ELECTRON BEAM WELDING OF Al-Cu-Mg AND Al-Li-Cu ALLOYS

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ABSTRACT In electron beam welding of Al-Cu-Mg and Al-Li-Cu alloy plates, effects of base metals and process parameters on mechanical properties have been investigated by microstructure, hardness, tensile, impact and EPMA tests. Butt welding was carried out without using a filler metal. In case of Al-Cu-Mg alloys in T4 temper, cracks, porosity and other weld defects are not observed under the optimum welding conditions and the joint efficiency of welds is 70%. With 0.02%Ti or 0.02%Zr addition to the base metal, tensile and impact properties of weld metal are improved. For Al-Li-Cu alloy in T8 temper, formation of arcing and hot cracking is low under proper welding conditions. However, the joint efficiency in as welded state is about 50% due to decreased hardness in the weld zone.

Keywords: electron beam welding, Al-Cu-Mg alloy, Al-Li-Cu alloy, alloying addition mechanical properties, weld defects.

1. INTRODUCTION

Although investigations for properties of welded joints by MIG and TIG welding[1-3], laser welding[4] and electron beam welding[5-7] have been reported, further study is needed to establish the welding technology for high strength aluminum alloys. Among these welding methods, electron beam welding is most suited for welding of thick plates of high strength aluminum alloys. In this paper, a study was carried out to clarify the joint properties of Al-Cu-Mg and Al-Li-Cu alloy plates in electron beam welding. For Al-Cu-Mg alloys, the effects of Ti and Zr additions, degassing treatment to the base metals and welding conditions on the properties of the welded joints were examined. In case of Al-Li-Cu alloy, the effects of welding conditions on the properties of the welded joints were studied.

2. EXPERIMENTAL PROCEDURE

The chemical composition of Al-Cu-Mg alloys (2024) is listed in Table 1. Ti and Zr were added to the base alloy by the amount of 0.02 mass%. The degassing time of base metal was changed from 1 minute (mark: L) to 5 minutes (mark: H). The size of the base metal was 7(t)× 50(w) ×100(l) mm in T4 temper. The chemical composition of Al-Li-Cu alloy (2090) is listed in Table 2. The base metal was in T8 temper and 11(t)×40(w)×70(l) mm in size.

Table 1 Chemical composition of Al-Cu-Mg alloys.

Materials	Marks	Chemical composition (mass%)									
		Cu	Si	Fe	Mn	Mg	Zn	Cr	Ti	Zr	Be(PPM)
A2024	Al-L	4.40	0.06	0.17	0.59	1.51	Tr	Tr	Tr	-	6
A2024+Ti	Al-Ti-L	4.36	0.06	0.18	0.58	1.44	Tr	Tr	0.03	-	4
A2024+Zr	Al-Zr-L	4.48	0.08	0.18	0.58	1.58	Tr	Tr	Tr	0.02	5
A2024	Al-H	4.47	0.06	0.17	0.59	1.38	Tr	Tr	Tr	-	5
A2024+Ti	Al-Ti-H	4.38	0.06	0.18	0.59	1.38	Tr	Tr	0.02	-	5
A2024+Zr	Al-Zr-H	4.37	0.08	0.17	0.57	1.48	Tr	Tr	Tr	0.02	4

Table 2 Chemical composition of Al-Li-Cu alloy.

Material	Chemical composition (mass%)							
	Li	Cu	Mg	Si	Fe	Ti	Zr	Al
2090	2.46	2.46	0.12	0.03	0.06	0.02	0.12	Bal.

An electron beam welding machine of high voltage type (6kW,40mA,150kV) was used under a vacuum of 2.7×10^{-3} Pa. Butt welding of I type joint with no groove clearance was performed without using a filler wire. Microscopic observation, Vickers hardness, tensile and impact tests were carried out. The parallel part of a tensile test specimen was 5(t)×20(w)×30(l) mm. Impact test specimen with a V notch of 2 mm in depth was used for Sharpy impact tests. SEM observation and the EPMA analyses were also carried out.

3. RESULTS AND DISCUSSION

3.1 Welding characteristics of Al-Cu-Mg alloys

3.1.1 Selection of proper welding condition

When the welding condition was properly selected, bead appearance was satisfactory. Table 3 shows the welding conditions used in the experiment. Here, the accelerating voltage was kept constant at 150 kV, the beam current and welding speed were changed, and the welding condition was optimized. For a proper welding condition, the wedge type weld penetration with excellent bead appearance was obtained at beam current 10mA and welding speed 300 mm/min (condition 1). Moreover, another condition at beam current 20mA and welding speed 600 mm/min (condition 2) was examined.

Arcing phenomenon is observed during electron beam welding of the aluminum alloy. When arcing was generated, a rapid increase of the beam current and drop of vacuum of chamber occurred. Beam focus position (ab parameter) was adjusted to be 1.3 from a viewpoint of arcing prevention.

Table 3 Welding conditions for Al-Cu-Mg alloy joints.

	Beam current (mA)	Welding speed (mm/min)	ab Parameter
Condition 1	10	300	1.3
Condition 2	20	600	1.3

3.1.2 Structure and hardness distribution of weld zone

The base metals show fibrous structures, whereas the weld metals show dendrite cell structure, in which the dendrite arm spacing is 10 μ m in condition 1 and 18 μ m in condition 2 for Ti added materials. On the other hand, Zr added materials show dendrite arm spacing of 8 μ m.

EPMA analysis revealed a decrease of Mg content in the weld metal compared to the base metal. Some Cu segregation is observed in the bond. The hardness of base metal in T4 temper is about 145HV. The weld metal softens to 107HV. The cracks, porosity and other weld defects are not observed by microscopic observation.

3.1.3 Mechanical properties of weld zone

Tensile strength of base metal and welded joint is shown in Fig.1. In case of degassing treatment for 1 minute, tensile strength of base metals is 426-443 MPa, and in case of degassing treatment for 5 minute, tensile strength of base metals is 454-464 MPa. As for welded joints with degassing treatment for 5 minute, joint efficiency of about 70% was obtained. Tensile strength is 286-319 MPa for Ti added materials and 310-343 MPa for Zr added materials. Tensile fracture occurred at the weld metal. The elongation of base metals is 21-33% with degassing treatment for 1 minute and 29-40% with degassing treatment for 5 minute. The elongation of welded joints is 8-12%.

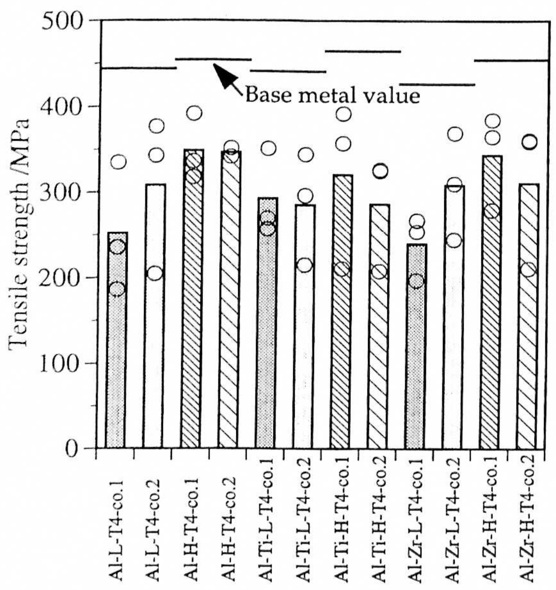


Fig.1 Tensile strength of Al-Cu-Mg alloy joints.

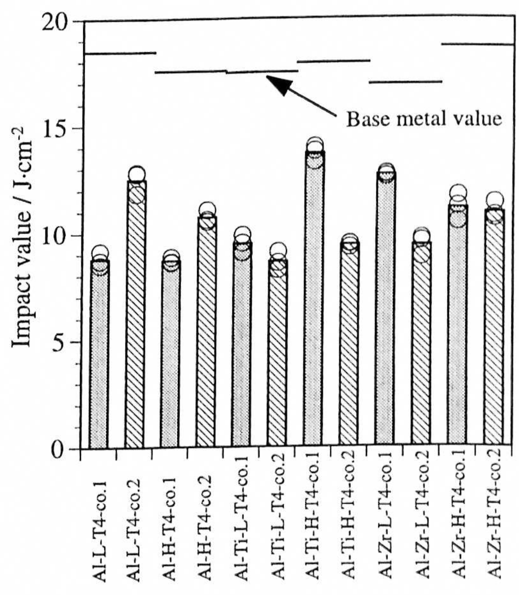


Fig.2 Impact value of Al-Cu-Mg alloy joints.

The impact values of the base metals and welded joints are shown Fig.2. The impact value is higher for the base metals with degassing treatment for 5 minute. In case of welded joints of Ti added base metal with degassing treatment for 5 minute, impact value is 76% of the base metal.

3.2 Welding characteristics of Al-Li-Cu alloy

3.2.1 Selection of proper welding condition

As the welding condition, the accelerating voltage was kept at 150 kV and the beam current and welding speed were changed. The welding conditions are shown in Table 4. Proper welding conditions were selected as the beam current 10mA and welding speed 200 mm/min (condition 1) Moreover, beam current 20mA and welding speeds 600 mm/min (condition 2) were examined.

Table 4 Welding conditions for Al-Li-Cu- alloy joints.

	Beam current(mA)	Welding speed (mm/min)	ab Parameter
Condition 1	10	200	1.3
Condition 2	20	600	1.3

3.2.2 Structure and hardness distribution of weld zone

The bead surfaces were smooth and cracking and arcing are not observed at both conditions The bead width was 4 mm at condition 1 and 6 mm at condition 2. Dendrite arm spacing in weld metal is 6.5 μ m in condition 1 and 8.8 μ m, and hence cooling rate is lower in condition 2 than in condition 1. Moreover, cracks are not observed in the weld zone. However, the porosity of about 500 μ m is present on the weld metal side of the bond line in condition 2.

Fig.3 shows hardness distribution in the cross section of the weld. The hardness in weld metal softens considerably to about 80HV in condition 1 while hardness of base metal is about 180HV. It is thought that the weld metal and the heat affected zone softened by the welding heat cycle, since the base metal is strengthened by work hardening and temper treatment.

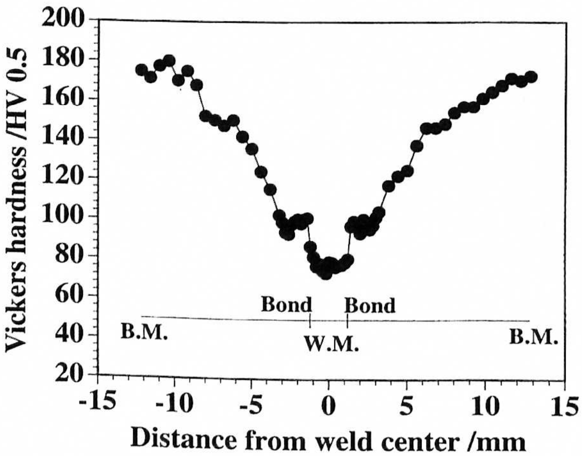


Fig.3 Hardness distribution of Al-Li-Cu alloy joints (condition 1).

3.2.3 Mechanical properties of weld zone

The Tensile strength of base metal and welded joints is shown in Fig.4. Tensile fracture occurred at the weld metal bond in condition 1 and weld metal center in condition 2. The tensile strength of the base metal is about 600 MPa. Tensile strength at the welded joints is about 300 MPa in condition 1 and 160 MPa in condition 2. The joint efficiencies are 27-50%, because of decreased hardness in the weld zone.

The impact values of the base metal and welded joints are shown in Fig.5. Crack initiation occurred from V notch, and crack propagated at the weld metal center in condition 1 and bond line in condition 2. The impact value of the base metal is about 6.7 J/cm^2 and that of welded joint is about 7.1 J/cm^2 in condition 1.

Fracture of the base material after tensile test shows cleavage pattern. Fig.6 shows a fractograph of tensile fracture surface in condition 1. The dimple pattern of size 5-10μm was observed.

3.3 Improvement of properties of welded joints

The properties of weld zone for 2024 alloy was discussed in terms of added elements and degassing treatment. Formation of cracks, porosity and other defects is prevented by selecting optimum welding conditions. Zr addition is considered to be desirable for tensile strength and Ti addition desirable for impact value. Mechanical properties of welds are improved for longer degassing time due to reduced gas contents.

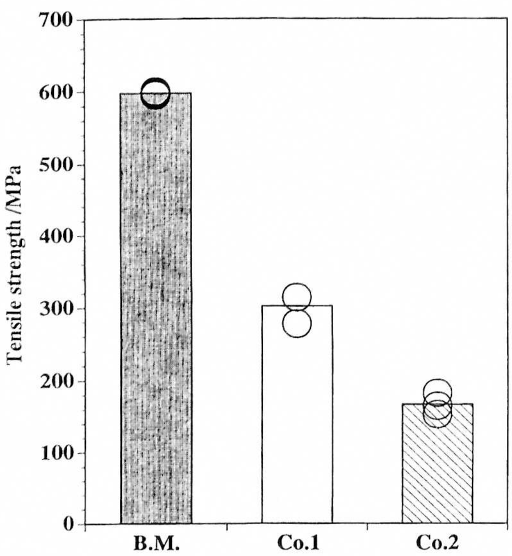


Fig.4 Tensile strength of Al-Li-Cu alloy joints.

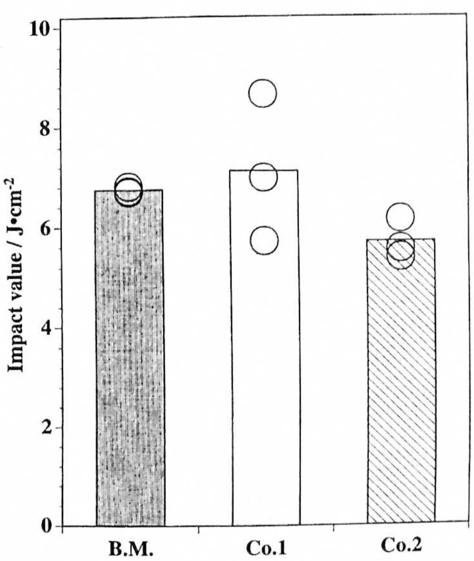
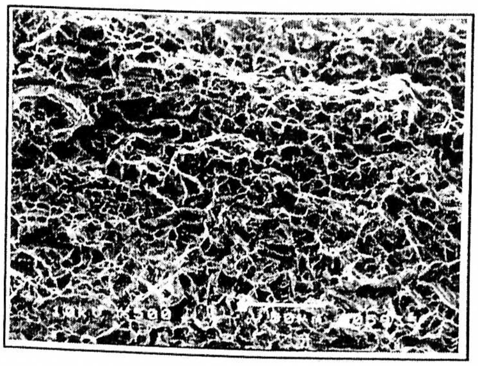


Fig.5 Impact value of Al-Li-Cu alloy joints.

Tensile properties of welded joint for 2090 alloy is on low level and joint efficiency is 50% due to decreased hardness in the weld zone from the T8 treated base metal. It is thought in this case that insert type welding and post heat treatment are necessary for improvement of tensile properties. Impact values of welded joints are slightly higher than that of the base metal due to decreased hardness and increased ductility in the weld metal.



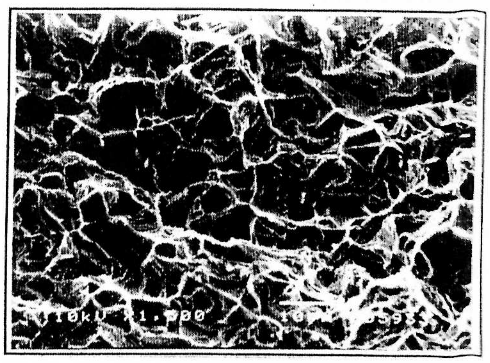


Fig.6 Fractographs of tensile fractured surface for Al-Li-Cu alloy joints (Condition 1).

4. COCLUSIONS

(1) In electron beam welding of Al-Cu-Mg alloys, cracks, porosity and other defects are not observed. The joint efficiency showed 70% of the T4 treated base metal. The proper Ti, Zr additions to the base metal and degassing treatment for longer time influenced the improvement of weldability.

(2) In electron beam welding of Al-Cu-Li alloy, the joint efficiency showed 50% of the T8 treated base metal and weld defects such as cracks were not observed. Impact values of the welded joints were slightly higher than those of the base metal.

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