



Tungsten Inert Gas Welding–Brazing of AZ31B Magnesium Alloy to TC4 Titanium Alloy



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Tungsten inert gas (TIG) welding–brazing technology using Mg-based filler was developed to join AZ31B Mg alloy to TC4 Ti alloy in a lap configuration. The results indicate that robust joints can be obtained with welding current in the range of 60–70 A. The joint interface was found to be likely composed of Mg–Ti diffusion reaction layer accompanied with Mg₁₇Al₁₂ precipitate phase, indicating that metallurgical joining was achieved. The optimized joint with average tensile-shear strength of 190 N/mm² was obtained and fracture occurred at the Ti/fusion zone interfacial layer during tensile test. Moreover, the fracture surface was characterized by equiaxed dimple patterns accompanied with a few lamellar tearing. Finally, finite element modeling (FEM) numerical simulation was developed to analyze the distribution characteristics of the temperature field of joints.

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1. Introduction

Titanium alloys, which are characterized by its extraordinary combination of high specific strength, excellent mechanical properties and good corrosion resistance, are used extensively in fields such as aerospace and aircrafts industries^[1,2]. Magnesium alloys, which are considered as the lightest family of the structural metals with a density of one-third of titanium alloys, are of great potential application in automobile industry for the sake of weight saving^[3–5]. Currently, energy saving and ease of exhaust gas emission are important issues and must be urgently resolved. Since weight reduction of the energy consuming components such as vehicles and aircrafts is an effective approach, the joining of lightweight metallic alloys of magnesium to titanium alloys would be a promising approach to achieve this goal.

However, in spite of the great technological importance of Mg/Ti hybrid structure, it is quite challenging to achieve robust joining of Mg/Ti dissimilar alloys owing to the notable mismatch in physical and mechanical properties and lack of metallurgical compatibility^[6]. The maximum solid solubility of Mg in Ti is 0.9 at.% and that of Ti in Mg is 0.02 at.%. The melting points of pure Mg and Ti are about 922 K and 1941 K, respectively. The tremendous difference in the melting points between these two kinds of metals causes the difficulty in melting them at the same time during fusion welding.

Furthermore, the boiling point of Mg (1363 K) was much lower than the melting point of Ti (1941 K), indicating that the molten Ti will cause severe vaporization of Mg when they contact with each other. Therefore, the joining of dissimilar Mg/Ti alloys is difficult with commonly used fusion welding method in theory. Consequently, a wide spectrum of alternative joining techniques such as transient liquid phase (TLP) brazing^[7–9], friction stir welding (FSW)^[10,11], laser keyhole welding^[12,13] and tungsten inert gas (TIG) welding–brazing^[6] have been recently developed specific to the dissimilar joining Mg alloy to Ti alloy. Atieh and Khan^[7–9] achieved TLP brazing of Mg and Ti alloys with double Ni and Cu sandwich foils. The ϵ phase (Mg), CuMg₂ and Mg₂Ni were observed and the maximum shear strength was 57 MPa. Existing literature reveals that FSW of Mg to Ti would result in the formation of Al–Ti intermetallic compounds, which tended to reduce the mechanical strength of joints^[10,11]. Furthermore, Gao et al. achieved Mg/Ti joining by laser keyhole welding with very strict control of laser offset from welding seam to Mg base plate^[12,13].

Of the joining techniques mentioned above, TIG welding–brazing is characterized by its advantages of high efficiency, flexibility, and excellent joining quality^[14–17] and offers a potential for the joining of dissimilar metals, which have tiny mutual solid solubility and great difference in melting point, e.g., Mg and steel^[18–20]. The results showed that the sound joints were obtained. The maximum tensile–shear strength reached 270 N/mm², representing 82.4% joint efficiency relative to the Mg alloy base metal^[20]. In light of the above evidence, it is reasonable to expect that the welding–brazing technology would be applicable in Mg/Ti dissimilar joining as well, according to their

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Table 1
Chemical composition (wt%) of base metal

Base metals	Al	Zn	Mn	Fe	V	Mg	Ti
AZ31B	2.5–3.5	0.5–1.5	0.2–0.6	0.005	–	Bal.	–
TC4	5.5–6.5	–	–	0.3	3.5–4.5	–	Bal.

similarities. However, few reports on the TIG welding–brazing of Mg to Ti can be found in the open literature so far.

In the present work, TIG welding–brazing of AZ31B Mg alloy to TC4 Ti alloy using AZ31B Mg alloy filler was performed. The microstructure, mechanical properties and fracture mechanism of the joint upon tensile–shear loading were studied and discussed by the experimental observations.

2. Experimental Procedures

The experiments were performed with a TIG welding machine (YC-300WP5HGN). Commercially TC4 and AZ31B alloy plates with the same size of 80 mm × 50 mm × 1 mm were employed in the present study, and their chemical compositions are given in Table 1. An AZ31B Mg alloy wire with the diameter of 1.6 mm was chosen as the filler metal. Before welding, the overlapping surfaces were manually polished to remove the oxide film and subsequently assembled in the lap joint configuration with the Mg alloy plate placed on the top of Ti alloy, as shown in Fig. 1. Argon gas was provided to prevent oxidation of the molten filler metal. Furthermore, the optimized welding parameters are shown in Table 2.

After welding, the weldment was machined into a rectangular shape with the width of 15 mm. The specimens were tested on the electronic tensile testing machine with a travel speed of 1.5 mm/min and three specimens were tested for each set of parameter. The cross-sectional microstructures of Mg/Ti lap joints were analyzed by scanning electron microscope (SEM) in Back-scattered electron (BSE) mode with energy dispersive X-ray spectroscopy (EDS). The FEM numerical simulation was carried out by ABAQUS. In addition, the phase constituents at the fracture surface of joints were identified by X-ray diffraction (XRD).

3. Results and Discussion

3.1. Bead shape

Fig. 2 shows the cross-section of the typical Mg/Ti lap joints. Under the TIG heat source, all of the filler metals and Mg base metal

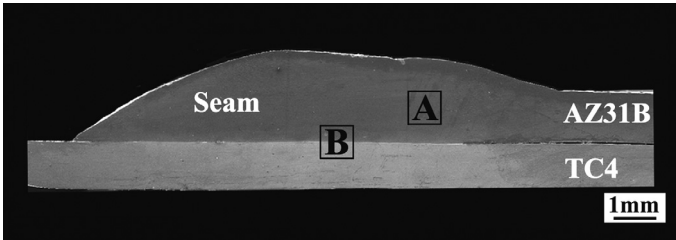


Fig. 2. Typical cross-section of Mg/Ti lap joint.

were welded to form fusion welding zone and then fully spread on the Ti alloy surface to form a robust joint, as shown in area A. On the other hand, brazing occurred between the Mg-based filler metal and the Ti alloy plate, resulting in the formation of metallurgical reaction layer (MRL), as shown in area B.

3.2. Microstructures of joints

Fig. 3 presents the BSE images of interfacial zone of Mg/Ti lap joints. The location in which the interfaces were observed is indicated in Fig. 1. As shown in Fig. 3(a), with the welding current of 40 A, a crack was clearly visible at the initial interface, and the interfacial layer was discontinuous and uneven. Table 3 shows the average thickness of interfacial diffusion reaction layer (DRL). However, with the welding current being increased to 50 A, an average of 2-μm-thick interfacial diffusion reaction layer can be observed at the interfacial zone, as indicated in Fig. 3(b). In addition, since temperature and reaction diffusion time of the interfacial zone increased with the increase of welding current, the average thickness of diffusion reaction layer gradually thickened from 3 to 5 μm, as shown in Fig. 3(c–e).

EDS line scan results of interfacial diffusion reaction layer are also shown in Fig. 3. As shown in Fig. 3(a), no element was detected in the crack, indicating that this area is indeed an unbonded region, which can be ascribed to the insufficient heat input. Therefore, the Mg/Ti assembly could only be partly metallurgically bonded with the welding current of 40 A. However, with the welding current in the range of 50–80 A, the Ti and Al contents gradually increased across the interface from seam to the Ti side, while the Mg content varied in the opposite direction. A thin Mg/Ti diffusion reaction layer was observed at the interfacial zone, which was indicative of the atom diffusion and interfacial reaction occurred despite the fast thermal cycle and short reaction time. The interfacial diffusion reaction layer would be discussed in other section. Note that the reaction layer exhibited a maximum thickness of 5 μm and hence was below the critical thickness of 10 μm^[21]. Namely, the thin interfacial layer was beneficial to the joint strength.

Table 2
Experimental parameters used in the process

Welding parameters	Value
Welding current (A)	40–80
Welding speed, <i>v</i> (m/min)	0.2
Wire feed speed, <i>v_w</i> (m/min)	0.6
Flow rate of shielding gas Ar (L/min)	10
Welding arc length (mm)	2

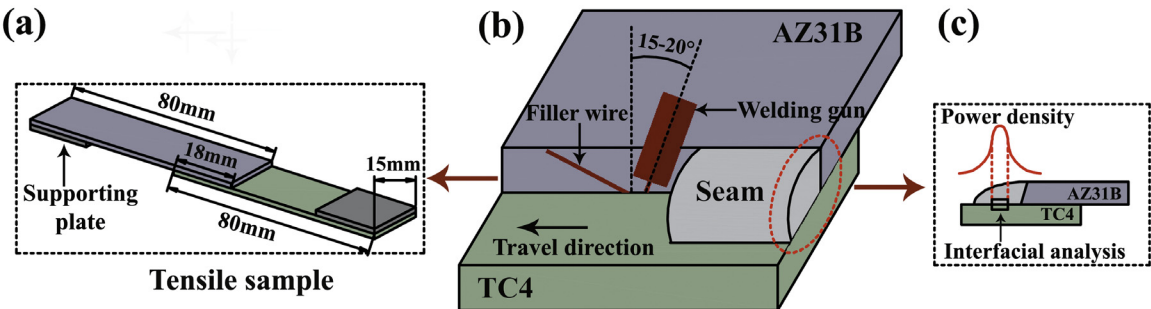


Fig. 1. Schematic diagram of TIG welding–brazing process and tensile test specimen.

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