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TLP bonding of SiCp/2618Al composites using mixed Al–Ag–Cu system powders as interlayers

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Abstract Mixed Al–Ag–Cu and Al–Ag–Cu–Ti powders were used as interlayers for transient liquid phase diffusion bonding (TLP bonding) of SiC particulate reinforced 2618 aluminum alloy matrix composite (SiCp/2618Al MMC). The results show that by using mixed Al–Ag–Cu powder with the eutectic composition as an interlayer, SiCp/2618Al MMC can be TLP bonded at 540 °C, however, the joining layer is porous. Adding a certain amount of titanium into the Al–Ag–Cu interlayer, the TLP bonding quality can be improved. The titanium added into the Al–Ag–Cu interlayer has an effect of shortening the solidification time of the joining layer, thus decreasing SiC particles from the parent materials entering into the joining layer. The joints bonded using Al–Ag–Cu–Ti interlayers have a maximum shear strength of 101 MPa when 2.1% titanium is added.

Introduction

Compared with general aluminium alloys, particle reinforced aluminium metal matrix composites (Al MMCs) have a unique combination of mechanical and physical properties, such as high specific strength and specific modulus of elasticity, low thermal expansion coefficient and high resistance to wearing, and are expected to be used as structural components in aerospace engineering, automotive industry, electronic packaging, etc. Joining is an indispensable processing for industrial applications of any material. Because of the specific characteristics in composition and microstructure, however, Al MMCs display a poor weldability [1–6]. The process called transient liquid phase diffusion bonding (TLP bonding) can join materials without melting them during bonding which is considered to be an effective method for joining of Al MMCs. Up to the present, some pure metals which have an eutectic reaction with aluminium such as copper [7–12], silver [12] and nickel [13], have been used as interlayers in the shape of foil to TLP bond Al MMCs. Also, a Cu/Ni composite interlayer was employed for TLP bonding of Al_2O_3/6061Al composites [14].

It is noteworthy that all the above pure metal interlayers require a high bonding temperature. Even copper having an eutectic reaction temperature of 548 °C with aluminium requires a bonding temperature of at least 560–580 °C. As is well known, the aluminium alloys used as matrixes of Al MMCs often possess a comparatively low solidus temperature. This means that using copper, silver and nickel foils as interlayers to TLP bond Al MMCs, the bonding temperature approaches or even exceeds the solidus temperature of several matrix alloys of Al MMCs. In theory, zinc and magnesium have a low eutectic reaction temperature of 382 °C and 451 °C with aluminium, respectively, and may be used as interlayers to TLP bond Al MMCs at a low bonding temperature. However, zinc and magnesium are not ideal interlayer metals, because they have high vapour pressures, and are prone to oxidation.

Al–Ag–Cu ternary system having a low eutectic temperature of 500 °C, an interlayer of mixed Al–Ag–Cu powder should be able to TLP bond Al MMCs at a temperature slightly higher than 500 °C. In this paper, therefore, mixed powders of Al-Ag-Cu system (Al–Ag–Cu and Al–Ag–Cu–Ti) were employed as interlayers to bond Al MMCs. The microstructures and properties of the joints and the effect of titanium on them were investigated.

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Experimental

The composite material to be bonded in this investigation was 17 vol.%SiCp reinforced 2618 aluminium alloy matrix composite (SiCp/2618Al MMC), which was cut into samples of $15 \times 10 \times 5$ mm. Before bonding, the surfaces to be bonded were ground by SiC grinding papers of 120 grit and then cleaned in acetone. All the particle sizes of the Al, Ag, Cu and Ti powders used in interlayers were 300 mesh (40–45 μm). The Al, Ag, Cu and Ti powders were mixed in eutectic compositions of 40.0%Al + 40.7%Ag + 19.3% Cu and [40.0%Al + 40.7%Ag + 19.3%Cu]$(1 - \eta) + \eta$Ti (by weight), and with ethanol to prepare slurries, where η 0.7, 1.4, 2.1, and 2.8%, respectively. The interlayers for bonding were prepared by coating the slurries on surfaces of the samples to be bonded. The TLP bonding was performed at 540 °C for 60 min in a furnace with vacuum of 3.8×10^{-3} Pa. A piece of tungsten heavy alloy was put on the samples to provide a low bonding pressure of about 3×10^{-3} MPa on the mating surfaces. Scanning electron microscopy (SEM) with an energy dispersive X-ray spectrometer and an electron probe X-ray microanalyser (EPMA), and X-ray diffractometer (XRD) were employed to analyze the microstructures of the joints.

Results and discussion

Figure 1 shows the SEM micrographs (back-scattered electron images) of a typical SiCp/2618Al MMC joint, TLP bonded using the interlayer of the mixed Al–Ag–Cu powder. It can be seen that although a joint is formed between the two parent materials, there are large quantities of porous zones within the joining layer, especially at the joining interfaces. The high magnification view shown in Fig. 1b and analyses by energy dispersive X-ray spectrometer (EDS) reveal a small amount of Al_2O_3 and considerable SiC existing in the porous zones. Evidently, the SiC in the porous zones comes from the parent materials. As for the Al_2O_3, it should be from the surfaces of the composites or the Al powder used in the interlayer. These indicate that an appreciable amount of the parent materials have dissolved into the joining layer during bonding, resulting in the porous zones of the SiC collection.

It is believed that the bad wettability of Al–Ag–Cu eutectic liquid to SiC and aluminium oxide film on surfaces of the bonded composites is responsible for the SiC collection and results in the porous zones in the joints. As a matter of fact, inferior wettability of SiC has been one of the problems for preparation of the SiCp reinforced aluminium metal matrix composites. In order to improve the wettability of Al–Ag–Cu eutectic liquid to SiC and surfaces of the bonded composites during bonding, a certain amount of titanium was added into the mixed Al–Ag–Cu interlayer. Figure 2 shows the back-scattered SEM images of a typical SiCp/2618Al MMC joint TLP bonded using a mixed Al–Ag–Cu–Ti powder containing 2.1% Ti. It can be seen from Fig. 2 that a dense joining layer of high quality forms between the two bonded materials, and no obvious SiC collection and porous zones are present in the joining layer. The joining interfaces appears to be even as shown in the low magnification view of Fig. 2a. Figure 2b shows that there is no distinct interface between the bonded composites and the joining layer, which exhibits a reaction between the parent materials and eutectic liquid during bonding.

Figure 3 shows the microstructures of the joining layer of the TLP bonded SiCp/2618Al MMC using an Al–Ag–Cu–Ti interlayer containing 2.1% Ti. Figure 3a is a general high magnification view of the joining layer. It is further confirmed in Fig. 3a that the joining layer is dense, and no porous zones exist in it. In addition, two typical microstructural regions, A and B can be found in Fig. 3a. Their microstructures are shown in Fig. 3b and c, respectively. Electron probe X-ray microanalyses (EPMA) combining with X-ray diffraction (XRD) reveals that 'A' region is composed of needle-like intermetallic compound Ag_2Al and Al matrix, and 'B' region contains intermetallic Al_4Cu_9, Al_3Ti, pure Ag and matrix phase Al, as shown in Fig. 3b and c. In the back-scattered SEM image (Fig. 2a), a

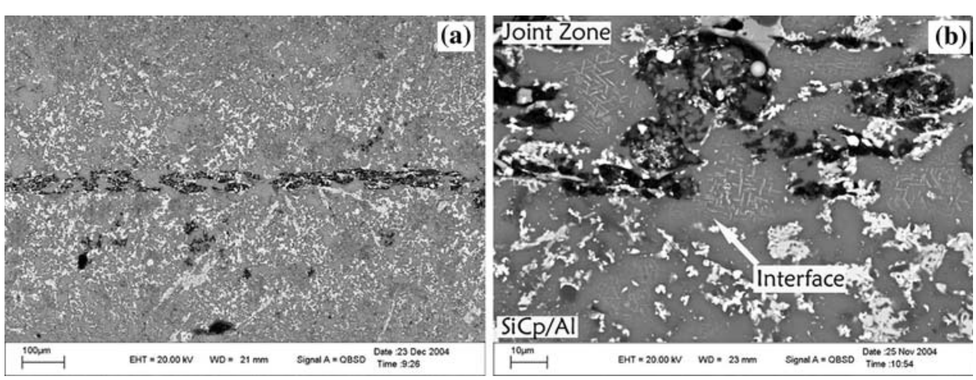

Fig. 1 SEM micrographs of a typical SiCp/2618Al joint bonded using an interlayer of mixed Al–Ag–Cu powder (**a**) low magnification view and (**b**) high magnification view of the joining interface region

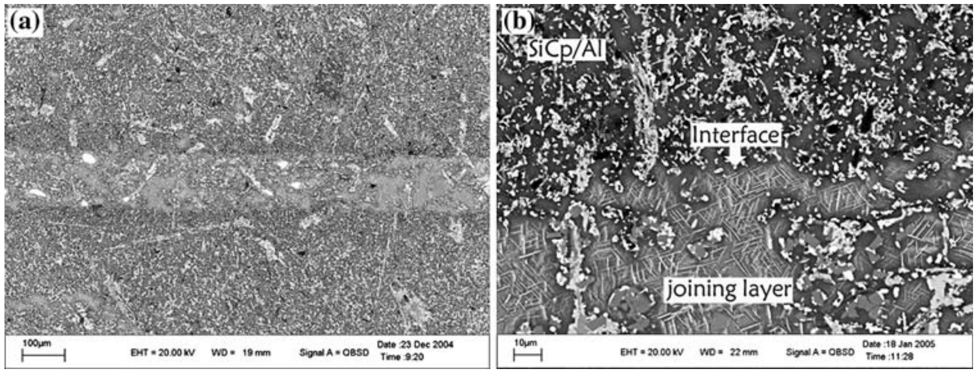

Fig. 2 SEM micrographs of a typical SiCp/2618Al MMC joint bonded using an interlayer of mixed Al–Ag–Cu–Ti powder containing 2.1% Ti (**a**) low magnification view and (**b**) microstructure of the joining interface region

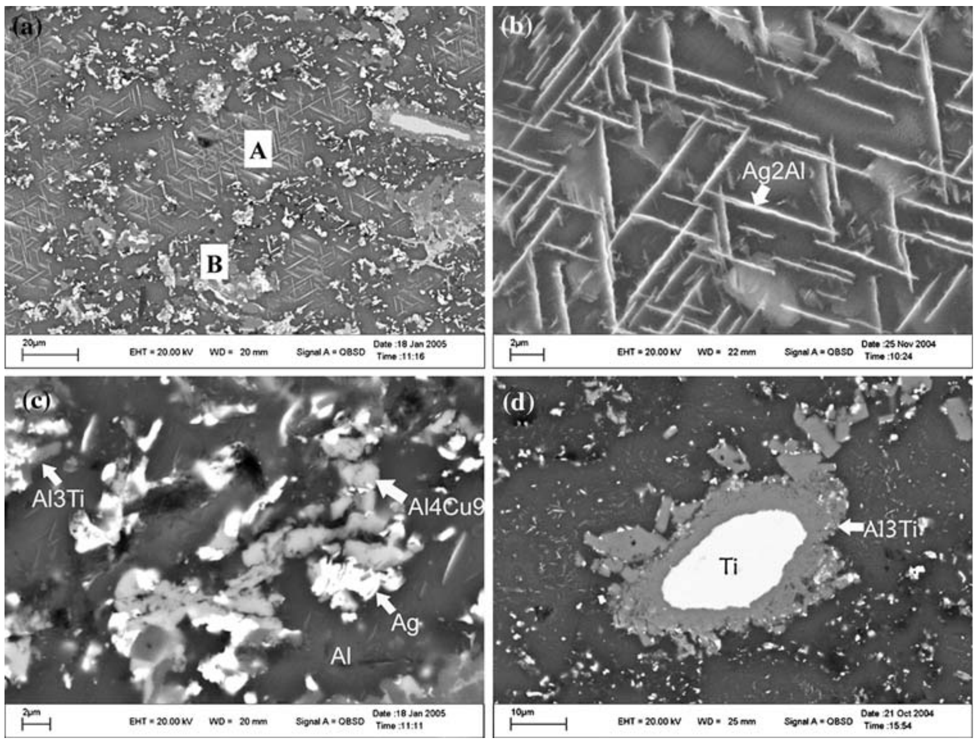

Fig. 3 Microstructures of the SiCp/2618Al MMC TLP joining layer bonded using an Al–Ag–Cu–Ti interlayer containing 2.1% Ti (**a**) high magnification view of the joining layer, (**b**) microstructure of A region in (**a**), (**c**) microstructure of B region in (**a**) and (**d**) Ti particle not dissolved in the joining layer

few white particles can also be observed in the joining layer. These are always surrounded by a grey layer, as shown in the high magnification micrograph of Fig. 3d. Electron probe X-ray microanalyses indicate that the white region are pure Ti, and the grey surrounding layer is intermetallic compound Al_3Ti. Evidently Ti particles did not dissolve completely during bonding Al reacts with Ti on the surface of the Ti particles to form the Al_3Ti compound.

The reaction between Al and Ti in the Al–Ag–Cu–Ti interlayer will deplete Al to increase fusion point of the Al–Ag–Cu system, thus accelerating solidification of the joining layer. Generally, the Ti powder added in the interlayer should be dissolved. However, some Ti particles in the Al–Ag–Cu–Ti interlayer are found to have not completely dissolved during bonding, which demonstrate that the period in liquid state of the Al–Ag–Cu–Ti interlayer is very short. Additionally, under the same bonding conditions, especially under the same bonding pressures, the thickness of a joining layer is determined by the period in the layer remains in the liquid state. In the case of a long period in liquid state of the interlayer, the interlayer liquid is liable to be squeezed out of the joining interface, and a thin joining layer will be formed. Comparing Fig. 1a with Fig. 2a, we can see that the thickness of Al–Ag–Cu–Ti joining layer is obviously greater than that of Al–Ag–Cu joining layer, though the bonding conditions, especially bonding pressures of the two cases are the same. This confirms that the Al–Ag–Cu–Ti interlayer has a period in liquid state shorter than that of Al–Ag–Cu interlayer, or a liquidation degree lower than that of Al–Ag–Cu interlayer. Therefore, besides improving the wettability of Al–Ag–Cu

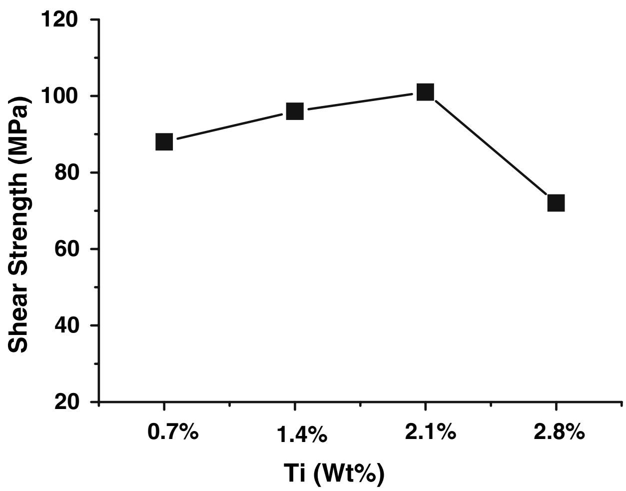

Fig. 4 Shear strength of the joints versus amount of added titanium in interlayers

eutectic liquid to SiC and surfaces of the bonded composites during bonding, adding Ti into interlayer has an effect shortening solidification time of the joining layer. This will decrease the quantity of the parent materials (including SiC) entering the joining layer, and avoid the metal liquid to be squeezed from the joining layer to form a joint, in which a lot of SiC particles remain and gather together as shown in Fig. 1.

The effect of added titanium in interlayers on shear strength of the joints bonded using Al–Ag–Cu–Ti interlayers is shown in Fig. 4. The joints have a maximum shear strength of 101 MPa at adding 2.1% titanium (by weight). Formation of more brittle Ti–Al intermetallic compound in the joining layer may be responsible for the decrease in shear strength of the joints, when more than 2.1% titanium is added in the interlayers.

Conclusions

(1) By using mixed Al–Ag–Cu powder with the eutectic composition as an interlayer, SiCp/2618Al MMC can be TLP bonded at 540 °C. However, the joining layer is porous.

(2) Adding a certain amount of titanium can improve the joining quality of SiCp/2618Al MMC TLP bonded by using the Al–Ag–Cu interlayer. The joints bonded using Al–Ag–Cu–Ti interlayers have a maximum shear strength of 101 MPa when 2.1% titanium is added.

(3) The Ti added into the Al–Ag–Cu interlayer has an effect shortening the solidification time of the joining layer, thus decreasing SiC particles from the parent materials entering into the joining layer, and avoiding to form a joint, in which a lot of of SiC particles remain and gather together.

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