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Microstructure and properties of magnesium AZ31B–aluminum 7075 explosively welded composite plate

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ABSTRACT

A composite plate of Mg alloy (AZ31B) and an Al alloy (7075) was fabricated by explosive welding. The microstructure and properties of the bonding interface after explosive cladding were investigated. The results show that the bonding interface had a wavy appearance with solidified melts in a regularly spaced pattern of discrete regions. Adiabatic shear bands and twin structure were found on the AZ31B Mg alloy side. "Metallurgical bonding" of the explosive welding interface was achieved by local diffusion with an approximate 3.5 μm thick diffusion layer. No intermetallics were formed. Shear strength across the bonding interface of AZ31B/7075 composite was ca. 70 MPa. The maximum bending stress reached 670 MPa.

1. Introduction

Aluminum alloys, which offer high strength to weight ratio, good formability and good corrosion resistance, are used extensively in fields such as the aerospace and automobile industries [1]. Magnesium alloys, the lightest of the structural metals with a density two-thirds that of aluminum alloys, have been researched extensively for practical industrial applications during the past decade [2]. With the requirement of economical energy sources and environment protection, the strength/weight ratio (specific strength) was the prime driver for materials selection and continues to be of major importance [3]. Composite laminates of magnesium alloys and aluminum alloys would be promising structural materials to meet these requirements. Recently, macrocomposite and/or multilayer laminates of aluminum and magnesium have received much attention [4–10]. This composite laminate can offer a combination of the properties of aluminum and magnesium alloys.

The production of composite laminates of Mg alloys and Al alloys needs reliable joints between dissimilar alloys of Mg and Al. A variety of welding techniques were attempted to weld these dissimilar alloys. Fusion welding and friction stir welding (FSW) are two commonly used techniques [11–15]. However, high-strength aluminum alloys such as 2XXX and 7XXX series are difficult to join by conventional fusion welding due to the occurrence of hot cracking during welding [3]. As in traditional fusion welding, butt and lap joint designs are the most common joint configurations in friction stir welding. However, it is impossible for friction stir welding to be used to clad large sections of plate to form a composite laminate. In addition, fusion and friction welding of Mg and Al alloys results in the formation of brittle intermetallics in the weld zone that greatly decreases ductility [13–15].

Explosive welding is well known for its capability to directly join a wide variety of both similar and dissimilar combinations of metal plates and is most often used where conventional fusion welding is impractical. Explosive welding is a solid phase process in which the bonding is produced by the oblique high velocity collision between the two plates using an explosive process [16]. This technique enables very large sections of plate to be clad in a single operation and allows the fabrication of large scale composite laminates. So far, there have been several studies describing explosive techniques for production of dissimilar metal combinations, such as aluminum–steel, aluminum–copper and aluminum–titanium [16–19], However, there have been no reports about explosive welding of Al alloys and Mg alloys.

In this work, a composite plate of Mg alloy (AZ31B) and Al alloy (7075) with a sheer strength of 70.4 MPa was produced using an

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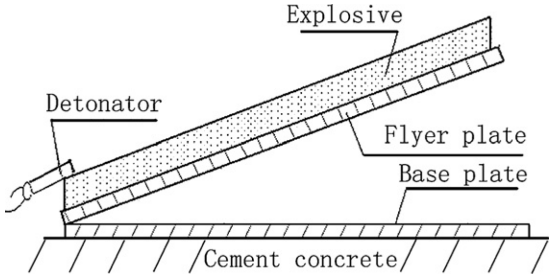

Fig. 1. Schematic view of experimental set-up in explosive welding.

explosive welding technique. This paper describes research on the microstructure and properties of the bonding interface.

2. Experimental

Fig. 1 shows a schematic illustration of the explosive welding process. Wrought magnesium alloy (AZ31B) was used as base plate and aluminum alloy (7075) was used as the flyer plate. The aluminum and magnesium alloy plates were fabricated with dimensions of 1000 mm × 600 mm × 10 mm. The plates were polished mechanically to obtain a clean surface prior to the explosive welding. The chemical compositions of AZ31B Mg alloys and 7075 Al alloys are presented in Table 1. The 7075 Al alloys were hot rolled and then aged at 120 °C for 24 h before welding. Explosive was packed on the flyer plate and a detonator was set on one end of the flyer plate. The explosion was carried out on a flat concrete surface.

After explosive welding, specimens for metallographic observations were cut paralleling the explosion direction from the explosively welded plates. The specimens were prepared using standard metallographic techniques and etched for 30 s in a solution containing 1 ml HNO_3, 1 ml CH_3COOH, 1 g $C_2H_2O_4$ and 150 ml de-ionized water. The metallographic examinations of samples were carried out using optical microscopy and scanning electron microscope (SEM). Elemental analysis of the Mg–Al welds was performed using an SEM equipped with an energy-dispersive spectrometry (EDS).

The Vickers hardness values were measured using a HVS-1000Z tester with a 25 g load on different regions of the bonding interface. Shear testing was performed using an Instron-3367 instrument in the compression direction to investigate the properties of bonding interfaces in accordance with GB/T6396-2008 (Chinese national standards, which is similar to JISG0601-2002). The maximum shear strength was obtained from an average of 5 shear tests per specimen. Fig. 2 shows the shear test specimen and a schematic illustration of the shear test apparatus. The shearing area was fixed as 10 mm × 10 mm and a compression speed of 1 mm/min was used. The shear stress, τ, is given by [20]:

$$\tau = \frac{P}{ae}$$

where a and e are width and height of test interface, respectively. In this study, both a and e are 10 mm.

Table 1
The chemical composition (wt%) of the AZ31B Mg alloy and 7075 Al alloy.

Elements	Al	Zn	Mn	Cr	Mg	Cu	Fe	Ti	Si
AZ31B	3.1	1.2	0.15		Bal.				
7075	Bal.	5.6	0.3	0.2	2.7	1.8	0.5	0.2	0.4

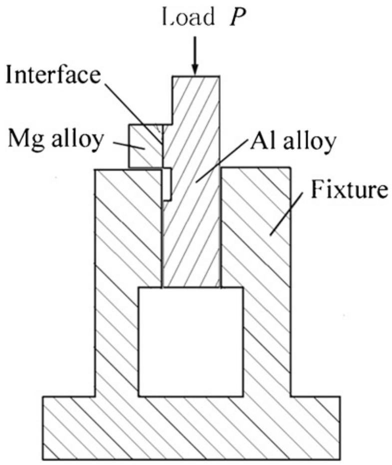

Fig. 2. Schematic illustration of shear test apparatus.

The properties of bonding interfaces and the influence of the interface on the mechanical properties of the explosively welded AZ31B/7075 composite plate were determined by three-point bend testing conducted in accordance with GB/T6396-2008. The size of the specimens for bend tests was 120 mm × 25 mm × 10 mm (the thicknesses of AZ31B and A7075 were both 5 mm). The bend test was performed using an Instron-3367 machine under displacement control at a rate of 1 mm/min. The stress, σ, and the strain, ε, were calculated from the recorded raw data using the following relations [20,21]:

$$\sigma = \frac{3Pl}{2ae^2}, \qquad \varepsilon = \frac{6ed}{l^2}$$

where a is the width of the sample, e the thickness, l the span length between the supports (60 mm), p the force applied on the sample and d the midspan displacement of the sample.

3. Results and discussion

3.1. Microstructures of bonding interface

Fig. 3 shows a typical interfacial microstructure of the AZ31B/7075 composite. It is evident that after the explosive process, no apparent intermediate layer occurred between the two components. Metallographic studies show that bonding at the interface has a wavy morphology. Solidified melts were also observed in a regularly spaced pattern of discrete regions as shown in Fig. 3. Experimental results show that cladding of AZ31B to 7075

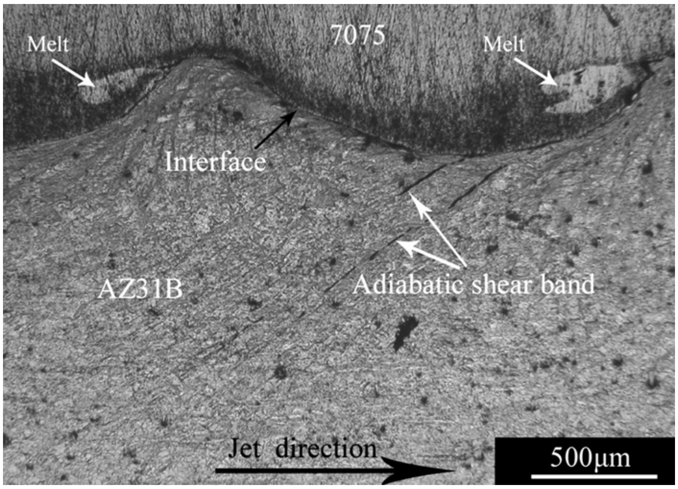

Fig. 3. Typical interfacial microstructure in AZ31B/7075 composite containing solidified melts and adiabatic shear band.