Optics and Laser Technology 108 (2018) 378–391

Contents lists available at ScienceDirect

Optics and Laser Technology

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

Full length article

Influence of Ni-coating thickness on laser lap welding-brazing of Mg/Ti

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ARTICLE INFO

Article history:
Received 10 May 2018
Received in revised form 19 June 2018
Accepted 10 July 2018

Keywords:
Dissimilar materials
Laser welding-brazing
Microstructure
Titanium alloy
AZ31B Mg

ABSTRACT

Dissimilar lap joining of magnesium alloy to titanium alloy was performed using Ni coating by laser welding-brazing process. The influence of different Ni-coating thicknesses on microstructure and mechanical properties were investigated. In laser irradiation region, Ti_3Al phase formed at fusion zone/Ti interface. In middle region, Ti_3Al phase still existed at fusion zone/Ti interface, while Mg-Al-Ni ternary IMC generated at fusion zone. In weld toe region, Ti-Ni binary IMC were observed at the interface of fusion zone/Ti. The particles of Mg-Al-Ni ternary compound grew bigger and thickness of Ti-Ni compound layer increased with the increase of Ni-coating thickness. TiNi IMC transformed into (TiNi + Ti_2Ni) mixtures when the Ni-coating thickness exceeded 5.8 μm. Interfacial microstructure evolution was clarified according to thermodynamic calculation results of formation enthalpy and chemical potential. The fracture load first increased and then decreased slightly with increasing coating thickness, the maximum fracture load (2430 N/cm) represented 90% joint efficiency in relation to the Mg base metal. The fracture mode changed from interfacial failure into fusion zone fracture when the Ni-coating thickness was greater than 4.0 μm. The interfacial bonding were relatively low, while the performance of fusion zone fracture was relatively high. Further increase of coating thickness has little effect on the performance deterioration. The bonding mechanism of Mg to Ni-coated Ti were illuminated.

1. Introduction

In recent years, magnesium (Mg) and its alloys have gained popularity in industrial applications due to excellent properties such as high specific strength, low density and good damping characteristics [1,2]. Titanium and its alloys, with combination of high specific strength and corrosion resistance [3,4], are attractive for engineering applications in the aerospace and defense industries. The fabrication of lightweight structural materials is of great interest for many fields since it offers advantages over weight reduction and energy consumption [5], as well as provides better flexibility by using different materials in one product. Reliable joining of Mg to Ti would achieve further weight reduction and fuel efficiency, which in turn expands the engineering application of both alloys in automotive and aerospace industries.

However, direct joining of Mg to Ti alloys poses some unique challenges due to their great discrepancy in metallurgical and physical characteristics. The melting points of Ti and Mg are 1678 °C and 649 °C. The boiling point of Mg is as low as 1091 °C, indicating severe vaporization of the molten magnesium is unavoidable if both Mg and Ti melt simultaneously by using conventional fusion welding process. Moreover, the immiscibility characteristics of Mg and Ti make it difficult to produce reaction layer or atomic diffusion after melting and solidification process. Therefore, an available approach using an intermediate element which can react with and possess substantial solid solubility in Mg and Ti is employed to realize metallurgical bonding at the interface.

Intermediate element adopted in welding process can be summarized mainly in three ways: from base metal [6–8], filler metal [9–13] and interlayer [14–18] in previous studies. In the friction stir welding (FSW) process [6], the diffusion of Al element from Mg base metal to Ti base metal occurred at the comprehensive action of stirring effect and friction heat. The Ti-Al intermetallic compound layer formed at the interface resulted in metallurgical bonding of Mg/Ti joint. Gao et al. investigated laser keyhole welding of thicker Mg and Ti. The interfacial reaction was found to occur in the Ti-weld interfacial layer. The intermetallic compound was identified as $Mg_{17}Al_{12}$ [19].

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https://doi.org/10.1016/j.optlastec.2018.07.007
0030-3992/

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.	–

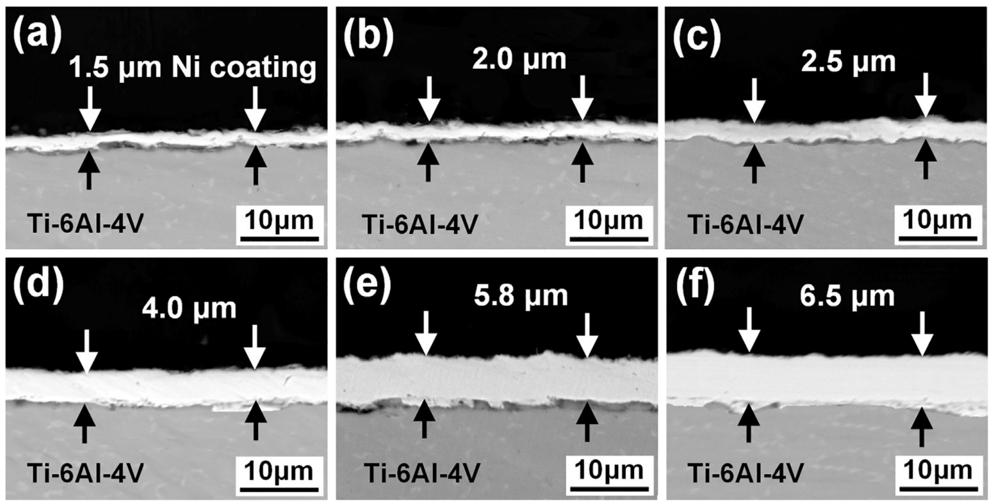

Fig. 1. SEM for cross sections of Ni coating on Ti substrate at different electroplating times: (a) 0.5 h, (b) 1 h, (c) 1.5 h, (d) 2 h, (e) 2.5 h, (f) 3 h.

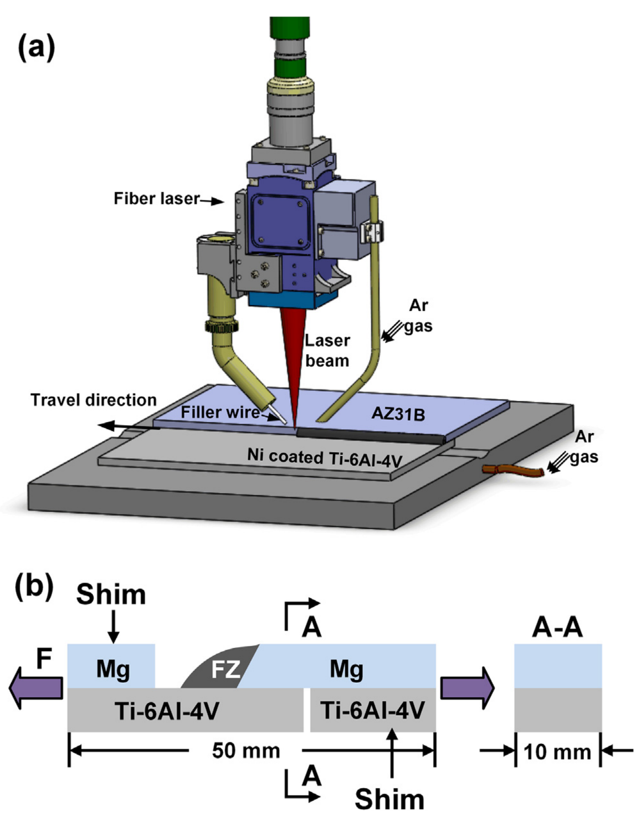

Fig. 2. Schematic of laser welding-brazing and the tensile-shear testing specimen: (a) laser welding-brazing process of Mg/Ni-coated Ti; (b) tensile-shear test specimen.

With regard to the intermediate element from filler metal, Cao et al. used the Al element from AZ61 Mg based filler to bond Mg and Ti by cold metal transfer welding-brazing (CMT) process. Results indicated newly formed Ti_3Al phase occurred at the brazing interface, suggesting elements Al in Mg filler metal are crucial to realize metallurgical bonding between Mg and Ti base metals [9]. In our previous work, AZ92 Mg based filler containing 9 wt% Al element was employed to bond Mg and Ti using laser welding-brazing process. An ultra-thin reaction layer formed at the interface, indicating that metallurgical bonding of Mg and Ti occured. The newly formed phase was identified as Ti_3Al phase [20]. In the case of interlayer, pure aluminum foil was adopted to bond Mg alloy to Ti alloy by transient liquid phase (TLP) method. $Mg_{17}Al_{12}$ and $TiAl_3$ formed at the interface and the maximum tensile strength reached 72.4 MPa [14]. Atieh et al. employed Ni interlayer to join Mg-AZ31 and Ti-6Al-4V alloys in the TLP joining process. Eutectic formed at Mg-Ni interface, while solid-state diffusion occured at Ni-Ti interface [15]. In our previous study [21], successful attempt was made by laser welding-brazing of Mg to Ti using Ni electro-coated layer on the Ti surface. The presence of Ni coating was proved to improve wetting-spreading ability of molten Mg on Ti substrate and sound joint was obtained. The influence of laser power was found to affect microstructure and mechanical properties greatly. However, another important factor-thickness of the interlayer was worth investigating since it directly determined the thickness and morphology of the reaction layer within the joint, which was seldom investigated in detail.

The objective of the current work, therefore, is to investigate the influence of thickness of Ni coating on microstructural evolution and mechanical properties during laser lap welding-brazing of Mg to Ti. The joining mechanism of Mg to Ti with different thickness of Ni coating were also elucidated.

2. Experimental procedure

2.1. Materials and electrodeposition process

Ti-6Al-4V titanium alloy sheet (100 × 30 × 1 mm) and AZ31B magnesium alloy sheet (100 × 30 × 1.5 mm) were used in the