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Influence of laser power on microstructure and mechanical properties of laser welded-brazed Mg to Ni coated Ti alloys

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ABSTRACT

AZ31B Magnesium (Mg) and Ti-6Al-4V titanium (Ti) alloys with Ni coating were joined by laser welding-brazing process using AZ92 Mg based filler. The influence of laser power on microstructure and mechanical properties were investigated. Ni coating was found to significantly promote good wetting-spreading ability of molten filler on the Ti sheet. Acceptable joints without obvious defects were obtained within a relatively wide processing window. In the process metallurgical bonding was achieved by the formation of Ti_3Al phase at direct irradiation zone and Al-Ni phase followed by a layer of Mg-Al-Ni ternary compound adjacent to the fusion zone at the intermediate zone. The thickness of reaction layers increased slowly with the increasing laser power. The tensile-shear test indicated that joints produced at the laser power of 1300 W reached 2387 N fracture load, representing 88.5% joint efficiency with respect to the Mg base metal. The corresponding failure occurred in the fusion zone of the Mg base metal, while joints fractured at the interface at lower/higher laser power due to the crack or excessive intermetallic compound (IMC) formation along the interface.

1. Introduction

Magnesium (Mg) is the lightest of all structural metals currently available in the world [1]. Recently magnesium and its alloys have received an increasing attention in automotive, aerospace and electrical applications due to their attractive properties, such as low density, high strength-to-weight ratio, good formability and easy recyclability [2–4]. Titanium (Ti) alloys have a variety of excellent physical and mechanical characteristics, including high strength-to-weight ratio, corrosion resistance, high-temperature performance, and biocompatibility [5]. As one of the most widely used titanium alloys, Ti-6Al-4V offers great advantages in aerospace, defense and nuclear industries [6,7]. Therefore, the joining of dissimilar metals Mg to Ti is of great interest for many fields where weight reduction, better fuel economy and specific strength are essential factors for its choice. Attaining reliable hybrid joint between Mg and Ti is the precondition for facilitating lightweight industrial fabrication, and will also expand the application of Mg alloys in the aerospace industry.

Joining of Mg to Ti is, however, a huge challenge because of great differences in physical and metallurgical properties. The melting points of Mg and Ti are 649 °C and 1678 °C, respectively. Moreover, the boiling point of Mg is only 1091 °C, lower than the melting point of Ti, making conventional fusion welding not applicable for direct joining Mg to Ti. In addition, Mg and Ti do not react with each other because of their immiscibility characteristics. Therefore, an intermediate element which can react with or possess substantial solid solubility in Mg and Ti must be adopted in order to achieve metallurgical bonding.

Transient liquid phase (TLP) bonding [8–11], friction stir welding (FSW) [12,13], tungsten inert gas (TIG) welding [14,15], cold metal transfer (CMT) welding [16] and laser welding [17,18] have been employed to join Mg and Ti in previous studies. In the TLP bonding process, liquid eutectic was observed to form at Mg/Ni coating interface and solid-state diffusion occurred at Ni coating/Ti interface [9]. In addition, coating thickness was proved to affect microstructural developments and mechanical properties [10]. Nanoparticle Ni or Cu dispersion in the Ni coating was found to enhance joint formation by affecting the isothermal solidification rate [11]. In the FSW process, metallurgical bonding of Mg/Ti joint was achieved by the formation of Ti-Al intermetallic compound layer at the interface. The diffusion of Ti base metal and Al element from Mg base metal was induced by the combined action of friction heat and stirring effect [12]. Results indicated that calcium (Ca) added in Mg alloy suppressed the excessive formation of Ti-Al intermetallic and resulted in higher joint strength [13]. In the case of CMT welding, Al element from the molten AZ61

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Table 1
Chemical compositions of base metals and filler metal (wt%).

	Al	Zn	Mn	Fe	V	Si	Mg	Ti
AZ31B	2.5–3.5	0.5–1.5	0.2–0.5	< 0.005	–	0.1	Bal.	–
Ti-6Al-4V	5.5–6.8	3.5–4.5	–	0.3	3.5–4.5	–	–	Bal.
Filler metal	8.3–9.7	1.7–2.3	0.15–0.5	< 0.005	–	< 0.05	Bal.	–

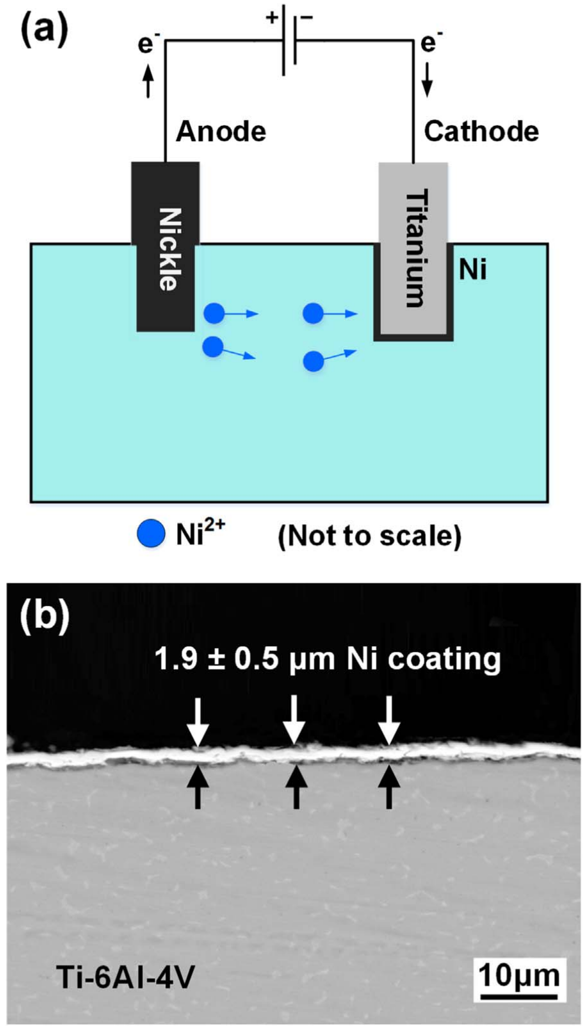

Fig. 1. **(a)** Schematic of the Ni electrodeposition process on Ti-6Al-4V; **(b)** SEM image for cross section of Ni coating on Ti-6Al-4V substrate.

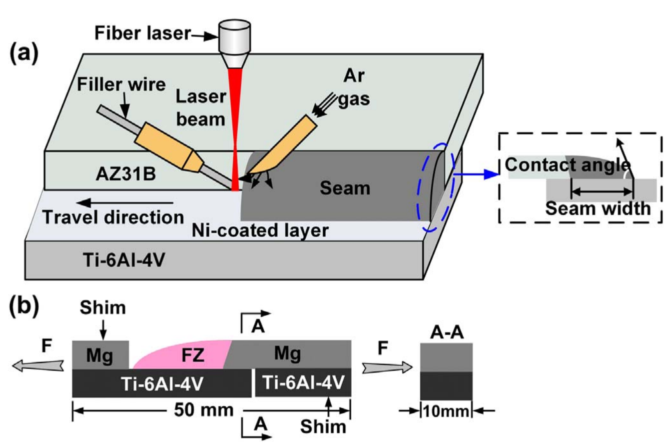

Fig. 2. Schematic of laser welding-brazing of Mg to Ti: **(a)** laser welding-brazing process; **(b)** specimen for tensile-shear test.

filler metal was employed to react with Ti substrate giving rise to metallurgical bonding [16]. With regard to laser welding, Gao et al. [17,18] investigated laser welding of Mg to Ti using AZ31 filler or melting of thicker Mg base metal to realize interfacial bonding. They reported that laser beam offset played an important role in the joining mechanism and thereafter mechanical properties of Mg/Ti butt joint in the laser keyhole welding. The acceptable joint with an interfacial layer was composed of α-Mg and Mg-Al eutectic reaching the tensile strength of 266 MPa [18].

As an advanced welding technique, laser welding-brazing (LWB) process has the great potential for increased flexibility and adaptability when joining dissimilar materials, such as Al/Ti [19], Al/steel [20,21], Mg/steel [22,23] and Mg/Ti [24,25]. In our previous studies [24,26], the immiscibility of Mg/steel and Mg/Ti was improved regarding interfacial bonding when the LWB process was performed. Metallurgical bonding was achieved by atomic diffusion from Zn coating or filler metal.

AZ91 filler was employed to join Mg and Ti in our previous work, where Al element acted as the intermediate element to bond Mg and Ti resulting in metallurgical bonding of dissimilar joints. To further improve the flexibility of controlling the interfacial reaction, Ni was selected as another potential interlayer element based on binary and ternary diagrams. The aim of the present work is to investigate the characteristics of laser welding-brazing dissimilar metals Mg to Ti using a Ni interlayer. Influence of laser power on microstructure and mechanical properties were studied. Based on these analyses, joining mechanism of Mg to Ni coated Ti with AZ92 filler using the LWB process was expected to be elucidated.

2. Experimental procedure

Commercially available AZ31B magnesium alloy sheet and Ti-6Al-4V titanium alloy sheet were used in the present study. The dimension of these sheets was 100×30×1 mm. A 1.6-mm-diameter Mg-Al-Zn based alloy (AZ92 filler) was selected as filler wire. The chemical compositions of the base metals and filler metal are listed in Table 1. The Ti–6Al–4 V alloy was pickled for 3 min in acid (15% HCl, 5%HF, 80% distilled water) followed by tap water rinse for 30 s to remove surface oxides. The prepared surfaces were then electroplated with electrolytic pure nickel immediately. The electrodeposition of Ni coating was carried out in a 500-mL glass beaker using plating solution prepared by dissolving 200 g $NiSO_4{\cdot}6H_2O$, 10 g NaCl, 32 g H_3BO_3, 70 g Na_2SO_4 and 60 g $MgSO_4{\cdot}7H_2O$ in 1 L of distilled water. In the Ni electroplating process, the cleaned titanium sample was the cathode and nickel sheet was the anode. Fig. 1(a) shows a schematic of the Ni electrodeposition process used in the present work. The cathode current density was set at 1.2 A/dm^2, pH level was maintained at 5,

Table 2
Experimental parameters used in the process.

Welding parameters	Value
Laser power (W)	1100–1900
Defocus distance from steel surface (mm)	+20
Welding speed (m/min)	0.5
Wire feed speed (m/min)	2.5
Flow rate of shielding gas Ar (L/min)	16