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Effect of joining parameters on microstructure of dissimilar metal joints between aluminum and galvanized steel

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ABSTRACT

The interfacial microstructures of aluminum and galvanized steel dissimilar joint formed by pulsed double electrode gas metal arc (Pulsed DE-GMA) welding–brazing were characterized. Electron probe microanalyzer (EPMA) analysis revealed that the intermetallic compound layer of the welding–brazing joint consisted of Fe_2Al_5 and $FeAl_3$. Comprehensive analysis of the effect of the heat input parameters showed that, at a constant total welding current (I_{total}), the thickness of intermetallic compound at the interface of aluminum and steel decreased with the increase of bypass current. Thermodynamic calculations were carried out to derive the Gibbs free energy diagram for Fe_2Al_5 and $FeAl_3$. These calculations presented that Fe_2Al_5 firstly formed, subsequently $FeAl_3$ precipitated during welding process. Further model of the Fe_2Al_5 and $FeAl_3$ intermetallic compounds formation process was proposed.

1. Introduction

There has been increasing demands for dissimilar metal joints in industrial applications, such as weight reducing, environmental concern, energy saving, high performance and cost saving [1,2]. Since aluminum alloys are widely used in the transportation industry for the purpose of weight reduction [3,4], the joining of steel and aluminum becomes an essential research and application focus [5]. It is however very difficult to join them together due to the great differences in physical characteristics of these two metals, such as the melting temperature, thermal expansion and the poor metallurgical compatibility. Thus, studies on the joining of aluminum and steel should be carried out to overcome these obstacles [6,7].

It is proved difficult to obtain a sound joint between steel and aluminum by using the conventional fusion-welding process, because hard and brittle intermetallic compounds (IMCs) are formed at the interface due to mutual diffusion during welding [8]. Therefore, many other welding methods have been used to join steel and aluminum, such as the solid-state bonding methods like diffusion bonding [9], explosion welding [10], ultrasonic welding [11], friction stir welding [12], and the welding–brazing methods like Gas Metal Arc Welding (GMAW) [13], Gas Tungsten Arc Welding (GTAW) [14], laser welding [15] and Cold Metal Transfer welding (CMT) [16]. The welding–brazing technique involves welding between the parent aluminum alloy and the filler wire, and brazing between liquid filler wire and solid steel [17,18]. These methods, however, have drawbacks of either high cost or lacking versatility.

In this study, pulsed double electrode gas metal arc (Pulsed DE-GMA) welding–brazing method was adopted to join aluminum and galvanized steel. Pulsed DE-GMA welding–brazing process is a novel welding method with low heat input to the work-piece which is finalized by varying the bypass current with constant total melting current. This paper reports the characterization and thermodynamic modeling of the weld seam appearance and joint interface microstructure between aluminum and galvanized steel with respect to the welding parameters.

2. Experimental details

The materials used in the present investigation were aluminum alloy wire ER5356 with 1.2 mm diameter and galvanized steel work-pieces coated with a Zn layer of 100 g/m^2 (base material was Q235 mild steel). The Zn layer plays the role of corrosion protection, wettability promotion and reduction of weld temperature, therefore, galvanized steel plate was chosen for the present work. The nominal compositions of Q235 mild steel and ER5356 were presented in Table 1. The galvanized steel was supplied as 300 mm × 100 mm × 2 mm sheets. Prior to welding, the surfaces of the galvanized steel samples were cleaned with acetone to remove grease and residues. The welding parameters were shown in Table 2.

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Table 1
Nominal compositions of ER5356 and Q235.

Filler material and base material	Nominal composition (wt.%)											
	Mg	Cr	C	Si	Cu	S	Zn	Mn	P	Ti	Fe	Al
ER5356	5.00	0.10	–	0.30	0.05	–	0.05	0.15	–	0.01	0.40	Balance
Q235	–	–	0.12	0.30	–	0.045	–	0.30	0.045	–	Balance	–

Table 2
Welding parameters of Pulsed DE-GMA welding–brazing.

Dimension of galvanized steel sheets (mm × mm × mm)	Argon gas flow of GTAW welding torch (L min^{-1})	Argon gas flow of GMAW welding torch (L min^{-1})	Average total current (A)	Average current of base metal (A)	Average current of bypass torch (A)	Welding speed (m min^{-1})	Current duty cycle (%)	Pulse frequency (Hz)
300 × 100 × 2	20	5	77	77	0	0.5	20	80
300 × 100 × 2	20	5	77	55	22	0.5	20	80
300 × 100 × 2	20	5	77	45	32	0.5	20	80

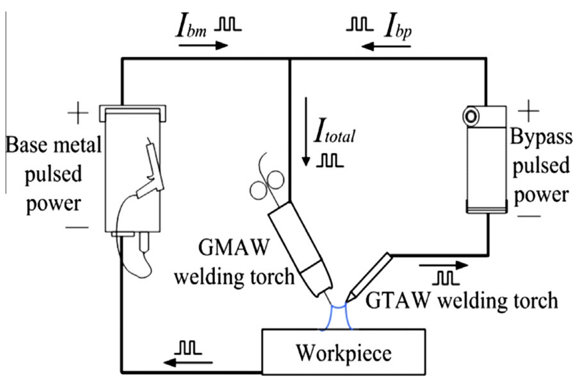

Fig. 1. Schematic illustration of Pulsed DE-GMA welding–brazing.

Basic principles of Pulsed DE-GMA welding–brazing [19,20] were presented in Fig. 1. As illustrated, the welding–brazing system is established based on a conventional GMAW system by adding a bypass torch (nonconsumable tungsten electrode) to decouple the total melting current (I_{total}) into base metal current (I_{bm}) and bypass current (I_{bp}). In this way, the total melting current that melts the wire is the sum of currents, i.e. $I_{total} = I_{bm} + I_{bp}$. Hence, the bypass current and the base metal current can be varied without changing the total melting current. Pulsed currents were employed for both I_{bm} and I_{bp} to reduce heat input to work-piece and increase the electromagnetic force of droplet at the detachment interval which helped to control the thickness of intermetallic compound in weld joint and to achieve good formation of weld seam. Fig. 2 shows the shape of coupling arc under pulsed current.

The pictures of the weld joints were taken following Pulsed DE-GMA welding–brazing process and samples were cut perpendicular to the welding direction of the joint for microstructural examination. For optical microscopic (OM) observations the cross-sections were ground with wet abrasive paper and mechanically polished to obtain mirror-polished section, then etched by 0.5% HF solution. Microstructural characterizations were further carried out by means of scanning electron microscopy (SEM). An EPMA microprobe was employed to study the variation in the chemical composition around the joint interface of weld seam and quantitatively analyzed the composition of the two different intermetallic compound layers formed at the dissimilar joint between the Al alloy and galvanized steel. X-ray diffractometer (XRD) was used to further identify these compounds on the peeled surfaces of the weld joints.

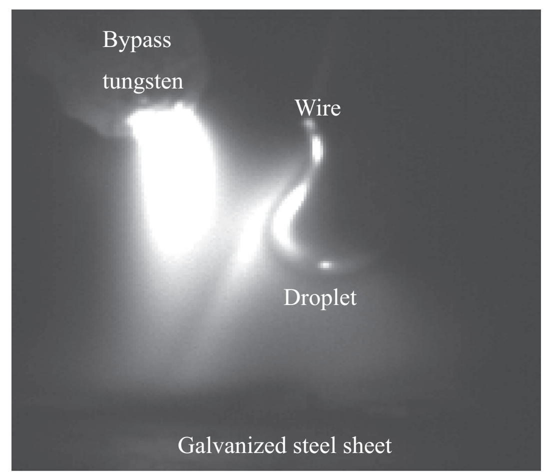

Fig. 2. Shape of coupling arc of Pulsed DE-GMA welding–brazing.

3. Results and discussion

3.1. Weld joint morphology

The appearances of the weld joints obtained with different welding parameters (Table 2) were shown in Fig. 3. It was found that weld width decreased significantly and bead height increased slightly when bypass current increased. The specific changes were shown in Fig. 4. As mentioned above, at a given constant total welding current, the base metal current decreases when the bypass current increases which results in the decease of the heat input and therefore temperature of the base material. The measured highest temperature at the back center of weld joints under different welding parameters was shown in Table 3. Results in Fig. 4 indicate that the increase of the bypass current caused the reduction of the spreading and wetting ability of the weld droplets and therefore the weld width due to the decrease of the base metal temperature. The reason that the wettability of the weld droplets is reduced when the bypass current is increased is that the base metal temperature decreases with the increase of the bypass current which results in the decrease of the wettability.

3.2. Microstructure of weld joint

A low magnification overview of cross-sections of Pulsed DE-GMA welding–brazing joint was shown in Fig. 5. It can be seen