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Full Length Article

Characteristics of friction welded AZ31B magnesium–commercial pure titanium dissimilar joints

A.K. Lakshminarayanan [a,*], R. Saranarayanan [a], V. Karthik Srinivas [a], B. Venkatraman [b]

[a] *Department of Mechanical Engineering, SSN College of Engineering, Kalavakkam 603 103, Tamil Nadu, India*
[b] *Radiological Safety and Environmental Group, Indira Gandhi Centre for Atomic Research, Kalpakkam 603 102, Tamil Nadu, India*

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Abstract

It is essential to understand the weld interface characteristics and mechanical properties of dissimilar joints to improve its quality. This study is aimed at exploring the properties of friction welded magnesium–titanium dissimilar joint using tensile testing coupled with digital image correlation, optical and scanning electron microscopy, x-ray diffraction and microhardness measurements. Microstructurally different regions such as contact zone, dynamic recrystallized zone, thermo-mechanically affected zone, and partially deformed zone in the magnesium side were observed. No discernible regions were observed in the titanium side, as it had not undergone any significant plastic deformation. Phase analysis indicated that the aluminium from the magnesium side diffused toward the weld interface and formed a thin continuous intermetallic layer by reacting with the titanium. Microhardness mapping showed a steep hardness gradient from the titanium to magnesium side. Critical analysis is done on the tensile characteristics of the specimen and the response of the local regions to the deformation process is mapped.

Keywords: Friction welding; Dissimilar joints; Microstructure; Digital image correlation

1. Introduction

Dissimilar combinations are widely gaining prominence as they cater to stringent industrial requirements [1]. Dissimilar welded joints of titanium (Ti) and magnesium (Mg) alloy are an attractive combination for automotive applications (e.g. multi-material light weight vehicles). However, their significant difference in the physical properties, like melting point (Ti: 1668 °C, Mg: 650 °C), thermal conductivity (Mg: 156 $Wm^{-1} k^{-1}$, Ti:21.9 $Wm^{-1} k^{-1}$), lower mutual solubility, absence of reaction layer, unavailability of suitable filler materials makes joining them by fusion welding techniques difficult [2]. Hence, an appropriate joining technique that overcomes the above mentioned problems is to be applied. A literature survey indicated that attempts were made to join this combination using techniques like diffusion bonding, laser beam welding, friction stir welding, friction welding and cold metal transfer welding [3–7]. Tanabe and Watanab [3] investigated the effect of friction stir welding process parameters, namely rotational speed, tool pin profile and offset distance on the quality of dissimilar commercial pure titanium–AZ31 magnesium alloy joints and indicated that the fracture location was decided by the diffusion of aluminum from the magnesium side to the titanium side. Gao et al. [4] used laser keyhole welding to join Ti-6Al-4V grade titanium to AZ31B magnesium alloy and reported that the laser offset distance plays a major role in the weld quality, and further stated that the optimum laser offset distance should be in the range of 0.2–0.5 mm to get defect free joints. They also stated that titanium alloys with the presence of aluminum and vanadium increase the solubility of magnesium in titanium. Aonuma and Nakata [5] explored the possibility of joining ZK60 magnesium alloy with titanium and they observed that a thin Zn and Zr-rich layer formed at the interface, which had a significant effect on the tensile strength of the joint. Cao et al. [6] joined pure titanium and AZ31 magnesium alloy in a lap configuration with the use of AZ61 filler wire by cold metal transfer welding and brazing. Although it was reported that sound welds can be obtained using this technique, the observed values of maximum tensile shear failure load were very low. To the best of the authors' knowledge, only one study

* Corresponding author. Department of Mechanical Engineering, SSN College of Engineering, Kalavakkam 603 103, Tamil Nadu, India. Tel.: +914427474844; fax: +914427474844.

E-mail address: lakshminarayananak@ssn.edu.in (A.K. Lakshminarayanan).

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Table 1
Chemical composition of base metal, Wt % (measured).

	O	H	N	C	Fe	Ti
CP-Ti	0.11	0.008	0.021	0.0019	0.0438	Bal
	Al	Zn	Mn	Cu	Fe	Mg
AZ31B	3.1	0.94	0.21	0.02	0.002	Bal

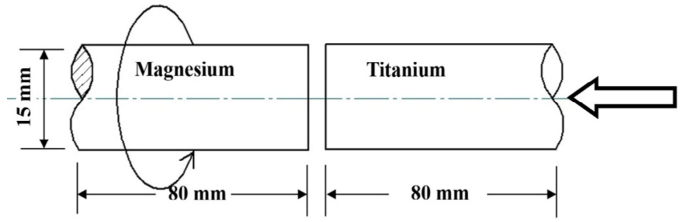

Fig. 1. Dimensions of Specimens.

was reported by Li et al. [7] on the friction heat production and atomic diffusion behavior during the friction welding of titanium–magnesium dissimilar joints. They reported that rotational speed and axial pressure play a major role in the generation of temperature and friction coefficient. However, the microstructural and mechanical characteristics of friction welded magnesium-titanium dissimilar joints have not yet been reported. Hence, an attempt was made to understand the localized tensile characteristics of friction welded Mg-Ti dissimilar joints using digital image correlation and results obtained are correlated with microhardness distribution, microstructural features and phases present at the weld interface.

2. Experimental work

The chemical composition and mechanical properties of commercial pure titanium and AZ31B magnesium alloy are presented in Tables 1 and 2 respectively. Before welding, the workpiece was degreased with acetone solution to remove the oxide layer and the surface of the rods to be welded was milled to make the mating surface uniform. Rotary continuous drive friction welding machine (Maker: RV Machine tools, Coimbatore) was employed to fabricate the dissimilar Mg-Ti joints. From the trail runs carried out in our laboratory, the optimum process parameters were identified and they are presented in Table 3.

An arrangement was made in such a way that magnesium rod rotate about its axis and titanium rod was kept stationary (Fig. 1). The joints fabricated were cut along its cross-section by wire cutting electric discharge machine. The specimen was then polished with emery sheets of varying grit sizes. The polished specimen was etched with 4.2 g picric acid, 10 ml acetic acid, 10 ml water and 100 ml ethanol for duration of about 30 s. Optical microscope (Maker: Olympus, Japan) was utilized to capture the macrostructure and microstructure of the base metals and different regions of the dissimilar joint. Scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDS) was employed to determine the element distribution across the interface of the joint.

Tensile specimens were prepared according to the ASTM E8M-09 standard. The fabricated joint, the specimen used for metallurgical characterization and the tensile test specimen are displayed in Fig. 2. The tensile test specimen was loaded onto a 100 kN displacement controlled servo hydraulic tensile testing machine. The CMOS camera (Marlin-F131) of DIC setup was focused on one side of the surface of the specimen which is coated with random speckle (black and white) pattern. The resolution of 1380 × 1035 pixels, frame rate of 10HZ, strain resolution of 50 με was used for the experiments. DIC systems were started from the beginning of loading capturing images at 50 Hz and 5 Hz frame rate. Images for performing image correlation were captured using a CMOS camera from which strain fields were computed using associated DIC processing software (Vic2D). Vickers microhardness testing machine (Maker:

Table 2
Mechanical properties of base metals (measured).

Material	Yield strength	Tensile strength	% Elongation	Microhardness (HV)
CP-Ti	275	390	38	170
AZ31B	174	260	20	60

Table 3
Welding conditions used.

Sl. No	Parameters	Unit	Values
1	Rotational speed	rpm	1100
2	Friction pressure	MPa	20
3	Friction time	S	4
4	Forging pressure	MPa	50
5	Forging time (s)	s	8

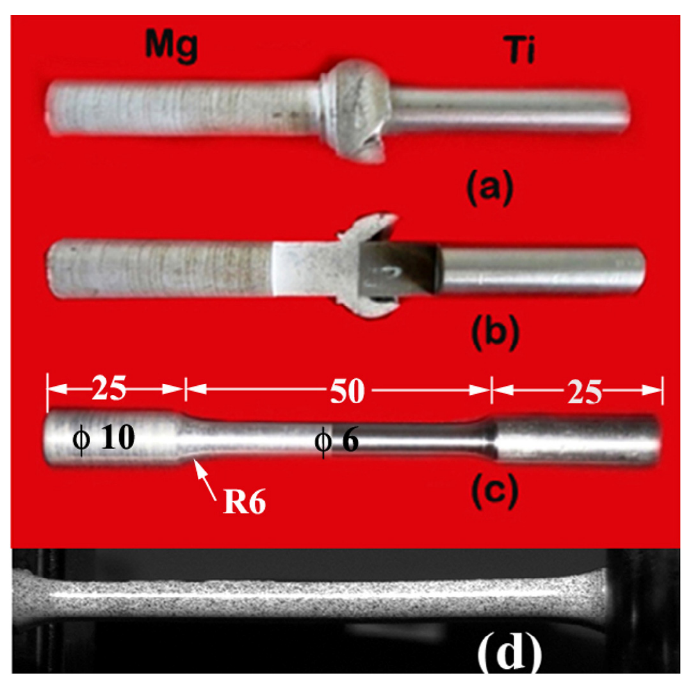

Fig. 2. (a) Mg-Ti Joints, (b) Mg-Ti Joints (cross sectional view), (c) photographs of tensile specimens before testing (d) specimen prepared for DIC test.