Ain Shams Engineering Journal (2014) **5**, 831–838

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Ain Shams Engineering Journal

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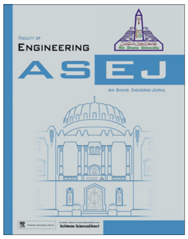

MECHANICAL ENGINEERING

Microstructural and corrosion behavior of Al/SiC metal matrix composites

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Received 12 June 2013; revised 16 February 2014; accepted 16 March 2014
Available online 16 April 2014

KEYWORDS

Corrosion;
Al/SiC;
Matrix;
Composites;
NaCl

Abstract Several Al/SiC MMCs having several volume fractions up to 15 vol.% and different SiC particulates average sizes, typically, 11, 6 and 3 μm were fabricated using conventional powder metallurgy (PM) route. The effect of the size and volume fraction of SiC particulates on the microstructural and corrosion behavior of Al/SiC metal matrix composites (MMCs) were studied. The results revealed that the Al/SiC MMCs exhibited higher density than pure Al matrix. The static immersion corrosion tests of Al/SiC MMCs in 3.5 wt.% NaCl aqueous solution at several temperatures showed that, at ambient temperature, the Al/SiC MMCs have better corrosion resistance than the pure Al matrix. Reducing the SiC particles size and/or increasing the volume fraction of the SiC particulates reduce(s) the corrosion rate of the Al/SiC MMCs. In contrast, the Al/SiC composites exhibited higher corrosion rates at 50 °C and 75 °C than the pure Al matrix.

1. Introduction

Aluminum alloys reinforced with ceramic particulates have significant potential for structural applications due to their high specific strength and stiffness as well as low density [1–3]. These properties have made particle-reinforced metal matrix composites (MMCs) an attractive candidate for the use in weight-sensitive and stiffness-critical components in aerospace, transportation and industrial sectors [4]. Corrosion behavior is very important parameter for assessing the application potential of composites as structural materials [5].

While considerable work has been done on the physical, mechanical and tribological characteristics of Al MMCs, very little systematic studies have been done to study the corrosion behavior of Al MMCs [6–10]. Reinforcement particulates may interact electrochemically, chemically, or physically with the matrix leading to accelerated corrosion [4–6]. In addition, galvanic interactions between the reinforcement and matrix can also accelerate corrosion. Preferential corrosion along a particle matrix interface can lead to rapid penetration along the large interfacial areas in composites. This can result in enhanced corrosion of MMCs in comparison with the corrosion of the respective monolithic matrix alloys. Crevice attack at the metal/reinforcement interfaces and preferred localized attack on structural and compositional inhomogeneities can occur within the matrix. Since corrosion decreases the load-bearing capacity resulting in catastrophic failures, corrosion can limit the application of MMCs in corrosive environments especially in the presence of stresses.

Previous corrosion studies conducted of Al matrix composites have been focused on the corrosion susceptibility in NaCl

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Peer review under responsibility of Ain Shams University.

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http://dx.doi.org/10.1016/j.asej.2014.03.003

solution, as well as pitting potential and pit morphology [11–15]. Researchers reported that pits initiate at the secondary particles within the matrix; therefore, composites generally have more pits than the monolithic matrix. For example, improvement in corrosion resistance has been declared with decreasing volume fraction of Al_2O_3 particles in Al–4 wt.% Mg alloy matrix composites [11]. Kiourtsidis and Skolianos [12,13], explained the progress of corrosion by two anodic reactions; namely corrosion of the α-phase adjacent to intermetallic regions, and pitting of the dendrite cores, instead of galvanic corrosion developed between the reinforcing particles and the matrix. Additionally, they supported this argument by a further report that the pitting potential is unaffected by the SiC particles. Since the processing method can heavily alter the microstructure, the contradictory results of corrosion tests conducted on Al MMCs, may arise from processing methods [14,15].

The aim of the current investigation is to study the static immersion corrosion behavior of Al/SiC MMCs in 3.5 wt.% NaCl solution at both ambient and elevated temperatures. The Al/SiC MMCs were fabricated using the conventional powder metallurgy (PM) route. The effect of the SiC particulates size and volume fraction on the corrosion characteristics was extensively studied.

2. Experimental procedures

Commercially pure aluminum powder having minimum purity of 99.8% was used as a matrix material. The aluminum powders have an average size of ~60 μm. The SiC ceramic particulates were used as reinforcement. The SiC particulates have three different average sizes, typically, 11, 6 and 3 μm. The SiC particulates were dispersed in the Al matrix with 5, 10 and 15 vol.% using conventional PM route as follows: Both Al powder and the SiC particulates in addition to 1–1.5 wt.% paraffin lubricant wax were placed into a blender, mechanically mixed until a homogeneous mixture is achieved, and then placed into containers. The mixed Al/SiC powders were cold compacted in a tool steel die shown schematically in Fig. 1. The powders were then pressed using a hydraulic press having a capacity of 500 kN. The compaction pressure applied was about 400 MPa. The Al/SiC composites produced from the cold compaction step were subjected to sintering at 600 °C for 120 min. The sintering process was performed under argon inert gas atmosphere. After sintering, the Al/SiC composites were subjected to hot extrusion. The Al/SiC composites billets were extruded at 490 °C. The extrusion reduction ratio was 2:1 by area. The final Al/SiC composite samples had cylindrical shape of 8 mm diameter and about 12 mm length. The Al/SiC composites cylindrical extruded rods were cut in the transverse directions for microstructural examinations using optical and scanning electron microscopes (SEM).

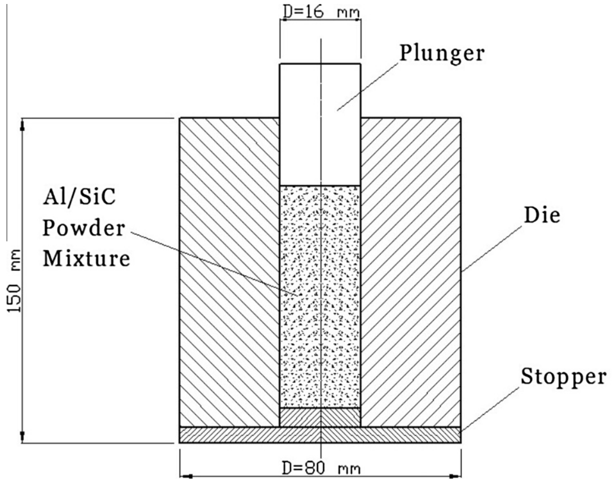

Figure 1 A schematic illustration of the cold compaction die used for preparation of Al/SiC composites.

Specimens were ground under water on a rotating disk using abrasive disks of increasing grade up to 1000 grit. Then they were polished using 3 μm alumina paste and 1 μm diamond paste, then cleaned with acetone. The density of the Al/SiC composites was calculated using water displacement approach (Archimedean density) according to ASTM B311-08. The theoretic density of Al/SiC composites was calculated using the rule of mixtures. The cylindrical sample was weighed in air (W_a), then suspended in distilled water and weighed again (W_w). The actual density was calculated according the following equation:

$$\rho_a = \frac{W_a}{(W_a - W_w)} \times \rho_w \tag{1}$$

where ρ_a is the actual density, W_a is the mass of the cylindrical sample in air, W_w is the mass in distilled water and ρ_w is the density of distilled water. The sample was weighed using a digital balance with an accuracy of 0.1 mg. Vicker's hardness test measurements were carried out using a load of 10 kg. A minimum of ten readings were taken for each sample and the average value was determined.

Static immersion corrosion tests were carried out at three different temperatures, typically, room temperature, 50 and 75 °C. Weight loss was measured to determine the corrosion rate of Al/SiC composites using a digital accuracy with an accuracy of 0.1 mg. Each specimen was first weighed before being immersed in 3.5 wt.% NaCl solution and later taken out after 24, 48, 72, 96 and 120 h, respectively. After drying thoroughly, the specimens were weighted again. The weight loss was measured and converted into corrosion rate expressed in mm penetration per year (mm/year). The corroded surfaces were examined using SEM. Corrosion tests were carried out by suspending the Al/SiC composite samples in a still solution of 3.5 wt.% NaCl aqueous solution. To avoid crevice corrosion, the specimens were suspended in the solution with a plastic string. The results of corrosion tests were evaluated using weight loss measurements, performed following the ASTM-G31 recommended practice [16]. Before immersing in 3.5 wt.% NaCl aqueous solution, the Al/SiC composite samples were ground to 1000 grit and then cleaned with deionized water followed by rinsing with methanol and dried. For the elevated temperatures corrosion tests (i.e. accelerated tests), a 3.5 wt.% NaCl solution was prepared, and heated to 50 ± 1 and/or 75 ± 1 °C using an electric heater. The specimens were put into the warm solution and a glass cover was put on the top of the vessel to prevent evaporation.

The corrosion rate CR (from the mass loss) was calculated using the following equation [5]: