Materials Letters 172 (2016) 146–148

Contents lists available at ScienceDirect

Materials Letters

journal homepage: www.elsevier.com/locate/matlet

Study on MIG-TIG double-sided arc welding-brazing of aluminum and stainless steel

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ARTICLE INFO

Article history:
Received 17 September 2015
Received in revised form
16 February 2016
Accepted 27 February 2016
Available online 2 March 2016

Keywords:
Double-sided arc welding-brazing
Welding
Microstructure
Metals and alloys
Dissimilar metal welding

ABSTRACT

MIG-TIG double-sided arc welding (DSAW)-brazing process was firstly conducted to join aluminum alloy and stainless steel using Al-Si filler metal and Nocolok flux. The joints were made at different welding parameters. The formation and microstructure of the weld interface were investigated. The bonding quality of the joints was examined by standard tensile tests. Based on the results, a sound welding-brazing joint with excellent front and back formation was formed. Compared with conventional welding, the welding heat input of T/M-GSAW was smaller and more uniform along the joint thickness. The thickness of the intermetallic compound layer, equal under the same welding condition, was thinner and altered with the welding heat input. The tensile strength of most joints reached 80 MPa and fracture occurred in the HAZ of aluminum.

1. Introduction

By virtue of weight reduction and energy saving, hybrid structures of aluminum alloy and stainless steel are potentially useful in spacecraft, airplane and automotive [1,2]. In the conventional welding, it is difficult to joining aluminum alloy and stainless steel together. The reason for this is large number of brittle intermetallic compounds (IMCs) is formed in the joint. Further, differences in thermal properties lead to residual stress after welding, which often generates deformation and cracks. Therefore, solid-state welding methods, such as explosive welding, friction stir welding and ultrasonic welding, have been used to join these dissimilar metal joints, but the shape and size of such solid-state joints are extremely restricted [3–5].

The welding-brazing offers a great potential for aluminum alloy and stainless steel joining, being an effective approach to reduce the residual stress and control the thickness of the intermetallic layer. In welding-brazing process of aluminum alloy and stainless steel, the sheets and filler metal are heated or melted by heat source, and the joint has a dual characteristics: in aluminum alloy side it is a welding joint, while in stainless steel side it is a brazing joint [5,6]. In the conversional welding-brazing, the heat source is located on one side of the joint, which leads to heat input of the joint back is insufficient. Also, for inadequate protection of the joint back, the molten metal can easily be oxidized. Therefore, the liquid aluminum alloy cannot wet and spread on the back of stainless steel, it is difficult to realize butt joining of the hybrid structure [7,8].

MIG-TIG double-sided arc welding is a novel method, which is a kind of double-sided arc welding (DSAW) proposed to improve the welding efficiency [9,10]. By now, there is no report about MIG-TIG DSAW-brazing of aluminum alloy and stainless steel. The main feature of this method is double-sided protection, MIG and TIG vertically placed in both sides of the joint respectively, which can keep the joint clean during welding process. As both sides of the joint are heated at the same time, welding heat input is re-distributed compared with the conventional arc welding-brazing, which can make the joint back receive enough welding heat for liquid aluminum alloy wetting and spreading. Also, the welding heat input is smaller and more uniform, which can decrease or even eliminate residual stress in the joint and restrict the IMC more effectively. Another advantage adding MIG filler reduces the sensitivity of the welding process on linear misalignment.

In this paper, MIG-TIG double-sided arc welding–brazing combining non-corrosion flux is firstly applied to join pure aluminum and stainless steel. After welding, the joint formed by the method is investigated and its microstructures, especially the brittle IMC structures in the interfacial layer, are characterized; the tensile strength of the joint is evaluated.

2. Experimental procedures

A schematic diagram of the MIG-TIG double-sided arc welding–brazing process is shown in Fig. 1. The consumable welding torch

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http://dx.doi.org/10.1016/j.matlet.2016.02.146
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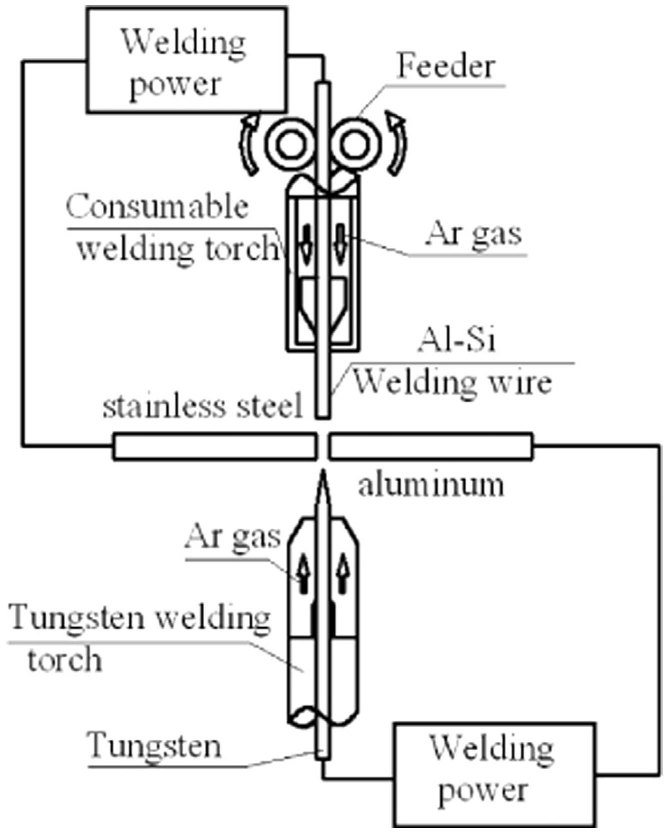

Fig. 1. Schematic diagram of the MIG-TIG double-sided arc welding–brazing process.

and the tungsten welding torch are located in the front and back of the weld vertically. And the base metals are heated and protected by the two torches. By the energy and

space position of the two torches, the wetting and spreading of the AlSi5 filler and aluminum alloy base metal on the TC4 titanium alloy and controlling the growth of the intermetallic compound are attained. So a Ti/Al dissimilar metal butt joint with the sound appearance and the excellent mechanical properties is achieved.

The materials used for these investigations were 1060 pure aluminum and 304L austenite stainless steel sheets in 2.0 mm thickness. The filler metal was 4043 Al-Si welding wire with the diameter of 0.8 mm. The non-corrosive flux in welding was Nocolok flux. Before welding, the sheets were cut in the size of 200 mm × 60 mm, the surface of which was prepared by conventional grinding and polishing techniques. Subsequently, samples were cleaned in acetone and dried using compressed air. The flux suspension (Nocolok flux dissolved in acetone) was smeared in 0.2–0.5 mm thick on the faces of the stainless steel. The length of butt gap was 1–2 mm. The butt MIG-TIG double-sided arc welding–brazing was carried out using MILLER MIG and TIG welding sources. The TIG welding parameters were welding current of 20–40 A, arc length of 4 mm, welding rate of 200–400 mm/min and argon flow rate of 15 L/min. And the MIG welding parameters were welding voltage of 13–15 V, wire extension length of 10 mm and wire feed of 5.8–6.8 m/min with the same welding rate and argon flow rate as TIG's.

Typical transverse sections of the joints were observed by scanning electron microscopy (SEM). The composition of the intermetallic compound layer at the interface between the weld metal and stainless steel was determined by energy dispersive X-ray spectroscopy (EDS). In order to examine the quality of the joint between 1060 pure aluminum and 304L austenite stainless, the tensile strength were performed. Three samples in same condition were tested and the average value was reported.

3. Results and discussion

3.1. Appearance and macrostructure

Fig. 2(a) and (b) shows the appearance of the Al-stainless steel butt joint made by MIG-TIG double-sided arc welding–brazing. A continuous uniform bead can be formed during the process. On both sides of the joint, the filler metal has fully spread on stainless steel and the quantities of the molten metal are basically identical, for the distribution of welding heat is more reasonable and uniform. A good front and back formation has been obtained and no crack appears on the surface of welded seam.

The typical cross-section of Al-stainless steel joint is shown in Fig. 2(c). Under the interaction of the arc and Nocolok flux, the Al-Si filler metal spread fully on steel surface to form a sound joint. The joint is a typical welding–brazing: In stainless steel side, the steel surface with high melting temperature is a brazing joint, which reacts with the molten filler metal to form the brazing interface layer, while in aluminum side, the pure Al with a low melting point is a welding joint, which mixes with the molten filler wire to form fusion zone.

3.2. Microstructure and inter metallic

Fig. 3 exhibits SEM images in different areas of the joint in Fig. 2. A thin intermetallic compound layer which presents an irregular shape with a slightly serrated border has formed between the stainless steel and welded seam, as shown in Fig. 3(a), (b) and (c). The IMC layer almost has the same pattern along the boundary, because of low and uniform heat input on both sides of the joint. For double-sided arc welding heating, the welding heat input is smaller and more even. Hence the thickness of the IMC layer is the smallest and 2–3 μm at the middle, the upper is 3–4 μm and the bottom is 3–5 μm. And the thickness of the whole IMC layer is uniform and less than the limited value of 10 μm [11]. The welded seam, as shown in Fig. 3d, mainly consists of dark grey matrix, distributed with light grey phase. Fig. 3e shows the interface between aluminum and welded seam is in arc shape, as the heat input in upper and lower position of the joint is higher than that in the middle due to the two arcs in both sides.

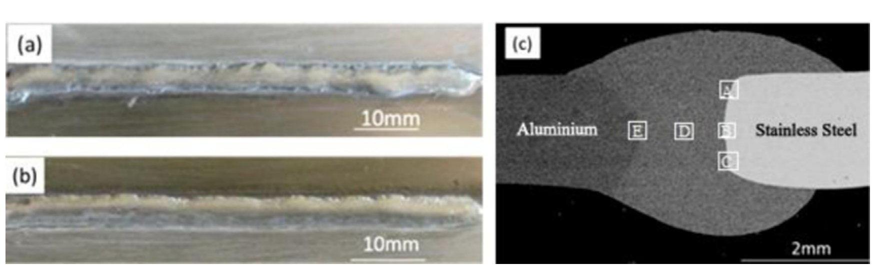

Fig. 2. Appearances and cross-section of the aluminum–stainless steel butt joint: (a) the joint face (b) the joint back (c) the joint cross-section.

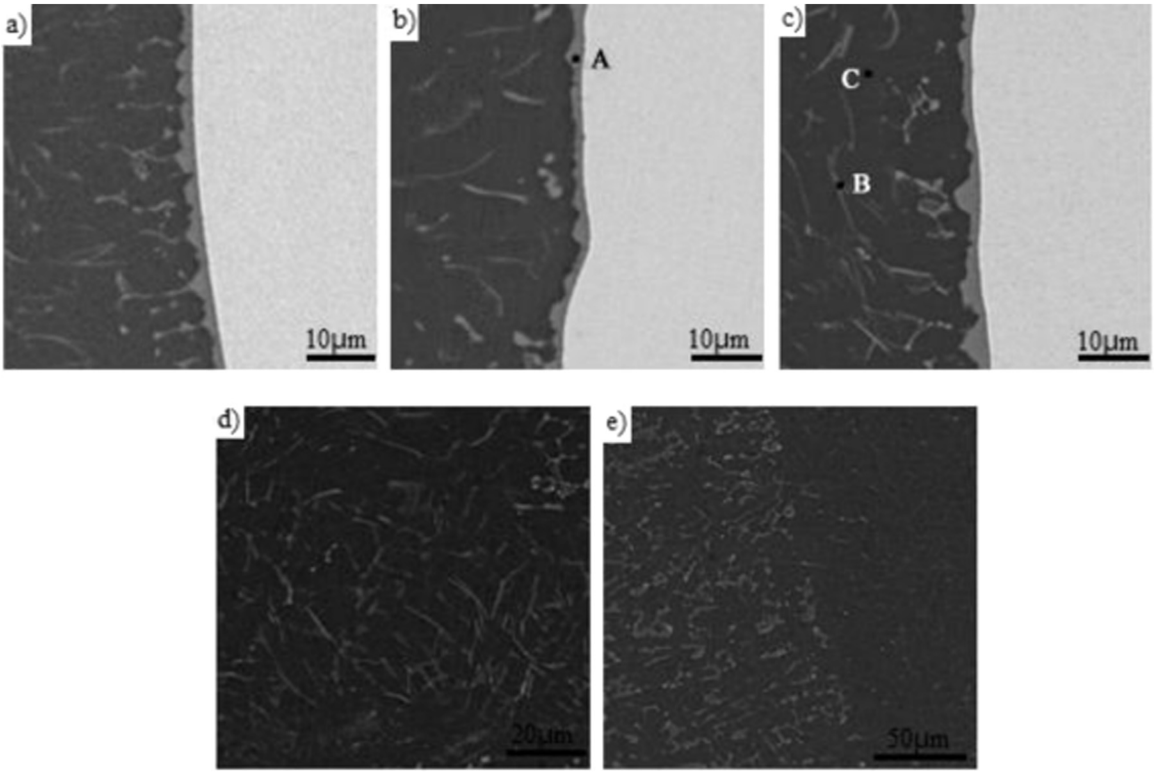

Fig. 3. SEM images in different position of the Al-stainless steel joint: (a) IMC layer in A zone, (b) welded seam in B zone, (c) fusion area in C zone.

Table 1
EDS results of intermetallic phases in the joint (at%).

	Chemical composition (at%)					Phase constituents
	Al	Si	Fe	Cr	Ni	
A	70.80	8.22	16.17	4.01	0.80	τ_5-$Al_{7.2}Fe_2Si$
B	80.09	11.72	8.19	–	–	Al-Si eutectic phase
C	97.17	2.83	–	–	–	α-Al

In order to identify the phase structures pointed by arrows in Fig. 3a, the EDS analysis was carried out, as shown in Table 1. According to the Al-Fe-Si ternary phase diagram, the interface between welded seam and stainless steel is speculated toτ_5-$Al_{7.2}Fe_2Si$ which inhibits liquid aluminum reacting with solid stainless steel, for growth energy of Al-Fe-Si ternary phase is lower than that of Al-Fe binary phase and cooling rate is rapid. Different from previous researches, the IMC layer is simpler and thinner, as the welding heat input is smaller. The welded seam consists of α-Al matrix (dark grey C) and Al-Si eutectic phase (light grey B), with Fe dispersed in the welded seam.

3.3. *Tensile test results*

The tensile tests are carried out to measure the joint strength and behavior. Most of average tensile strengths of the butt joint, under the welding parameters above, reach 80 MPa and fracture occurs at the HAZ of 1060 aluminum. Only when TIG welding current is 40 A, MIG welding voltage is 15 V, MIG wire feed is 6.8 m/min and welding rate is 200 mm/min, the average tensile strength is about 30 MPa and fracture occurs is located at the IMC layer, for too high welding heat input makes IMC layer thicken.

4. Conclusions

(1) Sound welding-brazing butt joints, with excellent front and back formation, are achieved by MIG-TIG double sided arc welding- brazing with Al-Si filler metal and Nocolok flux.
(2) Wetting and spreading behavior of liquid aluminum alloy is excellent on both sides of stainless steel surface and no welding deformation happens.
(3) The thickness of the IMC layer, nearly equal under the same condition, is thinner and simpler than that of conversional welding-brazing. And the IMC layer is τ_5-$Al_{7.2}Fe_2Si$ phases.
(4) Most of average tensile strengths of the butt joint reach 80 MPa, with fracture located at HAZ of 1060 pure aluminum. When the thickness of the IMC layer is 15 μm, the tensile strength declines sharply and fracture occurs at the IMC layer.

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