Tribology International 43 (2010) 544–553

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Wear and friction behavior of sand cast brake rotor made of A359-20 vol% SiC particle composites sliding against automobile friction material

A. Daoud *, M.T. Abou El-khair

Composite Materials Laboratory, Central Metallurgical Research and Development Institute (CMRDI), P.O. Box 87, Helwan, Cairo, Egypt

ARTICLE INFO

Article history:
Received 28 October 2008
Received in revised form
10 September 2009
Accepted 16 September 2009
Available online 23 October 2009

Keywords:
Aluminum matrix composite
Friction material
Dry sliding wear
Sand cast brake rotor

ABSTRACT

The effect of load range of 30–100 N and speed range of 3–12 m/s on the wear and friction behavior of sand cast brake rotor made of A359-20 vol% SiC particle composites sliding against automobile friction material was investigated. Dry sliding frictional and wear behavior were investigated in a pin-on-disc type apparatus. Automobile friction material was used as pin, while the A359-20 vol% SiC particle composites formed the rotating disc. For comparison, the wear and friction behavior of commercially used cast iron brake rotor were studied. The results showed that the wear rate of the composite disc decreased with increasing the applied load from 30 to 50 N and increased with increasing the load from 50 to100 N. However, the wear rate of the composite disc decreased with increasing the sliding speed at all levels of load applied in the present work. For all sliding speeds, the friction coefficient of the composite disc decreased with applied load. The worn surfaces as well as wear debris were studied using scanning electron microscopy (SEM), energy dispersive X-ray (EDX) analyzer and X-ray diffraction (XRD) technique. At load of 50 N and speed range of 3–12 m/s, the worn surface of the composite disc showed a dark adherent layer, which mostly consisted of constituents of the friction material. This layer acted as a protective coating and lubricant, resulting in an improvement in the wear resistance of the composite.

1. Introduction

Aluminum matrix composites reinforced with SiC particles exhibit better frictional and wear behavior, higher specific heat capacity and thermal conductivity, and especially, lower density in comparison to conventional cast iron [1,2]. Thus, these composites have emerged as a potential material for wear resistant and weight critical applications such as brake rotors and drums, and cylinder liners, pistons, cylinder blocks, etc. [3].

Brake rotor made of Al–SiC particle composites in automotive brake systems is being considered among the important applications for metal matrix composites (MMCs). In practical situations, brake rotors slid against brake pad materials. However, a considerable amount of work has been done on the tribological behavior of Al–SiC composites tested against ferrous materials [4–7]. These tests did not reflect the real tribological behavior of Al–SiC composites used for brake rotor applications. Although, in these applications, the rotor material slides against automotive friction material, very little information is available in the open literature on the tribological interactions between Al–SiC composites and brake pad materials. Thus, investigations are needed to study the real wear behavior of the Al–SiC composites sliding against automotive friction materials.

Recently, a few studies involving a brake pad material as a counter body have appeared. For example, the influence of sliding speed on the wear and friction behavior of two aluminum matrix composites reinforced with 13 vol% of SiC or B_4C particles sliding against a commercial phenolic brake pad has been investigated under dry condition by Shorowordi et al. [8]. The wear tests were carried out using a pin-on-disc type apparatus at two linear sliding speeds of 1.62 and 4.17 m/s under a constant contact pressure. The authors have observed that higher sliding speed leads to lower wear rate and friction coefficient of both composites. Straffelini et al. [9] have studied the effect of load and external heating on the friction and wear behavior of two AlSi alloys containing 10 and 20 vol% of SiC particles dry sliding against a semi-metallic friction material. They have found that for loads lower than 200 N, the wear is by abrasion and adhesion, and the friction coefficient is quite high (around 0.45). For loads higher than 200 N, the friction coefficient decreases with increasing the load in both materials, whereas the wear rate increases with increasing the load. External heating induces a decrease in the wear rate of both composites, but also an unacceptable decrease in the friction coefficient and increase in the wear rate of the counterface friction material. The investigation carried out by Uyyuru et al. [10] on the tribological behavior of AlSi–SiC particle

* Corresponding author.
E-mail address: ADAOUD_eg@yahoo.com (A. Daoud).

0301-679X/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.triboint.2009.09.003

composites sliding against automobile brake pads has shown that the wear rate increases with the increase in the normal load and decreases with increasing the sliding speed. However, the friction coefficient decreases with the increase in the normal load and sliding speed. Natarajan et al. [11] have compared the wear behavior of A356-25 vol% SiC composite sliding against automobile friction material with that of the conventional grey cast iron. They have reported that the A356-25 vol% SiC composite has higher wear resistance than conventional grey cast iron sliding against friction material under identical conditions. In addition, they have observed a gradual reduction in the friction coefficient with increasing the applied load for both cast iron and composite. Zhang et al. [12] have investigated the friction and wear behavior of brake material dry sliding against two different brake drums made of aluminum matrix composite reinforced with different sizes (3.5 and 34 μm) of 25 vol% SiC particles, in place of the conventional cast iron brake drum for a Chase Machine. They have observed that the friction performances and wear resistance for the brake material sliding against the drum with large-size SiC particles are better than those against the drum with small-size SiC particles.

In the last few years, considerable development has occurred in the potential use of cast MMCs for automotive applications. However, a few issues have restricted wider industrial acceptance of brake rotor made of Al–SiC composites. Some of these issues are associated with the high cost of composite fabrication relative to the current low-volume market potential and integration of laboratory-scale processing experience into commercial production. Ultimately, manufacturability, product performance and cost-competitiveness of Al–SiC brake rotor relative to traditional cast iron brake rotor will determine whether this component will graduate from laboratory curiosity to commercial production with meaningful market potential.

To the best of our knowledge, there has been no previous work dealing with a comparative study between the wear and friction behavior of sand cast brake rotor made of A359-20 vol% SiC particles and commercially used cast iron brake rotor. Accordingly, the present work was undertaken to produce sand cast brake rotor made of A359–20 vol% SiC composite manufactured by using a low-cost stir casting technique. The influence of load range of 30–100 N and speed range of 3–12 m/s on the tribological behavior of cast iron and MMC brake rotor material was investigated. A comparative study between the wear resistance and frictional behavior of the composite and cast iron was conducted. Furthermore, the worn surfaces of the composite and friction material as well as the wear debris were studied in order to ascertain the wear mechanisms.

2. Experiments

2.1. Fabrication of MMC brake rotor

A359 alloy (Al9Si0.7Mg) was used as a matrix material and SiC particles with an average size of 5 μm were used as a reinforcement. The composite was prepared by stir casting technique. The A359 alloy was placed in a crucible and heated to 100 °C above its liquidus temperature. The SiC particles were heated to 600 °C to avoid the molten A359 alloy excess cooling when mixing. Then, a stirrer driven by a motor was introduced into the molten metal and a vortex was created on the top surface. After the preheated SiC particles were added, the stirring was continued for 3 min. The composite slurry was then poured into a sand mould having the configuration of commercial automobile brake rotor. Then, the solidified brake rotor was removed and subjected to T6 heat treatment by using a computerized furnace (Vulcan 3-550) in the following manner: solution treatment at 538 °C for 8 h, water quenching at 60 °C and isothermal aging at 154 °C. Vickers hardness was measured using a HBV-30A macrohardness tester at a load of 10 Kgf. Maximum hardness of 126 HV (peak-aged condition) of the composite was obtained after 14 h aging time. The cast brake rotor was then machined and checked for voids. No large-scale defects such as cracks or porosity were detected.

2.2. Preparation of the discs

For comparison, the wear and friction behavior of commercially used cast iron and the proposed composite brake rotor and their counterface commercial automobile friction material were studied in this investigation. The cast iron and MMC discs were machined from a commercial passenger car brake rotor and A359–20 vol% SiC brake rotor produced in the present work, respectively. The inner and outer diameters of the disc were 140 and 180 mm, respectively. The surfaces of the discs were machined to an average roughness value of 1.5 μm, which is same as the roughness value of the sliding surface of the actual commercial brake rotor. Photograph of the A359-20 vol% SiC disc used for the wear test and its microstructure are shown in Fig. 1 and Fig. 2(a), respectively. The density of the composite was measured using Archimedes method.

2.3. Preparation of the pins

A commercial automotive brake material was used as pins for the wear test. Since these commercial friction materials are proprietary items, their compositions are not exactly known. However, it is generally known that commercial friction material may contain phenolic resin, filler materials ($BaSO_4$/$CaCO_3$) and small amount of metal chips (e.g. iron) as friction modifier, etc [8,13,14]. XRD pattern of the friction material used in the present work detected a number of elements, viz. C, Fe and Cu, and compounds, viz. $CaCO_3$, TiO_2 and ZnO as can be seen in Fig. 2(b).

The pins were machined such that each pin was of 10 × 10 mm square in cross-section and a height of 20 mm. The square cross-section was chosen for two reasons: firstly, it was preferable over circular cross-section since the use of rectangular cross-section results in less scatter in the friction and wear data [10,15], secondly it was difficult to machine pin of circular cross-section from the brake material. The pin surfaces were cleaned and conditioned before starting of every experiment.

Fig. 1. Photograph of as-machined A359-20 vol% SiC composite disc.