Mechanical Properties of Aluminum-Based Dissimilar Alloy Joints by Power Beams, Arc and FSW Processes

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Dissimilar smart joints are useful. In this research, welded quality of dissimilar aluminum alloys of 3 mm thickness by various welding processes and process parameters have been investigated by hardness and tensile tests, and observation of imperfection and microstructure. Base metals used in this study are A1050-H24, A2017-T3, A5083-O, A6061-T6 and A7075-T651. Welding processes used are YAG laser beam, electron beam, metal inert gas arc, tungsten inert gas arc and friction stir welding. The properties of weld zones are affected by welding processes, welding parameters and combination of base metals. Properties of high strength aluminum alloy joints are improved by friction stir welding.

Key Words: aluminum alloy, mechanical properties, welding process, dissimilar joints, process parameters, LBW, EBW, MIG, TIG, FSWt

1. Introduction

The aluminum-based dissimilar alloy joints such as different alloy joints can enhance design flexibility for light weight parts and structures. Fundamental research on joints of aluminum with other metals is reported by Miller¹⁾. According to the report, a number of fusion methods are available for joining aluminum to other metals. The welding of dissimilar aluminum alloys for TIG welding was investigated by Luijendijk²⁾. One of the authors was reported^{3,4,5)} concerning electron beam welding for high strength aluminum alloys. We are recommended that dissimilar aluminum alloys joints are investigated for power beams, arc and friction stir welding (FSW) processes. Dissimilar aluminum joints can be thought to be useful for the use expansion of aluminum alloys.

The present work focuses on mechanical properties of five selected processes such as YAG laser beam welding (LBW) by the optical energy, electron beam welding (EBW) by the electronic

energy and MIG, TIG welding by the arc energy and FSW. The thickness of all the base metals used is 3mm.

In this paper, a study was carried out to clarify the properties of dissimilar alloy joints in terms of hardness, tensile and microstructure of joints by various joining processes. The optional welding conditions to be proper based on the characteristics of each welding process were discussed. The present study has observed the welded bead and evaluated hardness and tensile properties of joints.

2. Experimental Method

2.1 Materials and welding equipments

Wrought aluminum alloys used in this research are A1050-H24 pure aluminum, A2017-T3 Al-Cu alloy, A5083-O Al-Mg alloy and 6061-T6 Al-Mg-Si alloy and A7075-T651 Al-Zn-Mg alloy.

Table 1 shows the chemical compositions of the base metals.

Fig. 1 shows welding procedures for LBW, EBW, MIG and

Table 1 Chemical composition of base metals.

Materials	Elements(mass%)								
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
A1050-H24	0.10	0.29	0.01	–	–	–	–	0.02	bal.
A2017-T3	0.59	0.26	3.87	0.72	0.57	0.01	0.02	0.03	bal.
A5083-O	0.15	0.21	0.01	0.71	4.70	0.12	0.01	0.02	bal.
A6061-T6	0.57	0.40	0.27	0.03	0.96	0.24	0.02	0.03	bal.
A7075-T651	0.06	0.12	1.51	0.03	2.62	0.20	5.80	0.03	bal.

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Fig. 1 Welding procedure for LBW, EBW, MIG and TIG.

Fig. 2 Welding procedure for FSW.

TIG. The LD-YAG (CW) laser welding machine has a maximum output power of 6kW. The EBW machine used has the highest output power of 15kW. The MIG welding machine has inverter welding equipment with a maximum output of 500A. The TIG welding machine has alternating current welding equipment with a maximum output of 350A.

Fig. 2 shows a welding procedure for FSW. The FSW machine has a rotating tool which travels along the weld line. Base metals are fixed on the backing plate.

2.2 Selection of process condition

LBW was performed with an output of 3.5kW and a welding speed of 3.3×10^{-2} m/s. EBW was performed with an accelerating voltage of 120kV, and a welding speed of 1.7×10^{-2} m/s. The atmosphere for EBW is 5.0×10^{-2} Pa. MIG welding was performed with a welding current of 130A and filler wire used was A5356-WY of 1.6 mm in diameter. TIG welding was performed with a welding current of 100A. In case of TIG welding, no filler material was used in order to evaluate a melting behavior.

A1050	
A6061	
A2017	
A5083	
A2017	
A7075	
A5083	
A6061	
A5083	
A7075	

Fig. 3 Bead appearances of dissimilar alloy joints for LBW.

Optimum FSW condition was selected for each dissimilar alloy joint, but the joining speed was kept constant as 6.7×10^{-3} m/s.

2.3 Evaluation of welded joints

Appearance of the cross section of welded joints was observed by an optical microscope. Micro Vickers hardness test was performed on the cross section. Tensile test was carried out by utilizing an Instron-type testing machine with a cross-head speed of 1mm/min. Gage length of the tensile specimen is 50 mm and the cross sectional size of 3mm in thickness and 25mm in width.

3. Results and Discussion

3.1 Observation of weld bead and bead width

Good bead appearance, full penetration are obtained under the process condition that heat affected zone became narrow. Fig. 3 shows bead appearances of dissimilar alloy joints for LBW. Power beam energy is suitable for the welding of aluminum alloys due to its high quality⁶⁾. In particular, laser welding is a promising welding method because it doesn't need vacuum chamber.

The bead widths of joints by LBW are in the range from 4.0 to 2.5mm. The bead widths of joints by EBW are from 1.0 to 3.5mm, which became narrower than those by LBW. The bead width is about 12 mm for the case of TIG and MIG welding. FSW showed 14 mm of bead width.

3.2 Hardness distribution of joints

Hardness in the weld zone exerts a great influence on the properties and weldability of dissimilar joints. A1050 and A5083 aluminum alloys are not aged-hardening alloys, while

age-hardening phenomena takes place in A2017, A6061 and A7075 aluminum alloys. The hardness distribution in the weld zone of A1050/A6061 aluminum alloy joint under various welding processes is shown in **Fig. 4**. Highest hardness was observed at weld center of joints made by FSW.

The hardness distributions in the weld zone of A2017/A5083 aluminum alloy made by various welding processes are shown in **Fig. 5**. In case of EBW, hardness distribution shows the highest level among all the processes, since hardness is strongly influenced by aging behavior in which the highest cooling rate is realized by EBW.

The hardness distribution in the weld zone of A2017/A7075 aluminum alloy joints with various welding processes is shown

in **Fig. 6**. The weld metal zone made by MIG welding shows the hardness level of around 75HV, which is the lowest among all the welding processes performed in the present study. This is because that the MIG welding used a filler wire called A5356-WY and so the hardness of weld metal was diluted with this low hardness material.

The hardness distributions in the A5083/A6061 aluminum alloy joints made by the various welding processes are shown in **Fig. 7**. The hardness distribution in stir zone was almost the same level as that of base metal. There the combination of A5083 and A6061 aluminum alloys are preferable for realizing the most reliable joint.

The hardness distribution in the A5083/A7075 aluminum alloy

Fig. 4 Vickers hardness distribution of weld zones in A1050/A6061 alloy joint.

Fig. 6 Vickers hardness distribution of weld zones in A2017/A7075 alloy joint.

Fig. 5 Vickers hardness distribution of weld zones in A2017/A5083 alloy joint.

Fig. 7 Vickers hardness distribution of weld zones in A5083/A6061 alloy joint.

Fig. 8 Vickers hardness distribution of weld zones in A5083/A7075 alloy joint.

Fig. 9 Tensile strength of base metal and weld zones in A1050/A6061 alloy joint.

Fig. 10 Tensile strength of base metal and weld zones in A2017/A5083 alloy joint.

joints by the various welding processes are shown in Fig. 8. Quite different hardness level was observed for both sides. The reasons are attributed to the difference in the chemical compositions and the age hardening behavior of base metals.

3.3 Tensile properties of welded joints

FSW is one of the suitable process as compared with the other conventional fusion welding processes for joining aluminum alloys⁷⁾. Since FSW is one of solid state joining process. Ericsson⁸⁾ reported that fatigue strength of friction stir welded Al-Mg-Si alloy joint is higher than the joints made by MIG-pulse and TIG welding processes, which is very useful for designing light welded constructions.

Tensile strength of A1050 pure aluminum, A2017, A5083, A6061 and A7075 aluminum alloys are 118 MPa, 445 MPa, 318 MPa, 303 MPa and 590 MPa, respectively.

Tensile strength values of the A1050/A6061 aluminum alloy joints with various welding processes are shown in Fig. 9. The joint by FSW showed the highest tensile strength than the other fusion welding methods, and the fracture occurred almost in the heat affected zone on the A1050 aluminum side.

The tensile strength values of A2017/A5083 aluminum alloy joints with various welding processes are shown in Fig. 10. MIG welding shows the highest joint efficiency of 95 % against A5083 aluminum alloy, suggesting that the filler wire used for A5356-WY type was optimum.

As for the A2017/A7075 aluminum alloy joint, the results of tensile test is summarized in Fig. 11, indicating that tensile strength of the FSW joint showed the highest value among the joints tested. Thus, FSW is suitable joining method for heat-treatable alloy such as A2017 and A7075 aluminum alloys.

The result of tensile strength for A5083/A6061 aluminum alloy

Fig. 11 Tensile strength of base metal and weld zones in A2017/A7075 alloy joint.

Fig. 12 Tensile strength of base metal and weld zones in A5083/A6061 alloy joint.

Fig. 13 Tensile strength of base metal and weld zones in A5083/A7075 alloy joint.

joints with various welding processes is shown in Fig. 12. The highest tensile strength in the A5083/A6061 aluminum alloy joint of 252 MPa was achieved by means of EBW. Compared with base metal of A6061 aluminum alloy, the FSW joint showed a joint efficiency of about 83 %, which is comparable to the average tensile strength of 240 MPa for the joint by MIG, and is slightly higher than that by TIG or other welding process.

Tensile strength of A5083/A7075 aluminum alloy joints by the various welding processes is shown in Fig. 13. The joint by MIG welding shows the highest value of 280 MPa.

3.4 Microstructure of weld zones

In case of power processes such as LBW and EBW, dendrite arm spacing is known to be very narrow. In this study, dendrite arm spacing of fusion zones are about 15.2 μm for LBW and about 8.6 μm for EBW. Fig. 14 shows a typical microstructure of SZ in an A5083/A6061 aluminum alloy joint by FSW. In this case, solid state welding reflects the metal flow of A5083 and A6061 aluminum alloys with different chemical composition. In this Figure, left side corresponds to A5083 alloy composition and right side is A6061 alloy composition. A border between un-mixed of each alloy region is featured. Metal flows in the FSW were investigated by Ouyang⁹⁾, Colligan¹⁰⁾ and Reynolds¹¹⁾ etc. In these reports, the degrees of material mixing are affected by complex factors.

4. Conclusions

The present research evaluated the joints of different aluminum alloys by various welding processes in which the principle is different in terms of heat source. From this research, selection of joining process and combination of base metals are discussed.

Fig. 14 Microstructure of A5083/A6061 alloy joint by FSW.

The following results are obtained.

(1) A5083/A6061 aluminum alloy joint by FSW showed the highest hardness value in stir zone though the weld metal as compared with the other fusion welding processes that showed a tendency of becoming softer than base metals.

(2) FSW was the most effective way to obtain the highest tensile strength of A2017/A7075 age-hardening aluminum alloy joint. LBW yielded a similar tensile strength in comparison with the other fusion welding processes.

(3) In power beam welding such as EBW and LBW processes, fusion and solidification zones are very narrow. Thus, the heat input is in low level compared to MIG and TIG welding processes. Typical stir zone by FSW shows a border between two un-mixed dissimilar compositions of base metals.

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