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Contributed Paper

Effect of Wear Tests on Silicon Carbide Nanowires/ Aluminium Metal Powder Composites

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ABSTRACT

This research studies the effect of wear tests on silicon carbide nanowires (SiC NWs)/aluminium metal powder (Al) composites for different volume ratios of SiC NWs. Composites with 0, 5, 10 and 15% by volume of SiC NWs were fabricated by a hot pressing technique, using a temperature of 600°C, a pressure of 40 MPa and a duration of 1 h. The wear resistance of all nanocomposite samples was investigated using Pin-on-Disk Tribology. Furthermore, the morphology of composite samples was examined using scanning electron microscopy (SEM). SEM micrographs revealed that Al/SiC NWs form a complex structure and cling between particles of aluminium. The wear resistance increased with increasing volume percentage of SiC NWs.

Keywords: Aluminium (Al), Silicon carbide nanowires (SiC NWs), Composites.

1. INTRODUCTION

Interest in developing metal matrix composites for use in high performance applications has increased significantly in the last few years [1]. Among these composites, aluminum alloy matrix composites attract much attention due to their lightness, high thermal conductivity, moderate casting temperature, etc. [2,3]. Various hard ceramic particle materials such as SiC, Al_2O_3, MgO and B_4C are used extensively to reinforce aluminum matrices. The superior properties of these materials such as high refractive index, high hardness, high compressive strength, wear resistance, etc. makes them suitable for use as reinforcement in matrices of composites [4-8]. Silicon carbide nanowires (SiC NWs) have been attracting considerable attention as a novel type of reinforcement filler due to their excellent properties such as high thermal stability, high thermal conductivity, good mechanical properties and chemical inertness [9,10]. They also have potential as materials

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(Effect of Wear Tests on Silicon Carbide Nanowires/
Aluminium Metal Powder Composites)

โดย

อาจารย์ถนัด จินตโกศล

ภาควิชาวิทยาศาสตร์ทั่วไป คณะวิทยาศาสตร์ มหาวิทยาลัยศรีนครินทรวิโรฒ

ทุนอุดหนุนการวิจัยจากงบประมาณเงินรายได้คณะวิทยาศาสตร์ ปีงบประมาณ 2553

suitable for the reinforcment of composites due to their much larger strength compared to their bulk counterparts and strong interfacial bonding [11]. It is reported that the elastic modulus and ultimate bending strengths of SiC nanorods several tens of nanometers thick were 610-660 GPa and 53.4 GPa, respectively. The strength of these nanorods is a factor of two or more times higher than earlier observations for SiC whiskers of micrometer diameter [12]. They can therefore be used in nanoelectronics, field emission devices, biomedical engineering, nanocomposites and applications in high temperature nanoscale devices [9, 13-14].Although much research is dedicated to SiC NWs, most of the work focuses on the fabrication of SiC NWs and properties of SiC/ceramic composites [11, 15-17]. The improvement in materials' properties by using SiC NWs as fillers in metal matrix composites has not yet been reported.

In this work, composite samples made up of SiC NWs and pure Al powders were fabricated using a hot pressing technique. The reinforced phase SiC NWs were synthesized by a current heating technique (CHT). The wear resistance properties of composites samples were investigated and the micro-structure of the samples was determined using SEM.

2. MATERIALS AND METHODS

2.1 Materials

The SiC NWs were synthesized via current heating technique [18]. The raw materials used were 60 wt.% of carbon powder (Sigma-Aldrich, graphite powder, >99.99%), 39 wt.% of SiO_2 (Fluka, Silica gel 60) and 1 wt.% of Al_2O_3 powder (Riedel-de Haën, 98%). They were mixed and pressed into a rod shape 12 mm in diameter and 25 mm in length. Before applying the main heating power, the rod was preheated at approximately 50 watts for 5 min under an argon gas flow at the rate of 2 l/min. After that, the rod was gradually heated to ~ 1,400°C (630 watts) for 30 min under an argon atmosphere. SiC NWs was taken out from the surface of the rod were ground using an agate mortar for 10 min to get rid of hard agglomerations.

2.2 METHODS

The SiC NWs and pure aluminium metal powder (Acros Organic, 99%, 200 meshes) were mixed in different wire/Al ratio varying from 5% to 15 % by volume. In order to get a homogenous mixture, the SiC NWs were ultrasonically dispersed in ethanol for 10 min before mechanically vibro-mixing with the Al powders for 30 min. The slurry was dried at 120°C and sieved into a fine powder. The prepared composite powders were hot pressed at 600°C under pressure of 40 MPa for 1 h in argon gas. Pure Al was fabricated using the same procedure but without any addition of SiC NWs. The size of hot-pressed samples was 25 mm in diameter and 10 mm in length. The composite samples were polished to 1 mm finish, ultrasonically cleaned and dried before wear test [19,20].

Wear resistance of the composites sample were measured using Pin-on-Disk Tribology testing, an ISC-200 Tribometer (Implant Science Corp.). The counterpart was rotated at 60 rpm, corresponding to linear speed of 5 ms^{-1}. The sliding distance was 50 m with a normal 100 g load applied on the unlubricated WC-Co ball pin with a diameter of 8 mm at room temperature and dry air. After testing, the track width observed by an optical microscope was measured and the values were used for calculation of wear rate based on the Archard wear equation [21]. Friction coefficient (μ) was alsomonitored during wear test.

3. RESULTS AND DISCUSSION

The density values of SiC NWs/Al metal composite and monolithic Al are listed in Table 1. The results show that the densities of composite sample are in the range of 2.487-2.636 g/cm^3. It is noted that the density of the composite samples is much higher than that of the monolithic SiC NWs (0.996 g/cm^3) [22] and slightly higher than the monolithic Al (2.408 g/cm^3).

Table 1. The density, width of wear track and wear rate values of the composite samples.

Vol% of SiC NWs (%)	Density (g/cm^3)	Width of wear track (μm)	Wear rate (μm^2)
0	2.408	1108.046	35.707
5	2.487	945.833	22.208
10	2.636	735.288	10.223
15	2.586	679.335	8.229

Calculation of wear rate based on Archard equation showed that the wear rate of metal composite samples is much lower than for monolithic Al, especially for 15% vol of SiC NWs phase, which showed a wear rate 76.95% lower than that found for monolithic Al (8.229 μm^2 compared to 35.707 μm^2), as shown in Figure 1. A possible explanation for these findings could be that as the SiC NWs content increases, the degree of effective contact between the asperities of the composite surface and counter surface decreases, and thus the wear rate of composites reduces with increase in volume percent of SiC NWs phase.

Figure 2 shows the relation between coefficient of friction and distance as a function of SiC NWs content. The results show that the friction coefficient at room temperature were ~1.58 for pure Al and ~0.72-1.49 for SiC NWs/Al metal composite

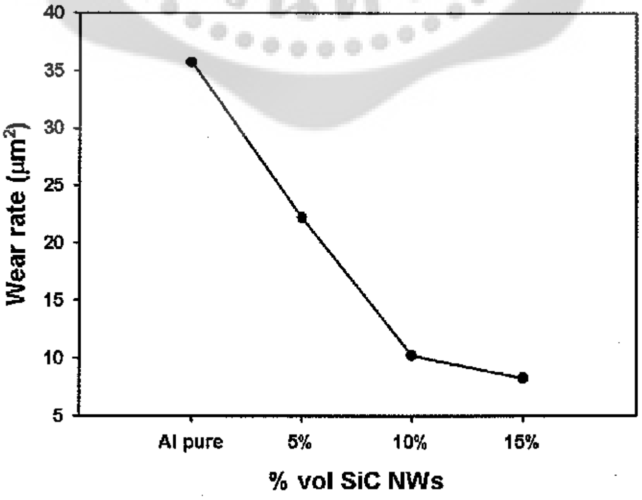

Figure 1. The wear rate of the composite sample.

samples. Within the composite materials, the minimum friction was obtained in 15%SiC NWs/Al and dramatically decreased with increasing volume fraction of SiC NWs. This observed trend of friction coefficient was somewhat agreement with their wear behavior. The photographs of wear track after 50 m sliding distance are shown in Figure 3. All sample composing of SiC NWs phase had narrow track width compared to monolithic Al and decreased with increasing volume percent of SiC NWs phase. The width of wear track for 15 vol% SiC NWs composites was 38.69% smaller than for monolithic Al. One of the parameter affecting friction coefficient could befriction heat and thermal conductivity of the samples. Hence, the thermal stress in the former due to built up local heat would be less and the surface spalling would also be reduced giving higher wear resistance and reduced friction coefficient [23].

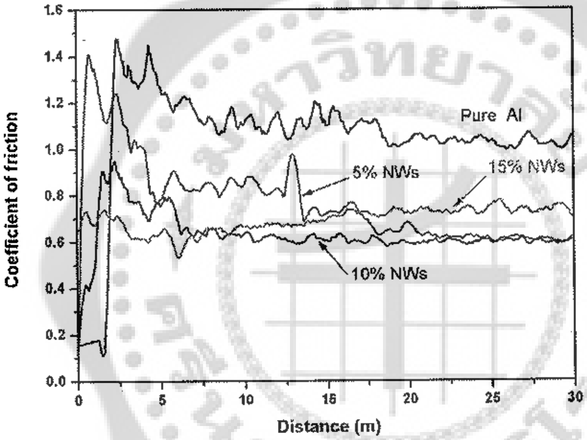

Figure 2. Coefficient of friction of pure Al and SiC NWs/ Al composites.

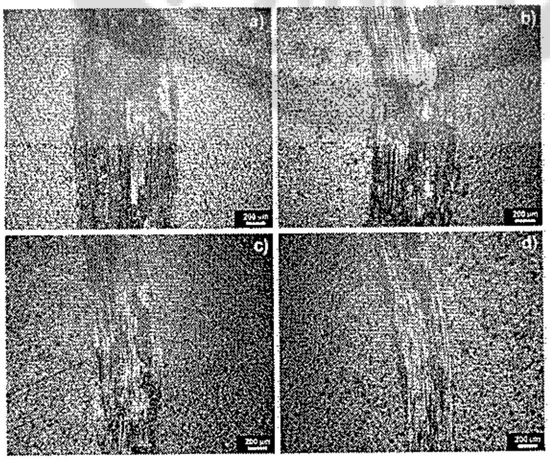

Figure 3. Wear track of composite samples (a) monolithic Al, (b) 5% vol, (c) 10% vol and (d) 15% vol of SiC NWs.

Microstructural investigation within wear scars of the metal composite illustrated in Figure 4. Wear scar of the monolithic Al was rather rough suggesting an occurrence of oxidative wear type due to thermal oxidation during the wear test as can seen in high magnification worn surface in Figure 4 (a). In contrast, the wear scar of 15% SiC NWs/Al metal composite represented smoother surface with plastic deformation that contain flat and polished region (Figure 4(b)).

The SEM micrographs and EDS spectrum of the as-received SiC NWs are shown in Figure 5. The SEM images have shown a 1D nanostructure with sizes of approximately 50-200 nm in diameter and several micrometers in length. The catalyst particles are observed at the tip of wires as shown in the Figure 5. The EDS analysis showed that the element of nanowires with a wrapping layer contain silicon, carbon and oxygen. The wrapping layer is thought to be SiO_2 [18]. Figure 6a shows the SEM micrographs at different magnifications of the 15% SiC NWs/Al metal composites. The brighter zone is the reinforced (SiC NWs) whereas the dark area is the matrix (Al). The microstructure of the nanocomposites was coarse, which implies that the composites have good toughness due to the presence of the nanowires. Figure 6b shows good interface bonding between SiC NWs and the Al matrix.

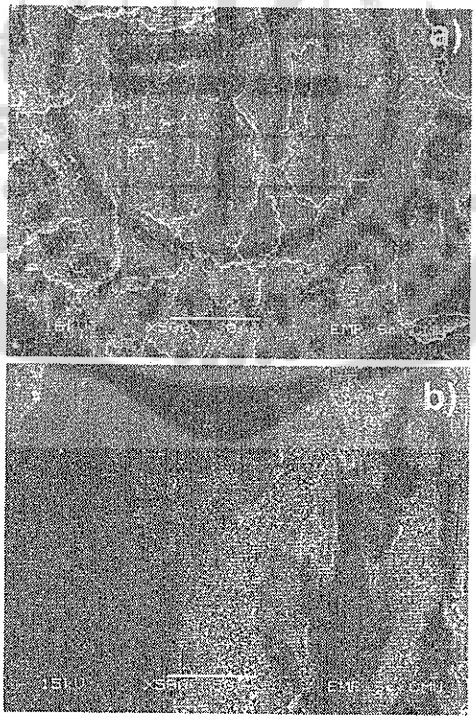

Figure 4. The SEM micrographs of worn surfaces inside the wear track of (a) monolithic Al, (b) 15% vol SiC NW/Al.

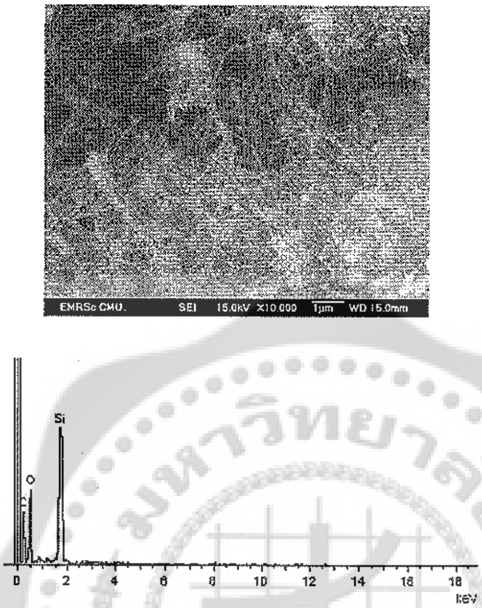

Figure 5. SEM micrographs and EDS spectrum of SiC NWs.

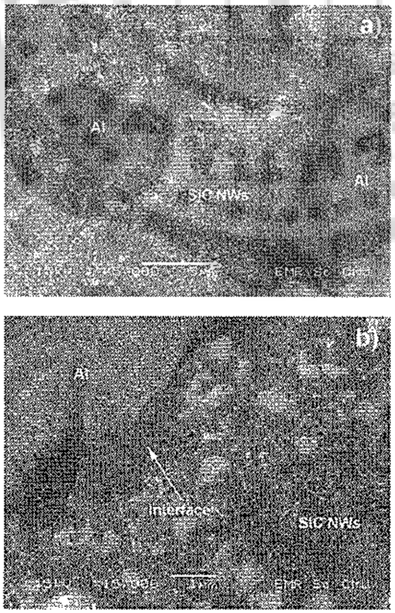

Figure 6. SEM micrograph at different magnification of 15% vol SiC NWs/Al composites a) × 5,000, b) × 15,000.

4. CONCLUSIONS

SiC NWs/Al composites were fabricated using a hot pressing technique. The SiC NWs were used as reinforcing fibers to improve the wear resistance properties of the composite samples. The results revealed that the SiC NWs were well dispersed within the Al matrix. The wear resistance of metal based materials is significantly improved due to the addition of the SiC NWs. The composites with 15% vol of SiC NWs show the best wear resistance, with a 76.95% decrease in wear rate compared to pure Al (from 35.707 μm^2 to 8.229 μm^2). It is therefore reported that SiC NWs/Al composites show improved wear resistance properties compared to single phase metal materials.

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