Materials Science and Engineering B 177 (2012) 1707–1711

Contents lists available at SciVerse ScienceDirect

Materials Science and Engineering B

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

Short communication

Vacuum brazing of aluminium metal matrix composite (55 vol.% SiC_p/A356) using aluminium-based filler alloy

Jitai Niu[a,b,*], Xiangwei Luo[b], Hao Tian[b], Josip Brnic[c]

[a] Harbin Institute of Technology, China
[b] Zhengzhou University, China
[c] University of Rijka, Croatia

ARTICLE INFO

Article history:
Received 23 August 2011
Received in revised form
16 November 2011
Accepted 23 December 2011
Available online 9 January 2012

Key words:
Aluminium matrix composites
Vacuum brazing
Microstructure
Shear strength

ABSTRACT

Aluminium matrix composites with high volume fractions of SiC particles, as the reinforcements, are potentially suitable materials for electronic packaging. These composites, due to their poor weldability, however, have very limited applications. The microstructure and shear strengths of the bonds made in 55 vol.% SiC_p/A356 composite, using an aluminium based filler alloy containing Cu, Si, Mg and Ni, were investigated in this paper. The brazing temperature had a clear effect on the bond integrity, and the samples brazed at 560 °C demonstrated good bonding between the filler alloy and the SiC particles. The maximum shear strength achieved in this work was 102 MPa.

1. Introduction

Aluminium metal matrix composites (Al-MMCs) reinforced with high volume fraction of SiC particles are considered as candidate materials for electronic packaging and thermal management applications because of their excellent thermo-physical properties such as low thermal expansion coefficients and high thermal conductivity. Moreover, these composites display good net-shape fabrication capability with relative low costs [1]. Welding technologies play an important role in the practical application of most materials, but substantial differences in the physical and chemical properties of the matrix alloy and reinforcements have hindered achieving high quality joints in aluminium composites.

Substantial work has been carried out on welding Al-MMCs with low volume fractions of reinforcement particles, using various processes such as arc welding, laser welding, electron beam welding, diffusion welding, friction stir welding and resistance welding [2–6]. However, these welding processes proved unsuccessful for joining Al-MMCs with high volume fractions of the reinforcements (i.e. >45 vol.%).

Vacuum brazing does not require temperatures as high as the fusion welding process and is therefore a suitable alternative to join Al-MMCs with high volume fractions of reinforcement particles. Zhang et al. reported achieving bonds with shear strengths up to 224 MPa in 55 vol.% SiC_p/A356 when using ultrasonic dissolution and Zn-Al alloy as the filler alloy [7]. The use of electroless nickel plating on the faying surfaces of the composites makes the brazing process more feasible because of the metallic bond formed between the nickel coat and filler alloy [8,9]. However, these methods are complex, costly and hence not feasible in mass production.

Although researchers [10,11] have investigated the joining of Al-MMCs reinforced with low volume fractions of reinforcements by direct brazing and the results are reasonably good, the direct brazing of Al-MMCs reinforced with high volume fractions of reinforcements have not been reported. In this work, an Al-Cu-Mg-Si-Ni alloy was used as the filler metal to braze an Al-MMC with a high volume fraction of SiC particles. As the brazed materials are aluminium metal matrix composite the filler alloy must be aluminium-based alloy. The element of Cu and Si can enhance the fluidity and wettability of filler alloy, Mg in the filler metal might rupture the aluminium film, and Ni might improve the joint strength. The wetting behaviour of the filler metal on the SiC particles, the effect of brazing temperature on the joint microstructure were studied and a limited number of shear tests were also carried out.

2. Experiment

The Al-MMCs selected for this work were A356 aluminium alloy reinforced with 55 vol.% SiC particles, fabricated by pressureless

* Corresponding author. Tel.:+86 451 8641 4234; fax: +86 451 8641 4234.
E-mail address: niujitai@163.com (J. Niu).

0921-5107/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.mseb.2011.12.042

Table 1
Chemical composition of A356 aluminium alloy matrix and filler (wt.%).

	Si	Mg	Cu	Ti	Ni	Al
A356	7.0	0.4	–	0.1	–	Bal.
Filler metal	5.0	1.5	24.0	–	0.5	Bal.

Table 2
Thermo-physical properties of 55 vol.% SiC_p/A356 composite.

Thermal expansion coefficient (ppm/K)	Thermal conductivity (W/m K)	Specific gravity (g/cm^3)
8.0	170	2.93

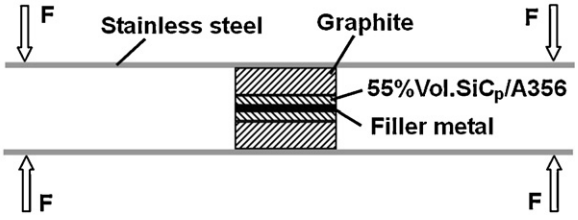

Fig. 1. Specimen setup used for brazing composite samples (schematic and not to scale).

infiltration process. The average particle size was 50 μm. The chemical compositions of the matrix alloy and filler metal are given in Table 1 and the thermo-physical properties of the composite are shown in Table 2. The filler metal with 100 μm thickness was produced by rapid solidification, and then annealed at 350 °C for 3 h to improve its ductility. The melting temperatures of the filler alloy and the A356 aluminium alloy matrix are 525–542 °C and 577–624 °C measured by DSC, respectively.

The dimensions of the specimens were 17 mm × 10 mm × 2 mm. The overlapping length was 8 mm for the shear test samples, and the metallographic samples were fully overlapped. The composite plates and the filler metal foil were carefully ground using emery papers (grit 800) and then cleaned in an ultrasonic bath containing acetone. Fig. 1 shows the specimen setup used for brazing the samples in this work.

The brazing tests were carried out in a commercial vacuum furnace (2.7×10^{-3} and 8.0×10^{-3} Pa). The sample was placed in the furnace and heated 20 °C/min up to the bonding temperature of 550 °C or 560 °C. The brazing time was 3 min and the samples were cooled in the furnace.

The shear strength of the samples was measured using a special jig made of 40Cr steel (Fig. 2). The shear test was performed with a constant speed of $3 \times 10^{-4}\,S^{-1}$ at the room temperature, using a conventional tensile testing machine (Instron-5569). For reliable results, three samples, made in identical conditions, were tested in each case.

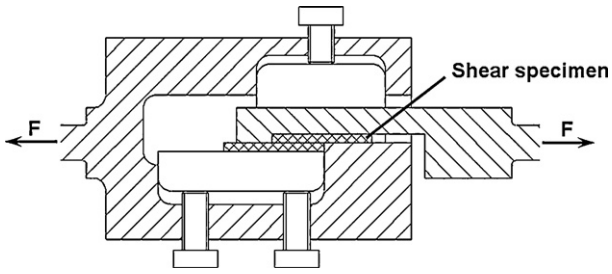

Fig. 2. Special jig used for shear testing brazed samples.

Cross-sections of metallographic samples were prepared for metallographic analysis by standard polishing techniques, using 800 grit emery papers and 3.5 μm diamond paste (no etchant was used). Microscopic examination was performed using optical microscope (OM, BH2-UMA) and scanning electron microscope (SEM, S-570) equipped with an energy dispersive X-ray spectrometer (EDX, TN5500).

3. Results

Optical microscopy of the as-received composites showed the presence of bonding between the SiC particles and the aluminium alloy matrix (Fig. 3). The composites mainly consist of very large SiC particles and some much smaller ones.

The typical microstructures of the brazed joints are shown in Fig. 4. There was no evidence of oxide films between the filler metal and the matrix of the composite. Although there were good bonding interfaces between the SiC particles on the composites surface and filler metal when brazing was carried out at 550 °C, a few voids (black portion) were present in the same sample (see Fig. 4a and b). Such voids were also found when brazing of Al-MMCs containing alumina particles [10]. So it was concluded that the wettability of filler metal on SiC particles is not always good when brazing at 550 °C. With the brazing temperature raised to 560 °C, the flowability and activity of the filler metal were substantially improved (Fig. 4c).

Fig. 5 shows the SEM micrographs of the bonds made at 550 °C and 560 °C in which the bright phases (A) were mostly seen on the bond line of the sample made at the lower temperature. The EDX analysis (Fig. 6) showed that the bright phases consisted of Cu and Ni. It was also concluded that the use of higher temperature led to the dissolution of these Cu/Ni rich phases and this resulted in better bonds.

The maximum shear strength was 102 MPa and Fig. 7 shows the fracture surfaces of a shear tested sample. Almost entire fracture surface was covered by the filler metal with a few exposed SiC particles. This showed that the filler metal was wetted and bonded to the SiC particles during brazing at 560 °C. The bonding between

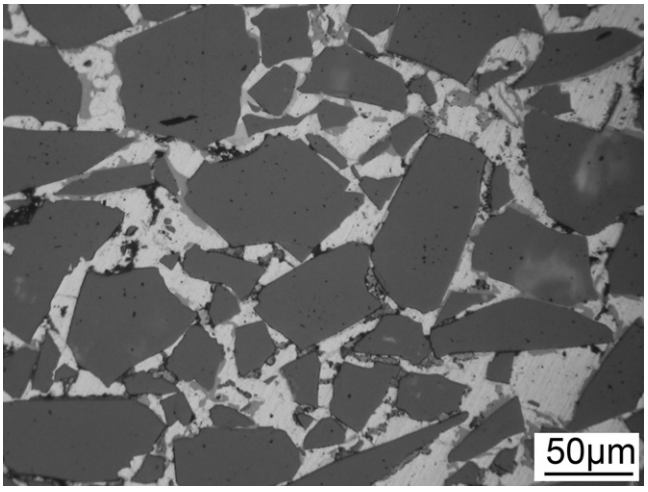

Fig. 3. Optical micrograph of as-received composite used in this work.