Size Effect of SiC Particle on Microstructures and Mechanical Properties of SiCp/Al Composites

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ABSTRACT

The size effect of SiC particles on microstructures and mechanical properties of SiCp/Al composites produced by spontaneous infiltration technology was investigated. In this study, samples of SiCp/Al composites were fabricated using aluminum alloy ZL101 as the matrix material, and SiC particles with different sizes as reinforcement particles. The microstructures and micro-deformation of the samples were analyzed using optical micrograph, scanning electron microscope, energy dispersive spectrometer and WDW-50 respectively. The results show that the SiC particles can distribute uniformly in the aluminum matrix using the proposed method. Examing samples with different SiC particle sizes, the sample with the largest size of particle can significantly decrease the mechanical properties of the composites. Tensile strength of SiCp/Al composite increases along with a decrease in the size of SiC particles, but the ductility of the composites decreases. It was found that an obviously toughness fossa appeared in the fracture surfaces of composites, which indicated it behaviors tearing and plastic deformation characteristics.

Keywords: SiCp/Al composites, Microstructures, Micro-deformation, Mechanical properties, Particles size

1. Introduction

Metal matrix composites reinforced with ceramic particles have some attractive properties such as high strength, elastic modules, fatigue resistance and wear resistance, as compared with those of corresponding either matrix or reinforced materials [1-5]. They are promising materials for aerospace, automotive, thermal management, electronic, and recreational and infrastructure industries due to their high structural efficiency, excellent wear resistance, and attractive thermal and electrical characteristics. These reinforced composites offer nearly isotropic properties compared to short fiber or whisker-reinforced counterparts, and they can also be produced using conventional metal manufacturing process with low cost [6, 7]. The mechanism of strengthening for SiC particle (SiCp)-reinforced aluminum alloy composites is that, when a composite is stretched, most of external load transfers from soft Al matrix to hard SiCp reinforcement, which improves strength of the composite. Due to different thermal coefficients between SiCp and Al matrix, dislocation density and residual stresses in the Al matrix increased when the composite was cooled from an elevated processing temperature or heat-treatment temperature [8, 9]. It should be mentioned that the distribution and size of particles have

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significant effects on microstructure and mechanical properties of the SiCp/Al composites. For a composite with a constant particle volume fraction, there is a close relationship between the particles size and plastic work hardening rate of the composites whose plastic work increases with the decreasing of particles size [10, 11]. Larger particles are more prone to fractures during extrusion process and tensile testing and less efficient to transfer external load from matrix to reinforcements. The present investigation mainly aims at exploring thermal conductivity, heat sink and wear resistance of SiCp/Al composites. In this paper, the dependence of the strength and micro-strain ratios of SiCp/Al composites on SiCp size is investigated in detail under uniaxial tension.

2. Experiments

In our experiment, a commercial aluminum alloy ZL101 was used as the matrix material, which is a material purposely developed by the manufacture for widely use as a matrix in the composite. Its chemical composition is Si 7.0, Mg 0.35, Ti 0.05, Cu 0.1, Mn 0.2, balance Al (wt. %). Green and abrasive grade SiC particles with a purity of 99% were employed as reinforcement particles. The number of SiCp is 70#, 100#, and 180#, accordingly SiCp reinforcements with the average diameters are 220 μm, 140 μm and 70 μm respectively. The volume fraction of the SiC particles in the composites is 55%. SiCp/Al composites were fabricated by spontaneous infiltration technology. The SiCp/Al composites were patterned into dog-bone shaped rectangular specimens for uniaxial tension test.

The uniaxial tensile test was carried out by electronic universal testing machine (WDW-50). At room temperature, the tensile test with quasi-static strain rate 0.05mm/min was applied to effectively avoid experimental error on account of deformation hardening. The microstructures and mechanical properties of the composites were studied using WDW-50, optical micrographs (XJP-6A), scanning electron microscope and energy dispersive spectrometer (QUANTA200).

3. Results and discussion

The optical micrograph (OM) of SiCp/Al composites with SiC particles (70#, 100#, 180#) are shown in Figure 1.

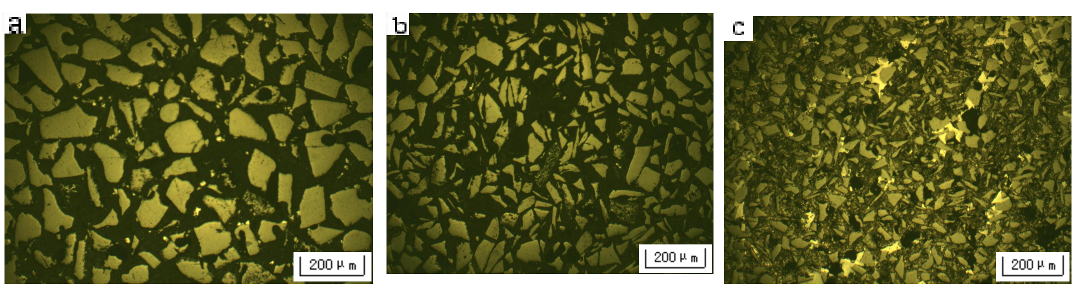

Figure 1. OM of SiCp/Al composites with SiCp of different size: (a) composite with SiCp (70#), (b) composite with SiCp (100#), (c) composite with SiCp (180#)

It is obviously seen from Figure1 that the morphology of SiCp/Al composite fully infiltrates, compact, clear. A dense microstructure was beneficial to electronic packaging applications because of improvement in mechanical strength and heat conductivity. SiCp were homogeneously distributed and no particles-rich phenomenon in Al matrix. It also indicates from Figure 1(a) - 1(c) that particles cluster or agglomeration was hardly observed in the composites. The uniform distribution of reinforcement particles is beneficial to reduce the stress concentration and enhance the load-bearing ability of the composite. OM of SiCp/Al composites also appeared to be well combined and homogeneous, thus isotropic properties of composites could be assumed in tensile testing.

The particle size of SiC had a significant influence on micro-deformation behavior of the composites. The curves of stress and micro-deformation are shown in figure 2.

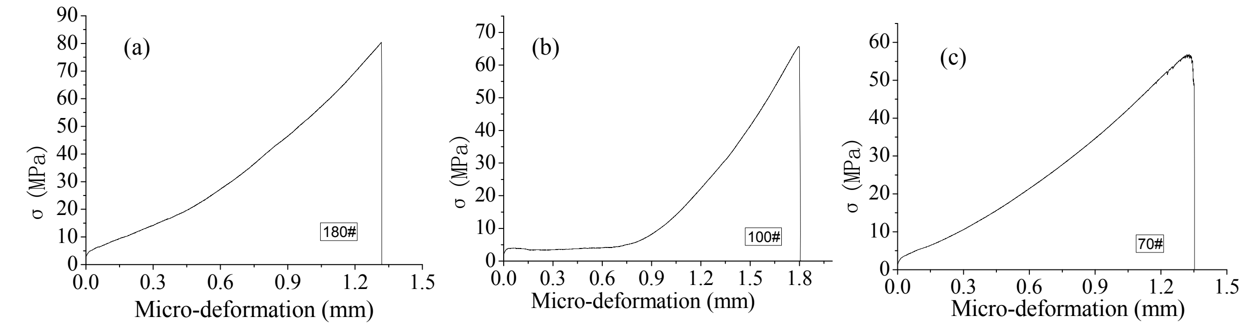

Figure 2. The uniaxial tension curves of SiCp/Al composites with three different particles size, (a) composite with SiCp (180#), (b) composite with SiCp (100#), (c) composite with SiCp (70#)

Figure 2 shows uniaxial tension curves of SiCp/Al composites with three different particles size, namely, (a), composite with SiCp (180#), (b), composite with SiCp (100#), (c), composite with SiCp (70#), respectively. It can be seen from figure 2 shows that, under uniaxial tension, composite with SiCp (180#) has the lowest micro-deformation and the highest applied stress than the other composites. The tensile strength of SiCp/Al composites increased with the decrease of SiC size. This could be ascribed to two factors. On one hand, the effective loading volume increased as the size of SiC decreased and most applied load transmitted to the reinforcement, at the same time, the smaller particles have more interfaces in the composites, and thus the stress is not easy to concentrate and increase in the composites, then help to improve the tensile strength of SiCp/Al composites. Thus we concluded that composite with SiCp (180#) presents a good resistance to micro-deformation behavior. The composite with larger particle size would result in a higher strain and consequently lower fracture strength. This may be attributed to the inter-particle spacing, which decreases with the decreasing of the SiC particle size at a given particle volume fraction, and micro-deformation is essentially determined by the inter-particle spacing. During deformation, the geometrically necessary dislocation is stored in the matrix, and a larger interparticle spacing can accommodate larger dislocation during deformation between two neighboring particles to improve the ductility of the composites [12].

Figure 3 shows images of the composites with different SiC particle sizes from scanning electron microscope (SEM).

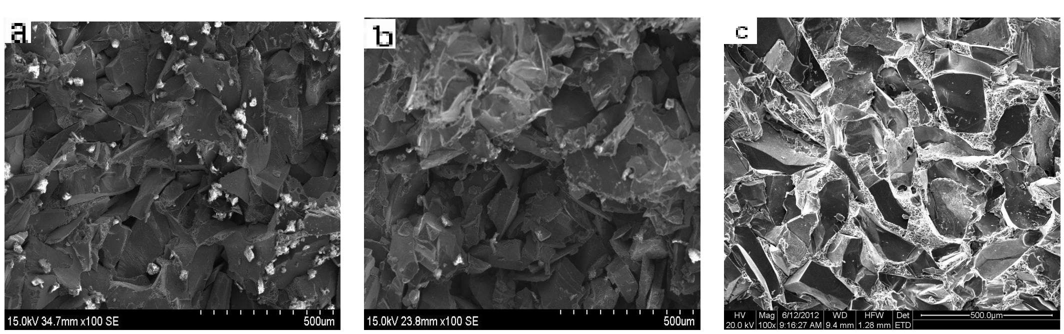

Figure 3. SEM images of composites with three SiCp sizes, (a) composite with SiCp (70#), (b) composite with SiCp (100#), (c) composite with SiCp (180#)

It shows that, in the experiment, whether SiC particles size is large or small, as shown from figure 3 (a) to 5(c), all SiC particles can distribute uniformly in the Al matrix. For the composites with small SiC particles size, segregation of the SiC particles along the surface of the Al metal is not generally observed.

Our experiments showed that by reducing the reinforcement size, a finer microstructure can be obtained and mechanical properties of the composites can be improved for a given particle volume fraction due to the smaller inter-particle spacing and larger working hardening rate. A decrease in the particle size will increases the effects of both direct and indirect strengthening [13-15]. As SiCp size decreased, the interfacial area between the matrix and the SiC particles also increased, and more loads could thus be transferred from the matrix to the SiC particles. It is evident from figure 2 that a large interfacial area can facilitate the generation of more dislocations in the matrix, thereby improving the mechanical properties of composites. On the other hand, the larger-sized particles are more easily fractured than the smaller ones during tensile testing process because of following two reasons [16]. Firstly, small-sized particles have more interface area with the matrix, and thus can endure higher stress concentration, secondly, the particle fracture strength was controlled by the intrinsic flaws within the particle. Larger particles were more likely to have many larger defects such as fracture, void and stress concentration because they had a greater statistical probability of containing a flaw that was greater than the critical size [17]. Since the fractured particles could not withstand any load, but acted as preferential failure sites, the composite with larger SiC particle size shows obvious degradation of mechanical properties.

Figure 4 shows SEM fracture cross-section microstructures of SiCp/Al composite with three SiC particles sizes.

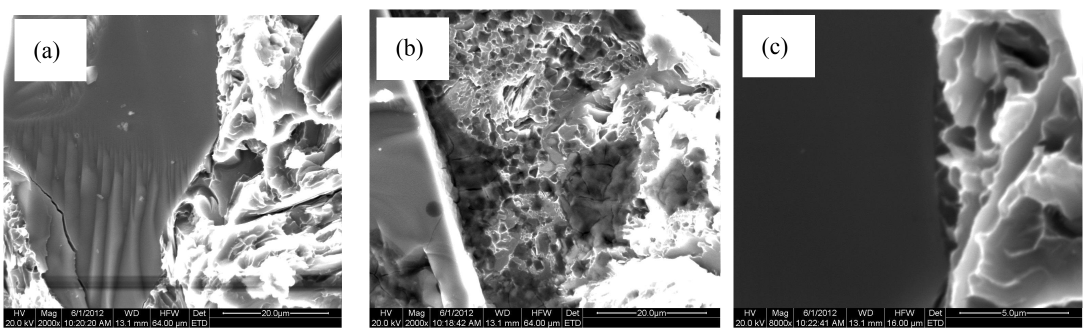

Figure 4. SEM image of fracture cross-section of composite with three SiCp sizes, (a) composite with SiCp (70#), (b) composite with SiCp (100#), (c) composite with SiCp (180#).

Figure 4 shows that, when SiCp/Al composites with three SiCp sizes were pulled off, SEM image of fracture cross-section of composites. An obvious honeycomb tough fossa appeared which shows the ductile fracture characteristics and the shape is irregular. The matrix failed in a ductile manner, and the SiC particles are brittle fracture, and especially some facets were obviously found in the larger SiC particle as figure 4 (a), (b), indicating that fracture propagated through the particles with shear mode. Meantime, it was found that there was a well completed combination between reinforcement and matrix, which has a positive influence on the properties of SiCp/Al composite. Figure 4 (c) also indicates that, smaller SiCp are more able to resist external loads and nearly maintain the integrity of the particles, which predicts the good mechanical properties of the composite with smaller SiCp. It agrees with the above figure 4. It was found that the fracture and crack extended along SiC-Al matrix interface. Figure 4 also shows the tearing and plastic deformation characteristics [18-20].

SEM image of fracture surfaces and EDS analysis of the composites with 100# SiCp are shown as Figure 5.

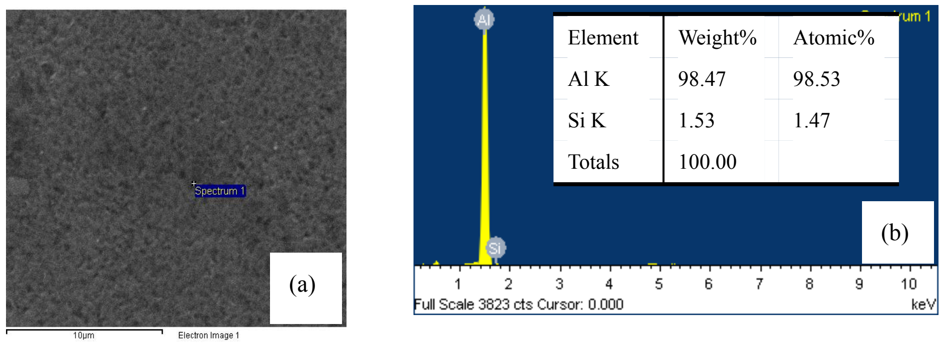

Figure 5. (a) SEM image of fracture surfaces of the composites with 100# SiCp and (b) EDS analysis marked area on the surface of the composite.

Figure 5(a) shows that composite reinforced by 100# SiC is well combined with the matrix. It is also found that uniformly distributed in Al matrix, and the segregation phenomena did not happen in the composite. EDS analysis shows that Al and Si elements could be found in the base area, but enhance particle phase could not be found in the matrix as (see figure 5 (b)). The experimental results indicate that the method of pressureless infiltration could prepare uniform and little impurity SiCp/Al composites, meanwhile, it did not generate second phase in Al matrix. SiC particles were evenly distributed in the Al matrix, thus, it indicates that SiCp/Al composite with smaller SiCp had a good mechanical property.

4. Conclusions

SiC particles-reinforced ZL101 Al composites were fabricated by spontaneous infiltration technology. The experimental results showed that particle size of SiCp had significant influence on the microstructures and mechanical properties of the resulting composites. The composite reinforced by smaller-sized SiCp had a more compact and uniform microstructure and better mechanical properties. Tensile strength of composites increases along with a decrease in the size of SiC particles. SiCp/Al composites prepared have enhanced phase particle distribution uniformity. All composites have good microstructure characterization, no obvious shrinkage and porosity defects. Meanwhile it was found that the interface between SiC particles and matrix was clear and well combined.

Acknowledgements

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