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ScienceDirect
Procedia Engineering 68 (2013) 674 – 680
Procedia Engineering
www.elsevier.com/locate/procedia

The Malaysian International Tribology Conference 2013, MITC2013

Tribology Behaviour of Alumina Particles Reinforced Aluminium Matrix Composites and Brake Disc Materials

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Abstract

Aluminum Matrix Composites (AMCs) are well known for high strength to weight ratio, and high temperature applications. In the present study, wear behavior of alumina particles reinforced Aluminum Matrix Composites (AMCs) and brake disc material has been investigated. AMCs used in this study contain 30%vol. alumina particles in Al alloys and was developed by squeeze casting. The wear rate was measured using a pin-on-disc type wear testing machine at room temperature under dry sliding condition. Wear rate was measured at 25, 50, 75 and 100N and sliding speed of 250, 500, 750 and 1000 rpm. The coefficient of friction of both AMCs and brake disc was also measured. The microstructures of both materials were also examined after each load. Results showed that wear rate increased with increase in load. The coefficient of friction was consistent up to 50 N load and then decreased at 75N and 100N. The microstructure showed that the AMCs experienced a combination of adhesive, abrasive and fatigue types of wear under various loading conditions. The coefficient of friction decreased as the surface of the AMCs become rougher at higher load. This was considered due to removal of alumina particles from the surface of AMCs during wear test and the remaining aluminum alloy without alumina particles made the material softer.

Selection and peer-review under responsibility of The Malaysian Tribology Society (MYTRIBOS), Department of Mechanical Engineering, Universiti Malaya, 50603 Kuala Lumpur, Malaysia

Keywords: Wear Rate; Coefficient of friction; adhesive;abrasive; Fatigue; Aluminum matrix composites; Brake Disc

1. Introduction

Aluminum alloys are being extensively used in various field of life, especially in aerospace and automobile industries, because of good thermal stability and excellent specific strength. Low weight aluminum alloys lead to reduction of weight resulting in considerable economic advantages [1-4]. Wear is removal of material from a solid surface by the sliding action of another solid and is caused by friction, fatigue or vibration [5]. Both sliding surfaces are damaged by these processes [6]. The sliding surfaces undergo some distortion that may be purely elastic or some additional plastic deformation [7]. Wear causes progressive damage involving material loss and occurs on the surface of the component due to sliding. The sliding surfaces may be dry or lubricated and loss of material will be

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Selection and peer-review under responsibility of The Malaysian Tribology Society (MYTRIBOS), Department of Mechanical Engineering, Universiti Malaya, 50603 Kuala Lumpur, Malaysia
doi:10.1016/j.proeng.2013.12.238

different in each case. The wear rate of the surface is also dependent on sliding speed, temperature, thermal, mechanical and chemical properties of the materials investigated. Contamination on material's surface such as debris or particles between the sliding surfaces also increase wear rate and damage to the surfaces [8]. Bhansali [9] studied abrasive wear of alumina particle reinforced composites and SiC particle reinforced composites and found that alumina particle improved wear properties. Ma [10] studied abrasive behavior of discontinuous SiC reinforced aluminum alloy composites and concluded that abrasive resistance of composites is dependent on the type of reinforcement, and properties of matrix. Zhang [11] reported adhesive wear mechanism of ceramic particles reinforced aluminum matrix composites against steel and found wear rate of AMCs increased hundred time when applied normal load exceeded a critical level. Wear occurs by five principal processes: adhesive, abrasive wear, corrosion, surface fatigue and erosion [12-15]. Earlier study [16] for SiC particles reinforced composites showed that wear was strongly dependent on the contents of reinforcement, sliding distance and speeds. Manish et al [17] investigated sliding wear of 15%v alumina particles reinforced aluminum composites. They used pin-on-disc machine with steel disc as counter-material. The wear rate was initially comparable and finally wear rate was increased for composites. Deuis et al [18] presented a review of wear of metal composites. Shipway et al [19] studied wear of TiC-reinforced MMCs produced by casting. They concluded that reinforced material reduces wear rate. Al-Qutab and Allan [20] studied wear and friction of AMCs containing 10, 20 and 30 % alumina. They concluded that an increase in reinforcement decreases wear rate. They also concluded that coefficient of friction (COF) decreases with increasing sliding speed. Hosking at el [21] studied wear behavior of alumina particles reinforced aluminum alloy using pin-on disc type machine for wear properties measurement. They found that increase in contents of reinforcement reduces its ductility and improves wear properties. Pin-on-Disc testing technique [18] has been reported for measurement of wear of aluminum composites. Pin-on-Disc uses volumetric loss, and is evaluated from decrease in length of pin. Vaccari [22] identified aluminum matrix composites as potential substitute of brake pad material.

In this study, the wear rate of alumina particles reinforced aluminum matrix composites (AMCs) and brake disc material was compared. Wear tests were carried out under different loads and speeds. The resulting microstructures were examined under scanning electron microscope to assess the type of the wear occurred on the surfaces of both AMCs and brake disc materials.

2. Experimental Details

2.1. Materials

Aluminum alloy-242 reinforced with 30%volume of alumina particles (AMCs) and cast iron, brake disc material were selected in this study for comparison of wear rate and COF. Test samples of AMCs and brake disc materials were prepared according to ASTM, D-91 and diameter was 5 mm, length 120 mm. Test samples of AMCs were prepared using diamond tool while the test samples of brake disc were prepared using conventional tooling.

2.2. Procedures

2.2.1 *Multi Specimen Tester (TR-701-M6)*

Multi-specimen equipment is used in this study to obtain data under various parameters. The wear properties of both materials were recorded under various loading conditions ranging from 25, 50, 75, and 100 N at speed of 250, 500, 750 and 1000 rpm. COF and wear rate was also measured under a fix load of 25 N using different speed. Scanning electron microscope (SEM) was used to examine the surface of test samples after each loading and speed for both materials to assess type of wear on the surface of both materials.

3. Results and Discussions

3.1. Effect of speed on weight loss

Fig. 1 shows a comparison in weight loss of both materials tested at various speeds under a load of 25N. The weight loss measured at 250rpm was 0.0236 g for brake disc material and 0.0063 g for AMC. Data showed that brake disc experienced 43% higher weight loss compared to AMCs. At 500 rpm, weight loss for brake disc was increased to 78% compared to AMCs. The weight loss measured at 750 rpm was reduced to 68% for brake disc compared to AMCs. The weight loss measured at 1000 rpm was about 52% higher for brake disc when compared with AMCs. The data showed that AMCs has lower weight loss compared to the brake disc. This was considered due to reinforcement of hard alumina particles (30%v) in aluminum alloy in order to improve the stiffness, wear resistance, strength and fatigue resistance of AMCs [11, 20].

3.2. Effect of load on weight loss

In order to study the effect of load on wear, wear properties were measured at various loads at 250 rpm. Fig. 2 shows wear date collected at various loads and a fix speed of 250 rpm. Results showed increase in load increased the weight loss for both AMCs and brake disc. At 25 N, the loss of weight was 0.0116 g for brake disc while AMC experienced 0.0063 g weight loss which is 46% lower than brake disc. An increase in load to 50 N, the weight loss of brake disc increased to 0.0239 g and 0.0146 g for AMC. This is 39% higher for brake disc. At 75 N, the weight loss was 0.0402 g and 0.0256 g respectively for both brake disc and AMC. The weight loss for brake disc was reduced to 36% for brake disc. As the load was increased to 100 N, the weight loss increased to 0.0610 g for brake disc and 0.0401 g for AMC. So, the AMCs have 34 percentages less weight loss than break disc. Data showed that the percentage difference in weight loss was decreased at high load at a fix speed. It was noted that AMC has experienced less amount of weight loss because it has a higher wear resistance due to reinforcement of high contents of hard alumina particles compare to the brake disc [12]. Hard Alumina acts as counter surface barrier and improves the structural properties of AMCs. So as load increases the alumina debris shows high wear resistance and structure of AMCs is prevented from excessive wear of foreign elements.

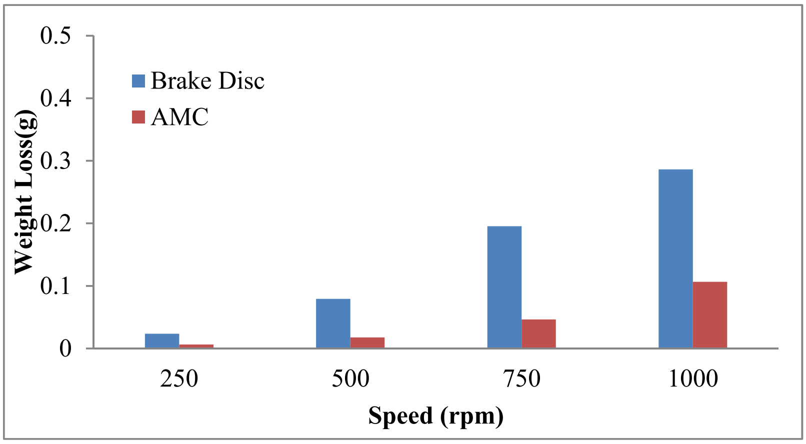

Fig. 1. Weight loss for brake disc and AMC versus load at 250 rpm.

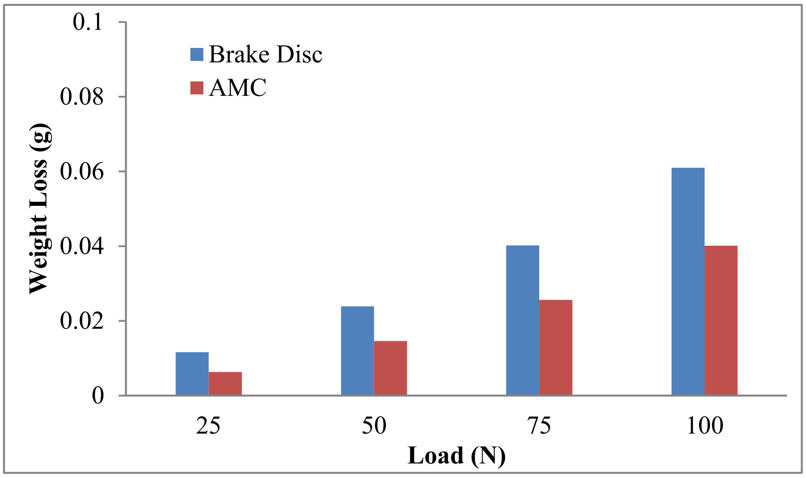

Fig. 2. Comparison of weight loss between AMCs and brake disc at 25N.

3.3. Wear mechanism analysis

3.3.1 Microstructure of Aluminum Matrix Composites and Break Disc

Test samples of AMCs and break disc tested for wear at various speed and a fix load were examined under SEM and micrographs of AMCs are shown in Fig. 3a-3d. Fig. 3a and b show a comparison of microstructure for AMCs and break disc at 250 rpm under 25 N loads. It was noted that AMC experienced adhesive, abrasive and fatigue type of wear. Fig. 3b shows the wear behavior of break disc that experienced abrasive and fatigue type of wear. Fig. 3c showed adhesive, abrasive and fatigue type of wear caused by testing at 750rpm at 25N. It showed that increase in speed resulted adhesive type of wear. SEM micrographs shows adhesive, abrasive and fatigue wear on the surface

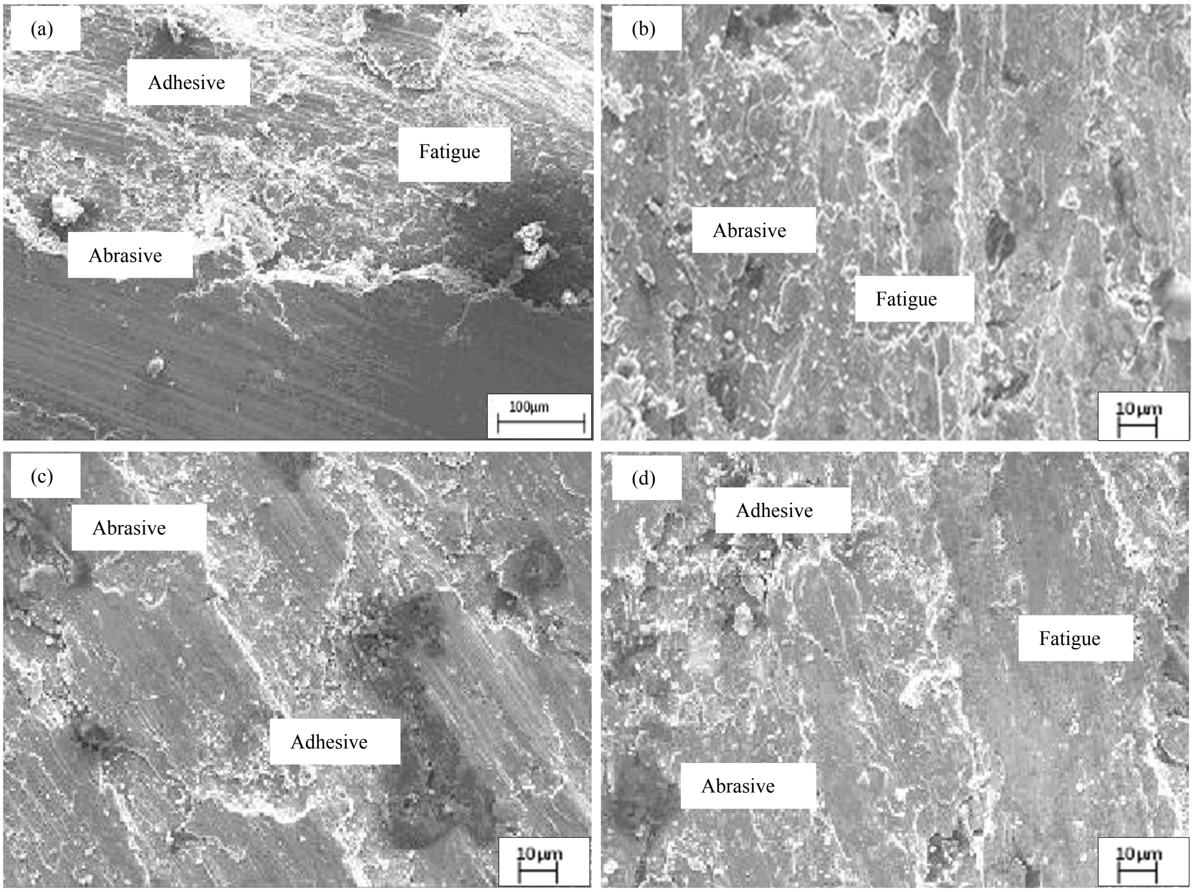

Fig. 3. Illustration of pressure particles for (a) upstream inlet condition in high temperature fields and (b) downstream moving water front in low temperature field (c) AMC at 750 rpm, at 25 N (d) Break disc at 750 rpm, at 25 N.

3.3.2 EDX of AMCs

The results of the surface analysis of the AMCs after wear obtained from EDX are shown in Fig. 4. The location selected for EDX analysis from the test samples was random. EDX spectrum shows the presence of six elements on the surface of the composite. These elements are oxygen (O), nickel (Ni), aluminium (Al) , copper (Cu), magnesium (Mg), and iron (Fe). This indicates no contamination of the surface. Moreover, it is evident from the Fig 2 that AMCs exhibits a slight gradual weight loss by increasing applied load. EDX analysis of AMCs, after wear test, shows only compositional elements of AMCs and it can be confirmed that debris produced during wear test on the surface are free from contamination.

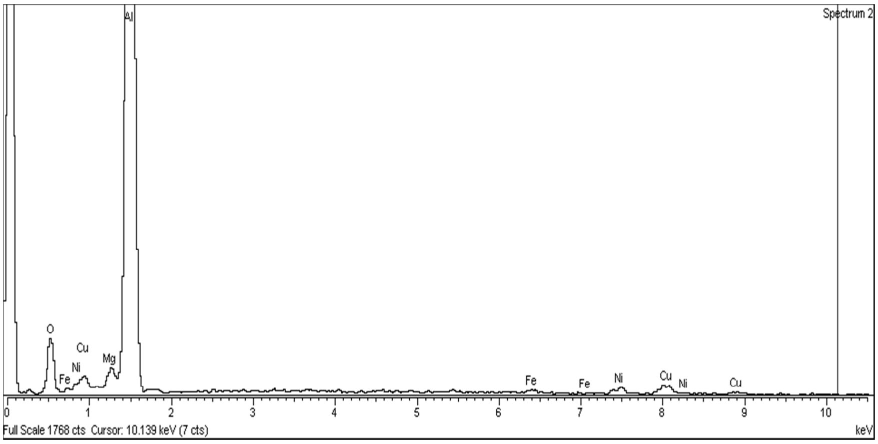

Fig. 4: Spectrum Composition of Aluminum Matrix Composite.

3.3.3 Effect of Speed on Coefficient of Friction

Fig. 5 shows a comparison of coefficient of friction (COF) between brake disc and AMCs. An increase in speed reduced the coefficient of friction (COF) at a constant load 25N for both materials; brake disc and AMC. At 250 rpm, COF measured for brake disc and AMCs was 0.342 and 0.322 respectively. It was noted that COF is about 7% higher for brake disc compared to AMCs. At 500rpm, the COF of brake disc and AMCs was decreased to 0.322 and 0.283 values. However, COF of brake disc was 11% higher. COF recorded for brake disc and AMCs at 750rpm was 0.258 and 0.192. Brake disc possess 26% higher COF. At 1000rpm, the COF decrease to 0.233 for brake disc and 0.158 for AMC and increase in COF of brake disc was about 32%. The reduction in COF of AMCs indicates that alumina (Al_2O_3) particles leave aluminum matrix (AMC) leaving soft matrix material compared to cast iron brake disc.

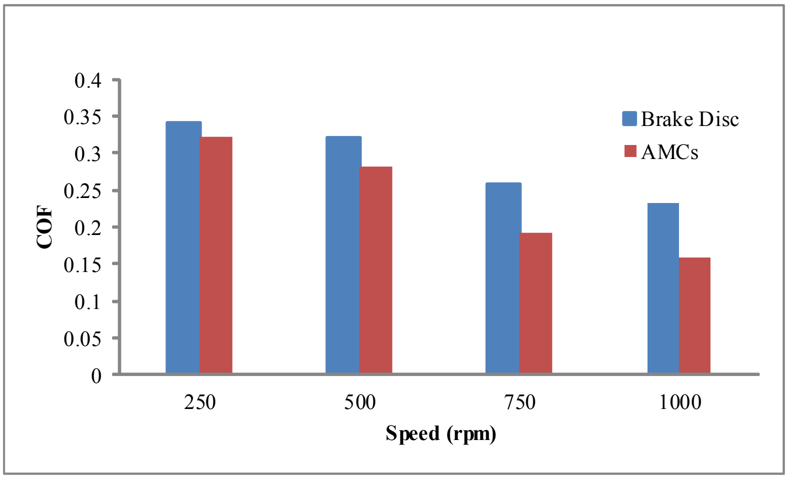

Fig. 5: Comparison of coefficient of friction between AMCs and break disc materials.

The mechanism that affected the coefficient of friction was the rate of wear or debris produced. An increase in load resulted increased deformation of the friction layer. Wear debris also increased the surface roughness of both materials and destroyed the surface layer of the materials. Thus an increase in wear rate reduced the coefficient of friction.

4. Conclusion

This study concluded that the percentage difference in weight loss of aluminum matrix composites (AMCs) was approximately 52%. The percentage difference in weight loss decreased at higher load. The coefficient of friction was almost the same for both materials at lower load. At higher load, 100N, the percentage differences between coefficients of friction for both materials increased up to 25%. The percentage difference in weight loss of AMCs between 250 rpm to 500 rpm was 70%. The percentage difference decreased to 32% at 750 rpm to 1000 rpm. The percentage difference of coefficient of friction between AMC and brake disc at 250 rpm was 7%. At higher speed the percentage difference for both materials was 32%.

Acknowledgement

The authors would like to thanks Advanced Materials Laboratory, Ottawa, Canada for providing AMCs for this study and Universiti Teknologi PETRONAS for providing necessary facilities for the experimental work.

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