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Investigation of abrasion in Al–MgO metal matrix composites

Muharr em Pul [a,*], Recep Çalin [a], Ferhat Gül [b]

[a] Kırıkkale University, Department of Metallurgy and Mechanical Engineering, Kırıkkale, Turkey
[b] Gazi University, Department of Metallurgy and Mechanical Engineering, Ankara, Turkey

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ABSTRACT

In this study, the effects of reinforcement volume fractions on abrasive wear behavior were examined in Al–MgO reinforced metal matrix composites of 5%, 10% and 15% reinforcement – volume ratios produced by melt-stirring. Abrasive wear tests were carried out by 60, 80 and 100 mesh sized Al_2O_3 abrasive papers and pin-on-disc wear test apparatus under 10, 20 and 30 N loads at 0.2 m/s sliding speed. The mechanical properties such as hardness and fracture strength were determined. Subsequent to the wear tests, the microstructures of worn surfaces were examined by scanning electron microscope analyses. While increased MgO reinforcement volume fraction in the composite resulted increased hardness, fracture strength was determined to decrease. Additionally, it was found that increased MgO reinforcement volume fraction in the composite was accompanied with increased wear loss and porosity as well as reinforcement – volume ratio was identified to be significant determinants of abrasive wear behavior.

1. Introduction

With the developments in technology and the growing needs of industry, researches and developments on manufacturing composites with different properties have recently shown an increase. A reason for this increase may be that the low specific gravity of some composite materials shows a marginal resistance. Furthermore, they can be manufactured at different levels of resistance and with different combinations, have ideal levels of fatigue and toughness, show resistance under high temperatures, are highly resistant against oxidation and wear; all of which add up to the reasons for the upswing in their use [1].

The wear pattern of composite materials is an important subject for research. Use of reinforcing components in composite materials creates hard phases within the soft structure, adding to the resistance and toughness. The resistance to wear changes according to the amount, size and distribution of hard particles, the hardness of the reinforcing components with matrix and their fracture toughness [2,3]. Composite materials with high levels of resistance are commonly used in different fields of engineering. Composites with Al matrix are manufactured with different techniques such as molding, compression molding, infiltration and powder metallurgy. However, one of the possible problems with the molding is that the reinforcing components may only partially mix in the main matrix or not at all. Different methods of molding are tested in order to resolve such problems.

One of the methods of manufacturing metal matrix composites (MMCs) with reinforcing particles, stir-casting, is potentially a way of manufacturing low-cost MMCs materials for general use. Researches in which different matrix and reinforcing materials are used feature some mechanical properties, such as the distribution of the reinforcing material in the composite, its effect on the microstructure, porosity, stiffness, wear resistance and ultimate tensile strength; along with other subjects, e.g., the effects of the time and speed of embedding the reinforcement [4–15].

The wear resistance of MMCs materials varies depending on the matrix and the properties of the reinforcing materials [16]. Many researchers, worked on wear resistance and friction of the composites with Al metal matrix, ascertain that the composites with hard reinforcement particles prove highly resistant to wear more than the alloy matrix [17]. The chemical composition of the matrix material, the volume and the distribution of the reinforcing material within the structure have an impact on the level of wear, sliding speed, particle size, strength, and load applied [4–21]. In literature, it is reported that abrasive speed increases along with the volume and the particle size of the stiff phases [9,16,22–24].

In this study, the effects of reinforcement–volume (R–V) ratio, the pressure and the abrasive particle size on the microstructure and the abrasive wear behavior of the composites of 5%, 10% and 15% R–V ratios manufactured with melt-stirring method are investigated.

* *Corresponding author. Tel.: +90 3183574242; fax: +90 3183574242.
E-mail address: mpul61@hotmail.com (M. em Pul).

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2. Experimental

2.1. Manufacturing composite specimens

99.5% pure aluminum (Al) as liquid matrix and MgO as reinforcement material are used to manufacture the specimen composites. The chemical compositions of the matrix Al and the MgO of −177 μm particle size embedded into the melting pot are given in Tables 1 and 2.

In order to manufacture the specimen composites, the melting process began after putting Al as matrix material into the melting pot shown in Table 1 and continued until the liquid matrix temperature rises to 750 °C. The liquid metal was mixed using a mechanism designed the liquid matrix material. During this process, the stirring speed was gradually increased up to 500 rev/min, stirring certain amount of MgO powder, determined according to the reinforcement rate, with the help of a funnel. After stirring the reinforcement material MgO into the liquid matrix Al, stirring continued for about 4 min at 500 rev/min speed in order to have a homogenous distribution of the MgO particles in the compound. Right after stirring, the melting pot was taken out of the heater and the half solid compound was poured into steel casts of 30 mm in diameter and 100 mm in height and left them at room temperature to get cold. The same process was applied for each R–V rate. Pictures were taken with scanning electron microscope (SEM) in order to investigate the microstructures of the specimen composites.

To test hardness, specimens of 20 mm in diameter were prepared out of the composites manufactured at 5%, 10% and 15% MgO R–V rates. The tests were carried out with INSTRON WOLPERT GmbH Diastestor 7551 Brinel tensile strength tester, using 31.25 kgf load and 2.5 mm marble. Tensile strength tests were carried out on 10 points on the specimen of each R–V ratio and their arithmetical averages are shown in the graphic.

2.2. Abrasive wear tests

Abrasive wear tests were carried out at room temperature in dry and greaseless shifting conditions. The tests were carried out with specimens of 6 mm diameter × 25 mm height prepared from the composite materials at 5%, 10% and 15% MgO R–V ratio. The abrasive wear tests were carried out on a pin-on-disc apparatus, using aluminum oxide (Al_2O_3) abrasive with 60 mesh (250 μm), 80 mesh (177 μm) and 100 mesh (149 μm) particle size. The composite specimens on the abrasive were moved vertically across the wear direction so that they always touched a fresh surface of the abrasive. Tests were carried out at 5 m sliding distance and 0.2 m/s sliding speed applying 10, 20 and 30 N load options. In total, 27 different tests were recorded nine abrasive tests were carried out with three different load options and three different particle sizes on the composite specimens of 5%, 10% and 15% MgO R–V rate. The composite specimens were weighed at a scale with 0.1 mg sensitivity before and after each test and the amount of wear was noted.

In step two, in order to make comparisons, abrasive tests were carried out on the specimens prepared from the 99.5% pure matrix material ENAW1050A. The SEM images of wear after the tests were carefully evaluated. The images of the abrasive test apparatus are illustrated in Fig. 1.

Table 1
Chemical compositions of matrix material Al.

Norm	Al %	Fe %	Si %	Cu %	Zn %	Ti %	Mg %
ENAW 1050A	99.5	0.4	0.25	0.05	0.07	0.05	0.05

Table 2
Chemical compositions of reinforcement material magnesia.

MgO %	FeO %	SiO_2 %	CaO %
98	0.6	1	0.4

3. Results and discussions

3.1. Evaluation of microstructures

Fig. 2 shows the SEM images of MMCs specimens produced at different R–V rates with stir-casting method, and Fig. 3 shows the specimen EDS analysis.

SEM images show that the homogenous distribution of the MgO particles in the composites increase together with the R–V ratio. The white particles in the microstructure are the MgO reinforcement elements. It is clear that the 5% MgO reinforcement elements are not homogeneously distributed in the composite (Fig. 2a). It is probable that the low R–V rate MgO particles dragged and formed lumps during stirring. Images show that the 5% R–V ratio specimens have the lowest homogeneity, while the 10% R–V ratio specimens look better than the initial (Fig. 2b) and the 15% R–V ratio specimens are the closest to the desired amount of homogeneity (Fig. 2c). Furthermore, EDS analyses to chemically ascertain the MgO reinforcement and the matrix Al in the composite specimens are shown in Fig. 3a and b.

When we examine the microstructure in Fig. 3, it is visible that the composites have slight pores and these pores form on the reinforcement-matrix hybrid interface. It is probable that the amount of pores could be reduced by increasing the stirring period. Such conformation may occur because of the difficulty in soaking the ceramic-based reinforcement elements in the matrix material Al. Similar results were reported by Çalın-Çıtak, Acılar [11,12].

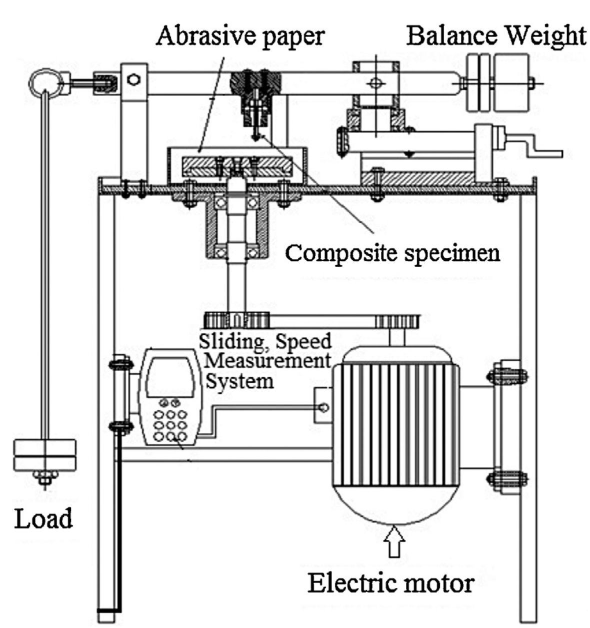

Fig. 1. Schema of pin-on-disc wear test apparatus.