

Investigation of Wear Behavior of Aluminum Alloy Reinforced with Carbon Nanotubes

Deniz Uzunsoy
Bursa Technical University

Tao Peng and Isaac Chang
Univ. of Birmingham

Ilyas Istif
Yildiz Technical University

ABSTRACT

The material demands for advanced technologies have led to development of new generation, light-weight, and multi-functional materials. Aluminum matrix composites (AMCs) have captured considerable attention in aviation, space and automotive industries in recent years. Carbon nanotubes (CNT) are one of the most promising candidate of reinforcements used to improve mechanical strength and hardness of metal matrix composites (MMCs). In this study, dry sliding wear behavior of aluminum (Al) matrix (MMCs) reinforced with different amounts (0, 0.5, 1 and 2 wt%) of CNTs were prepared through ball milling, the process was followed by compaction at room temperature and pressureless sintering at 630 °C under argon atmosphere for 1hr. Wear tests were performed on a pin-on-disk tribometer against SAE 1040 steel counter body under constant load and sliding speed at room temperature. Worn surfaces of composites were characterized by scanning electron microscopy (SEM) technique in order to identify dominant wear mechanism of the as-produced composite materials. Preliminary result of this study showed that the composite displayed lower wear rate and friction coefficient under mild wear conditions comparing to aluminum alloy without reinforcement.

CITATION: Uzunsoy, D., Peng, T., Chang, I., and Istif, I., "Investigation of Wear Behavior of Aluminum Alloy Reinforced with Carbon Nanotubes," *SAE Int. J. Mater. Manf.* 7(3):2014, doi:10.4271/2014-01-1008.

INTRODUCTION

In the recent decade, great deals of research were carried out to incorporate CNT into metal matrix, especially Al matrix due to its high strength-weight ratio. The introduction of CNT into Al matrix is focused on significantly improving mechanical properties, such as strength and stiffness, while keeping lightweight. To date, most of the Al-CNT composites fabricated by powder metallurgy (P/M) achieved dramatically enhancement in stiffness and strength. Kuzumaki et al.[1] reported a 100% improvement in the tensile strength by adding 10 vol.% CNT into aluminum matrix. In the study of George et al. [2], both multi wall carbon nanotube (MWCNT) and single wall carbon nanotube (SWCNT) were used in reinforcing aluminum, where their results showed that the Young's moduli of the composites increased by 12% and 23% with 0.5 vol.% and 2 vol.% addition of MWCNT separately. However, the SWCNT-Al composite with the same volume fraction of the reinforcement did not display a considerable increase in Young's modulus.

On the contrary, the systematic study conducted by Esawi and Morsi [3] fabricated a 2 wt% MWCNT-Al composite which presented a deterioration in both hardness and indentation modulus compared to pure aluminum due to the poor bonding between CNT and Al matrix. In another study, [4] 6.5 vol.% CNT reinforced aluminum composites via chemical vapor deposition (CVD) method obtained 184% increase in tensile strength and 333% increase in hardness. Deng et al. [5] made the 1wt% and 2wt% CNT-Al composite by hot extrusion, in which the high temperature and high pressure promoted the formation of Al_4C_3 . A desirable high density (98.4%) of hot extruded parts with CNT pullouts was found in 1 wt% CNT-Al samples, while clusters and interfacial bonding were observed in 2 wt% CNT-Al samples. Choi et al used MWCNT as a reinforcement in Al composites, they reported that wear resistance is significantly enhanced [6]. So far, the study of the wear behavior of CNT-Al composite has been limited.

The objective of this work is to investigate the wear and friction behavior of Al alloy reinforced with carbon nanotubes prepared through ball milling, compaction and pressureless sintering.

MATERIALS AND EXPERIMENTAL PROCEDURE

Materials Processing

Aluminum powder supplied by ECKA Granulate GmbH & Co. KG) and multi-walled carbon nanotube (Sigma-Aldrich Co.) were used in this investigation. The purity of Al powder was 99.7% and powder size varied between 75µm and 106µm. Multi-walled carbon nanotubes had a purity of 95%, with a diameter of 6-9nm and an average length of 5µm. Homogenous composite powders containing 0, 0.5, 1 and 2 wt.% CNT were prepared through mechanical milling followed by compaction at room temperature and pressureless sintering. The mechanical milling of Al powders and multiwall carbon nanotubes were performed in a FRITSCH-pulverisette 5 planetary ball mill. Stainless steel ball with a diameter of 10mm together with aluminum powder and carbon nanotube were put into a stainless steel milling jar with a volume of 250ml. In some cases, 1wt% of process control agent namely stearic acid or ethanol was added into the milling powders to act as lubricant for the powders to avoid welding to milling media. 30 grams of Al and CNT mixtures were loaded in each running, maintaining a constant ball to powder (BTP) ratio of 10 to 1. The mechanical milling was selected as a processing route for Al-CNT composites to (1) reduce the agglomeration of CNT, (2) induce homogeneous distribution of CNT, (3) obtain strong interfacial bonding of CNT and Al matrix in CNT reinforced Al-MMCs.

The milling performed at a constant speed of 250 rpm with an interim period of 10 min for every 20 min in order to prevent over-heating. After a certain period of milling, all the mixtures were taken out from the milling pot for analysis and subsequent sintering operation. The mixture of powders was cold pressed uniaxial into cylindrical preforms (10 mm diameter and 20 mm length) at pressure of 475 MPa. The green preforms were sintered at 630 °C under an argon atmosphere with a heating rate of 10 °C/min for 1 hr followed by gas quenching with rate of 10 °C/min to room temperature.

Materials Characterization

A scanning electron microscopy of Philips-XL30 and a field emission scanning electron microscopy (FESEM) of JEOL JSM-7000F were employed to characterize the morphology and surface conditions of the as-milled particles. The powder samples were first uniformly dispersed on the thin adhesive carbon disc before they were studied by SEM with secondary electron imaging model, operated at 20kV. The structure of carbon nanotube was investigated by Renishaw-InVia Raman microscope with an argon green laser light (wavelength: 532 nm, laser powder: 100%, scanning time: 100s). The as-produced samples for Raman microscope were evenly spread on the surface of thin glass slice prior to Raman spectroscopy. The particle size and the size distribution of the as-milled powders was examined using particle size analyzers (QICPIC and HELOS/BF Sympatec, wavelength of laser: 632.8 nm, laser power: 5mW, measurable size range: 0.5 - 875 nm),

where dry particles were poured through the lenses and the laser diffraction automatically recorded and analyzed the particle size. Tribological properties of the samples were determined by dry wear behavior test. The density of the sintered samples was measured by Archimedes' principle.

Wear tests of the produced composites was performed according to ASTM G99-95 standard [7]. Dry sliding wear test was carried out using traditional pin-on-disk test machine operating at room temperature, constant wear load of 10 N and rotational speed of 75 rpm against 1040 steel disc of hardness 180 HV. Friction coefficient between the pin and the disk stress was measured using a pressure sensor. The pin samples were approximately 20 mm in length and 10 mm in diameter. Prior to and after each test all samples were cleaned in an ultrasonic bath with acetone for 15 min and weighed up to an accuracy of 0.001mg using microbalance. Three sets of specimens have been tested in each experimental condition and the average results were obtained. The experiment was subjected to certain interruptions at each 500m sliding distance whereby the pin weight was measured after careful cleansing. The wear rate was calculated with this formula,

$$WS = \frac{\Delta m}{L \cdot \rho \cdot F_N} \quad (1)$$

where, WS is the wear rate, Δm is the weight loss, L is the sliding distance, ρ is density and FN is the normal force.

Results and Discussion

Microstructure of Aluminum (Al), Carbon Nanotube (CNT) Al/C Nanotube Samples

Aluminum powders reinforced with 0.5, 1 and 2 wt% CNT were fabricated successfully using mechanical milling. Figure 1a, 1b, 1c and 1d show the typical microstructures of the composites without reinforcements and with 0.5, 1 and 2 wt.% CNT's, respectively. The micrographs presents the particles without CNT have a small, flat shape and smooth surface, comparing to large, irregular shape and rough surface of CNT added particles. This is because during the mechanical milling process, CNT or CNT agglomerates formed the core of composite powder: ductile aluminum powder was first flattened and then covered CNTs or their clusters layer by layer, which lead to the increase of particle size. This can be confirmed by deforming the larger as-milled particles and then fracturing the particles to reveal the fracture surface. It is expected to refine the particles by adding higher content of CNT to reduce the contact of the freshly surface of Al particles [8].

Figure 2 shows the Raman spectra of raw CNT, milled Al-1wt%CNT with 1wt% stearic acid or ethanol. It can be seen from Figure 2 that peaks composed of D band and G band located at 1350cm⁻¹ and 1580cm⁻¹ respectively. D band represents the lattice defects and finite crystal size thus it will become higher and broad with the increase of defects while G band stands for the perfect hexagonal graphite structure.  Documents
Downloaded from SAE Global Engineering Hub