Wear Behaviour of Al-SiC and Al-Al_2O_3 Matrix Composites Sliding Against Automobile Friction Material

P. R. K. Fu[1], D. Sujan[1], Z. Oo[1], A. Gorin[2] and W. Y. H. Liew[3]

[1]*Curtin University Sarawak Campus, CDT 250, 98009 Miri, Sarawak, Malaysia*
[2]*Swinburne University of Technology Sarawak Campus, Jalan Simpang Tiga, 93350 Kuching, Malaysia*
[3]*Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Malaysia*

Abstract. This paper presents a study on the wear behaviour of metal matrix composites (MMC), which is a criterion for potential material for the development of the automotive brake disc. The wear tests have been carried out on a wear and friction monitor machine, using commercial automobile brake pad as pin and Al-SiC MMC and Al-Al_2O_3 MMC as discs. Pins have been machined from commercial automobile brake pad of a passenger car. The Al-SiC MMC and Al-Al_2O_3 MMC discs have been fabricated by stir casting technique using aluminium alloy 6082; 5 wt%, 10 wt% and 15 wt% of silicon carbide particles and alumina particles. The friction and wear behaviour of MMCs and the automobile brake pad pins have been investigated at two applied loads; 5N and 10N. The worn surfaces formed on the MMCs discs have been analysed using scanning electron microscopy (SEM). The present investigation shows that the MMCs have considerable stable friction coefficient.

Keywords: metal matrix composite; automobile brake pad pin, dry sliding, wear.
PACS: 1 Wear, 81 Materials Science

INTRODUCTION

A disc brake is a device that slows or stops the motion of a wheel while it runs at a certain speed. Disc brake consists of a disc bolted to the wheel hub and a stationary housing called calliper. The calliper is connected to a stationary part of the vehicle such as the axle casing or the stub axle. There is a friction pad held in position by retaining pins and spring plates. Figure 1 shows the automotive disc brake configuration. The disc/pad design of disc brakes tends to exhibit better resistance to fade (the decrease in friction when the brake temperature rises too high) [1].

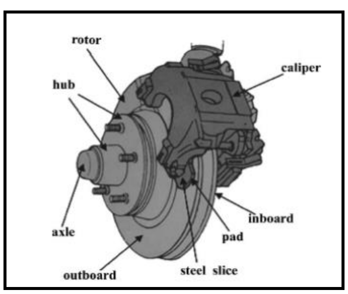

FIGURE 1. Automotive disc brake configuration [10]

In general, an automobile brake system consists of a brake disc and a pair of brake pads in order to maintain a steady friction coefficient. Braking system is a crucial safety component of the ground-based transportation systems. Thus the structural materials used in brakes should posses some combination of properties such as reasonable tensile strength, acceptable friction coefficient, wear resistant, good thermal capacity, economically viable and lightweight [2].

The main contribution of this paper is two-fold. First, the proposed materials, Al-SiC MMC and Al-Al_2O_3 MMC are being fabricated. Second, a study on the material, specifically their tribological behaviour is being carried out and their characteristic results are analyzed towards the end of this paper.

The rest of this paper is organized as follows. The detailed description of MMC is firstly reported which is followed by the experimental procedures required in our experimental work on the fabrication of MMC and the wear test. The results derived from our experiments are analyzed and discussed later. At the end of this paper, concluding remarks will be drawn.

METAL MATRIX COMPOSITE (MMC)

A composite material is a material consisting of two or more physically and/or chemically distinct phases. The reinforcing component is distributed in the continuous or matrix component. Composites can be classified into three categories depending on the matrix material, namely; polymer matrix composites (PMCs), ceramic matrix composites (CMCs) and metal matrix composites (MMCs) [3]. When the matrix is a metal, the composite is termed as Metal Matrix Composite (MMC). MMCs have different property combinations and processing procedures as compared to either PMCs or CMCs. MMC remains as an immensely used material for aerospace, automotive, medical, sports equipment and other engineering fields due to its several advantages [3]. Aluminium is the most popular matrix for the metal matrix composites materials. Aluminium alloys are attractive due to its excellent combination of properties such as good wear resistance, lightweight, increased strength, good corrosion resistance and high thermal conductivity [3].

Research showed that the wear resistance of the MMC can be attributed to the strength and hardness of the SiC particles and the Si phase [4]. Given that the SiC particles remain well bonded to the matrix during the sliding wear process, the aluminium matrix surrounding them will be worn away and all contacts will be between the friction material and SiC particles in the composite. In addition, as the size of the particle increases, large particle are likely to remain embedded longer than smaller particles until the matrix can no longer support them. Thus they are able to resist the deformation because the large particles protruding from the surface of the composite bear most of the wear load [4]. Zhang and Wang [5] also established that the friction performances and wear resistance for brake material sliding against drum brake with large-size SiC particles are better than those against the drum brakes with small-size SiC particles. Anoop et al. found that at high loads and temperature, aluminium-silicon carbide composites showed severe wear which is due to the heavy removal of matrix material by hard transfer particles [6]. Under these conditions, these SiC particles lose its ability to carry the load and it gets fractured which adds to the wear debris. This leads to cracking of the aluminium matrix followed by delamination. On the other hand, alumina (Al_2O_3) particulates acquire high hardness and high thermal conductivity [7]. Tatar and Ozdemir found that thermal conductivity of the Al_2O_3 particulate reinforced aluminium composites (Al/Al_2O_3-MMC) decreased with the increasing of Al_2O_3 volume fraction [7]. However, there have not been many studies on the wear properties of Al_2O_3 particulate reinforced aluminium composites.

Therefore in this paper, the tribological behaviour is investigated by the usage of two reinforcement particles (SiC and Al_2O_3) in MMC.

EXPERIMENTAL PROCEDURE

Fabrication of MMC discs

The materials used for fabricating MMC are aluminium alloy 6082 as a matrix material, alumina, Al_2O_3 (120µm) and silicon carbide, SiC (105µm) as reinforcement particles. Aluminium alloy rods were first cut into smaller pieces with each 1cm thickness. 500g of 1cm thickness with each piece of aluminium alloy and 1 wt% of magnesium (wetting agent) were melted in the furnace at temperature of 760°C. Preheated reinforcement particles of silicon carbide (5 wt%, 10 wt% and 15 wt%) were then added into the molten aluminium alloy. The reinforced particles were preheated beforehand at 500°C for 1 hour in the furnace to remove all the moisture on the particles' surface for better binding results. Stirring was done for the first 2 minutes on the molten metal matrix to create a vortex before adding the preheated particles in. After that, stirring was done for 3 to 5 minutes at 100rpm. The vortex method is believed to be able to distribute the particles among the metal matrix more evenly [8]. Stirring must not be done vigorously to avoid air bubbles and impurities on the surface because that could lead to porosity. Subsequently the composite was poured into a mould made of cast iron. The final casted MMC product was then machined into a diameter of 10cm with a thickness of approximately 0.85cm. The above experimental procedures were repeated with Al_2O_3 as the reinforcement particles.

Preparation of automobile brake pad pins

A commercial automotive brake pad was used as pins for the wear test. The brake pads were manufactured by the company, Lapco Auto Parts for local Perodua Kembara cars. Since these commercial brake pads are proprietary items, their compositions were not exactly known. It is commonly known that commercial friction material may contain phenolic resin, asbestos fiber, filler materials ($BaSO_4/CaCo_3$) and small amount of metal chips (eg. iron) as friction modifier [4].

Cylindrical grinding machine was used to cut the brake pads into a cylindrical form, with a diameter of 0.8cm and with a flat surface contact area. The pin surfaces were cleaned with acetone before starting of every experiment.

Wear Tests

The wear tests were carried out by using Ducom TR-20EV-M3 wear and friction monitor with vacuum chamber. The wear test specimens were carried out in accordance to the ASTM test method G99 for wear testing on a pin on disc apparatus. All specimens were tested at sliding speed of 1m/s under two different loads of 5N and 10N. All tests were conducted for a sliding distance of 2000m in ambient temperature (26ºC) and atmospheric pressure (1 bar). The disc was weighed before and after each test by using a microbalance having an accuracy of 0.01mg. The weight loss was used to determine the wear rate. The following equation was used to obtain the wear rate for the disc and brake pad pin: W=M/ρD [4], where W is the wear rate (mm3/m), M denotes mass loss (g) and ρ (g/mm3) and D (m) are the density and sliding distance respectively. After that, the worn surfaces of the composite discs were viewed in JEOL JSM-5610 LV SEM.

RESULTS & DISCUSSION

Wear of MMCs sliding against friction material

At low load (5N), as the weight percentage of silicon carbide particles increased, the wear rate remained constant as seen in Figure 2. However, at high load (10N), as the weight percentage of silicon carbide particles increased, the wear rate increased significantly (Figure 2). This could be due to the heavy removal of matrix material by hard transfer particles. Under these conditions silicon carbide particles lose its ability to carry the load hence the high disc wear rate. The present results reveal that the wear rate of Al-SiC MMC is in contrast to those obtained by Natarajan et al [10]. However, Uyyuru et al [9] have reported that higher fraction of reinforcement or reinforcement with wider size, the wear rate of MMC increases as load increase. This can be due to the wider size of silicon carbide particles being pulled out from the matrix material hence causing the increasing wear of the aluminium alloy matrix.

As seen in Figure 3 that as the weight percentage of alumina particles increased, Al-Al_2O_3 MMC showed decreasing wear rate. When compared with Al-SiC MMC, Al-Al_2O_3 MMC showed lower wear rate at higher weight percentage of alumina particles.

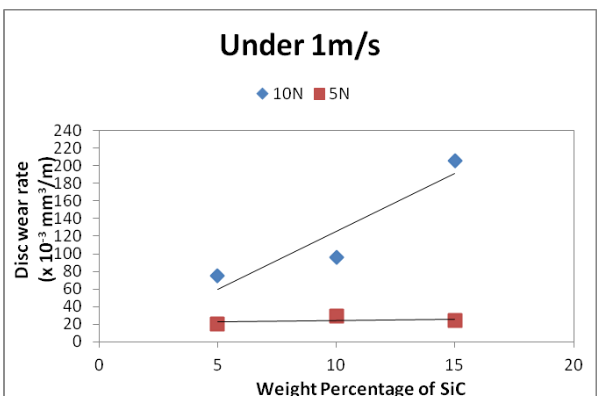

FIGURE 2. Variation of wear rate (mm^3/m) with different weight percentage of SiC for Al-SiC MMC samples under 1m/s sliding speed

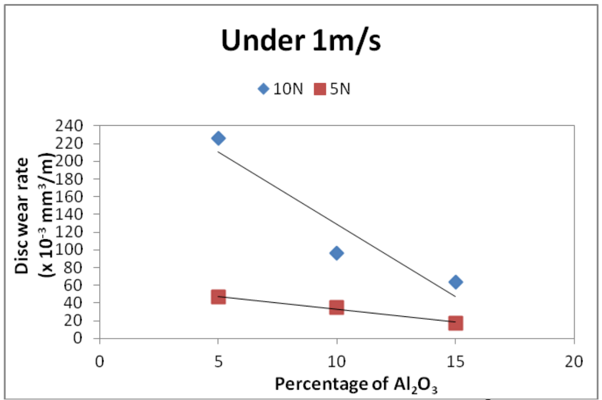

FIGURE 3. Variation of wear rate (mm^3/m) with different weight percentage of Al_2O_3 for Al-Al_2O_3 MMC samples under 1m/s sliding speed

Coefficient of friction (COF)

A stable coefficient of friction is essential for car brake applications. Typical range of coefficient of friction for car brake is from 0.3 to 0.6 [1]. Both Al-SiC MMC (Figure 4) and Al-Al_2O_3 MMC (Figure 5) exhibited reasonable COF values within the range of 0.3 to 0.6, at 5N applied load. Similar trend can be observed at 10N applied load as well. Researchers [4, 5, 6] have reported that Aluminium alloy reinforced with SiC MMC discs are sensitive to the applied load (as the applied load increases, the COF decreases). This is in agreement with the current experimental results (Figure 4).

As the weight percentage of Al_2O_3 increased, the COF decreased but remained at a reasonable range. However, for Al-SiC MMC, as the weight percentage of SiC increased, the COF increased.

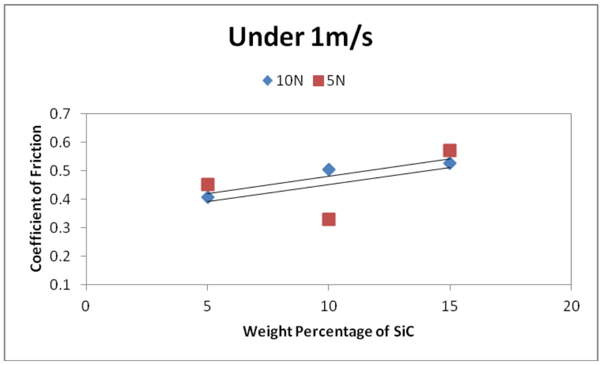

FIGURE 4. Variation of COF with different weight percentage of SiC for Al-SiC MMC samples under 1m/s sliding speed

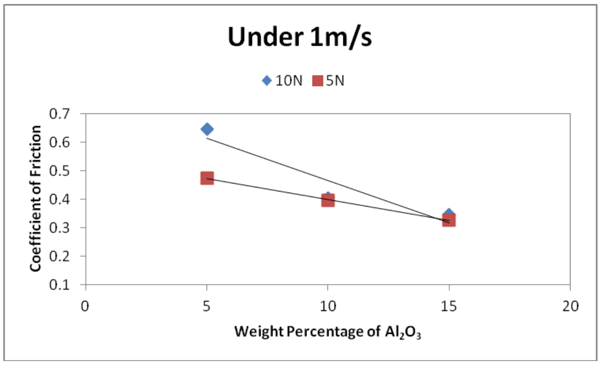

FIGURE 5. Variation of COF with different weight percentage of Al_2O_3 for Al-Al_2O_3 MMC samples under 1m/s

Pin wear rate

Natarajan et al [10] have reported that the wear of friction material is found to increase with applied load. As shown in Figure 6, at applied load of 10N, the wear rate of the pin increased with the increasing of weight percentage of SiC. This could be due to the presence of SiC particles as the protruding particles plough the friction material [10]. As shown in Figure 7, as the weight percentage of alumina increased in the Al-Al_2O_3 MMC samples, the wear rate of friction material decreased. This is the case for high load (10N). At applied load of 5N, the wear rate of friction material sliding against both Al-SiC MMC (Figure 6) and Al-Al_2O_3 MMC (Figure 7) remained at constant.

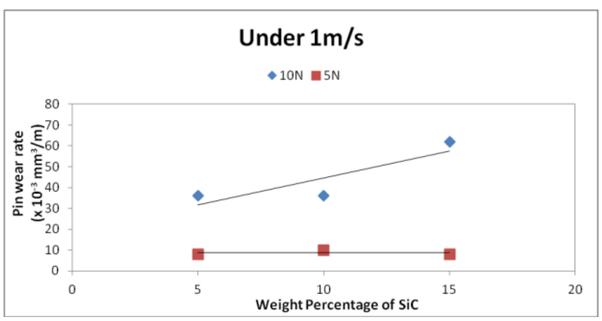

FIGURE 6. Variation of wear rate of friction material sliding against different weight percentage of SiC for Al-SiC MMC samples under 1m/s sliding speed

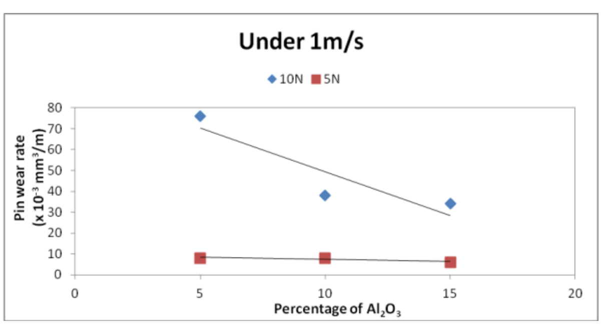

FIGURE 7. Variation of wear rate of friction material sliding against different weight percentage of Al_2O_3 for Al-Al_2O_3 MMC samples under 1m/s sliding speed

Scanning electron images of wear surface

At lower reinforced Al-SiC MMC and Al-Al_2O_3 MMC, Figure 8 (b) and Figure 11 (b) showed severe wear under sliding speed of 1m/s with high load (10N). There were not enough reinforcement particles to help carry the load hence this leads to cracking of the aluminium matrix followed by delamination. In addition, delamination of surface layer can be spotted in Figure 8 (a), Figure 8 (b), Figure 11 (a) and Figure 11 (b). Numerous ploughing and grooves can be observed in all SEM images (Figure 8 (a), Figure 8 (b), Figure 9 (a), Figure 9 (b), Figure 10 (a), Figure 10 (b), Figure 11 (a), Figure 11 (b), Figure 12 (a), Figure 12 (b), Figure 13 (a) and Figure 13 (b)). These ploughing and grooves are formed by abrasive action of wear debris.

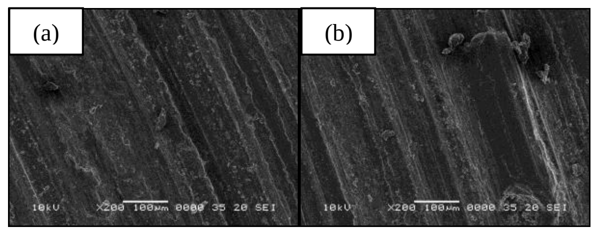

FIGURE 8. Scanning electron images of wear tracks for 5 wt% SiC Al-MMC (a) 1m/s, 5N (b) 1m/s, 10N

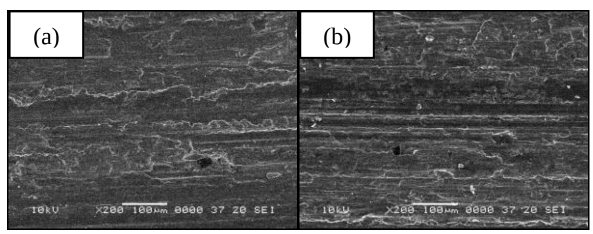

FIGURE 9. Scanning electron images of wear tracks for 5 wt% SiC Al-MMC (a) 1m/s, 5N (b) 1m/s, 10N

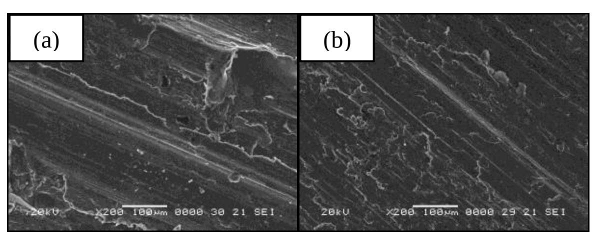

FIGURE 10. Scanning electron images of wear tracks for 15 wt% SiC Al-MMC (a) 1m/s, 5N (b) 1m/s, 10N

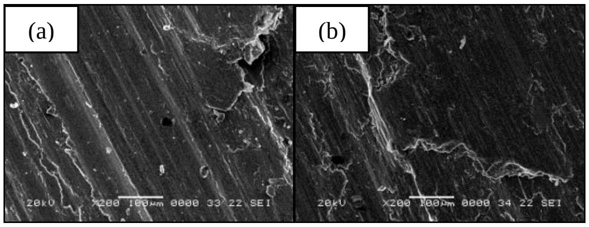

FIGURE 11. Scanning electron images of wear tracks for 5 wt% Al_2O_3 Al-MMC (a) 1m/s, 5N (b) 1m/s, 10N

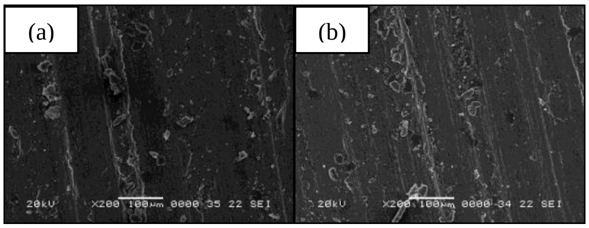

FIGURE 12. Scanning electron images of wear tracks for 10 wt% Al_2O_3 Al-MMC (a) 1m/s, 5N (b) 1m/s, 10N

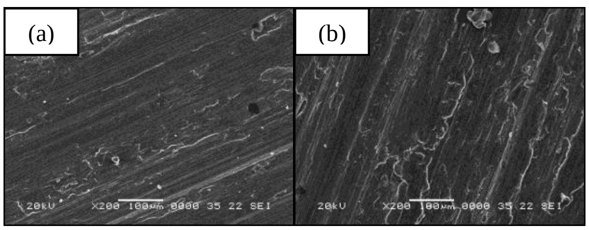

FIGURE 13. Scanning electron images of wear tracks for 10 wt% Al_2O_3 Al-MMC (a) 1m/s, 5N (b) 1m/s, 10N

CONCLUSION

The following conclusions are drawn from this present study:

- For all applied loads, both Al-Al_2O_3 MMC and Al-SiC MMC show a stable friction coefficient (0.30-0.60) [1] which is essential for brake rotor applications.
- Al-Al_2O_3 MMC showed lower wear rate at increasing weight percentage particles contents. However, Al-SiC showed higher wear rate at increasing weight percentage of silicon carbide. Further experimental study need to be establish whether they are promising candidate materials for car brake applications.

ACKNOWLEDGMENTS

This work made use of the wear and friction monitor and SEM facilities at University Malaysia Sabah (UMS). The authors wish to thank Curtin Sarawak Research Fund (CSRF) for providing research grant that has resulted in this article.

REFERENCES

1. P. Blau, B. Jolly, J. Qu, W. Peter and C. Blue, Tribological investigation of titanium-based materials for brakes, Wear. 263 (2007) 1202-1211.
2. M.A. Maleque, S. Dyuti and M.M. Rahman, Material selection method in design of automotive brake disc, WCE. Vol III (2010).
3. J.K. Lees, A.K. Dhihgra, R.L. McCullough, Composite Materials, Wiley, 2005.
4. A. Daoud and M.T. Abou El-khair, Wear and friction behavior of sand cast brake rotor made of A359-20 vol% SiC particle composites sliding against automobile friction material, Tribology International. 43 (2010) 544-553.
5. S.Y. Zhang and F.P. Wang, Comparison of friction and wear performances of brake material dry sliding against two aluminium matrix composites reinforced with different SiC particles, Journals of Materials Processing Technology. 182 (2007) 122-127.
6. S. Anoop, S. Natarajan and S.P. Kumaresh Babu, Analysis of factors influencing dry sliding wear behavior of Al/SiCp-brake pad tribosystem, Materials and Design. 30 (2009) 3831-3838.
7. C. Tatar and N. Ozdemir, Investigation of thermal conductivity and microstructure of the α–Al_2O_3 particulate reinforced aluminium composites (Al/Al_2O_3-MMC) by powder metallurgy method, Physica B: Condensed Matter. 405 (2010) 896-899.
8. S.N. Aqida, M.I. Ghazali and J. Hashim, Effects of porosity on mechanical properties of metal matrix composite: an overview, Matrix. 40 (2004) 17-32.
9. R.K. Uyyuru, M.K. Surappa and S. Brusethaug, Tribological behavior of Al-Si-SiCp composites/automobile brake pad system under dry sliding conditions, Tribology International. 40 (2007) 365-373.
10. Natarajan, N, S Vijayarangan, and I Rajendran, Wear Behaviour of A356/25SiCp Aluminium Matrix Composites Sliding Against Automobile Friction Material, Wear 261 (7-8) (2006) 812–822.