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Effect of welding speed on microstructural evolution and mechanical properties of laser welded-brazed Al/brass dissimilar joints

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ABSTRACT

Laser welding-brazing process was developed for joining 5052 aluminum alloy and H62 brass in butt configuration with Zn-15%Al filler. Effect of welding speed on microstructural characteristics and mechanical properties of joints were investigated. Acceptable joints without obvious defect were obtained with the welding speed of 0.5–0.6 m/min, while lower and higher welding speed caused excessive back reinforcement and cracking, respectively. Three reaction layers were observed at welding speed of 0.3 m/min, which were $Al_{4.2}Cu_{3.2}Zn_{0.7}$ (τ')/Al_4Cu_9/CuZn from weld seam side to brass side; while at welding speed of 0.4–0.6 m/min, two layers $Al_{4.2}Cu_{3.2}Zn_{0.7}$ and CuZn formed. The thickness of interfacial reaction layers increased with the decrease of welding speed, but varied little at different interfacial positions from top to bottom in one joint. Tensile test results indicated that the maximum joint tensile strength of 128 MPa was obtained at 0.5 m/min, which was 55.7% of that of Al base metal. All the joints fractured along the weld seam/brass interface. Some differences were found regarding fracture locations with three and two reaction layers. The joint fractured between Al_4Cu_9 and τ' IMC layer when the interface had three layers, while the crack occurred between CuZn and τ' phase in the case of two layers.

1. Introduction

The joining of dissimilar materials is becoming increasingly important in industrial applications due to their numerous advantages. These include not only technical advantages of desired product properties, but also benefits in terms of production economics [1–3]. Aluminum (Al), copper (Cu) and brass (a Cu-Zn alloy) are common engineering materials widely used in the aerospace, transportation, radiators, heat transfer systems, power plants, and electrical applications. The development Al and Cu or Al and brass hybrid structures for industrial components has been receiving great attentions, because of their economic and technical advantages not only in weight reduction and resource saving, but also for the requirement of some special performance in certain occasion. Welding technique has been considered as a top priority for fabricating these dissimilar joints. However, conventional fusion welding is not applicable for joining Al to Cu or Al to brass due to their huge differences in physical and chemical properties [4]. Moreover, easy formation of cracking and brittle intermetallic compounds (IMCs) is expected in fusion welded joint because of high affinity between Al and Cu, which seriously deteriorates the mechanical properties.

Therefore, various welding methods, such as cold roll welding [5–10], diffusion bonding [11,12], explosive welding [13,14], magnetic pulse welding [15–17], and friction stir welding (FSW) [18–20] have been developed as alternative joining processes for joining Al to Cu. Typical $CuAl_2$, Cu_9Al_4 and CuAl brittle phases were produced at the interface in these welding processes. The main works focused on the optimization of process parameters and investigation of microstructure evolution. Friction stir welding (FSW) is a solid state welding process, which is suitable for joining dissimilar metals Al/Cu and Al/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 researches mainly focused on the Al/Cu welding, but few works have been conducted on joining dissimilar Al and brass welding. Limited research results on joining Al and brass could be found using ultrasonic welding and FSW processes [21–27]. Satpathy et al. [21] designed the acoustic horn based on the finite element analysis and then optimized process parameters using ultrasonic welding technique. A1100 and CuZn37 sheets with thickness of 0.1 mm were successfully welded with maximum strength of 4.05 MPa. A nonlinear regression equation was proposed to help optimize its process parameters. Esmaeili et al.

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[22,23] investigated the metallurgical and mechanical properties of FSWed aluminum1050 to brass (CuZn30). Formation of a composite-like structure and a narrow multilayer IMCs including CuZn, $CuAl_2$ and Cu_9Al_4 were observed at optimized condition, resulting in a strong joint strength. However, large brass fragments lowered strength. Akbari and Behnagh also observed a dark area consisting of CuZn, $CuAl_2$ and Cu_9Al_4 at the stirring zone when joining of 5083 Al alloy to CuZn34 brass [24]. In addition, to inhibit the excessive formation of harmful Al-Cu IMCs, Huang et al. [25] recently placed Zn foil in between 6061 Al alloys and H62 brass by using friction stir brazing. Zn was considered to increase the solid solubility of Cu in Al and decrease the presence of IMCs.

Recently, welding-brazing or brazing technique has been proposed for joining dissimilar metals, particularly with large difference in melting point. The proper brazing filler was selected that readily mixed with Al base metal and wetted the surfaces of copper at the operating welding-brazing temperature. Some studies on welding-brazing and ultrasound-assisted brazing of Al/Cu were investigated and the results were reported in the literature [28–31], which mainly focus on the influence of interfacial reaction layer on mechanical properties and controlling the growth of IMC by adjusting the heat input accurately.

Laser welding or laser welding-brazing process was developed for joining Al to Cu as it could control heat input more precisely to inhibit the formation of IMCs and thus improve the joint performance. Laser welding of Al to Cu was attempted in the earlier study by Mai and Spowage [32]. They found joining of Al 6061 (heat-treated alloy) to Cu were not successful because of its poor weldability and high crack susceptibility. However, sound joints were obtained when joining Al 4047 to Cu at lower welding speed. When the welding speed was greater than 100 mm/min, solidification cracks were observed. Afterwards, laser welding-brazing of Al-Cu connections was performed and homogenous interface of IMCs was observed with a thickness of less than 3.2 μm [33,34]. Electrical performance was then investigated, and the results indicated two parallel weld seams with optimized spacing and overlap design provided lowest contact resistance. To our best knowledge, few attempts have been made on the joining of Al alloy to brass by laser welding-brazing process.

In this work, dissimilar metal joining of 5052 aluminum alloy to H62 brass was performed by laser welding-brazing dissimilar alloys with Zn-15%Al filler metal. The objective of this study is to investigate the effect of welding speed on the microstructural characteristics and the mechanical properties of laser welded-brazed joints. Furthermore, microstructural evolution and interfacial reaction mechanism was elucidated.

2. Experimental procedure

The base metals used in this work were 5052-H32 aluminum alloy and H62-Y2 brass sheets, both with thickness of 2 mm. The sheets were cut into 100 mm long and 75 mm wide. A 45° Y-shaped bevel with 1-mm root face height was cut on the brass side. The chemical composition and mechanical properties of Al alloys and brass base metals are listed in Tables 1 and 2, respectively. Zn based filler was selected as the appropriate filler metal for Al/brass brazing joint in previous studies, since Zn could increase the solid solubility of Cu in Al and reduce the formation of intermetallic compounds [28–31]. Therefore, the filler metal employed in the present study was Zn-15%Al flux-cored wire (Nocolok flux) with a diameter of 2.0 mm. To enhance the flowability of molten filler metal and obtain good weld appearance, A 45° Y-shaped groove 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 study. The focused spot size of laser beam was 0.2 mm, focused by a 200-mm lens and transmitted by a 200-μm core diameter fiber. The surface of the base metal sheets was cleaned using a wire brush, followed by 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 laser power, and laser defocusing distance were kept constant at 2700 W and +20 mm, respectively. The defocusing distance was optimized to completely irradiate the filler metal and thus improved the welding stability. Laser beam offset was optimized to be 0.3 mm from butt line towards Al side. The welding speed (represented by v) was varied

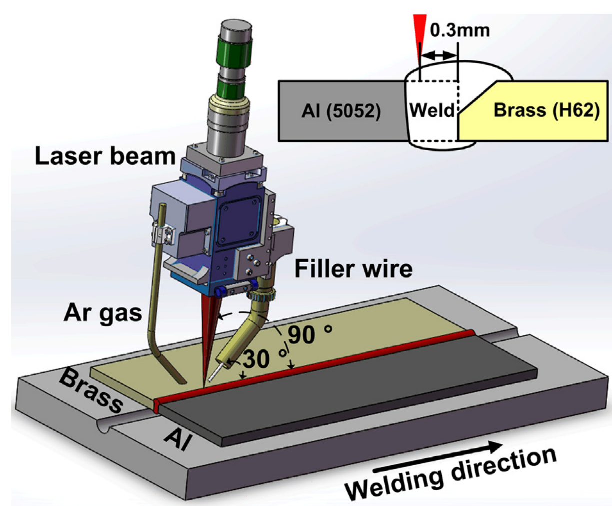

Fig. 1. Schematic of laser welding-brazing of Al to brass.

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

Table 2
Chemical compositions and tensile properties of brass H62.

Material	Composition (wt.%)					Tensile properties	
H62	Cu	Fe	Pb	Sb	Zn	σ_b (MPa)	δ (%)
	60.5–63.5	≤0.15	≤0.08	≤0.005	Bal.	315	18