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Wear behavior in Al_{2024}–CNTs composites synthesized by mechanical alloying

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ABSTRACT

The wear behavior of the 2024 aluminum alloy and its composites was evaluated through a pin-on-disk system. For this purpose the aluminum alloy was reinforced by carbon nanotubes dispersion produced by milling process. The nanotubes dispersion was carried out using a high energy mill for a fixed milling time. Milled powders were cold consolidated, sintered and then microstructurally and mechanically evaluated. The wear behavior of the alloy and its composites was evaluated considering the different nanotube contents under several abrasive conditions. The composites with higher nanotube concentration (5.0 wt%) displayed an improved wear resistance in all cases evaluated in this work.

1. Introduction

Aluminum and its alloys are attractive alternatives to ferrous materials for many industrial applications, due to their low density, high thermal conductivity [1], combined with good mechanical properties and corrosion resistance. Since poor tribological performance limits its use in wear related applications, many efforts have been made to improve their wear and mechanical resistance [2].

The aluminum matrix composites (AMC) reinforced with hard particles combine the ductility and low density of the metallic matrix with the high hardness and stiffness of reinforcement particles (phase) which results in good dimensional stability, high stiffness and improved mechanical resistance [3]. The high wear resistance of the reinforced AMC is due mainly to the ceramic particle content, which protects the metal matrix from wear [4]. So, AMC are an alternative when high strength-to-weight ratio is considered [5].

Various aluminum matrix composites using several reinforcement materials such as SiC, Al_2O_3, Ni_3Al, Pb and graphite, have been evaluated [4,6,7] for wear applications. However, the preparation of Al-based composites using the conventional casting technique becomes an issue due to the fact that Al and reinforcement particles generally are immiscible. Furthermore the large difference in specific gravity between ceramics and aluminum leads to a very strong sedimentary tendency upon solidification [7]. Conventional practice of preparation of Al-based composites involves the addition of particles to the liquid aluminum by several techniques; one of them is stir casting, which could lead to segregation of reinforcement particles and poor adhesion at the interface. Besides the high temperature associated to this process can induce the formation of unstable and/or undesirable phases which might drastically reduce the mechanical properties of the composite [8].

Mechanical alloying (MA) is a process which has been highly developed and widely applied to prepare many different kinds of alloys, intermetallic compounds, ceramics and composites in the amorphous or nanocrystalline state. Some alloys with homogenous microstructure can be easily obtained by MA in systems with components having great difference in specific weight, melting point or even virtually immiscible [7].

In this regard, the research of the carbon-based technology attracts the attention of the scientific community due to its special electrical and optical properties, in addition to the potential to improve the mechanical performance of novel composites. In particular, carbon nanotubes (CNTs) [9] have been proposed as

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aluminum couple [8,10–15] in composites due to their successful application in several metal matrix systems [16,17].

The aim of the present study is to compare the sliding wear of some Al-based composites synthesized by MA using a high energy mill. These composites were reinforced with different CNTs contents. Test samples were obtained from milled powders by cold consolidation and sintering. The wear behavior of the specimens was tested using different loads and SiC papers with different grit sizes as wear media in 300 m of sliding distance.

2. Experimental procedure

2.1. Production and characterization of the Al_{2024}–CNTs composites

Elemental powders were used to fabricate the 2024 aluminum alloy (Al_{2024}, Table 1). CNTs with a diameter in the range of 80 nm produced in bundle arrays by chemical vapor deposition (Fig. 1), were added in 1.0, 3.0 and 5.0 (wt%). The nanotubes were dispersed into the aluminum matrix by milling process in a high energy ball mill SPEX 8000. The mass of the powders was 8.5 g and a ball-to-powder weight ratio was 5:1. All milling runs were performed with methanol as process control agent (PCA) and argon was used as an inert milling atmosphere. The milling time was set to 5 h. Milled powders were cold consolidated at ~1500 MPa to form cylinders of 5 mm of diameter and 10 mm of high. Green products were pressure-less sintered for 2 h at 773 K with a heating and a cooling rate of 5 K/min under argon atmosphere. For the purpose of comparison an unreinforced alloy was prepared by the same route. The nomenclature for the composites studied in this work is given in Table 2.

X-ray diffraction (XRD, Panalytical X'Pert PRO with X'Celerator detector, interval 20 to 80 degrees) analysis was used to study the phase crystallization occurred during the sintering process. A semi-quantitative analysis was carried out by the X'Pert HighScore Plus software. On the other hand, the mechanical performance of the products was evaluated by microhardness test (15 s at a 150 g of load in a Future-Tech Corp model FM-7). The average values of at least five points of randomly selected regions in each sample are reported.

Table 1
Composition of the Al_{2024} alloy (wt%).

Al	Cu	Mg	Mn	Ti	Zn
93	4.5	1.5	0.6	0.15	0.25

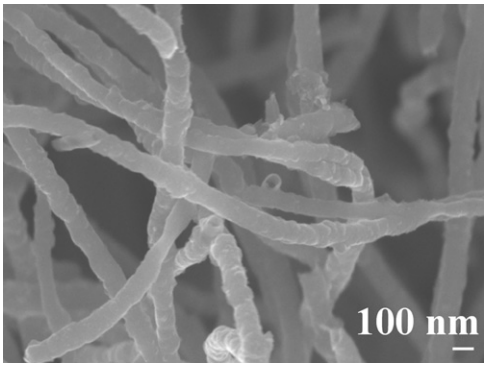

Fig. 1. Secondary electron SEM micrograph of the CNTs used as reinforcement material for composite materials.

Table 2
CNT concentration (wt%) used in the production of Al_{2024}–CNTs composites. All of them were mechanically alloyed during 5 h.

CNTs (wt%)	Sample identification
0.0	A_{00}
1.0	A_{10}
3.0	A_{30}
5.0	A_{50}

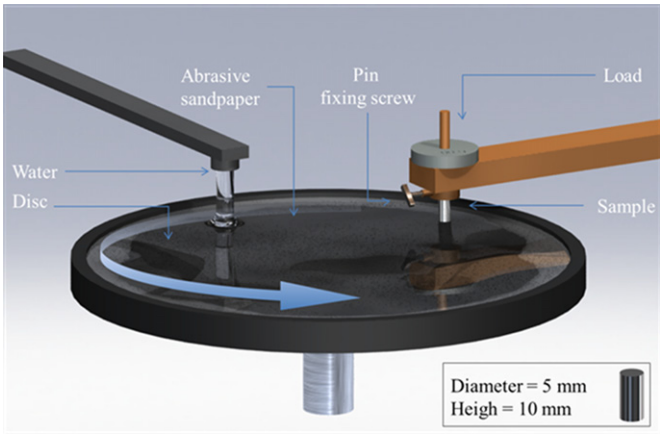

Fig. 2. Schematic process of the pin-on-disc apparatus to study the wear behavior of the Al_{2024}–CNTs composites. Samples slide against the abrasive SiC paper at two different loads.

2.2. Pin-on-disc tests for sliding wear

A schematic representation of the abrasion wear system in a very similar array to that used by Kök and Özdin. [4] is presented in Fig. 2 The elements shown in Fig. 2 were employed in order to get a pin-on-disc system with a holder positioned perpendicularly to the rotating disc. Specimens underwent the sliding wear tests against SiC abrasive papers of 220, 320 and 400 of grit. Loads of 0.5 and 1.0 N were transferred directly to the specimens with the use of the pin as it is indicated in Fig. 2. Tests were carried out at room temperature using water with a disc rotating at a fixed speed of 2 m/s against the samples. The total sliding distance was of 300 m and measurements in the weight of the specimens were taken every 100 m. The abrasive paper was conserved during the whole sliding distance and water was used as lubricant in order to prevent deterioration of abrasive SiC papers [4].

For statistical purposes, three runs were performed with different samples for each wear condition using new abrasive papers in each case. The samples were ultrasonically cleaned in methanol, then dried at 60 °C for about 30 s and weighted in order to calculate the weight loss of the specimens in each interval of the test. The microstructure study of the sintered samples after metallographic preparation was performed by scanning electron microscopy (SEM) as well as the worn surfaces of the specimens in a JEOL model JSM-7401F.

3. Results and discussion

3.1. Characterization of the Al_{2024}–CNTs composites

XRD patterns of the Al_{2024} and its composites prepared by MA and consolidated by sintering process at 773 K are shown in Fig. 3.