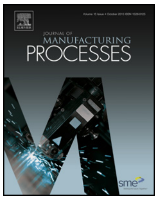
Journal of Manufacturing Processes 32 (2018) 595–605

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

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



Laser conduction welding characteristics of dissimilar metals Mg/Ti with Al interlayer

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ARTICLE INFO

Article history:
Received 17 December 2017
Received in revised form 9 March 2018
Accepted 13 March 2018

Keywords:
Dissimilar laser welding
AZ31B magnesium alloy
Titanium alloy
Interlayer
Microstructure

ABSTRACT

The immiscible and nonreactive characteristics of Mg/Ti dissimilar metals restrict the metallurgical bonding and reliable joining of them. To solve this problem, the Al interlayer between Mg/Ti was added. The Mg/Ti joint without addition of Al interlayer could not be welded, while relatively acceptable appearance was obtained when adding Al interlayer. The interfacial reaction was improved with the assistance of Al interlayer resulting in metallurgical bonding at the interface. The $TiAl_3$ phase formed at the direct laser irradiation zone. Note that the interfacial reaction layer increased little with the increasing thickness of Al interlayer. The interfacial reaction layer was mainly restricted by dissolution of Ti element. Temperature field and thermodynamic calculation assisted to prove the interfacial reaction at the fusion zone/Ti interface and the formation of $TiAl_3$. The tensile-shear testing indicated that the maximum tensile-shear force could reach 2230 N/cm (about 81% of that of AZ31B Mg alloy base metal) when the laser power was 2300 W and the thickness of added Al interlayer was 0.05 mm. The tensile-shear force decreased when network structure of $Mg_{17}Al_{12}$ precipitated in the weld zone. The fracture path changed from fusion zone/Ti to Mg fusion line when the thickness of Al interlayer exceeded 0.12 mm.

1. Introduction

Recently, environment protection and resource saving has received an explosively increasing attention and lightweight structure has an important significance to sustainable development. Magnesium (Mg), as the lightest structural material, has been widely paid attention for its low density, good formability and high strength-to-weight ratio [1,2]. Titanium (Ti) has various useful characteristics, including high strength-to-weight ratio, high-temperature performance, corrosion resistance [3]. Therefore, achieving the reliable bonding of Mg to Ti can make a further development in weight reduction and expand application range, such as reducing vehicle weight and improving fuel efficiency.

However, there is a great challenge to achieve the joining of Mg to Ti for their different metallurgical and physical properties. The melting point of Ti is 1678 °C, while the boiling point of Mg is only 1091 °C which is lower than the melting point of Ti. Moreover, no reaction or diffusion occurs between Mg and Ti elements. Therefore, an intermediate element which can react with or possess substantial solid solubility in Mg and Ti should be used to realize metallurgical bonding between them.

Some welding processes have been employed to join Mg and Ti, including friction stir welding (FSW) [4,5], transient liquid phase (TLP) bonding [6–9], cold metal transfer (CMT) welding [10], tungsten inert gas (TIG) welding [11,12], and laser welding [13,14]. In the FSW process, Ti–Al intermetallic compound played an essential role in the joining of Mg/Ti, but the tensile strength decreased with the increased thickness of this compound [4]. In the TLP bonding process, Ni coating was used and solid-state diffusion was dominant at Ti interface while intermetallic formed at Mg/Ni coating interface [7]. It was proved that microstructural developments and mechanical properties were affected by coating thickness [8]. In addition, nanoparticle within the joint region affected the isothermal solidification rate, giving rise to the enhancement of joint formation [9]. As for CMT welding, Al and Zn elements from Mg base metal and Mg wire was essential to realize successful joining of Mg and Ti metals [10].

As an advanced welding technique, laser beam welding (LBW) is expected to be a suitable technique for joining dissimilar materials, such as, Mg/steel [15], Nb/steel [16], Al/steel [17,18], and Mg/Ti

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https://doi.org/10.1016/j.jmapro.2018.03.019
1526-6125/

Table 1
Chemical compositions of base metals and interlayer metal (mass fraction %).

	Al	Mn	Zn	Si	Fe	V	Ti	Mg
Ti-6Al-4V	5.5–6.8	–	3.5–4.5	–	0.3	3.5–4.5	Bal.	–
AZ31B	2.5–3.5	0.2–0.5	0.5–1.5	0.1	<0.005	–	–	Bal.
Interlayer	100	–	–	–	–	–	–	–

[19,20]. Gao et al. [13,14] investigated laser keyhole welding of Mg to Ti by using melting of thicker Mg base metal or Mg filler wire. Laser beam offset had great influence on the microstructure evolution and mechanical properties of the Mg/Ti joint. The maximum joint tensile strength reached 266 MPa. The fusion zone was composed of α-Ti, α-Mg and $Mg_{17}Al_{12}$ [14]. Tan et al. [21] studied the laser welding-brazing characteristics of AZ31B alloy and Ni coated Ti-6Al-4V alloy using AZ92 Mg based filler. Metallurgical bonding was achieved by the Ti_3Al interfacial reaction layer and Al–Ni phase, with Mg–Al–Ni ternary compound formed near the fusion zone. These results indicated that Al element played an essential role in realizing the metallurgical bonding of Mg/Ti. Therefore, Al element could act as the suitable intermediate element to bond Mg/Ti base metal.

Compared to using filler, it was easier to add and control the amount of Al element through interlayer. Therefore, in this work, Al interlayer has been employed to join Mg and Ti based on previous studies and the Mg–Al and Al–Ti binary diagrams. This work aimed at investigating the characteristics of laser conduction welding dissimilar metals Mg/Ti using different thickness of Al interlayer. The interfacial microstructure and mechanical properties of joints with different thicknesses of Al interlayer were studied. Finally, the conduction welding mechanism of Mg/Ti with Al interlayer was clarified.

2. Experimental procedures

The materials used in the present study were Ti–6Al–4V (TC4) and AZ31B magnesium alloy (Mg–3%Al–1%Zn) sheets, both with a thickness of 1.5 mm. Both sheets were machined into rectangular strips of 100 × 50 mm. The chemical compositions of Ti–6Al–4V (TC4), AZ31B and Al interlayer are listed in Table 1.

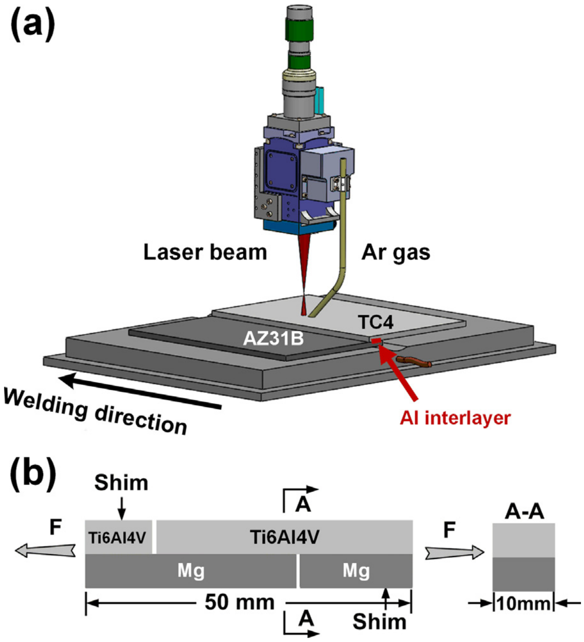

Fig. 1. Schematic of laser conduction welding and the tensile-shear testing specimen: (a) laser welding process of Mg to Ti with Al interlayer; (b) tensile-shear test specimen.

Fig. 1a shows the schematic diagram of laser conduction welding process. This work employed a 6-kW fiber laser (IPG YLR-6000) with a KUKA six-axis robot. The assembly was fixed in a lap configuration by placing Mg sheet under the bottom of Ti sheet. The laser beam was irradiated on the top surface of the Ti. Pure Al foil was added as the interlayer. Argon shielding gas was used to prevent oxidation. Before laser conduction welding, the oxidation films on the surfaces of the Mg sheets were polished by angle grinder and Ti sheets were cleaned by acid (5% HF, 15% HCL, 80% H_2O). To minimize the evaporation of Mg molten pool, the laser beam was defocused. Table 2 shows the experimental parameters employed in this work.

After laser conduction welding, test specimens were cut midway and then were processed by Standard metallographic preparation procedures. The interface, microstructures and fracture surface of the joints were observed by scanning electron microscope (SEM).

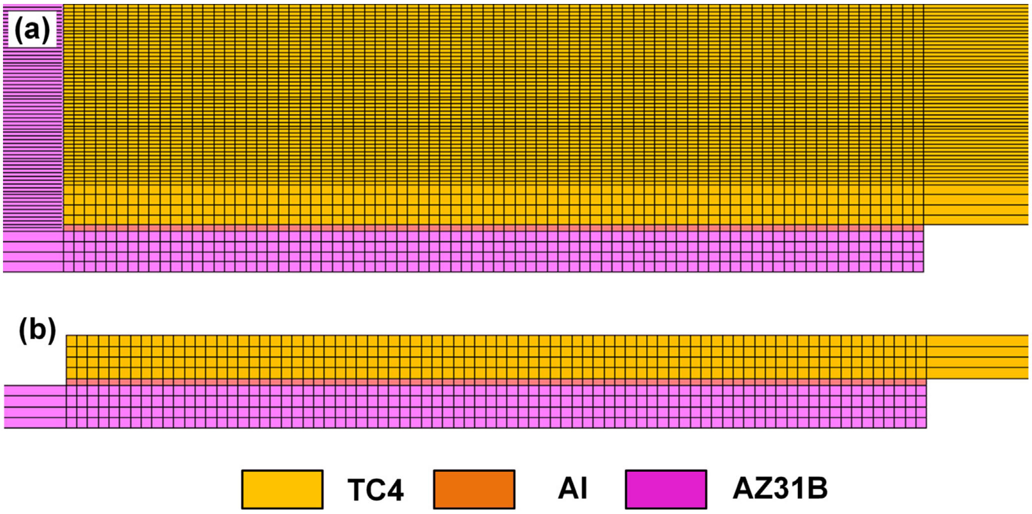

Fig. 2. Finite element analysis model of Mg/Ti joint.