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Effect of equal channel angular pressing (ECAP) on microstructure and properties of Al–SiC_p composites

G. Ramu [a,b], Ranjit Bauri [a,*]

[a] Department of Metallurgical and Materials Engineering, Indian Institute of Technology Madras, Chennai 600 036, India
[b] Research Centre Imarat (RCI), Vignayanakancha, Hyderabad 500 069, India

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ABSTRACT

Aluminium metal matrix composites were processed by stir casting technique with commercially pure aluminium as the matrix material and 5, 10 vol.% of SiC (30 μm) particulates as the reinforcement. Al–SiC_p composites were subjected to severe plastic deformation through equal channel angular pressing (ECAP). As cast Al–SiC_p composites shows uniform distribution of particles and there is no change in the particle distribution after ECAP. It was found that ECAP refines the grain size of matrix material. In Al–5 vol.% SiC_p composite grain size was reduced to 8 μm from 45 μm after two ECAP passes whereas in Al–10 vol.% SiC_p composite grain size was refined to 16 μm from 45 μm after first ECAP pass. Hardness and compression test were conducted at room temperature to evaluate the mechanical properties of the composites. Both the composites exhibit improvement in mechanical properties after ECAP.

1. Introduction

In recent years ceramic particle-reinforced metal matrix composites (MMCs) have gained wide acceptance because of their attractive properties. Amongst MMCs aluminium matrix composites (AMMCs) have received particular attention in the past three decades due to their high specific strength and stiffness and superior wear resistance [1–5].

Number of processing routes has been developed for the manufacture of particle/whisker/short fiber-reinforced composites [2,6–9]. Melt stirring or stir casting technique is currently one of the simplest and most economical fabrication routes for manufacturing particle-reinforced metal matrix composites. A careful control of process variables yields high degree of microstructural integrity and uniformity in this technique [10,11].

Severe plastic deformation is a useful processing tool to refine the grain size to the submicron or even nanometer size [12–14]. Although several severe plastic deformation techniques are available, equal channel angular pressing is an attractive process because it has potential to produce large samples [12–14]. Most investigations on ECAP have concentrated on pure metals and metallic alloys. Some limited reports are available on application of ECAP to metal matrix composites [15–18]. However, reinforcements in the composites used in these studies are primarily Al_2O_3 and no reports are found on Al metal matrix composites reinforced with SiC particles. Further, the ECAP process in these studies was carried out at elevated temperature. The aim of the present work is to fabricate Al–SiC composites by equal channel angular pressing at room temperature and evaluate the effect of SiC particles on the deformation behavior during ECAP. The effect of ECAP on the microstructure and mechanical properties of Al–SiC_p composites will also be evaluated.

2. Experimental details

2.1. Material selection and composite processing

The composites used here were processed by stir casting. Commercial pure Al was used as a matrix material in the present study. Silicon carbide particles of average particle size 30 μm were used as reinforcement. Fig. 1 shows the schematic of the stir casting set up used in this study. Weighed quantity of aluminium was taken for melting and corresponding SiC powder was weighed according to the required volume fraction. SiC powder was preheated at 850 °C for 4 h. This treatment was given to ensure good wettability between SiC_p and liquid aluminium [9]. Once Al was melted, temperature was measured with the help of a thermocouple and degassing was carried out with argon gas for 5 min. After degassing, a preheated graphite impeller was lowered in to the molten metal and rotated by a shaft connected to a motor (Fig. 1). Preheated SiC particles were added by an addition chute through the periphery of the vortex, which was created by the stirring action of the rotating mechanical impeller. During stirring small pieces of magnesium was added to the melt to improve the wettability of SiC particles with Al melt [9]. Once all of the powder

* Corresponding author. Tel.: +91 44 22574778; fax: +91 44 22574752.
E-mail address: rbauri@iitm.ac.in (R. Bauri).

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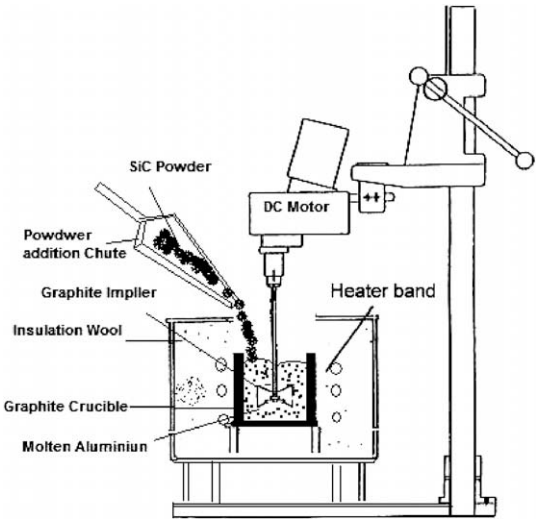

Fig. 1. Schematic of the stir casting set-up used for the fabrication of Al/SiC_p composite.

is added, the motor is stopped and the impeller is taken out from the melt. Finally, the composite melt was poured in preheated cylindrical cast iron molds. Two composites having 5 vol.% and 10 vol.% of SiC_p were processed.

2.2. Equal channel angular pressing of Al–SiC_p composites

2.2.1. Sample preparation for equal channel angular pressing (ECAP)

Samples of required diameter were machined from the cast composite billets for ECAP. The composite billets were encapsulated in pure aluminium hollow cylinder with a wall thickness of 2 mm to avoid die damage by the hard composite surface during ECAP and also to prevent instabilities at the surface of the composite that may occur during ECAP [19]. The size of the final sample was 19.3 mm in diameter and 90 mm in length. Press-fit encapsulated samples were annealed at 400 °C for 4 h to homogenize microstructure and relieve stresses introduced due to press fitting.

2.2.2. Equal channel angular pressing (ECAP)

Annealed composite billets were subjected to ECAP using a channel angle of 120°. MoS_2 was used as lubricant to minimize friction between die wall and the sample. Bc route, where the sample is rotated by 90° in one direction either clockwise or anti clockwise after each successive pass, was adopted in the present work. The ECAP was carried out at room temperature. Samples were taken after each pass for characterization. The ECAP experiments were repeated once to verify the reproducibility of the results. The pure Al layer was removed by machining for making samples for microstructural and mechanical behavior studies.

2.3. Characterization

2.3.1. Density and porosity

Density of Al–SiC_p composite was measured using Archimedes' principle. Distilled water was used as immersion fluid. Theoretical density was calculated by rule of mixture and compared with measured densities. Percent porosity was calculated from the difference between measured and theoretical densities.

2.3.2. Volume fraction

Volume fraction of as cast composites was measured by chemical dissolution method. Small pieces of composite were cut from different portions. Weight of composite pieces was measured using an electronic balance having an accuracy of 0.1 mg. Diluted hydrochloric acid was used for dissolution. Aluminium was dissolved in HCl and SiC particles were settled at the bottom of the beaker as a residue. Undissolved SiC powder was carefully filtered and dried in an oven at 120 °C. Weight of dried powder was measured using electronic balance and the corresponding volume fractions were measured using the following relation.

$$V_p = \left(\frac{m_p}{\rho_p}\right) \Big/ \left(\frac{m_p}{\rho_p} + \frac{m_m}{\rho_m}\right) \quad (1)$$

where V_p volume fraction of particles. m_p, ρ_p mass and density of the particles, m_m, ρ_m mass and density of matrix.

2.3.3. Microstructural characterization

Sliced samples of composites were polished with emery paper up to 400 grit size, followed by polishing with Al_2O_3 suspension on velvet cloth. Finally samples were polished with 0.5 μ diamond paste. Microstructural characterization was done by scanning electron microscope (SEM) and optical microscope. Particle distribution, interface features, particle orientation were observed in as cast, as annealed and as ECAPed condition. Fracture surface of cracks formed after second ECAP pass in Al/10SiC_p was also observed under SEM.

2.3.4. Microhardness

Microhardness of the composites was measured in as cast, as annealed conditions and after each ECAP pass using a Vickers micohardness tester (WILSON WOLPERT). A load of 1 kg and a dwell time of 9 s was used. Hardness was measured on the matrix of the composites. The values reported are average of at least five readings.

2.3.5. Compressive test

Room temperature compressive tests were carried out using standard ASTM samples on an Instron machine in as cast and as annealed condition and after each ECAP pass. Cylindrical samples with an aspect ratio of 1.2 were used for the compressive tests. A strain rate of 1.8×10^{-3} s^{-1} was used. At least three samples were tested for each material.

3. Results and discussion

3.1. Density and porosity

Table 1 shows the results of density and porosity measurements. Almost 100% densification was achieved in the unreinforced metal. However, some amount of porosity was observed in the composites in as cast condition. Porosity in Al/5SiC_p was found less compared to the Al/10SiC_p composite. The porosity is mainly due to gas entrapment during stirring of melt in open atmosphere. Longer stirring time and higher SiC content in Al/10SiC_p composite can be attributed to comparatively higher porosity in this composite.

3.2. Microstructural characterization

SEM micrographs in Fig. 2a and b shows the distribution of SiC particles in as cast Al/5SiC_p and Al/10SiC_p composites, respectively. The distribution is fairly uniform and there was no segregation or clustering of the particles. The interfacial bonding between SiC particle and matrix was also observed. The bonding between particle and matrix is good and there was no indication of any interfacial reactions. Fig. 3a shows the particle matrix interface in the Al/10SiC_p composite. The corresponding EDAX (Fig. 3b) taken on the