Journal of Alloys and Compounds 717 (2017) 78–92

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

Influence of laser offset on laser welding-brazing of Al/brass dissimilar alloys

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ARTICLE INFO

Article history:
Received 5 January 2017
Received in revised form
7 March 2017
Accepted 9 May 2017
Available online 10 May 2017

Keywords:
Dissimilar metals
Laser welding-brazing
Laser offset
Microstructure
Mechanical properties

ABSTRACT

Laser welding-brazing of dissimilar metals 5052 aluminum alloy and H62 brass in butt configuration was performed with Zn-15%Al filler metal. Laser beam offset was defined as the deviation from the center of the laser beam to the butted joint face. Influence of laser offset (defined Al side (−) and brass side (+)) on microstructure and mechanical properties of welded-brazed joints were investigated. Satisfied and defect-free joints were obtained when laser beam was irradiated at Al side, while poor wetting at the bottom, interfacial cracks and lack of penetration occurred when laser offset was shifted to brass side. When the laser offset was −0.6–0 mm, the interfacial microstructure mainly consisted of serrated layer $Al_{4.2}Cu_{3.2}Zn_{0.7}$ adjacent to the weld seam and continuous layer CuZn close to the brass substrate. When the laser offset moved towards brass side (0.3 mm), Al_4Cu_9 phase formed in between CuZn and $Al_{4.2}Cu_{3.2}Zn_{0.7}$, due to more melting and dissolution of brass. Tensile test indicated that joint strength increased first and then reduced with laser offset from Al side to brass side, and the maximum tensile strength of 128 MPa was obtained at laser offset of −0.3 mm, which was 55.7% of that of Al base metal. All the joints fractured along the bottom of brass side with brittle fracture surface and fracture location extended into the weld seam at the upper of the joints.

1. Introduction

In recent years, fabrication of hybrid lightweight structural components has been attracting much attention due to their economic and technical advantages [1]. Aluminum (Al) and brass (a Cu-Zn alloy) are two typical engineering metals which have high potential for use in the power plants, heat transfer systems, radiators and electrical applications [2,3]. Compared to pure copper, brass offers very useful properties, such as higher plasticity, strength, formability, wear resistance and corrosion performance. These advantages make the brass an excellent candidate for using in some parts of components, such as brass tubes, power plant condensers and petrochemical heat exchangers. The brass exhibits good deformability, machinability and weldability, and moderate ductility, which is more suitable to meet the requirement for the use in such components. Replacing part of brass with Al alloys is of great interest to build a resource-efficient society since the earth is rich in Al element. In addition, Al alloys could reduce materials cost and total weight while maintaining thermal and electrical conductivity [4]. Welding technique has been considered as an effective method to obtain Al/brass joint. However, joining of Al to brass poses great challenges because of their large differences in physical and chemical characteristics. Formation of brittle intermetallic compounds (IMCs) easily occurs when using conventional fusion welding technique, which deteriorates electrical conductivity and mechanical properties of Al/brass joints. Therefore, it is essential to control the formation and growth of Al-Cu IMCs when employing other alternative joining techniques.

Various welding methods, such as explosive welding [5,6], diffusion welding [7,8], cold roll welding [9,10], ultrasonic spot welding (USW) [11] and friction stir welding (FSW) [2,3,12–18] have been investigated for joining Al to Cu or Al to brass. Typical $CuAl_2$, Cu_9Al_4, CuAl brittle phases were produced at the interface in the fusion welding processes. The main works focused on the optimization of process parameters and investigation of microstructure evolution. However, no IMCs were produced at the Al/Cu

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http://dx.doi.org/10.1016/j.jallcom.2017.05.099
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interface when employing USW process by using Al 2219 alloy particle interlayer [9], which was favorable for the mechanical properties of the joint.

Friction stir welding (FSW) is a solid state welding process, which is suitable for joining dissimilar metals Al and brass since it could minimize the formation of brittle IMCs without any melting of base metals under the action of stirring effect and a lower heat input. Previous studies mainly focused on the joining of Al to copper, but few works have been conducted to dissimilar Al and brass welding. Few research results on joining Al and brass could be found by using FSW process [2,3,16–18]. The process parameters were optimized using Taguchi technique [17] and effect of rotation speed on intermetallics formation was investigated [18]. Formation of $CuAl_2$, Cu_9Al_4, CuAl, CuZn was observed at the stirring zone and some reaction products were dispersed in the shape of irregular particles or blocky fragments due to strong stirring action. These composite-like structures were beneficial to the metallurgical bonding and mechanical properties [15,19]. In addition, Zn foil in between Al and brass was found to improve the mechanical properties of friction stir brazed joint by inhibiting the excessive formation of harmful Al-Cu IMCs [3].

Welding-brazing technique is an alternative method available for joining dissimilar metals, particularly with large difference in melting points [20,21]. During the welding-brazing process, fusion-welding joint forms at the side of low-melting point material by mixing filler metal and base metal, while brazed joint is produced through the brazing of filler in the high-melting-point material side. Some studies on welding-brazing of Al/Cu were reported in the literature [22–24], which mainly focus on controlling the growth of IMC by adjusting the heat input accurately. Peng et al. [22] and Zhou et al. [23] studied the microstructural characteristics of Al/Cu gas tungsten arc welding-brazing joints, and indicated that the interfacial layer mainly consisted of AlCu and Al_4Cu_9 phases with thickness varied with heat input. Feng et al. [24] reported that large heat input could promote the growth of the Al-Cu IMCs and suitable IMC layer thickness could improve the tensile strength of the lap-welded joints by cold metal transfer (CMT) welding.

To control heat input more precisely and improve the welding efficiency, laser welding-brazing of Al and brass is proposed. Laser welding-brazing technique can provide high energy density and low heat input compared to arc welding-brazing, and thus it can avoid many metallurgical problems associated with conventional fusion welding processes. Mai et al. [25] studied laser welding of Al/Cu dissimilar metals and found that the formation of brittle IMCs could be avoided by controlling the melting ratio of metals. Afterwards, laser welding-brazing of Al/Cu dissimilar metals was performed and a uniform IMC layer with thickness of less than 3.2 μm was formed [26–29]. Dong et al. [28] obtained Al-Cu joints by laser penetration brazing (LPB) and found brittle Al_2Cu_3 and Al_2Cu IMCs formed at the joint interface, and the maximum tensile strength was more than 94% of that of the aluminum alloy base metal. To our best knowledge, limited number of reference works has focused on topic of the joining of Al alloy to brass by laser welding-brazing process.

In the present work, laser welding-brazing of 5052 aluminum alloy to H62 brass dissimilar alloys with Zn-15%Al filler metal were performed. In previous reports [30,31], laser offset was found to have a significant influence on microstructure and mechanical properties during laser welding-brazing of dissimilar metals. Therefore, the objective of this study is to investigate the effect of laser offset on laser welding-brazing characteristics of Al/brass dissimilar joints. In addition, microstructural evolution and interfacial reaction mechanism were elucidated.

2. Experimental procedure

In the present study, 5052-H32 aluminum alloy and H62-Y2 brass sheets were used with both thickness of 2 mm. The sheets were cut into 100 mm in length and 75 mm in width. The chemical composition and mechanical properties of Al/brass base metals are listed in Tables 1 and 2, respectively. Zn-15%Al flux-cored wire (Nocolok flux) with diameter of 2 mm was used as a filler metal. Zn based filler was selected as the appropriate filler metal for Al/Cu brazing joint since Zn could increase the solid solubility of Cu in Al and reduce the possibility of formation of intermetallic compounds [32–35]. To enhance the fluidity of molten filler metal and obtain good weld appearance, an asymmetrical joint configuration was employed. A 45° Y-shaped bevel with 1-mm root face height was cut on the brass side.

Fig. 1 shows the schematic of laser welding-brazing of Al to brass. A fiber laser (IPG YLR-6000) with a wavelength of 1070 nm and a beam parameter product (BPP) of 7.2 mm mrad were used in this work. The laser beam was focused by a 200-mm lens to have a focused spot size of 0.2 mm, transmitted by a 200-μm core diameter fiber. Before welding, the surface of sheets was cleaned using a wire brush and acetone. The laser beam was irradiated on the workpiece vertically. The flux-cored filler wire was fed in front of the laser beam with an angle of 30°. The molten pool was protected by Argon shielding gas with a flow rate of 15 L/min to prevent oxidation. After preliminary trials, the main process parameters were optimized. The laser power, welding speed, filler wire feeding speed and laser defocusing distance from surface were kept constant at 2700 W, 0.5 m/min, 1.5 m/min and +20 mm, respectively. The laser beam offset (represented by ΔF) is defined as the deviation from the center of the laser beam to the butted joint face. Laser beam at brass side was defined as positive offset, as indicated in Fig. 1. The laser beam offset was varied from −0.6 mm to 0.3 mm in this work.

After laser welding-brazing process, typical cross sections of the joints were cut perpendicular to the welding direction by DK7732B-CG electro-discharge machining (EDM). The standard metallographic samples were prepared and etched with Keller's reagent (3 ml HNO_3, 6 ml HCl, 6 ml HF, 150 ml H_2O) for 2 s and then observed on a DSX510 optical microscope (OM) and a MERLIN COMPACT scanning electron microscopy (SEM) equipped with an energy dispersive spectrometer (EDS) for chemical composition analysis. Analysis for phase composition and structure was performed using a JDX-3530M X-ray diffractometer (XRD) with Cu Ka radiation. To further accurately identify the phase formed at the interface, transmission electron microscopy (TEM) was used. The focused ion beam (FIB) technique was used for the TEM sample preparation since it could precisely focus on the micro/nano-scale reaction layer in the Al/brass welded-brazed joints. TEM observation was performed with a TECNAI-G2 F30 operating at a nominal voltage of 300 kV. Phase identification was performed by selected-area electron diffraction (SAED). Microhardness distribution along the weld centerline was tested every 0.4 mm spacing on a MICRO-586 vickers hardness tester using a load of 200 g for 15 s. Specimens for tensile testing were cut

Table 1
Chemical compositions and tensile properties of 5052 Al alloy.

Material	Composition (Wt.%)							Tensile properties	
5052 Al alloy	Al	Si	Fe	Cu	Mg	Zn	Cr	σ_b (MPa)	δ (%)
	Bal.	0.17	0.16	0.02	2.48	0.01	0.20	230	15