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Large spot laser assisted GMA brazing–fusion welding of aluminum alloy to galvanized steel

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ABSTRACT

Through positioning the leading laser as an auxiliary role, and the trailing arc as the main heat source, aluminum alloy (Al) was joined to galvanized steel plate with lap joint. The brazed seam width w increased with the increasing of heat input. The appropriate laser-wire distance D_{lw} and defocusing distance d_f to obtain the good fusion weld appearance were 5 mm and +20 mm, respectively. The fracture position of tensile test sample was divided into brazed interface fracture ($P < 0.6$ kW) and HAZ$_{Al}$ fracture ($P > 0.6$ kW). The maximum tensile strength of dissimilar joint reached 75% of that of Al. The shear strength was mainly decided by heat input, and the brazed seam had the highest microhardness. Joining mechanism of this process was summarized into two factors: the effective function of laser and the metallurgical function of zinc. Compared to gas metal arc welding (GMAW), large spot laser assisted GMA process improved weld appearance and enhanced the process stability and its time-efficiency.

1. Introduction

Lightening in automobile industry needs joining aluminum alloys (Al) to steel, which can improve fuel efficiency and achieve lower exhaust emission. Various solid-state welding processes (e.g. friction welding, explosive welding, and friction stir welding) have been employed to join Al to steel and sound joints with good mechanical properties were obtained. These methods, however, are limited to workpiece shape, joint dimension, structure configuration, etc.

A novel technique named brazing–fusion welding has been proposed. Through combining the advantages of brazing and fusion welding, this method can limit the thickness of intermetallic compounds (IMCs) layer less than 10 μm, the critical value suggested by Schubert et al. (2001) to obtain good mechanical properties. Several trails employing different heat sources such as welding arc or laser beam have been conducted. Dong et al. (2012) conducted the brazing–fusion joining of Al and galvanized steel by gas tungsten arc welding (GTAW) through different filler wires, and found that IMCs layer could be suppressed to 2 μm with Al–12%Si filler wire. Flux-cored filler wires were also used in GTAW by Murakami et al. (2003) and Dong et al. (2010). Zhang and Liu (2011) investigated gas metal arc welding (GMAW) of Al/steel and claimed the tensile strength of the joint could reach 193.6 MPa under appropriate heat input. Following the focus on controlling heat input and spatter, cold metal transfer (CMT) brazing–fusion welding of Al/steel was studied. Jácome et al. (2009) showed that it was feasible to obtain resultant butt joints with strength as high as the ones of the parent materials after optimizing parameters. Zhang et al. (2007) found that despite the formation of IMCs, weakest location of the CMT brazing–fusion welded Al/steel joint was the heat-affected zone (HAZ) of Al. However, this process is only applicable to thin plate and has limitation in welding speed. Considering the advantages such as high speed, precise control of low heat input offered by laser beam, laser brazing–fusion technology was investigated consequently. Dharmendra et al. (2011) studied the effects of welding parameters on IMCs layer, high strength lap joints with failures on Al side were obtained. Nocolock flux was also used by Song et al. (2004) to enhance the wetting of liquid filler metal on steel surface in laser brazing–fusion process. This method, however, includes difficulties in poor gap bridging ability, low laser absorptivity, etc.

To solve above mentioned problems existed in Al/steel electric arc or laser brazing–fusion welding while further improve joint performance, laser-arc hybrid brazing–fusion process was proposed. Thomy and Vollertsen (2012) obtained joints with the strength exceeding 180 MPa at an elevated speed of 6 m/min on laser-CMT hybrid brazing–fusion welding of Al/steel. The IMCs layer formed during hybrid brazing–fusion process was further studied in depth by Mei et al. (2013).

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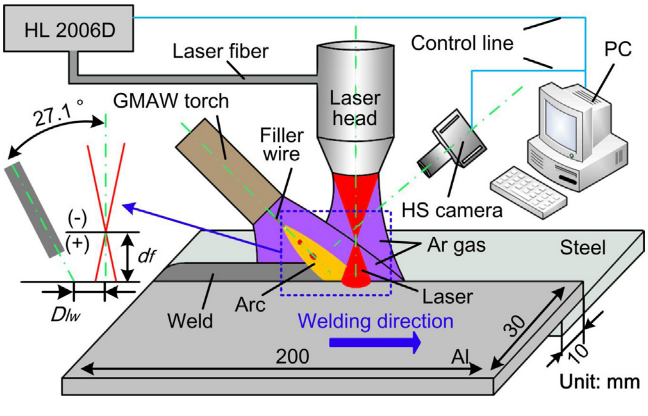

Fig. 1. Schematic of laser assisted GMA experimental system.

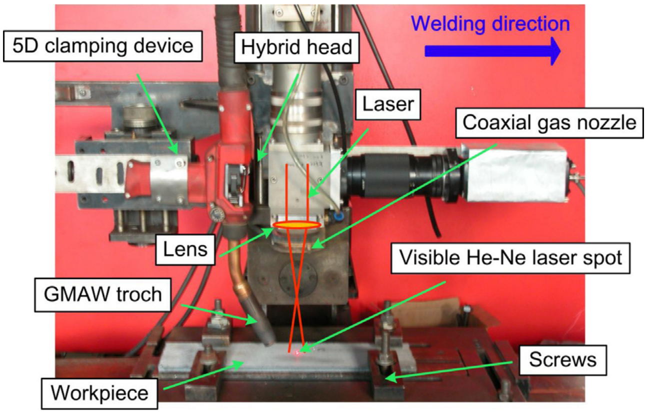

Fig. 2. Laser assisted GMA arc welding head.

In traditional laser-arc hybrid welding process, small spot laser beam with high energy density was used to get deep penetration, the positive effects of laser on stabilizing arc, improving bead formation, which were more important for brazing–fusion welding, were underestimated. In this paper, a modified laser-gas metal arc (GMA) brazing–fusion welding technique using large spot laser which was named large spot laser assisted GMA brazing–fusion welding was presented, in which the leading laser worked on the defocusing state in order to stabilize arc and preheat steel, while the trailing electric arc acted as the main heat source. Al to galvanized steel with lap geometry was successfully joined, and the effect of welding parameters on weld shape, mechanical properties of the joints were investigated. The joining mechanism of this new technique was revealed preliminarily.

2. Experimental details

2.1. Materials

The cold rolled hot-dip galvanized steel plate (zinc coating weight: 157 g/m^2, both surfaces coated) with the dimension of 200 mm × 30 mm × 1.2 (default) or 2 mm and commercial 5A02 Al alloy (Al–Mg system) with the dimension of 200 mm × 30 mm × 1.5 (default) or 1 mm were used in this study. Al based filler wire ER4043 with the diameter of 1.2 mm was used. The nominal chemical compositions and mechanical properties of substrates and filler wire are listed in Table 1.

2.2. Brazing–fusion welding process

Lap joints were prepared by placing Al over galvanized steel with an overlap length of 10 mm. Fig. 1 presents a schematic illustration of the experimental system, which was performed using Haas HL 2006D lamp-pumped Nd:YAG solid laser oscillator and Fronius TPS 5000 digital GMAW power source, operating in the one-droplet-one-pulse mode. A matched wire feeding system was used. Continuous wave laser with an emission wavelength of 1.06 μm was delivered by optical fiber to a 200 mm focal length focusing mirror providing a focus of 0.6 mm in diameter. Then, laser was defocused to obtain large laser spot with 3–5 mm in diameter on the top surface of Al. A paraxial hybrid welding head combined laser and GMAW torch was developed, as shown in Fig. 2. Laser irradiated on the workpiece vertically and the angle of filler wire to laser beam was maintained at 27.1°. Laser beam was aligned with the edge of Al base metal, while the filler wire offset to Al 1 mm with an extension length of 12 mm. Argon with flux of 16 l/min was used as the shielding gas, fed through GMAW torch and a coaxial gas nozzle. Plasma shape was video-graphed with a high speed color camera Photron Ultima 512 at the speed of 2000 fps, positioned transversally to the welding direction. The process variables in the experiments were divided into two categories: heat input parameters, which included welding speed v, welding current I and laser power P, and heat distribution parameters, which included laser-wire distance D_{lw}, defocusing distance d_f.

2.3. Analysis methods

The joint could be divided into brazed seam and fusion weld, as presented in Fig. 3(a). Cross-sectioned specimens were prepared according to the standard metallographic procedures, and then etched with 0.5% HF water solution and Nital (2% HNO_3 ethanol solution) to revealed Al and steel structures, respectively. Using Olympus PME-3 optical microscope, the macrostructure of joints was photographed while brazed seam width w was measured to describe weld shape quantitatively. The Vickers microhardness test was carried out to estimate local mechanical properties of different regions, three repetitions for each region were performed. The tensile test and pressure shear test were conducted using sheet-like samples at room temperature. The Instron 5569 universal testing machine operated in displacement control was used with a constant crosshead speed of 1 mm/min. The fixtures shown in Fig. 3(b) were designed to minimize torque and bending of the samples during shear test. The tensile strength and shear strength were calculated as:

$$\sigma_b = \frac{F}{A_1} = \frac{F}{l \times \delta} \qquad (1)$$

$$\tau = \frac{F}{A_2} = \frac{F}{l \times w} \qquad (2)$$

Table 1
Nominal chemical compositions and mechanical properties of base metals and filler wire.

Materials	Nominal chemical composition (wt.%)								Mechanical properties	
	C	Si	Mn	Mg	Cu	Zn	Fe	Al	UTS (MPa)	EL (%)
Steel	0.04	0.05	0.29	–	–	–	Bal.	–	380	39
5A02	–	0.06	0.15–0.4	2.71	0.01	–	0.16	Bal.	202	23–26
ER4043	–	4.5–6.0	0.05	0.05	0.30	0.10	0.80	Bal.	–	–