0.02
Average longitudinal shrinkage (AW-BW/3)		0.017	0.023	0.043	0.030	0.013

Fig. 3. Variation of longitudinal shrinkage as a function of the local measurement position using dial gauge indicator.

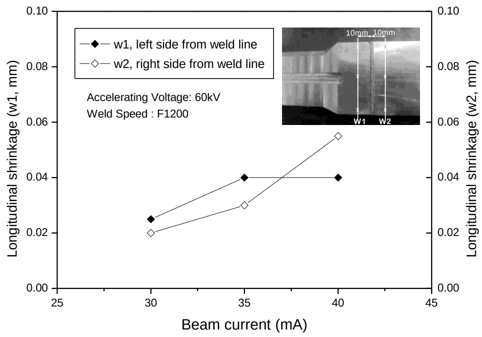


Fig. 4. Relationship between beam current and longitudinal shrinkage in EB welded sample.

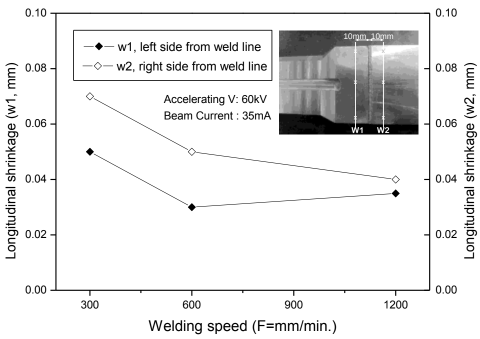


Fig. 5. Relationship between welding speed and longitudinal shrinkage in EB welded sample.

2.5 Weld inspection by computed tomography

To find the weld defects and to confirm the soundness of the weld joints, a computed tomographic examination was conducted. The main purpose of the examination was to find out whether some defects such as lack of fusion and pores inside a weld metal can be detected by a computed tomography.[4] The results of computed tomographic examinations are given in Fig. 10, which show a 3D image and three projections of a sample specimen without a clearly evident lack of fusion and pores. In order to obtain a sound weld between a side plate part and end fitting part based on the experimental results, metallographic and a computed tomographic examinations of the welds, it can be suggested that accelerating voltage of 60 kV, a beam current of 35 mA, and weld speed of F1200 with AA6061-T6 aluminum alloy are the optimized welding parameters for the joint design in Fig. 1. These properties are satisfied with the requirements of the plate-type fuel assembly fabrication for the installation and commercialization at the research reactor.

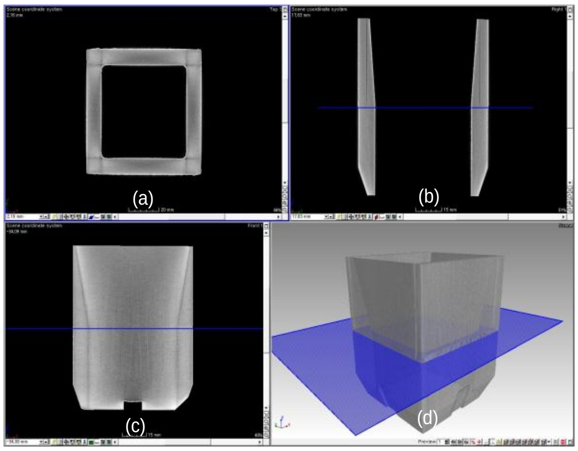


Fig. 5. Sample image made by computed tomography: (a)front, (b) side, (c) top view and (d) 3D image.

3. Conclusions

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 electron beam welding process of the full-sized sample was being developed. Based on this fundamental study, fabrication of the plate-type fuel assembly will be provided for the future Ki-Jang research reactor project.

Acknowledgements

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