

Abrasion of Novel Aluminum Metal Matrix Composites

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ABSTRACT

Ceramic-reinforced aluminum alloys offer distinct advantages over the base alloy. In this project, aluminum-based composites containing silicon carbide particle reinforcements were fabricated using an infiltration technique. Silicon carbide particles were incorporated into molten Al-10% Mg-5% Si (wt%). The resulting materials were characterized using optical and scanning electron microscopy to understand their microstructure. Phase analysis was conducted using X-ray diffraction. Vickers microhardness measurements were also obtained. The abrasion behavior of these composites was studied and compared to the matrix aluminum alloy as well as gray cast iron.

Keywords: Aluminum composites, Particulate reinforcement, Abrasion, Infiltration

INTRODUCTION

Metals and their alloys demonstrate useful combinations of strength, ductility, and excellent thermal and electrical conductivities. On the other hand, ceramic materials are very hard, brittle and are poor conductors of heat and electricity. Combining ceramics and metals can produce ceramic-metal or metal-ceramic composites. The designation of a ceramic-metal or metal-ceramic composite depends upon the class of material constituting the matrix and the class of material forming the reinforcement.¹ Metal matrix composites (MMC) have a metallic matrix with a ceramic or polymer reinforcement. MMCs offer tailorable wear and abrasion performance essential for automotive and industrial applications such as brake rotors and pumps.^{2,3}

There are different methods used to produce MMCs such as powder metallurgical routes involving sintering. Many of these MMC production methods are inherently expensive and not amenable for producing complex shapes. Melt infiltration methods,⁴⁻⁷ on the other hand, provide cost-effective alternatives for MMC fabrication while allowing for near net shape production. In this melt processing method, molten aluminum alloys are infiltrated into a ceramic particle bed. The ceramic particle bed serves as the reinforcement material within the aluminum alloy matrix of the resulting composite. In this study, a molten Al-10% Mg-5% Si (wt%) (Al-10Mg-5Si) alloy was infiltrated into a silicon carbide bed. UNS F12801 gray cast iron and Al-10Mg-5Si samples were compared against the resulting composite in a study of their abrasion behavior.

EXPERIMENTAL PROCEDURE

Aluminum metal matrix composites were fabricated from a base alloy of composition Al-10Mg-5Si (wt%). Samples of UNS F12801 cast iron and base alloy were used as controls throughout the study. The infiltration technique requires a non-permeable filler material on which to place the alloy within the crucible.³ The 220-grit silicon carbide (SiC) particulates placed on top of the alloy serve as a particle bedding which becomes reinforcement particulate material for the resulting MMC. The ceramic boat is then placed in a furnace and held at elevated temperatures in the presence of a suitable gas.

The aluminum metal matrix composite was compared against a UNS F12801 gray cast iron sample and Al-10Mg-5Si base alloy. The resulting composite materials and control samples were metallographically prepared for characterization. Samples were ground to 800 grit and polished to a 0.05 μm finish. Materials characterization was conducted via optical microscopy, scanning electron microscopy (SEM) with energy dispersive X-ray spectrometry (EDS), and X-Ray Diffraction (XRD). Standard coupons of the fabricated composite, base alloy, and gray cast iron were then subjected to the Vickers Microhardness Test.

The abrasion behavior was characterized via the Miller abrasion testing (Figure 1) guided by the ASTM G75-15⁸ standard with a 50 wt% slurry of silicon dioxide as the abrasive. Coupons of the MMC, base alloy, and gray cast iron were tested sequentially, two at a time for each type of material, in a specially designed and constructed Miller Abrasion test rig⁹. The silica slurry as well as the neoprene pad were replaced at 2-hour intervals for each test. Test coupon masses were recorded at these 2-hour intervals as well. Samples were sonicated in deionized water to remove any residue from the testing process, and air-dried prior to the mass measurements. A graph of cumulative mass loss per unit area with respect to time and a plot of net mass loss of each material were generated to compare the abrasion resistance of the different materials.

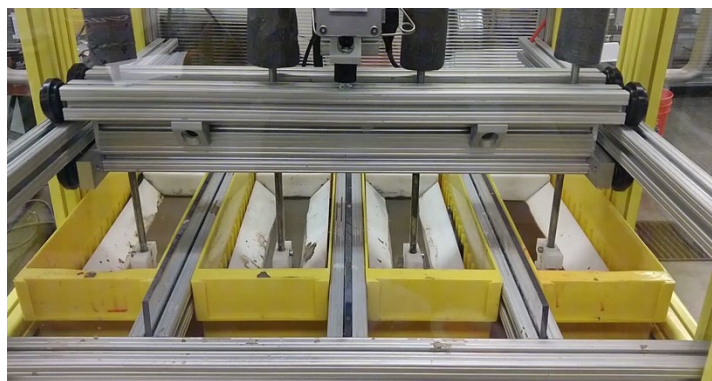


Figure 1: Miller abrasion test experimental setup.

RESULTS

After successful infiltration of the molten metal, the composite samples were cross-sectioned and metallographically prepared for microscopy. Micrographs show different layers in the metal matrix composite as seen in Figure 2. The top layer consists of aluminum nitride (Figure 3) that likely forms as a result of the surface reactions between the alloy and the atmosphere.² Trace amounts of magnesium nitride are present directly below this aluminum nitride layer and directly above the SiC particulate reinforcements. The aluminum alloy matrix exhibits a light gray contrast while the silicon carbide reinforcements exhibit a dark gray contrast in the optical microscope.



Figure 2: Optical Micrograph of the MMC cross-section

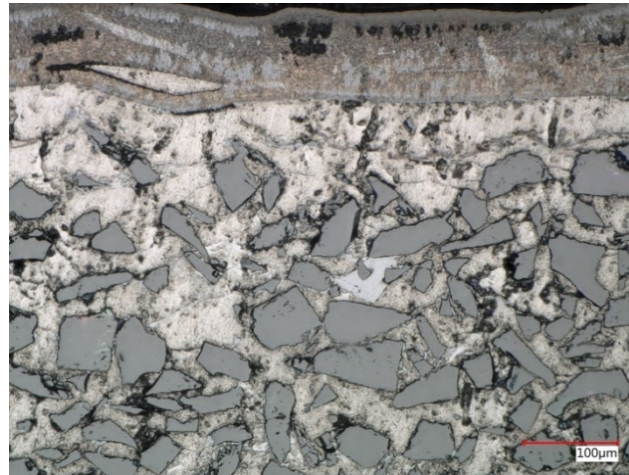


Figure 3: Micrograph of the cross-section of the MMC showing the bulk composite and the aluminum enriched surface

The presence and composition of these phases were confirmed using scanning electron microscopy (SEM) coupled with energy dispersive X-ray spectrometry (EDS). Figure 4 illustrates the interface between the surface layer (right side of micrograph) and the inner core of the metal matrix composite (to the left of the surface layer). Figure 4 shows the EDS elemental maps of silicon (Si), magnesium (Mg), and aluminum (Al) obtained via EDS. The intensity of the colors indicates the presence of the relevant element at that location. The SiC particulate reinforcements are clearly outlined in the elemental map of Si. The elemental map for aluminum confirms the presence of an aluminum matrix as well as a surface layer rich in both aluminum. The latter is also rich in nitrogen, supporting the earlier observation of the formation of aluminum nitride that likely formed through reactions between the aluminum and the atmosphere. The elemental maps confirmed the presence of Si and Mg in the dendrites present throughout the alloy. The elemental maps in Figure 4 have confirmed the presence of phases in the composite consistent with existing literature.^{1,7}

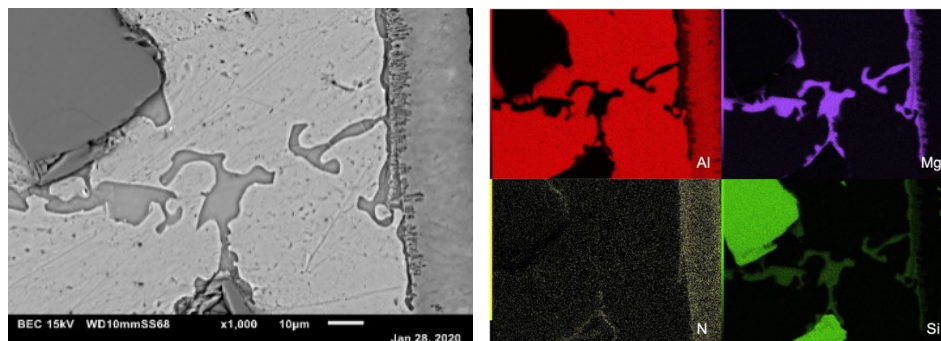


Figure 4: Backscattered electron image and corresponding EDS elemental maps of silicon, magnesium and aluminum in the MMC