Asian Journal of Chemistry; Vol. 25, No. 10 (2013), 5565-5567

ASIAN JOURNAL OF CHEMISTRY

http://dx.doi.org/10.14233/ajchem.2013.OH20

Study on the SiCp/Al Composites Prepared by Pressureless Infiltration†

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AJC-13263

SiCp/Al composites with high reinforcement content were fabricated by pressureless infiltration of aluminum alloy into porous SiC preform obtained by self-oxidation bonding at low temperature. The microstructure, composition and infiltration mechanism of SiC/Al composites were analyzed by scanning electron microscope, energy dispersion spectrometer and X-ray diffraction. The effects of SiC volume content on the mechanical properties of the composites were also examined. The relative density of the SiCp/Al composite reached 98 %. The reinforcement volume fraction achieved 55-65 % by using bimodal particle distributions. The bending strength ranged from 320 to 342 MPa, depending on the particle size.

Key Words: Metal matrix composites, Pressureless infiltration, Microstructure, Mechanical properties.

INTRODUCTION

High volume fraction SiCp/Al composites have drawn much attention in multifunctional electronic packaging due to their excellent thermal properties, such as low coefficient of thermal expansion and high thermal conductivity[1,2]. Infiltration is believed to be an ideal process to prepare high volume fraction SiCp/Al composites because it can realize the near-net shape forming of complex parts. And this process consists of two steps: preparing a SiCp preform and infiltrating the perform with the aluminum alloys under pressure or without pressure. Compared with the pressure infiltration, pressureless infiltration is more promising because of its low cost and simple equipment[3,4].

Although the wettability between Al and SiC can be improved at elevated temperature, the detrimental interfacial reaction, $4Al + 3SiC = Al_4C_3 + 3Si$, could easily occur when the temperature is over 900 ºC. The Al_4C_3 phase is known to be thermodynamically unstable and reacts slowly with the atmosphere moisture, so the composites containing Al_4C_3 are very sensitive to some corrosive environments, resulting in the degradation of the properties of the composite. So some methods have to be used to not only improve the wettability between Al and SiC, but also to avoid the formation of Al_4C_3. Until now, only one method has been widely researched by a number of authors, *i.e.*, the alloying of the matrix[5,6]. The basic principle is to enhance the Si activity by dissolving a certain amount of Si in the aluminum, resulting in the thermodynamic suppression of the interfacial reaction between SiC and Al. There have been many researches on the mechanism of the evolution of the microstructure of the corresponding composites. Pech-Canul *et al.*[7] Ren *et al.*[8] made a serial study on the pressureless infiltration of 55 vol % SiCp preform by Al-Si-Mg alloying, including the role of Si and Mg, the infiltration kinetics. However, the infiltration temperature is about higher than 1000 ºC and infiltration time is much more 1 h.

From above review, SiCp/Al composites have not yet achieved their full potential. In this paper, we investigate the possibility of attaining 55-65 vol.% SiCp/Al composites by pressureless infiltration of aluminum alloy into porous SiC perform at 850 ºC for 0.5 h. The microstructure and mechanical properties were characterized.

EXPERIMENTAL

Green and abrasive grade SiC particles with a purity of 98.5% were used in this study. Particle size was in the range of 14-85 μm. In order to achieve high SiC volume fraction, SiC particle with bimodal size distribution were designed. The SiC preforms were prepared by cold pressing molding using a stainless steel die. Some SiC preforms were oxidized in air at 1000 ºC for 3 h. In contrast, some performs were unoxidized. The chemical composition of the aluminum alloy is Al-10 wt % Si-8 wt % Mg. Infiltration was then carried out in a vacuum

†Presented to the 6th China-Korea International Conference on Multi-functional Materials and Application, 22-24 November 2012, Daejeon, Korea

furnace provided with end-cap fittings to control the process atmosphere. The system was heated in ultra-high purity nitrogen (99.999 %, $O_2 < 0.1$ vppm) at a rate of 20 ºC/min up to 850 ºC. After infiltration for 0.5 h, the specimens were furnace-cooled to room temperature.

The densities of the composites were measured by Archimedes' principle. The microstructure and the fractural surfaces were observed on the JSM-6490LV scanning electron microscopy (SEM). XRD analysis was performed on D/max-r B X-ray diffraction meter using Cu radiation. TC was determined by first measuring the thermal diffusivity by laser flash technique and then calculated by the equation: $K = \alpha\rho Cp$, where α, ρ and Cp are the thermal diffusivity, density and specific heat, respectively. Bending strength was determined using three-point-bending tests with a span of 30 mm on an DCS-3000 universal testing system.

RESULTS AND DISCUSSION

Microstructure and composition of SiC/Al composite: Preforms had no change in shape and dimension after infiltration, thus near-net-shape composites were easily achieved, the size of the composites all changed less than 1 %. The SEM, EDX and XRD analysis of the infiltrated sample, as shown in Fig. 1, revealed that a few new phases, such as Fe, $MgAl_2O_4$ and Mg_2Si were formed in during the infiltration process. SiC preforms not only has open pore-net for liquid metal penetrating in, but also provides SiO_2 film and Fe_2O_3 as a good initial interface for liquid-solid reactions listed as below[9]:

$$SiO_2(s) + 2[Mg] = 2MgO(s) + [Si] \quad (1)$$

$$2SiO_2(s) + Al(l) + 1/2[Mg] = 1/2MgAl_2O_4(s) + [Si] \quad (2)$$

$$[Si] + 2[Mg] = Mg_2Si \quad (3)$$

$$Fe_2O_3 + 2[Al] = Al_2O_3 + 2[Fe] \quad (4)$$

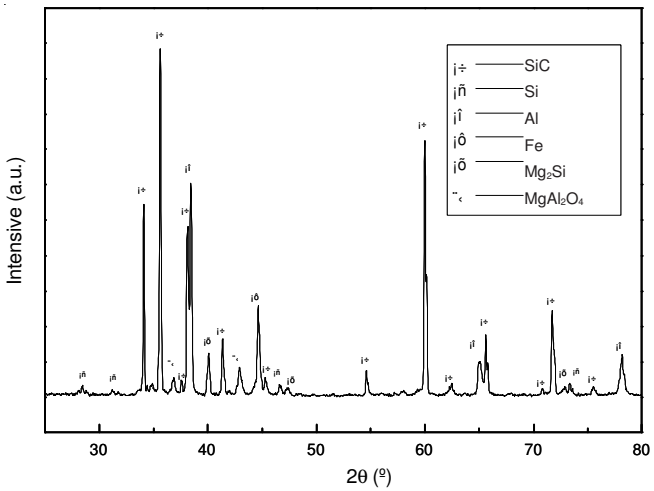

Fig. 1. X-ray diffraction patterns of the SiCp/Al composite

These reactions remarkably decrease the liquid-solid interface energy, which is beneficial to improve wettability of the two phases and the infiltration of liquid metal into porous SiC preform. It is seen from XRD pattern in Fig. 1 that Al_4C_3 did not form in the composite. The absence of Al_4C_3 was attributed to the relatively elevated level of Si in the system. Silicon retards the kinetics of the chemical reactions that result in the formation of these unwanted intermetallics.

The relative densities of SiC/Al composites with no $Fe(NO_3)_3$ was just 96.5 %, but the other two groups of SiC/Al composites were above 98.0 % which indicates that near completely dense SiC/Al composites were achieved by the pressureless infiltration of liquid Al alloy into porous SiC preforms enhanced by adding magnesium and $Fe(NO_3)_3$. Fig. 2 shows the metallographic photographs of pressureless infiltrating SiC preforms with the content of $Fe(NO_3)_3$ from 0 wt % to 20 wt % by Al-10 Mg-8 Si for SiC/Al composites with different SiC volume fractions. Fig. 2a,b and c shows the microstructures for 64 vol. % SiC/Al, 60 vol. % SiC/Al and 55 vol. % SiC/Al composites respectively. It was found that SiC particles (bright grains) with clear edges and corners which shows that they keep their original shape very well due to the protection of SiO_2 film on its surface. Fig. 2 showed that there are no obvious pores in the composites. It is mainly related to the bond mechanism of sodium silicate, during the dehydration process, the sol accumulated to a mass of floc SiO_2 and the pore-forming agents have decompounded into Fe_2O_3. With the aid of magnesium, liquid aluminum alloy reacted with SiO_2 film on the surface of SiC powders to form MgO and $MgAl_2O_4$ and the aluminum reacted with Fe_2O_3, which gave out heat and raised the temperature on the infiltration front to promote the wettability for SiC-Al system and the pressureless infiltration of liquid aluminum into the intervals among SiC preforms.

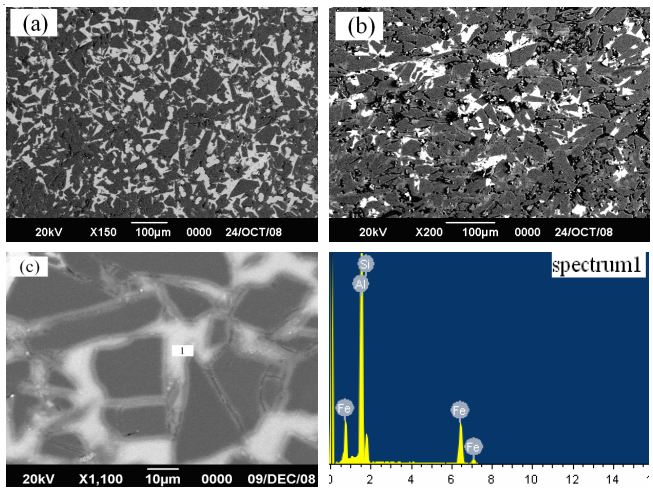

Fig. 2. SEM micrographs and EDS of SiCp/Al composite

Mechanical properties: Mechanical properties of the composite are also important requirement for the electronic packaging application. The bending strengths of the SiCp/Al composites are shown in Fig. 3. It can be seen that the particle size has noticeable effect on the bending strength. The bending strength decreases with increasing particle size. It is attributed to the fact that larger particles tend to fracture at low stress. Fig. 4 gives the fracture surface of the pressureless infiltrated SiCp/Al composites. From the fractographs, brittle rupture was mostly observed in SiC/Al composites. Cracks spreaded along the interface between SiC and Al matrix, traversed across the sintering necks among SiC particles, the scanning electron fractograph of SiC composites was shown as arrow A in Fig. 4. When cracks spreaded through the sample, tough metal matrix

was teared away with plastic deformation, the morphology of dimple fractures was shown as arrow B. And there was a little SiC powers were left by the cracks was shown as arrow C.

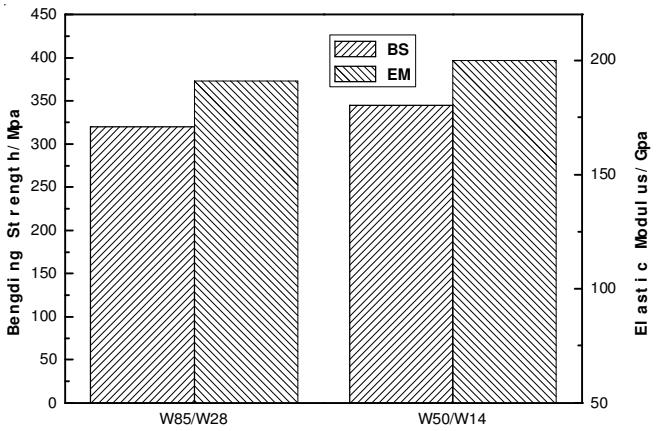

Fig. 3. Bending strength and elastic modulus of SiCp/Al composites

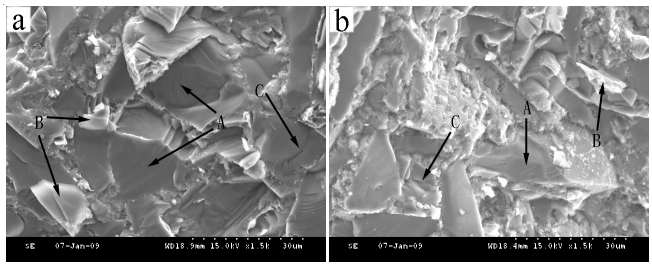

Fig. 4. SEM fractograph of 60 vol % SiCp/Al composites (a) SiC: W85/W28; (b) SiC: W50/W14

Conclusion

High volume fraction SiCp/Al composites were fabricated by pressureless infiltration. Their microstructure and mechanical properties were investigated. The following results can be presented:

(1) The composite has a high relative density up to 98%.With the use of bimodal or trimodal mixtures, SiCp/Al composites with 55-65 vol. % SiC particles were fabricated.

(2) The bending strength increased with decreasing particle size. It varied between 320 to 342MPa.

ACKNOWLEDGEMENTS

This research has been financially supported by Anhui Provincial Natural Science Foundation (1208085QE100), Educational Commission of Anhui Province of China (KJ2012ZD05).

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