Fabricating a 15 vol%-3.5 μm-SiCp/Al composite by a squeeze casting technique

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Squeeze casting process is an economic route for fabricating particle reinforced aluminum composites. In the squeeze casting process, aluminum melt infiltrates into the particle preform and then solidifies under a high pressure. It has been proved that when a conventional squeeze casting process is used for fabricating particle reinforced aluminum composites, the available particle volume fraction of the composites depends on the size of the particle and is greatly limited [1, 2]. When the SiC particle with an average diameter of 3.5 μm is used, the particle volume fraction of the SiCp/Al composite is 40–50% [1, 2]. 3.5 μm-SiC particle is a commercially available reinforcement of the SiCp/Al composites. It has been reported that the 20 vol%-3.5 μm-SiCp/Al composite fabricated by powder metallurgy shows the optimum properties [3]. Therefore it is important to improve the fabrication process to make aluminum based composites reinforced with a lower volume fraction of 3.5 μm-SiC particles by the cost effective squeeze casting route.

In this investigation, the SiC particles and pure aluminum powders were milled in a planetary mill using an Al_2O_3 ball at 200–400 rpm for 0.5–20 h. The effect of the milling conditions on the size of the mixed particle was investigated. The mixed particles, resulting from mixing SiC particles and aluminum powders by ball milling, were used to make the preform. Ball milling is a process in which the mixtures are milled together and it involves materials transfer to obtain a homogeneous alloy by means of repeated deformation/welding/fracture mechanisms [4–6]. The SiCp/Al composites with low volume fraction (15%) were fabricated by infiltrating the pure aluminum melt into the mixed particle preform.

The size of the mixed particle depends on the milling conditions. In this investigation, the mixed particles are divided into three groups according to their size: small mixed particle (smaller than 56 μm in diameter), middle mixed particle (between 56 and 128 μm in diameter) and large mixed particle (larger than 125 μm in diameter). Fig. 1 shows the effect of the mill rotating speed on the percentage of large mixed particle. It can be seen that the amount of the large mixed particle increases with increasing rotating speed. With the increase of the rotating speed, the interaction between the Al_2O_3 ball and the raw particles increases and the cold welding between the aluminum powders increases also, leading to the increasing amount of the SiC particle inserting into the welded aluminum particles. Meanwhile, the temperature of the mixing particles increases with increasing mill rotating speed, which also improves the enlargement of the mixed particle. When the rotating speed reaches 400 rpm, more than 50% raw particles aggregate together to form mixed particles with very large size. When the rotating speed is 200 rpm or less, the input energy is not enough to form the mixed particles, and most of the raw particles do not bonded each other. Therefore, 300 rpm is suggested here to be used for the ball milling to obtain idea mixed particles. The results shown in Fig. 1 were obtained when the Alp/SiCp ratio (wt) is 4:1 and the milling time is 4 h.

Experimental results indicate that the size of the mixed particle is also affected by the Alp/SiCp ratio when the milling conditions are fixed. Fig. 2 shows the effect of the Alp/SiCp ratio on the size of the mixed particle. It indicates that the amount of the middle and large size (larger than 56 μm in diameter) mixed particles increases with increasing relative amount of aluminum powder. Fig. 2 also indicates that in order to get higher percentage of middle mixed particle, the Alp/SiCp ratio should be higher than 3:1.

Fig. 3 shows the effect of milling time on the size of the mixed particle. It can be seen that the percentage of the large mixed particle increases and that of the small mixed particle decreases when the milling time increases from 0.5 to 2 h, while, an opposite tendency appears when the milling time is 4 h and more. It is easy to understand the size change of the mixed particle with increasing milling time from 0.5 to 2 h, because the cold welding and aggregation are enhanced with increasing milling time. With further increasing milling time, because of the deformation and strain hardening of the aluminum powder, the ductility of the mixed particle increases, leading to the increase of the breakage of the mixed particle and decrease of the particle size. From Fig. 3 it can be seen that the amount of the middle mixed particle is relatively higher when the milling time is 0.5 and 4 h. However, it has been found that the uniformity of the SiC particle in the mixed particle increases with increasing milling time, therefore, the milling time is optimized to be 4 h.

In order to measure the SiC particle content in the mixed particles with various sizes, the mixed particles

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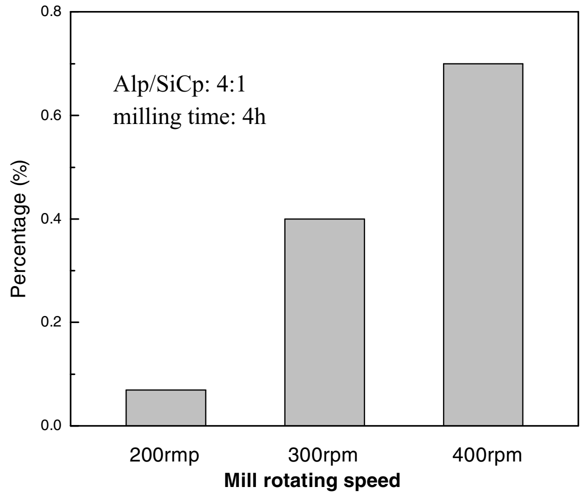

Figure 1 Effect of the mill rotating speed on the percentage of the large mixed particle.

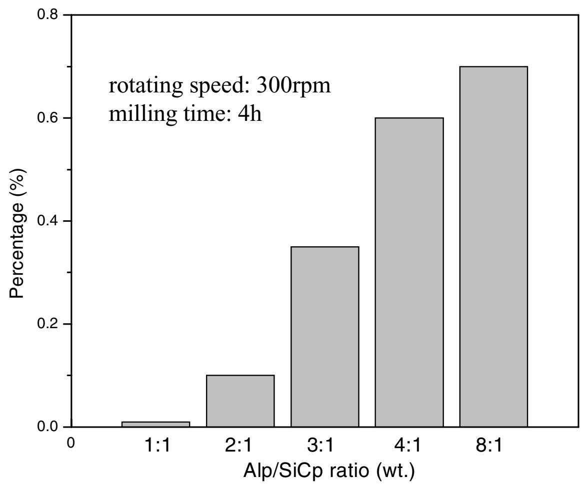

Figure 2 Effect of the Alp/SiCp ratio on the percentage of the mixed particle with size larger than 56 μm in diameter.

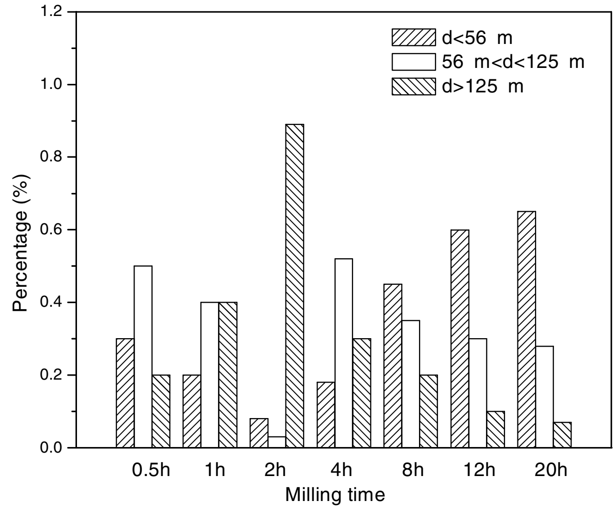

Figure 3 Effect of milling time on the size of the mixed particle with a mill rotating speed of 300 rpm.

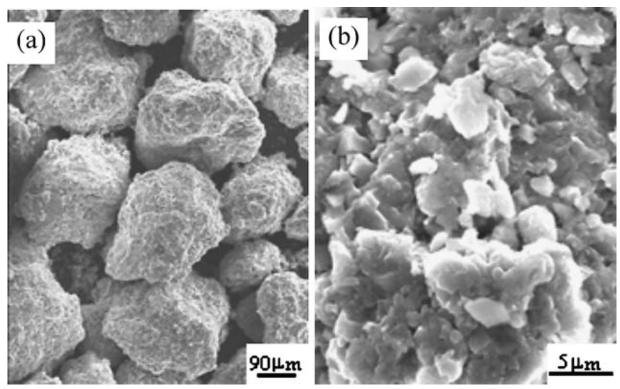

Figure 4 SEM photo showing the size and shape of the mixed particle in the preform (a), and the morphology of the surface of the mixed particle (b).

were put into an acid solution to extract the SiC particle. The results indicate that the SiC particle content in the mixed particles with different size is almost the same when the milling conditions are the same. Therefore it is reasonable to choose only the middle mixed particle for making the preform. When the Alp/SiCp ratio is 3.5:1, the SiC particle volume fraction in the preform is 15%. The preform was made by a dry forming technique. The optimum conditions used for making the mixed particle preform are shown in Table I. Fig. 4a indicates that the mixed particle in the preform has an equiaxed shape and an uniform size. Fig. 4b shows the morphology of the surface of the mixed particle. It indicates that the SiC particles distribute uniformly in the mixed particle.

SiCp/Al composite was fabricated by squeeze casting process. An aluminum melt with a temperature of 750 °C infiltrated into the mixed particle perform with a preheating temperature of 450 °C under a pressure of 5 MPa. After the infiltration process finished, the pressure was increased and the aluminum melt solidified under a higher pressure of 50 MPa. A 15 vol%-3.5 μm-SiCp/Al composite was successfully fabricated by the modified squeeze casting technique.

Tensile properties of the as cast 15 vol%-3.5 μm-SiCp/Al composite and unreinforced aluminum are shown in Table II. It can be seen that compared with the unreinforced pure aluminum, the tensile strength and modulus of the SiCp/Al composite increase by 120 and 30% respectively. Meanwhile, the ductility decreases because of the addition of the SiC particles.

All the results indicated that the present fabrication process is an effective process to lower the volume fraction and improve the distribution of the particle in the SiCp/Al composite.

TABLE I Conditions for making the mixed particle and its preform

Alp/SiCp ratio	Mill rotating speed	Rotating time	Pressure
3.5:1	300 rpm	4 h	2 MPa

TABLE II Tensile properties of the as cast 15 vol%-3.5 μm-SiCp/Al composite and the unreinforced pure aluminum

	Tensile strength (MPa)	Tensile modulus (GPa)	Elongation (%)
Unreinforced Al	68	60	30.2
15 vol% SiCp/Al	150	78	2.3

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