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WEAR OF AL_2O_3 AND SIC PARTICLES REINFORCED ALUMINUM METAL MATRIX COMPOSITES FABRICATED BY PRESSING AND EXTRUSION

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ABSTRACT

Dry sliding wear test of the Al matrix with 15% ceramic reinforcements of Al_2O_3 or SiC particles were performed using a pin-on-disc machine. The composites were prepared by powder metallurgy techniques followed by extrusion process. Some factors such as loads and sliding time on the degree of wear of particulate metal matrix composites (PMMC) were carried out. Tests were performed under different loads at room temperature and constant sliding speed of 1.67 m/s. Results indicate that the addition of Al_2O_3 and SiC particles in the Al matrix improve the wear resistance and hardness. PMMC with Al_2O_3 showed better performance than SiC reinforcement. SEM tests were carried out to reveal complex combination of wear mechanisms on the surface of the worn test specimens.

أجري في هذا البحث بعض التجارب للبري على عينات مواد مركبة ذات بطانة من الألومنيوم مسلحة بكربيد سيليكون أو أكسيد الألومنيوم وتم إعدادها باستخدام ميتالورجيا المساحيق ثم أجرى لها عملية بثق. تم إجراء اختبار البري تحت تأثير أحمال مختلفة وسرعة ثابتة. من النتائج يتضح أن مقاومة البري للعينات المسلحة باستخدام أكسيد الألومنيوم أفضل منها في حالة التسليح باستخدام كربيد السيليكون ويتضح ذلك من اختبارات الصلادة ، كذلك تم تصوير مسطح التآكل باستخدام الميكروسكوب الالكتروني لتحديد ما طرأ عليه من تغير

Keywords: Aluminum matrix composites; Powder metallurgy; Al_2O_3 and SiC particles; sliding wear

1. INTRODUCTION

Metal matrix composites have recently received substantial attention from the aerospace and automotive industries because of their improved strength, high modulus of elasticity and increased wear resistance over conventional unreinforced materials. Improvements of mechanical properties and wear resistance of PMMCs have already been demonstrated for variety of reinforcements [1-5]. Aluminum based alloys are widely used in applications where weight savings are important. However, the relatively poor wear resistance of aluminum alloys has limited their uses in certain tribological environments. In recent years, both fiber- and particle-reinforced aluminum alloy composites have been fabricated, giving significant improvement in tribological properties including sliding and abrasive wear, friction and seizure resistance [3-6]. One of the major problems in aluminum alloy composites that limit their tribological performance and may result in severe surface damage is their relatively poor seizure resistance. Moreover, the abrasive wear caused by hard ceramic particles may remove the soft aluminum matrix by forming microchips producing grooves or scratches. Therefore, the wear resistance and material parameters should be controlled to avoid excessive surface damage of wear.

The wear behavior of particle-reinforced composites greatly depends on many material factors such as volume fractions, shape, size, hardness and distribution of particles. In addition to experimental conditions including applied loads, sliding distance and speeds. In terms of abrasive wear resistance, reinforcement of Al-Mg alloy with coarse alumina (Al_2O_3) particles has been found to improve the low stress abrasive wear resistance [7-11].

The present work aims to investigate the effect of reinforcement type Al_2O_3 and SiC particles on dry sliding wear behavior of aluminum. Two composites were chosen for this investigation having the same matrix of aluminum and two different reinforcements of Al_2O_3 and SiC particles with same weight percentages of 15%. Material properties and experimental parameters were evaluated.

2. EXPERIMENTAL WORK

2.1. Materials and Fabrications

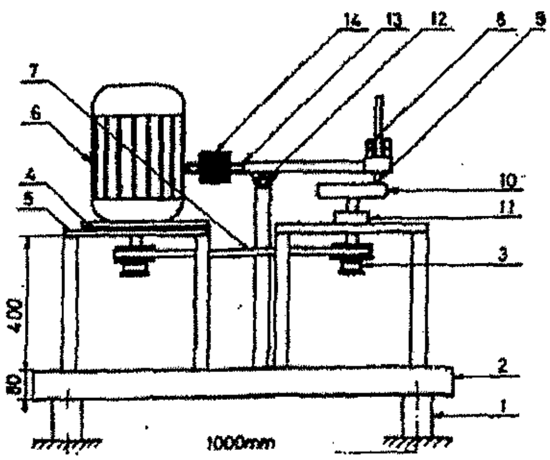
Metal matrix composites including 15% weight fractions of Al_2O_3 and SiC particles were produced by powder metallurgy techniques followed by extrusion. Previous work [4] and [11] mention that the abrasive wear test is suitable for high volume fraction of SiC (up to 40%) reinforced metal matrix composite. Commercial purity aluminum powder with the following chemical analysis: 99.4% Al, 0.2% Si, 0.15% Fe, 0.1% Cu, 0.1 % Mg, and 0.05% Mn was used as the matrix material; while of Al_2O_3 (40 μm) and SiC (70 μm) particles were used as the reinforcement materials. The composites were fabricated by mixing the aluminum powder with of 15% weight alumina (Al_2O_3) or 15% silicon carbide (SiC) powders. The mixed powders were pressed in air as billets under a pressure of 420 MPa and sintered at 450°C for 6 hours. The billet dimensions were 40 mm diameter, 40 mm long. Extrusion process was developed as secondary manufacturing process to consolidate Al-Al_2O_3 or Al-SiC composites. The compacted billets were extruded with an extrusion ratios equal 9.5 at temperature 550°C to reach a fully consolidated state. The final diameters of the extruded part was 12.8 mm.

2.2 Microstructure and Mechanical Property Tests

Microstructural investigation was conducted in composites by using light optical microscope. By using linear intercept method the volume fraction of the reinforcing particles (Al_2O_3 and SiC) were determined. The density (ρ) of extruded composite was determined by the Archimedes method. The theoretical density of extruded composite was calculated from the simple rule of mixtures. Brinell hardness tests were performed on all composite specimens. Readings were taken at various radial locations on the surfaces and the average results were reported.

2.3 Dry sliding wear tests

The dry wear test is conducted using a pin-on-disc tester designed and installed in our laboratory, as shown in Fig. 1. Samples from both Al matrix and the composites containing Al-15% Al_2O_3 and Al-15% SiC were prepared for the wear tests. The diameter of the pin specimens was 9 mm diameter and 10 mm length. The counter face disc was made of hardened alloy steel with 180 mm diameter and 10 mm thick. The hardness of the steel disc is 62 HRC and its chemical content is 0.2% C, 0.3% Si, 0.5% Mn, 0.25% P, 0.02 % S, 1.8 % Cr, 0.35 % Mo and 1.7 % Ni. The disc surface was flatly grounded to a surface finish of 0.3 μm centerline average. The dry wear tests were performed at room temperature. The rotation speed is fixed at 1.67 m/s. Two load values of 10 N and 20 N were applied at various sliding times up to 35 minutes (3.5 Km sliding distance). Wear rate was determined by the measurement of difference in weight of the pin sample before and after the test using a high precision balance (±0.05 mg) divided by sliding distance. Measurements were made after the initial run-in period when the pin surface was completely in contact with the disc surface. The scanning electron microscope (SEM) was JEOL JXA-840A type and equipped with energy dispersive spectrometer (EDS) to examine the pin worn surface characteristics and debris compositions.



POS.NO	PART NAME	DIMENSIONS	MATERIAL	NO OFF
1	COLUMN	4L 80X80X8	ST. 37	4
2	LOWER BASE	4L 80X80X8	ST. 37	1
3	PULLY SYSTEM		AL	2
4	DAMPER	PLATE 40X40X4	RUBBER	1
5	UPPER BASE	4L 40X40X4	ST. 37	1
6	ELECTRIC MOTOR	0.5HP-220V-50Hz		1
7	BELT			1
8	STANDERD DEAD WEIGHTS		C.I.	1
9	SPECIMEN	ϕ6mm-L=40mm		1
10	ABRASIVE DISC	ϕ150 THICKNESS 5		1
11	BEARING BOX			1
12	PIVOT			1
13	LEVER ARM		ST. 37	1
14	BALANCING WEIGHT		C.I.	1

Fig. 1 Wear Set-up

3. RESULTS AND DISCUSSIONS

Figure 2 shows the distribution of SiC and Al_2O_3 particles in aluminum matrix composites. The composites were pressed and direct extruded. The extrusion ratio was 9.5. The structure is shown in longitudinal direction parallel to extrusion axis. The Al_2O_3 and SiC particles were greatly aligned along the extrusion direction. The extrusion process of composites would lead to strong particle-matrix bond and fine particle size. The particle size was refined due to high die pressure applied during the extrusion process. Metallography showed that ceramic reinforcements were uniformly distributed and interfaces were well integrated. This indicate specially in the case of silicon carbide particles was broken due to extrusion action. The small particles of AL_2O_3 (40 μm) leads to improve the hardness o f composite than that incase of silicon carbide (70 μm) particle reinforcement. The spherical shape of AL_2O_3 particles have less surface area than that of flakes of silicon carbide particles which leads to improve the mechanical bond between particles and matrix.

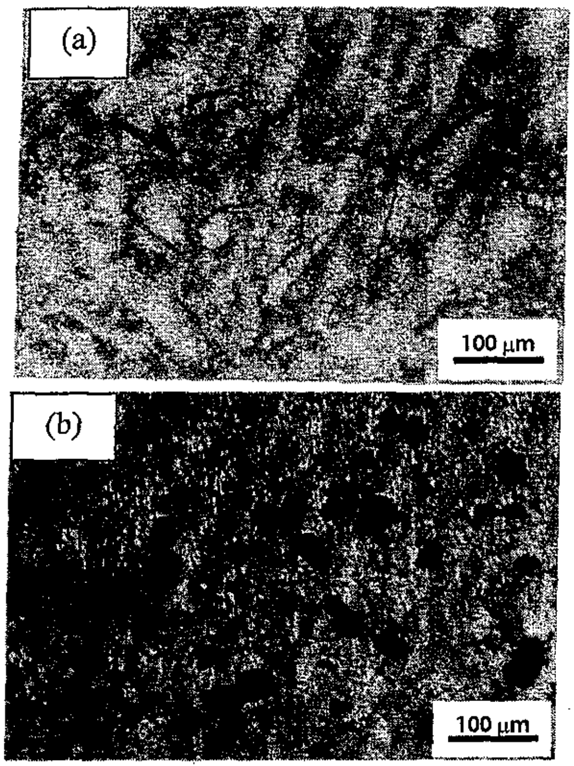


Fig. 2 Optical micrographs of the metal matrix composites; (a) Al-15% SiC and (b) Al-15%Al_2O_3

The results of density examination and hardness are given in Table 1. The results given in Table 1 show that the density of the extrusion samples as function of Al_2O_3 and SiC. Density was determined by the Archimedes method. As Al_2O_3 and SiC content increases, density of the sample increases.

Results of the examination of hardness of the extrusion samples, as a measure of reinforcement of the highly conducting Al matrix, show that the increase of hardness and density values are function of the increase of Al_2O_3 and SiC content. The effect is slightly larger in case of Al_2O_3 compared to SiC particles.

Table 1 Density and Brinell hardness of Composites

Materials	Al	Al-15% Al_2O_3	Al-15% SiC
Density (g/cm3)	2.67	2.81	2.77
Hardness (HB)	40	62	58

Figures 3 and 4 showed the relation between wear rate and sliding time, under dry conditions. Two loads 10 and 20 N were selected while sliding speed is kept constant at 1.67 m/s. Wear rates were found to be increased significantly as load or sliding time is increased. The effect of applied loads is more pronounced than effect of sliding times. The wear curves are similar to most metals; however the transition region is not apparent here in the selected range of sliding distances (1:3.5 Km) and applied loads. The figures also indicated higher wear resistance for PMMC reinforced with alumina particles compared to SiC particle. However both composites showed a much greater wear resistance values than that of unreinforced aluminum alloy.

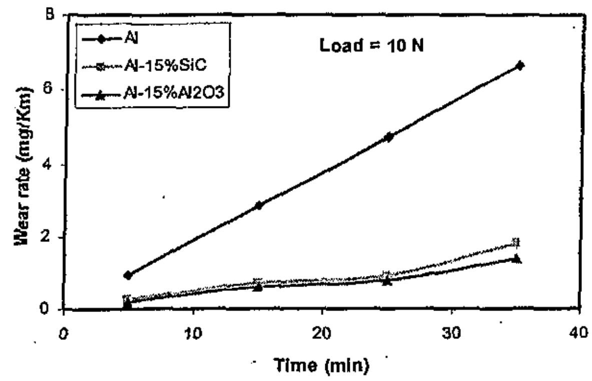


Fig. 3 Relation between wear rate and sliding time, under dry conditions at constant speed of 1.67 m/s and load 10 N

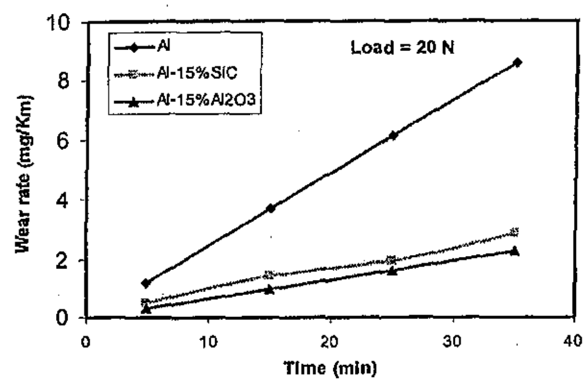


Fig. 4 Relation between wear rate and sliding time, under dry conditions at constant speed of 1.67 m/s and load 20 N.

Wear resistance seemed to be dependant on size and type of reinforced materials. Finer particulate of Al_2O_3 (40 µm) compared to SiC particle (70 µm) seemed to increase wear resistance of Al-Al_2O_3 composites because they are more difficult to pull out. The effect of Al_2O_3 particles to aluminum matrix may reduce the plastic flow of the matrix and change the wear mechanism from adhesive wear to mixed one made of oxidative- abrasive wear. These findings were reported in earlier investigations by several researchers [13-15]. Under light loads, the plastic zones are limited to the region beneath the individual asperities and no interaction between the zones occurs, leading to mild wear. As the load is increased, the plastic zones enlarge and interact to form entirely plastic subsurface regions, and severe wear occurs, leading to the release of fairly large and hard fragments into the wear system, especially under dry conditions [9]. However, again an increase in friction forces, as a result of increasing the load would in turn cause a temperature rise, decreasing the hardness of the matrix surface and, hence, increasing the resulting wear [16-17]. Also increase in temperature occurs, due to friction and to the increase in contact area which results in material softening and scuffing, leading to increased weight loss [18].

Figures 5 to 7 show scanning electron microscopic observation of the worn surface of Al, Al-15%SiC and Al-15%Al_2O_3 composites. SEM observation on the worn surfaces of composites were selected from specimens of worn surfaces tested at sliding times up to 35 minutes (3.5 Km sliding distance) and at constant applied load of 20 N.

Figure 5 showed the worn surface of unreinforced aluminum matrix, which indicated a formation of a build up edge (BUE) of iron counterpart. EDS confirmed the transfer of iron from the steel counter face to the composite on the worn surface. Cracks were found to be initiated at build up edge and propagate through the aluminum matrix. This leads to excessive wear of unreinforced aluminum [8-12].

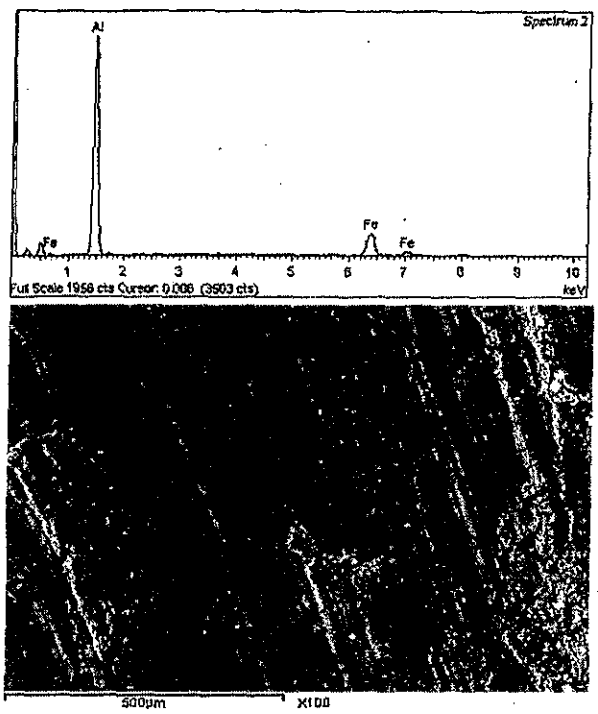


Fig.5 SEM micrographs of worn surface of Al and its corresponding EDS at 20 N and sliding time 20 min (≅ sliding distance 2 Km).

Figure 6 showed that SiC particles could penetrate easily inside aluminum matrix during sliding, resulting in excessive material removal from worn surface. EDS confirmed the transfer of iron from the steel counter face to the composite on the worn surface. Cracks were not found probably due to strengthen of ceramic reinforcement of composite. EDS analysis conducted on the worn surfaces of the composites revealed that the transferred layers contained constituents from the counter face, such as Fe, O and C. The peak of iron increased in composite than that shown for pure aluminum, as indicated in figures 5 for pure aluminum and figure 6 for Al-15% SiC composite. Iron rich transfer layer acts as a solid lubricant and prevent direct contact between the composite and counter face during wear testing [8].

For the composites reinforced with hard reinforcements, the overall friction force results from three factors [11]: the adhesion between the counterparts, ploughing and reinforcement fracture. The adhesion between the counterparts will be decreased by the incorporation of hard reinforcements. Therefore, real contact characteristic in the tribosystem will be decreased leading to a reduction in friction coefficient. The ploughing grooves formed due to reinforcements act as "cutting tools" and abrade the counterpart surface leading to an increase in friction coefficient. The composite metal matrix would be worn out firstly leaving SiC particles protrude and fracture subsequently during wear [11]. The hardness of the metal matrix is usually lower and more prone to wear and deform plastically at early stages.

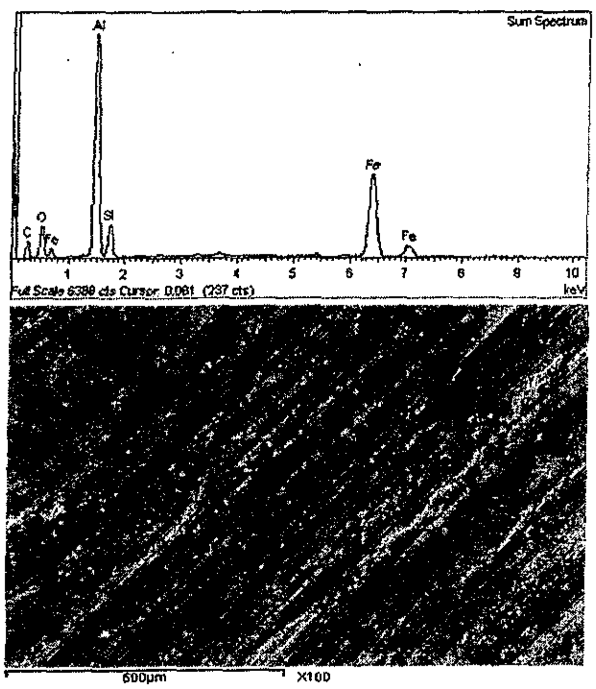


Fig. 6 SEM micrographs of worn surface of the Al-15%SiC composite and its corresponding EDS at 20N and sliding time 20 min (≅ sliding distance 2Km).

Figure 7 showed that the hard reinforcing Al_2O_3 particles whose hardness much greater than aluminum matrix. In case of composite with Al_2O_3 particles, the addition of ceramic Al_2O_3 particles improve the hardness of composite and acts as hard barriers to resist the plastic deformation of the matrix [11], which contributes to reduction of adhesion between metal matrix and steel counterpart. EDS analysis conducted on the worn surfaces of the composites in case Al_2O_3 as reinforcements revealed that transfer layers of Fe from the counterface is less than that in case of SiC particles at the same condition of testing. The alumina particles seemed to provide protection and strengthen the softer aluminum matrix. Hence the wear resistance of composite was improved due to alumina particles compared to SiC reinforcements.

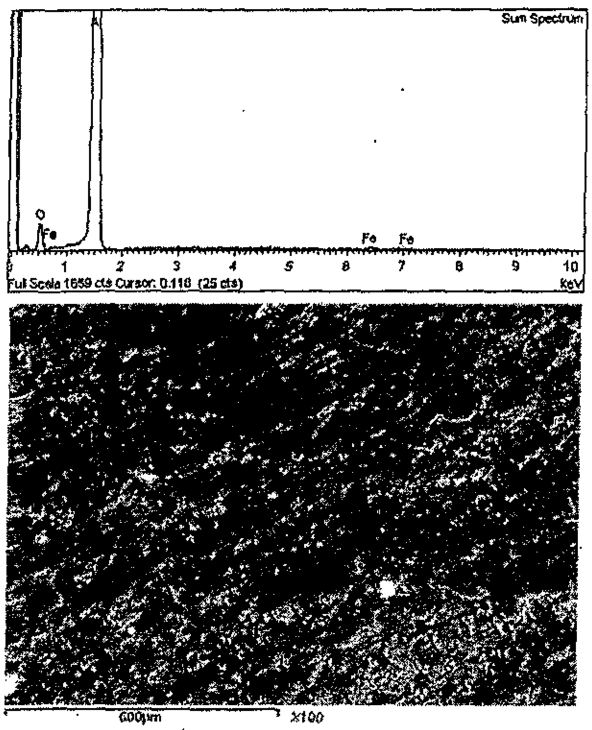


Fig. 7. SEM micrographs of worn surface of the Al-15%Al_2O_3 composite and its corresponding EDS at 20 N and sliding time 20 min (≅ sliding distance 2 Km).

4. CONCLUSIONS

1. In the abrasive wear test of composite reinforcement 15 % AL_2O_3 and SiC particles worn under different loads great differences in wear rates between matrix and composites was observed. The wear rate of composite decreased with increasing the hardness, while it increased with increasing applied load and sliding distance.
2. The wear rate of Al_2O_3 reinforced composites showed slightly more wear resistance values compared to SiC reinforcement. This improvement of alumina reinforcement may be attributed to matrix strengthening and finer alumina particle size.
3. The worn surface of un-reinforced aluminum matrix showed a build up edge (BUE) of iron counterpart. Cracks were found to be initiated at build up edge and propagate through aluminum matrix.
4. Worn surface examination of the composites revealed formation of Fe rich transfer layer during wear test.

5. REFERENCES

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