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Tribological properties of Al6061–Al_2O_3 nanocomposite prepared by milling and hot pressing

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A B S T R A C T

Tribological properties of bulk Al6061–Al_2O_3 nanocomposite prepared by mechanical milling and hot pressing were investigated. Al6061 chips were milled for 30 h to achieve a homogenous nanostructured powder. A 3 vol.% Al_2O_3 nanoparticles (~30 nm) were added to the Al6061 after 15 and 30 h from the beginning of milling. The milling times with Al_2O_3 in these two samples were then 15 h and 30 min, respectively. Additionally, 3 vol.% Al_2O_3 (1 μm and 60 μm) was added to the Al6061 after 15 h of milling; where, the micron size Al_2O_3 in these two samples, was milled 15 h with the matrix. Hot pressing of milled samples was executed at 400 °C under 128 MPa pressure in a uniaxial die. The hot pressed samples were characterized by micro-hardness test, bulk density measurements, pin on disc wear test, and finally scanning electron microscopy observations. Fifteen hour-milled nanocomposite with nanoscale Al_2O_3, showed improvement in wear resistance and bulk density compared with that of 30 min-milled nanocomposites due to better dispersion of Al_2O_3 nanoparticles, improved surface quality of nanocomposite particles before pressing and more grain refinement of Al matrix. Moreover, increasing the reinforcement size increased the wear rate because of reduction in relative density, hardness and inter-particle spacing.

1. Introduction

Wear is one of the most important phenomena that take place at a material's interface [1]. Metal matrix composites (MMCs) containing hard particulates offer superior operating performance and wear resistance [2]. Al based MMCs reinforced with ceramic particles exhibit better mechanical properties than unreinforced aluminum alloys [3,4] and has been used as tribological parts in some vehicles for years due to their high ratio of strength/density and better wear resistance [5,6]. Therefore, increased attention has been directed towards particulate reinforced aluminum alloy composites for tribological applications [7,8]. For instance, Kök and Özdin [9] studied the effect of Al_2O_3 particle content and size (16–32 μm average size) on the wear behavior of Al_2O_3 particle reinforced 2024 aluminum alloy composites fabricated by a vortex method. Surappa et al. [10] reported the influence of 5 vol.% Al_2O_3 particles addition (20 μm average size) on the wear resistance of hypereutectic Al–Si alloys. Recent investigations have revealed that further improvements in the tribological properties of MMCs can be achieved by synthesizing nanocomposite bulk materials where nonmetallic nanoparticles are embedded in a relatively compliant metallic matrix [11,12]. However, from the literature survey it is evident that very limited work has been reported on tribological properties of aluminum alloys nanocomposites. In this paper, the effect of milling time on tribological properties of bulk Al6061–Al_2O_3 nanocomposite prepared by milling and hot pressing has been investigated. Furthermore, there has been almost no work related to the assessment of tribological behavior differences between nano and micro Al_2O_3 as reinforcement particles in Al6061 based MMCs. As a result, a comparison between tribological behavior of Al6061/Al_2O_3 nanocomposites with nano and microsize reinforcement particles has been carried out.

2. Experimental procedure

2.1. Materials

To prepare Al6061–Al_2O_3 nanocomposite, commercial prealloyed Al6061 chips with chemical composition of Al–1.23 wt.%Mg–0.54%Si as well as Al_2O_3 particles with average size of approximately 30 nm, 1 μm and 60 μm were employed.

2.2. Mechanical milling

The Al6061 chips and 0.1 wt.% PCA were mechanically milled in a planetary ball mill (Fritsch P7 type) with a hardened steel container under a high purity argon atmosphere (99.99% purity) up to 30 h. The rotational speed of 500 rpm and ball to powder weight ratio of 10:1 was employed. Hardened steel balls with 20 mm

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diameter were used. In order to produce Al6061–3 vol.% Al_2O_3 nanocomposite powder, an ultrasonic treatment was carried out on the Al_2O_3 nanoparticles for 90 min. Al_2O_3 nanoparticles which had been dispersed ultrasonically were then added to the Al6061 after 15 and 30 h of milling. The milling times of Al6061 with Al_2O_3 in these two samples were then 15 h and 30 min, respectively. Moreover, 3 vol.% Al_2O_3 (1 μm and 60 μm) was added to the Al6061 after 15 h milling; consequently, the micron Al_2O_3 in these two samples, was milled 15 h with the matrix. Table 1 shows the specifications of Al6061–Al_2O_3 nanocomposite powders in the as-milled condition.

2.3. Hot pressing

The milled powders were filled in a uniaxial die made of X40CrMoV51 (AISI H13). Then, the specimen was heated to 400 °C and pressed at constant pressure of 128 MPa. The duration of hot pressing was 30 min. To avoid pore formation, the pressure on each specimen was not released until it was cooled down.

Table 1
Specification of Al6061–Al_2O_3 nanocomposite powders in the as-milled condition.

Nanocomposite samples	A	B	C	D
Al_2O_3 size	30 nm	30 nm	1 μm	60 μm
Total milling time of Al6061 (matrix)	30 h	30 h	30 h	30 h
Total milling time of Al6061 with Al_2O_3	30 min	15 h	15 h	15 h

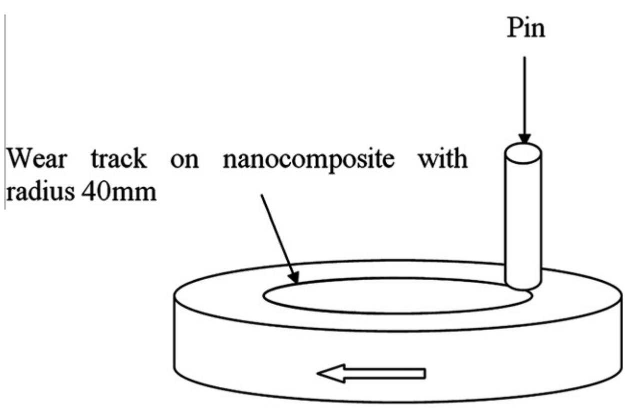

Fig. 1. Schematic diagram of wear monitor.

2.4. Wear

The wear tests were conducted with a pin-on-disk tribometer. For each specific sample, the test was repeated several times (at least for three times) in order to assure repeatability. All wear tests were conducted for a total sliding distance of 1000 m. The disk specimens with the size of ø50 × 15 mm were cut from the hot pressed samples. Each specimen was thoroughly cleaned by ethanol and dried. Pins made from AISI 52,100 carbon steel with the hardness of 63Rc were used as the counterfaces. In the wear test, a pin specimen was held with its axis perpendicular to the surface of a disk, and one end of the pin slid against the disk in a dry friction condition, under a constant axial load applied with a dead weight. The sliding speed and the axial load were 0.08 m/s and 20 N, respectively. A schematic diagram of wear monitor is shown in Fig. 1. The surface roughness of the nanocomposites was evaluated by surface texture measurements using Taylor Hobson instrument (with 0.01 μm precision). The surfaces profiles were recorded across the wear tracks. The roughness average, R_a (μm) and roughness height, R_z (μm) were used to assess the surface roughness after wear tests.

2.5. Characterization

The hardness of hot pressed nanocomposite was determined by HV at a load of 10 kg. Moreover, relative density measurements using Archimedes technique were carried out for each sample with precision of 0.5%.

The mass loss of the disk specimens was measured exactly at a 50 m interval in sliding distance with an accuracy of ±0.1 mg. The coefficient of friction between the pin specimen and the disk was also determined by measuring the frictional force with a stress sensor. At the end of each test, the specimen was re-weighed before morphological surface examination, in order to calculate the wear rate. The surface quality of powder particles before hot pressing in the A and B conditions (Table 1) was investigated by scanning electron microscopy (SEM) using VEGA//TESCAN. The SEM

Table 2
Specification of bulk Al6061–Al_2O_3 nanocomposite (samples A and B) after hot pressing.

Sample	Hardness (HV)	Relative density standard deviation (0.5%)	Wear rate/10^{-3} (mg/m)
A	116	75	26
B	244	98	4.3

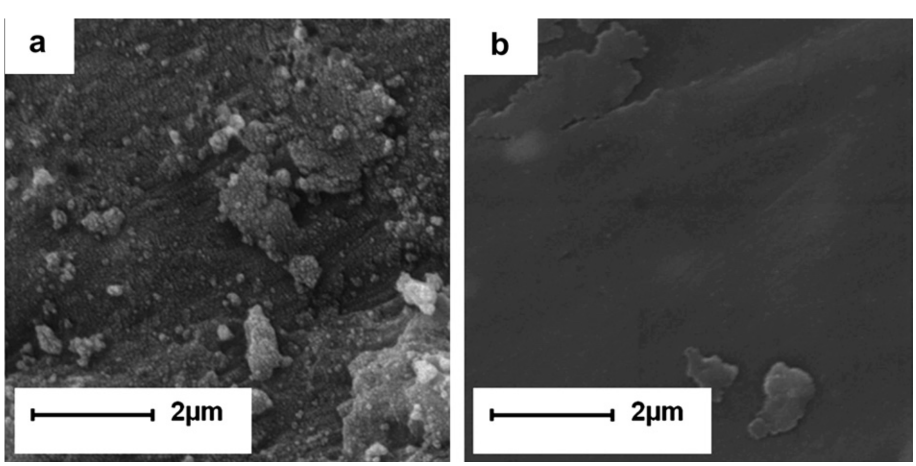

Fig. 2. SEM micrograph of surface quality of powder particles in the as-milled condition (a) sample A and (b) sample B.