Tribological Behavior of Al-SiC Metal Matrix Composite in Acidic Medium

Smrutiranjana Pradhan^{1, 2}, Tapan Kr. Barman¹, Prasanta Sahoo^{1, 2*},
Goutam Sutradhar¹ and Shouvik Ghosh³

¹ Department of Mechanical Engineering, Jadavpur University, Kolkata 700032, India

² Centre of Excellence on Phase Transformation and Product Characterisation, TEQIP-II,
Jadavpur University, Kolkata 700032, India

³ Department of Mechanical Engineering, NIT Sikkim, Sikkim 737139, India

*Corresponding author (E-mail: psjume@gmail.com)

Keywords: MMC, Al-5% SiC, Acidic medium, Friction, Wear

Abstract. In this present paper, the friction and wear performances of Al-SiC metal matrix composite (MMC) for varying operating parameters (applied load and sliding speed) have been studied under acidic environment. The composite material is developed by reinforcing SiC particle (5 wt. %) with aluminum alloy (LM6) using stir casting method. The tribological behavior is performed using a friction and wear monitor under sulphuric acid environment where sliding time is kept constant for 30 minutes. It is found that wear is directly proportional to the applied normal load and sliding speed. Coefficient of friction value decreases with increase in load but remains almost constant with variation of sliding speed. The surface morphology is studied with the help of scanning electron microscopy (SEM) and energy dispersed X-ray (EDX) analysis.

Introduction

Metal matrix composites (MMCs) are widely used in different industrial applications due to the ability to withstand high tensile strength, compressive strength, high corrosion resistance and low density. SiC reinforced MMCs have been widely used in the automotive industry for making the components like pistons, brakes rotors, crankcase etc [1-6]. Aluminium matrix composites have been used extensively in aerospace, automotive, mines and marine industries [7]. Tribological applications of such composites are quite remarkable as it is come across the acid and brine environment and thus researchers around the globe have shown interest to study the tribological characteristics, viz. friction, wear, corrosion resistance etc.

The wear resistance of the Al-SiC composite dependent on the percentage of reinforcement, applied load and sliding speed. Generally, MMCs are fabricated by the mixture of reinforcement and matrix phase by the use of various techniques like compo casting, powder metallurgy, liquid metallurgy etc. To set the goal of the present paper, some literatures are reviewed and presented below. Pradhan et al. [8] have investigated the tribological behavior of Al-SiC metal matrix composite in brine environment and have concluded that the wear pattern is mild at normal load but it is severe at high normal load. Lee et al. [9] have studied mechanical properties of Al-SiC metal matrix composite which is fabricated by powder metallurgy process of vacuum hot pressing. From the experiment, it is concluded that tensile strength and hardness of Al-SiC MMC having 12 wt% SiC reinforcement is higher than that of 10 wt. % SiC reinforcement and also wear resistance increases with increase in the weight fraction of SiC particles. It has been reported by Tjong et al. [10] that the metal matrix composites generally show more brittle than the corresponding unreinforced alloys and they have investigated the behavior of Al-Si alloy reinforced with low volume fraction of SiC particles. Natarajan et al. [11] have investigated the wear behavior of A356/25 SiC metal matrix composites using a pin-on-disk tribotester. The commercial semi-metallic brake shoe lining of a passenger car is used as a counter face in tribotester. From their experiment, it is concluded that the wear of MMC is lower than the cast iron. The MMC shows a better wear resistance and constant friction coefficient because of the presence of the hard SiC

particles in specimen. Al-Rubaie et al. [12] have studied the wear behavior of Al-SiC metal matrix composite using a pin-on-disc apparatus. The MMC contains aluminium powder Al 1100 having grain size 120 μm as matrix material and α -SiC with three variable sizes up to 5-20 volume percentage as reinforcement. They have concluded that volume fraction of 20 % SiC reinforcement shows a higher abrasion resistance and this resistance increases with increase in the volume fraction of SiC particles within the studied range. Ghosh et al. [13] have investigated tribological behavior of Al-SiC metal matrix composite using a block-on-roller multi tribotester. The metal matrix composites with varying their SiC reinforcement are tested in dry sliding condition. From their experiment, they have concluded that addition of SiC reinforcement increases the hardness of composite and the applied load and sliding speed are directly proportional to the coefficient of friction. Sharma et al. [14] have carried out the experiment on zinc aluminium/ SiC composite material and concluded that with the increase in the applied load, the wear rate increases but its wear resistance increases with increase in SiC content. Shorowordi et al. [15] have compared Al/B₄C and Al/SiC composites by conducting tribo tests under dry conditions. The wear rate of both composites increases with increasing contact pressure but coefficient of friction decreases with the increase in contact pressure. Tjong et al. [10] have studied the wear behavior of an Al-12% Si alloy reinforced with a low volume fraction of SiC particles and found that Al-12% Si alloy leads to decrease in tensile strength by the addition of low volume fractions of SiC at room temperature. Al-Rubaie et al. [12] have investigated the two body abrasive wear behavior of Al-SiC metal matrix composite which is prepared by the powder metallurgy method. From the experimental analysis, it is found that the reinforcement improves the abrasion resistance in metal matrix composites and plastic deformation is identified as the main mechanism of wear. Akbulut et al. [16] have developed aluminium MMC and concluded from the wear tests that the wear behavior depends on the load, sliding velocity and the production technique. Ghosh et al [17] have used Taguchi tool to optimize the friction and wear properties of Al/SiC composites considering different design parameters like normal load, sliding speed and sliding time. Kwok and Lim [18] have concluded for Al/SiC composites that wear rate increases with increasing load but coefficient of friction varies monotonically with the process parameters. Zhang and Wang [19] have investigated the Al/SiC metal matrix composite and found that coefficient of friction decreases with the increase of load and speed. Ma et al. [20] have compared the wear behavior of two Al/SiC metal matrix composites and shown that sliding wear resistance increases as SiC particle volume fraction increases.

From the literature review, it is seen that many researchers have investigated the tribological properties of different Al-SiC metal matrix composites. But the available literatures deal with the tribological tests under dry condition. In this present paper, Al-SiC MMC is prepared to do tribological tests under corrosive environment. Here, acidic environment is considered. The effects of design parameters viz. applied normal load and sliding speed on the responses viz. friction and wear are evaluated. Finally, SEM and EDX are done to study the microstructure of the worn out surfaces.

Materials

Aluminium metal matrix composites of compositions Al-5 wt% of SiC were fabricated by stir casting process in which LM6 is used as matrix metal. Table 1 shows the chemical composition of the matrix metal. A clay graphite crucible used for melting LM6 ingot with the help of electric resistance furnace as shown in Fig. 1. 5 wt% SiC reinforcement having 400 mesh size is preheated to around 900 °C for 2-3 hours in a box furnace (Fig. 2) before adding to matrix molten metal. After adding the reinforcement to liquid matrix, 3 wt % Mg is added in order to get the strong bonding between the matrix metal and reinforcement particles. A mild steel impeller is used as a stirrer to incorporate the SiC particles to the matrix metals and its speed is around 400-500 rpm driven by a mechanical arrangement. The processing of the composite is carried out at a temperature of 720 °C and finally poured at a temperature of around 690 °C into a green silica sand mould. After cooling, the casting is machined to prepare the pin sample of appropriate dimension (6mm $\times$ 6mm $\times$ 20mm).

Table.1. Chemical Composition of LM6 Element

Elements	Si	Cu	Mg	Fe	Mn	Ni	Zn	Pb	Sb	Ti	Al
Percentage	10-13.0	0.1	0.1	0.6	0.5	0.1	0.1	0.1	0.05	0.2	Rest

Experimental Procedure

Machine Used. The tribological tests have been carried out in a pin on disk tribo-tester (TR-208-M2, Ducom, India) (Fig. 3) at room temperature (28°C). Al-5%SiC MMC specimen (pin sample with 6mm × 6mm × 20mm dimension) has been mounted on the machine. The counter disk is alumina which has hardness value much higher than the specimen. The machine has the provision for applying the load externally of the range 1-10 kg. In order to control and measure the sliding speed, sliding time, frictional force and wear depth, the machine is connected to a controller and a computer (Fig. 4).

Tribological Test Environment. For tribological tests, in this study, sulphuric acid environment is used. There is an arrangement for providing the acid environment (9.8 wt. % H₂SO₄) in the tribo-tester where counter disk and some portion of pin sample are dipped inside the solution.

Process Parameters. For conducting the tribological tests, two design parameters, viz. applied normal load and sliding speed are varied while duration of the tests is kept constant for 30 minutes. The levels of applied normal load and sliding speed are shown in Table 2. Total 25 numbers of experiments have been conducted for acidic environment.

Table.2. Tribotest parameters with their ranges

Level	Load [N]	Speed [RPM]	Time [MIN]
1	10	20	30
2	30	60	
3	50	100	
4	70	140	
5	90	180	

Response Variables. Coefficient of friction and wear are considered as responses in this study. Wear is represented as weight loss of the pin sample and for this, the MMC specimen has been weighed before and after each test and their weight loss is measured. The average values of frictional forces are considered from the values recorded in the computer and after dividing with respective load, coefficient of friction has been measured.

Figure 1. Electric Resistance Furnace used for Fabrication of Al-SiC MMC.

Figure 2. Box furnace used for pre-heating of SiC reinforcement.

Figure 3. Pin-on-disk tribotester with corrosive environment chamber

Figure 4. Wear and friction monitor attached to tribotester

Results and Discussion

The friction and wear tests are conducted varying applied normal load and sliding speed for Al-5%SiC MMC under acidic environment. To see the effects of process parameters on coefficient of friction and wear, results are plotted and presented in the following sections.

Wear Behavior. Fig. 5 shows the variation of weight loss (wear) with applied load at different sliding speeds. It is seen from the figure that wear rate of the metal matrix composite increases with the increase in sliding speed. Again the wear rate also increases with the increase in applied load. From Fig.5 and Fig.6, it can be seen that mild wear is observed for low normal load but severe wear occurs as load increases from low to high. Normally, in a pin-on-disk experiment, quick plastic deformation occurs at the contact surface where the shear forces increase with normal load and this create large volume of material loss being sheared by the rotating counter hard disk.

Figure 5. Weight loss of Al-5% SiC with applied load at different sliding speed under acid environment

Figure 6. Weight loss of Al-5% SiC varying with sliding speed at different loading condition under acid environment

Friction behavior. Fig 7 and Fig.8 show the variation of coefficient of friction for Al-5% SiC in acidic environment with applied normal load and sliding speed respectively. From the figures, it can be said that friction coefficient decreases with the increase of applied load but while considering the relation between speed and coefficient of friction, it is almost steady.

Figure 7. Coefficient of friction for Al-5% SiC with load at different speed condition under acid environment

Figure 8. Coefficient of friction for Al-5% SiC with speed at different loading condition under acid environment

Microstructure Characterization. The microstructure study of Al-SiC sample is done by scanning electron microscopy (SEM) image and energy dispersed X-ray (EDX) analysis after the tribological test completed at 50 N normal load and 0.2 m/s sliding speed as shown in Fig.9 and Fig. 10 respectively. The parallel layers of wear track are seen on the SEM image and the wear is mainly the combinations of adhesive and abrasive wear. From the EDX image analysis, very less amount of oxide is found. So, it can be said that formation of protective layer is very weak and thus material losses occur easily.

Figure 9. SEM image of worn out sample after tribological test at 50 N load and 0.2 m/s

Figure 10. EDX spectrum of worn surface

Conclusion

The tribological behavior of Al-5% SiC metal matrix composite is evaluated in sulphuric acid environment taking applied normal load and sliding speed as input parameters. It is found that wear rate is directly proportional to the applied normal load. Coefficient of friction is found to decrease with increase in applied normal load but it remain steady with variation of sliding speed. Mild wear pattern is found in case of low normal load but it is severe at high normal load. From the microstructure study, it can be concluded that adhesive and abrasive are the main mechanisms of wear. It can be concluded that acid environment is more prone to material loss due to low weight percentage of oxide formation.

References

- [1] P.K. Rohatgi, Cast metal matrix composites past, present and future. In: Invited silver anniversary lecture by American Foundry Society, AFS Transactions 01–133 (2001). 633–57.
- [2] P.K. Rohatgi, B.F. Schultz, A. Daoud, Tribological performance of A206 aluminum alloy containing silica sand particles, *Tribol. Int.* 43 (2010) 455–466.
- [3] Rawal S. Metal–matrix composite for space applications. *JOM* 53 (2001) 14–17.
- [4] H. J. Quartz, (SiO₂p) reinforced chilled metal matrix composite (CMMC) for automotive applications. *Mater. Des.* 30 (2009) 323–329.
- [5] S. Suresh, A. Mortensen, A. Needleman, *Fundamentals of Metal Matrix Composites*, , first edition, Butterworth-Heinemann 1993.
- [6] R.L. Deuis, C. ubramanian, J.M. Yellup, Dry sliding wear of aluminium composites—a review, *Compos. Sci. Technol* 57 (1997) 415–435.
- [7] M. O. Bodunrin, K. K. Alaneme, S. J. Olusegun, Influence of thermomechanical processing on the corrosion behaviour of aluminium (6063)-SiC composites in NaCl and H₂SO₄ environment, *Science Journal.* 2 (2011) 17–25.
- [8] S Pradhan, T K. Barman, P. Sahoo, G Sutradhar, Tribological Behavior of Al-SiC Metal Matrix Composite in Brine Environment, *BLB-International Journal of Science & Technology, Special Issue* (2015) 116–121.
- [9] H. S. Lee, J. S. Yeo, S. H. Hong, D. J. Yoon, K. H. Na, The fabrication process and mechanical properties of SiC/Al-Si metal matrix composites for automobile air conditioner compressor pistons, *J. Mater. Process. Tech.* 113 (2001) 202–208.
- [10] S. C. Tjong, S. Q. Wu, H. C. Liao, Wear behaviour of an Al-12% Si alloy reinforced with a low volume fraction of sic particles, *Compos. Sci. Technol.* 57 (1998) 1551–1558.
- [11] N. Natarajan , S. Vijayarangan , I. Rajendran, Wear behaviour of 356/25SiCp aluminium matrix composites sliding against automobile friction material, *Wear.* 261 (2006) 812–822.
- [12] K.S Al-Rubaie, H.N Yoshimura, J.D.B de Mello, Two-body abrasive wear of Al-SiC composites, *Wear.* 233–235 (1999) 444–454.
- [13] S. Ghosh, P. Sahoo, G. Sutradhar, Study of Tribological Characteristics of Al-SiC Metal Matrix Composite, *International Journal of Advanced Materials Research* 1 (2015) 53–58.
- [14] S.C. Sharma, B.M. Girish, R. Kamath, B.M. Satish, Effect of SiC particle reinforcement on the unlubricated sliding wear behavior of ZA-27 alloy composites, *Wear.* 213 (1997) 33–40.
- [15] K.M. Shorowordi, A.S.M.A. Haseeb, J.P. Celis, Tribo-surface characteristics of Al-B₄C and Al-SiC composites worn nder different contact pressures, *Wear.* 261 (2006) 634–641.
- [16] H. Akbulut, M. Durman, F. Yilmaz, Dry wear and friction properties of δ -Al₂O₃ short fiber reinforced Al single bond Si (LM 13) alloy metal matrix composites, *Wear.* 215 (1998) 170–179.
- [17] S. Ghosh, P. Sahoo, G. Sutradhar, Wear behaviour of Al-SiCp metal matrix composites and optimization using Taguchi method and grey relational analysis, *Journal of Minerals and Materials Characterization and Engineering* 11 (2012) 1085–1094.
- [18] J.K.M. Kwok, S.C. Lim, High-speed tribological properties of some Al/SiCp composites: I. Frictional and wear-rate characteristics. *Compos. Sci. Technol.* 59 (1999) 55–63.
- [19] S. Zhang, F. Wang, Comparison of friction and wear performances of brake material dry sliding against two aluminium matrix composites reinforced with different SiC particles, *J. Mater. Process. Tech.* 182 (2007) 122–127.
- [20] T. Ma, H. Yamaura, D.A. Koss, R.C. Voigt, Dry sliding wear behaviour of cast SiC reinforced Al MMCs, *Mater. Sci. Eng. A.* 360 (2003) 116–125.