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Mechanical properties and fractograph of SiC foam-SiC particles-Al composites

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Abstract: A new type of hybrid SiC foam-SiC particles-Al composites used as an electronic packaging substrate material were fabricated by squeeze casting technique. The mechanical properties and the fracture mechanism of the hybrid composites were investigated. The influence of SiC particles and foam hybrid reinforcement on the behavior of the composites was studied. The results show that the interface bonding in the hybrid composites is good for the composites with the unique double interpenetrating structure. The compressive strength of the hybrid composite reinforced by the SiC with the volume fraction of 59.9% is 680 MPa, which is higher than that of any other composites with the same volume fraction of SiC particles reinforcement.

Key words: hybrid composites; double interpenetrating; mechanical property; fractograph

1 Introduction

Metal matrix composites attract attention for packaging applications because of their integrated thermal and physical properties and superior mechanical strengths[1−3]. Among them, particle-reinforced and interpenetrating aluminum matrix composites have shown promises as candidates for such applications[4−7]. Generally, the volume fraction of particles has to exceed 70% in order to make thermal expansion match between the substrate and chips when SiC_p/Al composites are used as substrate[8−10]. However, such high content of SiC particles reduces the thermal conductivity of the composites, which makes the high heat dispersion requirements difficult to meet in high-performance electronic packaging. The interpenetrating composites reinforced by three-dimensional ceramic networks, such as SiC foams, have much lower thermal expansion than SiC_p/Al composites containing the same content of SiC[11−13]. Nevertheless, foams with fine-sized pores and high SiC volume fractions are difficult to attain, and it is difficult to produce such composites to meet the requirements of low thermal expansion for electronic packaging. The novel composite which is called SiC foam-SiC particles-Al hybrid composite can overcome the shortcomings of 3-D SiC foam-reinforced composites, by substituting the aluminum matrix in interpenetrating composites with SiC_p/Al composites. The hybrid composites not only have the desirable low coefficients of thermal expansion, but also have relatively low content of SiC reinforcement compared with SiC_p/Al composites[14]. The hybrid composites were fabricated by squeeze casting technology, and their mechanical properties and the fractograph were investigated in order to apply them in electronic packaging.

2 Experimental

The commercial 4032 aluminum alloy with a relative low coefficient of thermal expansion was used as the matrix. The chemical composition of the aluminum alloy is listed in Table 1.

Table 1 Chemical composition of 4032Al (mass fraction, %)

Si	Cu	Mg	Ni	Al
11.8	1.0	1.1	1.0	Bal.

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The hybrid composites were fabricated by modifying an established procedure[15]. First, the SiC foams with a cell size of about 2 mm, shown in Fig.1(a), were produced by a solid-state sintering process through the polymer foam replication method[16]. The SiC foam is made up of cells and struts that consist of triangular shaped opening holes surrounded by strut walls as shown in Fig.1(b). Furthermore, there are numerous continuous tiny cavities in the strut walls (Fig.1(c)), which makes the struts have a three-dimensional reticular structure similar to that of the foam. This special structure was deliberately designed in the experiment in order to increase interfacial bonding between the matrix and struts for the interface area play important role in the mechanical bonding. SiC foams with different volume fractions were obtained through tuning the strut diameters with the cell size kept approximately constant. Second, SiC particles with mean particle size of 20 μm were dispersed in the SiC foam cells to form a hybrid preform by vibration. The volume fractions of SiC of the foams were 16.4%, 22.2% and 28.8%, and the corresponding total SiC volume fractions in the composites were 53.0%, 56.2% and 59.9%, respectively. The processing route used for the fabrication of composites is shown in Fig.2. Fig.3 shows the schematic of the apparatus used. The hybrid composites were fabricated by the use of the squeeze casting technology.

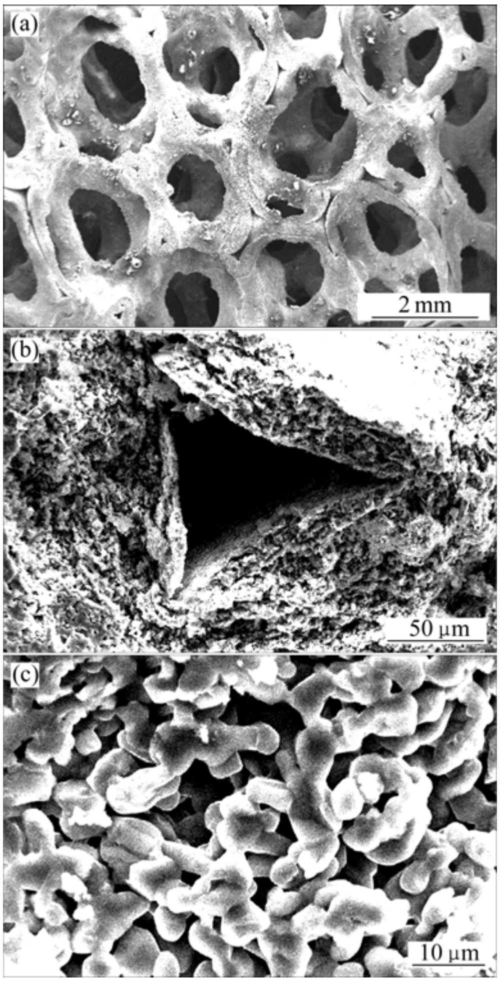

Fig.1 Morphologies of SiC foam reinforcement: (a) Macro-appearance; (b) Cross section of strut; (c) Surface of strut

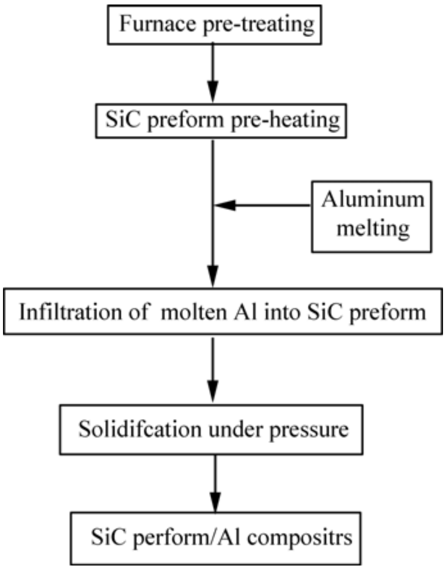

Fig.2 Flow chart for synthesis of hybrid composites

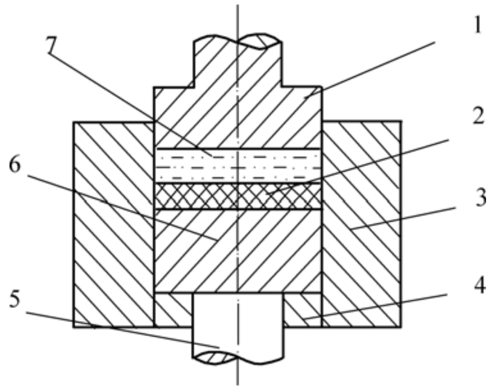

Fig.3 Schematic illustration of squeeze casting: 1—Male die; 2—Preform; 3—Female die; 4—Washer; 5—Mandril; 6—Gasket; 7—Liquid alloy

The microstructure of the composites was examined with an MEF4A optical microscope (OM) and an S360 scanning electron microscope. The dimensions of compressive test specimens are 15 mm×15 mm×30 mm. All the tests were conducted in an Instron testing machine at a strain rate of 5×10^{-3} s^{-1}.

3 Results and discussion

3.1 Composite characterization

It is found that the hybrid composites are composed of the gray SiC particles, the white aluminum alloy matrix and the gray SiC foam struts, as shown in Fig.4. The SiC particles distribute uniformly in the cells of SiC foam, but they are not found in the triangle holes of the struts. The SiC particles cannot be placed (by vibration) into the holes because the particles are larger than the cavities in the strut walls. And the axis direction is not open to the SiC particles, so the SiC particles can’t enter into the triangle holes of the struts. Because the strut walls are reticular, the walls have an interpenetrating structure after aluminum infiltrating the cavities of the boost the bonding of the SiC foam struts to aluminum in the triangle holes and in the cavities. In addition, a SiC foam network makes the overall hybrid composites an interpenetrating structure. The structure, which is called the overall interpenetrating structure, restricts the SiC particles and aluminum in the foam cells. The composites possessing both the local interpenetrating structure and the overall interpenetrating structure are called double interpenetrating structure composites. With the special double interpenetrating structure, the composites will attain the unique properties. With the increase of the diameter of the strut, the volume fraction of SiC reinforcement in the composite is increasing, as shown in Fig.5. When the struts of SiC foam are getting thicker, the volume fraction of SiC foam/Al is getting larger, that of SiC_p/Al is less. For the volume of SiC in the SiC foam/Al is larger than that in SiC_p/Al, the total volume fraction of SiC in the composites is getting larger with the diameter of the struts. Fig.5 shows the microstructures of the composites reinforced by the SiC foam ceramics and SiC particles. The volume fractions of SiC of the foams were 16.4%, 22.2% and 28.8%, and the corresponding total SiC volume fractions in the composites were 53.0%, 56.2% and 59.9%, respectively. The microstructures of SiC_p/Al in the hybrid composites are the same when the volume fraction of SiC foam is increasing.

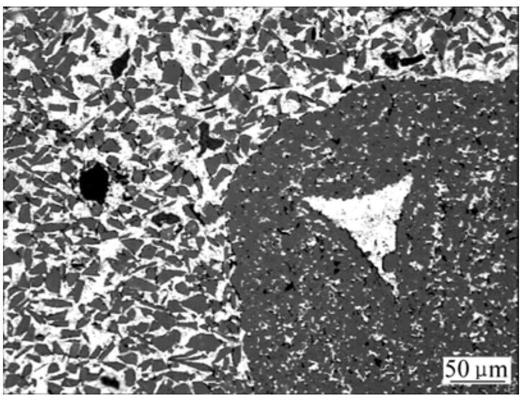

Fig.4 Morphology of hybrid composites

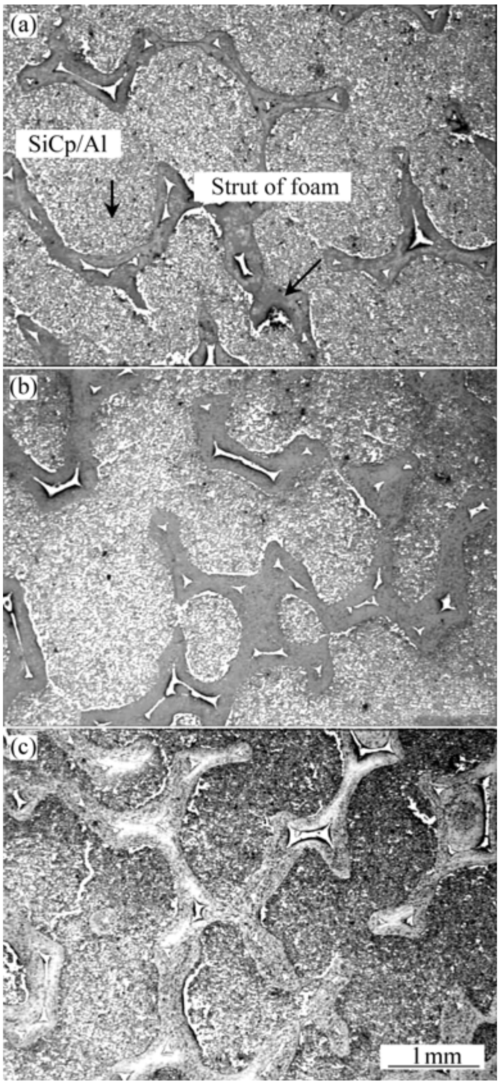

Fig.5 Macrographs of SiC foam/particle/Al composite reinforced by different volume fractions of SiC: (a) 53.0%; (b) 56.2%; (c) 59.9%

3.2 Mechanical properties

Fig.6 shows the relationship between the compressive stress and compressive strain. With the volume fraction of SiC reinforcement, the elastic moduli of the hybrid composites are increasing. The compressive strength of the hybrid composites is higher than that of the matrix alloy. For a given compressive strain, the compressive stress of the composites is increasing with the increase of composites. The compressive strength of the hybrid composite reinforced by SiC with the volume fraction of 59.9% is 680 MPa, which has not been reported in the conventional Al matrix composites reinforced by the SiC particles. The addition of the total SiC reinforcement in the hybrid composites depends on the diameter of the struts of SiC foam ceramics. When the total volume fraction of SiC is increasing, the strut of SiC foam is getting thicker. At that time, the strength of the struts of SiC foam ceramic is higher, the SiC foam reinforcement can support higher load when the hybrid composites are compressed, so the composites reinforced by high volume fraction of SiC reinforcement have the higher compressive strength. We consider the role of phase morphology in determining the compressive strength of the hybrid composites. For fixed content of the constituent phases, the volume fraction of SiC reinforcement in the hybrid strength of composites varies significantly depending on that the brittle ceramic phase is continuous. This is because the ductile metal phase has a lower elastic module and thus, deforms more easily when the metal phase supports compressive load. When the brittle ceramic phase, less compliant phase is continuous, deformation of metal phase is constrained severely by the surrounding, less compliant phase. Thereby, as the hybrid composite is compressed, the restriction of SiC foam reinforcement on aluminum matrix in the hybrid composite is much stronger than that of discrete particles on the matrix in particles reinforced composites, the compressive strength of the hybrid composites is higher compared with particles reinforced composites.

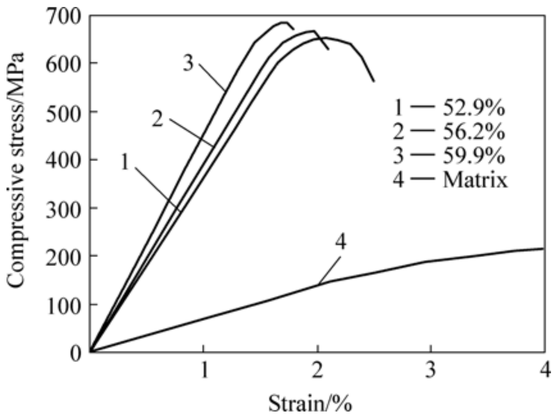

Fig.6 Relationship between compressive stress and strain of hybrid composites

3.3 Fractograph

The fracture surface of the hybrid composite reinforced by the SiC with the volume fraction of 56.2% is shown in Fig.7. Fig.7(a) shows the SEM image of the entire flat and smooth fracture surface, which shows most of the struts of SiC foam ceramic rupture at the inner of them and little of the struts rupture at the surface of the struts. Figs.7(b) and (c) show the microstructure of the fracture surface of SiC_p/Al and the interface between the struts and the alloy matrix at a high magnification. It is found that the hybrid composites are well bonded because little primary surface of SiC particles can be observed and the interface between the struts and the alloy matrix is still good. Many dimples, which are associated with the ductile fracture of the matrix, are found at the fracture surface. The fracture surface has the characteristic between those of other discontinuously reinforced Al matrix composites and the interpenetrating composites, showing brittle fracture macroscopically, and ductile fracture microscopically.

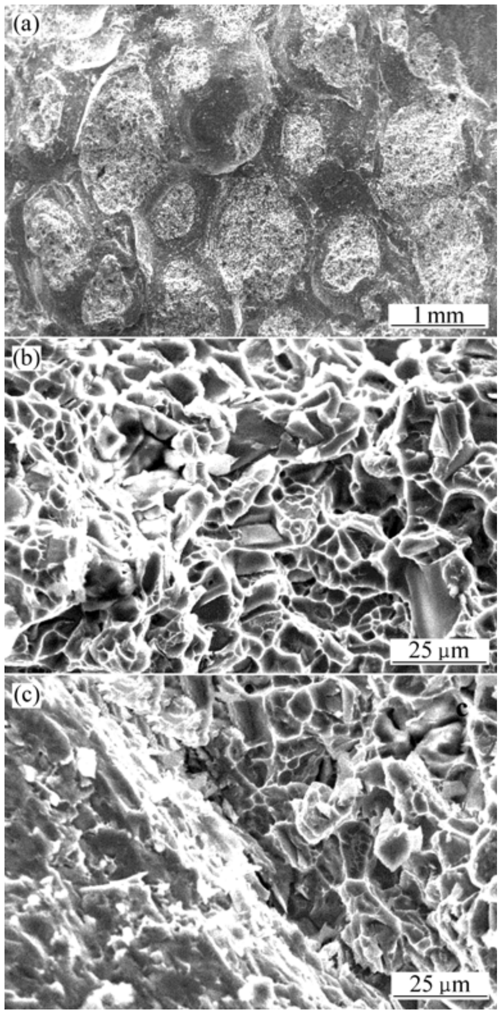

Fig.7 SEM images of fracture surface of hybrid composites: (a) Overview; (b) SiC_p/Al at high magnification; (c) Interface between struts and matrix

4 Conclusions

1) The hybrid SiC foam-SiC particles-Al composites with special double interpenetrating structure are fabricated by the squeeze casting technology.

2) The compressive strength is 680 MPa, which is higher than that of any other composites reinforced by SiC particles.

3) The interface bonding in the hybrid composites is good because the hybrid composite has the unique double interpenetrating structure.

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