Jurnal Penyelidikan dan Pendidikan Kejuruteraan. Jilid 2, 2005

Effect of Reinforcement Particle Size on the Properties of Dispersion Strengthened Al-SiC Composite

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ABSTRACT

The effect of reinforcement silicon carbide particle size on Al-20vol% SiC composite fabricated via powder metallurgy route has been investigated. Composite powders consist of alumina and silicon carbide of different particle sizes (i.e. 3.7µm, 12.5µm, 17.5µm and 50µm) were mixed for 2 ½ hours in a tumbler mill. Compacts were obtained by cold pressing the composite powder at 200 MPa and sintering in argon atmosphere at 600°C for 5 hours. Results showed that size of silicon carbide powder has a considerable effect on the composite properties. As a conclusion, the use of finer silicon carbide powder has increase the density, hardness, modulus of rupture and electrical resistivity of the composite.
KEYWORDS: Aluminum matrix composite, silicon carbide, reinforcement size.

INTRODUCTION

Powder metallurgy aluminum composite, in contrast to wrought aluminum, contains high and fine hard phase, and thus can be used for parts that must be light and must have anti-wear characteristics. Composite materials on aluminum alloys matrices are manufactured by powder metallurgy, applying the mechanical alloying process, and the co-spray deposition process of dispersion particles in atomized aluminum alloys as well as by squeeze casting methods [1,2]. However, powder metallurgy aluminum is too expensive for wide spread use in automobiles, and a cheaper technique for making powder metallurgy aluminium in needed. The work reported herein focuses on the investigation of the mechanical and electrical properties of Al matrix composites reinforced with low-cost SiC grade, which is usually used as metallographic polishing media, via powder metallurgy method.

The mechanical properties of composite materials reinforced with ceramic particles depend on the matrix properties, mutual wettability at interphase, and the amount of reinforcing phase and the diameter of the reinforcing particles [3]. Even though it is well accepted that the mechanical properties of aluminum based composite materials are superior to pure aluminum but in the case of reinforcing aluminum alloy 7901 reinforced by dispersion particles of 5 and 13 µm SiC, [4] ascertained even worsening of mechanical properties, which was explained by the weak bonding at the matrix/reinforcement interphases. Agglomeration of SiC due to geometric factors (size differences of Al and SiC particles) is a major problem in obtaining homogenous distribution of the reinforcement in the matrix. This is achieved by a proper choice of the particle sizes of Al and SiC and the use of polar solvent [5]. Therefore, the influence of SiC particle size on the properties of Al-SiC composite has been the focal point for this investigation.

MATERIALS AND METHODS

In this study, the material used were 32µm Al powder and SiC powder of different sizes namely, 3.7µm, 12.5µm, 17.5µm and 50µm. Powders of 20 vol% of SiC were mixed with Al-metal powder in a tumbler mixer for 2½ hours to produce four mixtures with different SiC particle sizes. Each mixture, and Al pure metal as well, was cold compacted in a rectangular mould using hydraulic press at compaction 200 MPa. The density of the non-sintered composite was determined by using the following equation:

$$\rho = m/v \qquad (1)$$

where ρ is the density of sample, m is the weight of the sample and v is the volume of the sample. The compacts were sintered in a horizontal tube furnace at 600°C for 5 hours in argon atmosphere. The density of the sintered composite was determined using pycnometer density machine, which apply helium gas displacement principle. The electrical resistivity of the composite was determined using Advantest Ultra High Resistance meter. In this test, electric current of 123.5V was applied to the sample and the sample resistance was measured. The electrical resistivity of the sample was calculated by using the following equation:

$$\rho = \frac{RA}{L} \qquad (2)$$

where ρ is the electrical resistivity, L is the length, R is the resistance and A is the area of the sample. Modulus of rupture of the composite was determined by using three points flexuring methods. Microstructural investigation was performed on both polished and fracture surfaces by using scanning electron microscope (SEM).

RESULTS AND DISCUSSION

The microstructures developed in the sintered composite reveals the differences in silicon carbide distribution and sizes. The homogenous distribution of reinforcement particles is observed even with the refinement of SiC particles (Figure 1). Figure 2 compares the green or unsintered and sintered compact densities as a function of silicon carbide particle size. It is evident that Al-SiC composites shrunk during sintering after about 2½ hours sintering time since the density of the sintered compact is higher than the density of green compact. Obviously sample swelling during sintering is avoided which might cause degradation in composite mechanical properties [6]. Powders containing finer silicon carbide have good compressibility, which enables the powder to be compacted to slightly higher green density. This, in turn, facilitates producing parts with higher sintered density.

Figure 3 shows that hardness and modulus of rupture of the Al-SiC (i.e., 52.6Hv-61.4Hv and 69MPa-139MPa respectively) composites are much higher than those of pure Al (i.e., 45.7Hv and 35 MPa respectively). This result is in agreement with the [7,8] since it was expected that the introduction of the SiC particles to the Al matrix should have resulted a slight increase in the hardness and modulus of rupture of the composites. The improvements in mechanical properties of the composite could be attributed to the effective particle dislocation interactions in the matrix and also by pinning of grain boundaries by the particles [9].

Investigation on the effect of SiC particle size on the hardness and modulus of rupture of Al-SiC composites showed a slightly increase in hardness but modulus rupture increases drastically with a decrease in SiC size, as shown in Figure 4. The improvement in mechanical properties of Al matrix composite attained with the usage of finer reinforcement particles can be to some degree related to the distance between the reinforcement particles. As explained by Orowan's mechanism, in the presence of very rigid particles in the metal matrix, the strengthening is achieved as follows [10]:

$$\tau = \frac{\mu b}{L} \qquad (3)$$

where τ is the external stress, μ is the modulus of rigidity of the matrix metal, b is the magnitude of Burgers vector and L is the interparticle distance. Therefore, if the volume percentage of dispersoid is constant, as the mean particle size decrease, namely as the mean interparticle distance L decreases, the external stress increase, leading to an increase of the strength of the composite. Thus, it is concluded that the refinement of the dispersed particles is important in order to obtain aluminum-based composite with high strength.

The above explanation is well supported by the microstructure observation of the composite (Figure 1). It is apparent that for a given amount of silicon carbide, the use of finer silicon carbide (3.7 μm) allows greater amount of carbide to be uniformly dispersed. Thus, the carbide interparticle spacing can be successively reduced with the addition of finer silicon carbide particle, giving increased benefits in hardness and modulus of rupture.

The electrical resistivity of pure Al (i.e., 263 ohm-m) is the lowest compared to that of Al-SiC composites (i.e., 264-269 ohm-m) indicating that incorporation of SiC particles tends to increase electrical resistivity of pure Al metal (Figure 4). When dispersion was present a further increase of resistivity was observed owing to a reduction in the current-carrying cross-sectional area and to scattering of the electrons by the fine particles [3]. Obviously, the electrical resistivity of the composites increases by decreasing the size of silicon carbide particle. From the microstructure study, it is observed that in the composite containing finer SiC, especially for Al-3.7 µm SiC composite, the distribution of fine SiC particles is so close until it forms a network of the non-conducting phase within the conducting matrix (Figure 1e). As a consequence, the resistivity of the composite shows a gradual increase due to the low conductivity of this non-conducting network.

When fracture samples were observed under scanning electron microscope, sample prepared from pure Al powder shows elongated grains indicating the ductile properties of pure Al metal (Figure 5). While in Al-SiC composite samples, other than elongated Al matrix grain, brittle type fracture is also observed in region containing silicon carbide particles. Surface topography of the Al-SiC composite shows that SiC particles clearly can be observed imbedded in the Al matrix, which indicate the interface failure mechanism [11]. No major changes in microscopic fracture appearance was observed as the SiC particle size varies, except the size of the void become smaller when the SiC size decrease from 50 µm to 3.7 µm. It can be concluded from this observation that the crack propagation occurs along the interface of matrix and reinforcement. Since finer silicon carbide has higher surface area, the total load able to cause crack propagation at the matrix-reinforcement interface is higher for sample containing finer SiC compared to sample with coarser SiC. As a result, composite with finer SiC has higher modulus of rupture.

CONCLUSION

A series of particulate composites in the system of Al-SiC with different reinforcement particle size was developed. The investigation leads to the following conclusions:

(1) Smaller SiC particle sizes in the Al matrix will increase the bulk density, hardness, modulus of rupture and electrical resistivity are also increase.

(2) Electrical resistivity of the composite is dependent on SiC particles size and distributions since the particles form a hard and non-conducting phase embedded in fairly soft and conducting aluminum matrix.

ACKNOWLEDGEMENT

Authors are grateful to the School of Materials and Mineral Resources Engineering of Universiti Sains Malaysia for the material and equipment provided to conduct the research.

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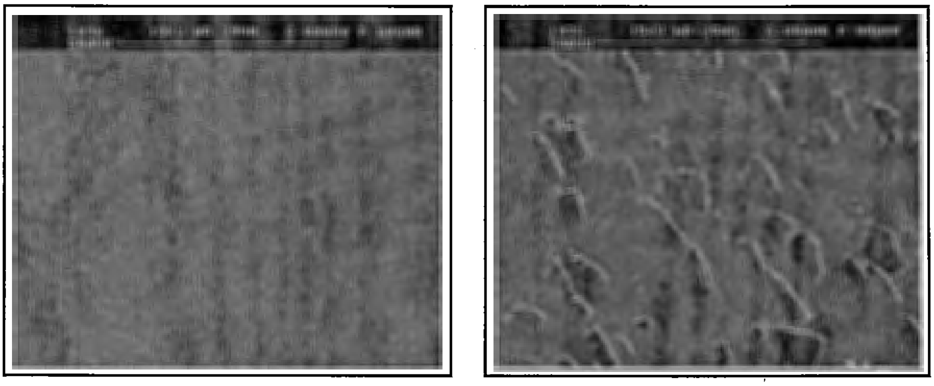
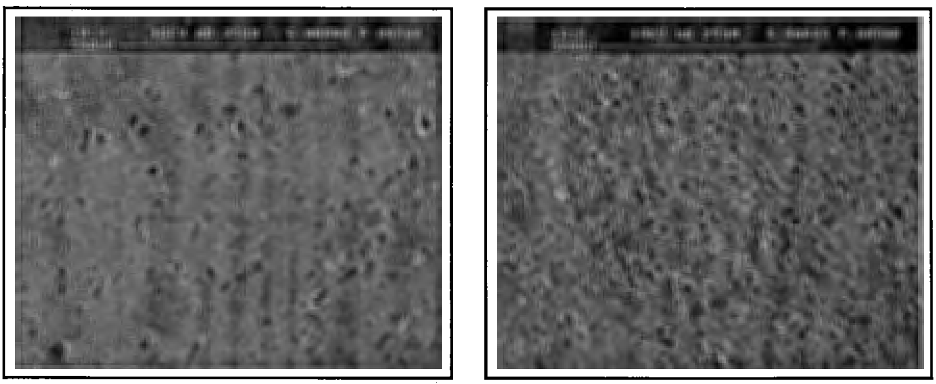
APPENDIX



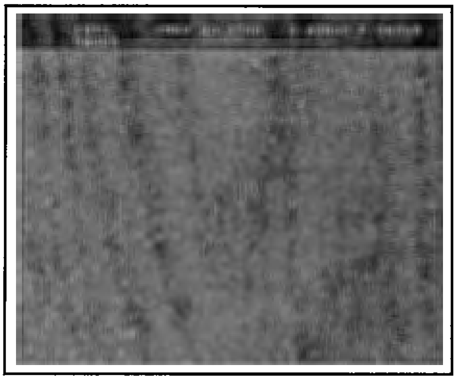
(a) pure Al

(b) Al-50 μm SiC



(c) Al-17.5 μm SiC

(d) Al-12.5 μm SiC



(e) Al-3.5 μm SiC

Figure 1: SEM micrograph of polished samples (a) pure Al, (b)-(e) Al-SiC composite (100x).

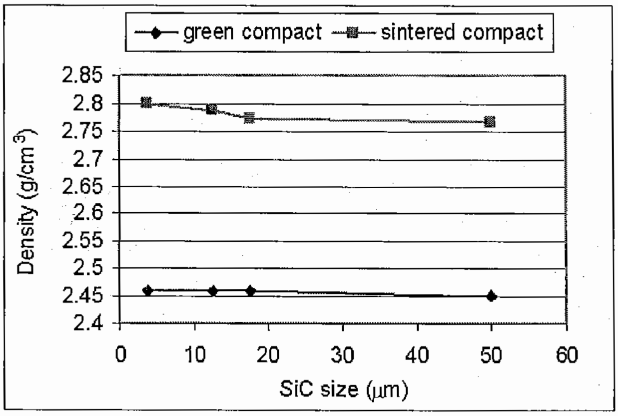


Figure 2: Green and sintered compact densities of Al-SiC composite.

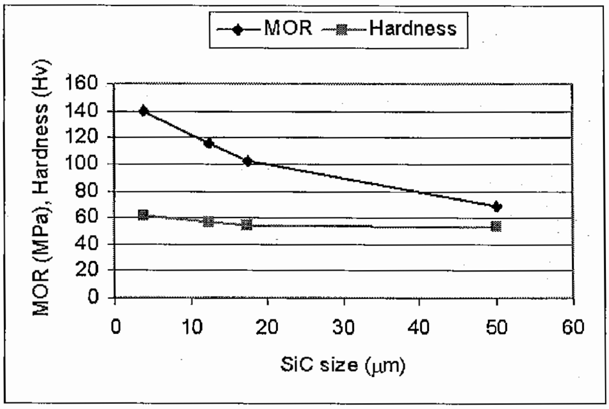


Figure 3: Hardness and modulus of rupture Al-SiC composite.

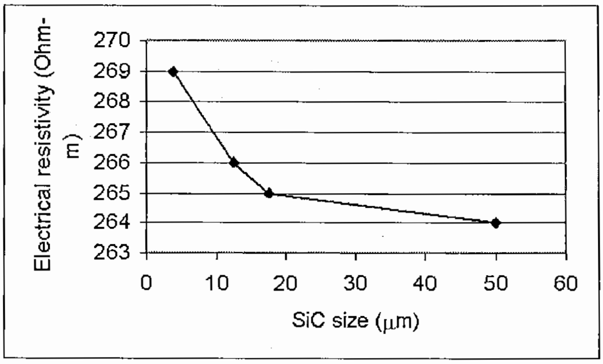
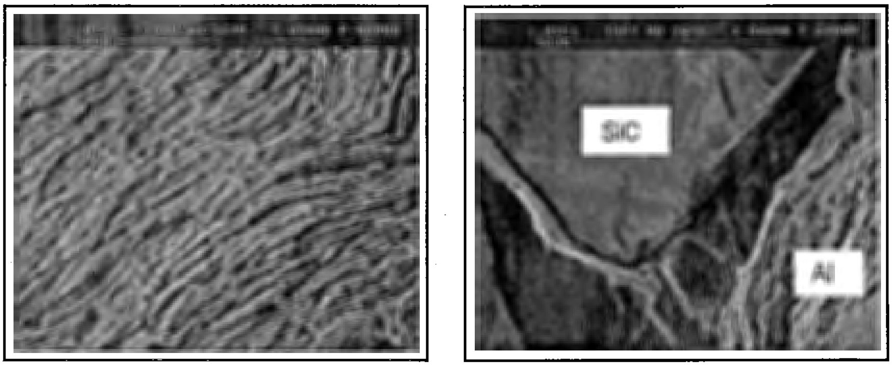
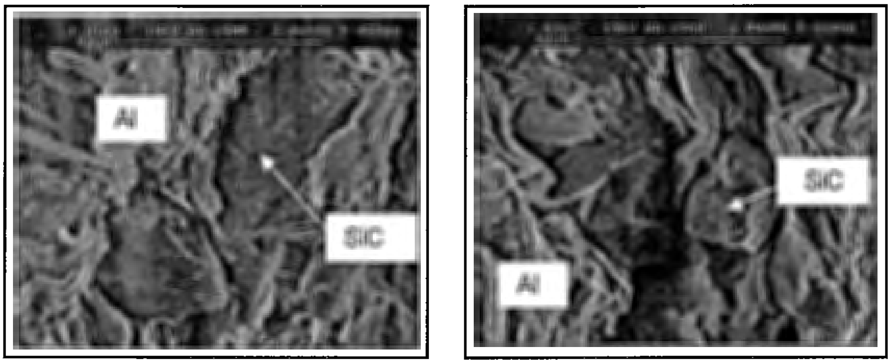


Figure 4: Electrical resistivity Al-SiC composite.



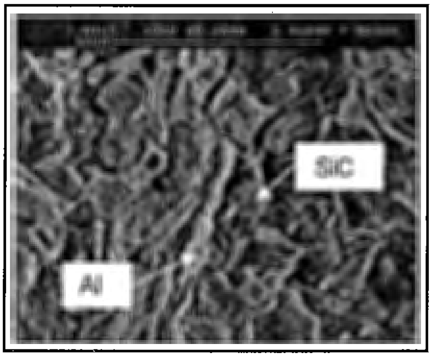
(a) pure Al

(b) Al-50 µm SiC



(c) Al-17.5 µm SiC

(d) Al-12.5 µm SiC



(e) Al-3.7 µm SiC

Figure 5: SEM micrograph of fracture surface. (a) Al, (b-e) Al-SiC composite (1000x).