Materials and Design 38 (2012) 19–25

Contents lists available at SciVerse ScienceDirect

Materials and Design

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

An investigation on microstructure and mechanical properties of Al7075 to Ti–6Al–4V Transient Liquid Phase (TLP) bonded joint

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ARTICLE INFO

Article history:
Received 17 December 2011
Accepted 27 January 2012
Available online 7 February 2012

Keywords:
D. Diffusion bonding
A. Non-ferrous metals and alloys
F. Microstructure

ABSTRACT

Transient Liquid Phase (TLP) bonding of two dissimilar alloys Al7075 and Ti–6Al–4V has been done at 500 °C under 5×10^{-4} torr. Cu was electrodeposited on Al7075 and Ti–6Al–4V surfaces, 50 μm thick Sn–4Ag–3.5Bi film was used as interlayer and bonding process was carried out at several bonding times. The microstructure of the diffusion bonded joints was evaluated by Light Optical Microscopy (LOM), Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS). The eutectic and intermetallic compounds formation along Al7075 grain boundaries and Ti/Al interface such as $\theta(Al_2Cu)$, TiAl and Ti_3Al were responsible for joint formation at the aluminum and titanium interfaces. Microhardness and shear strength tests were used to investigate the mechanical properties of the bonds. Hardness of the joints increased with increasing bonding time which can be attributed to the intermetallics formation at the interface. The study showed that the highest bond strength was 36 MPa which was obtained for the samples joined for 60 min.

1. Introduction

The aluminum alloy Al7075 and titanium alloy Ti–6Al–4V are used in a variety of applications in aerospace and chemical industries because of their properties such as high strength to weight ratio and good corrosion resistance [1–3]. The Al7075 is an Al–Zn–Mg–Cu heat treatable alloy. The Ti–6Al–4V is an $\alpha + \beta$ alloy which is the most commonly used Ti alloy. However, the high cost of processing and fabrication of Ti–6Al–4V alloy has been a major factor which has limited its use. Therefore, the ability to join Al7075 alloy to Ti–6Al–4V alloy can provide a product that is less costly, but retains the high strength and light weight properties which is necessary for the aerospace industry [4]. Two main challenges presents in Al alloys to Ti alloys joining. First, there are large differences in the physical properties between Al and Ti such as melting point, thermal conductivity, coefficient of linear thermal expansion, etc. Therefore, conventional fusion welding processes are not applicable for joining these metals [5,6]. The second challenge comes from the presence of stable oxide layer in the both Al and Ti surfaces. During the joining process, these stable oxide layers prevent metal to metal contact at the joint interface which affects the joint quality [7]. Therefore, special surface preparation should be done to bond aluminum to titanium. Moreover, to avoid formation of oxide layers, the bonding process should be carried out at a relatively high vacuum. Transient Liquid Phase (TLP) bonding is an advanced solid state joining process which has an ability to join similar and dissimilar metals such as aluminum and titanium [6–9]. An interlayer placed between the bonding surfaces is heated above its melting point and diffuses in base metals. Generally, the quality of the joint is affected by the chemical composition, microstructure and mechanical properties of the joint region. Therefore, process parameters such as temperature, pressure and bonding time should be optimized to obtain a good joint. Moreover, interlayer composition and thickness play an important role in the bonding process. Previous works on solid and liquid state diffusion bonding of Al/Ti has been reported [10–14]. Lead-free Sn-based alloys are widely used to join dissimilar alloys [15]. Addition of Ag to Sn improves the mechanical properties of the alloy [16]. Bi enhances the wettability and strength of the Sn–Ag eutectic system [17,18]. Coating the Al and Ti surfaces with Cu prevents the oxide formation on Ti/Al interface. Moreover, intermetallic compounds could form between Al/Cu, Ti/Cu and Cu/Sn interfaces [13]. In this study, the diffusion bonding of these dissimilar alloys was investigated with the aid of 50 μm thick Sn–4Ag–3.5Bi interlayer at different bonding times with the aim of optimizing the bonding mechanical properties.

2. Experimental procedure

The Ti–6Al–4V and Al7075 alloys were investigated for liquid state diffusion bonding experiment using interlayer with a thickness of 50 μm. Compositions of the Al and Ti alloys and the interlayer are

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doi:10.1016/j.matdes.2012.01.046

Table 1
Chemical compositions of the metals used in this study.

Alloys	Elements (wt.%)								
	Ti	Al	V	Cu	Mg	Zn	Sn	Ag	Bi
Ti–6Al–4V	Bal.	6.43	4.16	–	–	–	–	–	–
Al7075	–	Bal.	–	1.52	2.30	5.87	–	–	–
Interlayer	–	–	–	–	–	–	Bal.	3.78	3.34

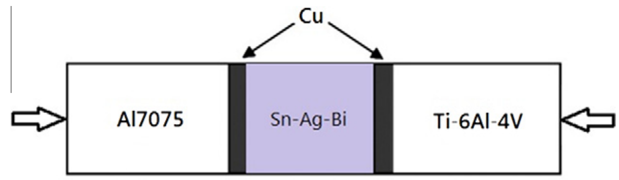

Fig. 1. Schematic representation of the sample assembly.

listed in Table 1. The base metals were received as plates of 3 mm thickness for Ti alloy and 10 mm thickness for the Al alloy. The samples were cut into dimensions of 12 × 12 × 3 mm^3. SiC papers down to 1000 were used for samples preparation.

Oxide films of Ti and Al could form easily on each surface, so to eliminate the oxide layer from the joining surface, Ti–6Al–4V sample were immersed in 3%HF + 30%HNO_3 solution, subsequently water flushed and dried. Also Al7075 surfaces immersed firstly in 6%NaOH, water flushed, and then immersed in 40%HNO_3, water flushed and dried [10]. The immersion time for each solution was 20 s. After that, samples and 50 μm thick Sn–4Ag–3.5Bi foils were ultrasonically cleaned in acetone for 15 min. A solution from 17.5 g copper sulfate ($CuSO_4$) and 175 g sulfuric acid (H_2SO_4) in a liter of distilled water was prepared for electrodepositing Cu onto samples surfaces [19]. Samples immersed in solution as cathode and the anode was 99.99%Cu. The deposition time for Al7075 and Ti–6Al–4V was about 1 min and 2 min, respectively. The Sn–Ag–Bi interlayer was placed between the surfaces of the samples being joined as shown in Fig. 1, and then the assembly moved into the diffusion bonding chamber.

Once a vacuum of 5×10^{-4} torr was achieved, samples were heated. The bonding temperature was set to 500 °C and the bonding process was carried out at several bonding times up to 60 min. Transverse sections were made by cutting the bonded samples through the joint region. Samples were polished down to 1 μm diamond suspension. The etchant for Al7075 was Keller's reagent (3 ml HCl, 5 ml HNO_3, 2 ml HF, and 90 ml distilled water) and for Ti–6Al–4V was Kroll's reagent (5 ml HNO_3, 3 ml HF, and 92 ml distilled water) [20]. The microstructures of the joints were observed using light optical microscope (LOM) and Philips XL30 scanning electron microscope (SEM). The distribution of different elements across the interface was examined by point analysis and element distribution map using Energy Dispersive Spectroscopy (EDS). In order to investigate the formation of the intermetallic compounds across the joint interface the X-ray Diffraction (XRD) technique was applied by a Philips 1940 machine from the fractured surface. Microhardness measurements were made with a Shimadzu Type M tester with a load of 50 g. To measure shear strength of the joints, lap joint specimens were prepared in accordance with ASTM standard D1002-99 [21] and joints strength were measured by Santam STM-600 machine with a cross head speed of 1 mm/min. Fig. 2a shows lap shear tensile test specimen and cross section of a diffusion bonded sample is shown in Fig. 2b.

3. Results and discussion

3.1. Microstructure and element distribution

Samples bonded at 500 °C with different holding times were studied in order to understand the microstructural changes in the diffusion zone. Fig. 3a shows a cross-section representative of the bond interface with a short bonding time of 15 min. A thin layer of interlayer is still remained along the bond length. However, as bonding time increases up to 30 and 60 min, the interlayer completely diffuses, as can be seen in Fig. 3b and Fig. 3c. At bonding time of 30 min, a eutectic phase can be seen along the Al7075 grain boundaries. From the calculated Al7075-Cu phase diagram [22] and as observed by earlier researches on the mechanism of the diffusion of Cu into Al [14], it can be concluded that eutectic liquid formation due to the solid state diffusion of Cu in base metals, is one of the initial bonding process stages at Al/Cu interface. As bonding time increases, Cu diffuses into Al and Ti and Al_2Cu eutectic phase was formed along the Al7075 grain boundaries which was demonstrated by AlHazaa and Khan [13]. Also, Intermetallics between Ti/Cu and Ti/Al can also be formed subsequently. Based on a previous work [4,13] the joint formation occurred at the Cu/Ti and Ti/Al interfaces as a result of solid state diffusion of Ti, Al and Cu atoms and intermetallic compounds formation. Moreover, the formation of TiAl and Ti_3Al intermetallics has also been reported during brazing experiments of TiAl [23].

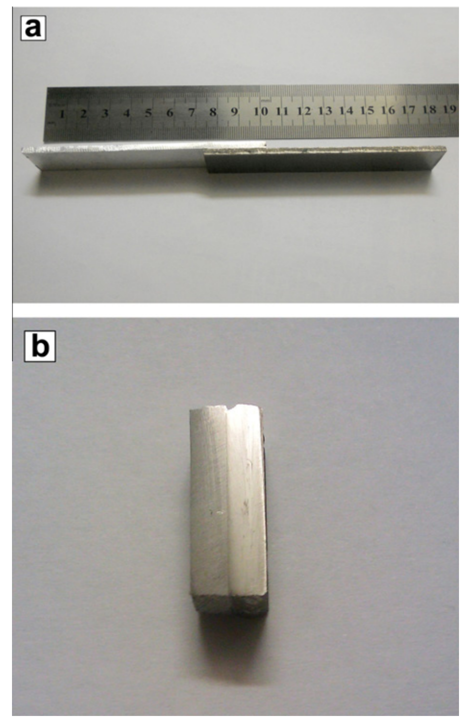

Fig. 2. (a) Lap shear tensile test specimen and (b) cross section of a diffusion bonded sample.

To investigate the microstructure more precisely, SEM micrographs from the bonded joints were taken (Fig. 4). It is obviously clear that the joint structure is highly dependent on the bonding time. At the bonding time of 15 min (Fig. 4a), the interlayer is clearly visible although, the diffusion of Sn, Cu and Al made the interlayer become discontinuous. On the other hand, the bond made for 30 min (Fig. 4b) shows the absence of the interlayer, however eutectic phase is formed which is along the Al7075 grain boundaries as seen in light micrographs. Also, small bright regions can be seen along the grain boundaries. Fig. 4c represents a completed joining process.