Muthukumar et al. 2014. *Int. J. Vehicle Structures & Systems*, 6(3), 82-87
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.6.3.07

International Journal of
Vehicle Structures & Systems
Available online at www.maftree.org/eja

Dry Sliding Wear and Friction of Aluminium Alloy Silicon Carbide Particulates Reinforced Composites

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ABSTRACT:

In this work, the dry sliding wear behaviour and friction characteristics of aluminium alloy Al6061 silicon carbide particulates (SiCp) of size 43 µm reinforced composites were evaluated through laboratory experiments. The content of SiCp in the alloy was varied from 5% to 35% in steps of 5% by weight. The metal matrix composites were manufactured using stir casting technique. A pin-on-disc wear testing machine was used to evaluate the wear rate, in which an EN-31 steel disc was used as a counter face. Results indicated that the wear rates of the composites were lower than that of the matrix alloy and further reduction in wear rate was achieved by increasing the SiCp content. The wear rate increased for an increase in the load and sliding velocity. Increase in the applied load increased the wear severity by changing the wear mechanism from abrasion to particle cracking. The observations have been explained using scanning electron microscopy analysis of the worn surfaces. The coefficient of friction was evaluated using friction forces measured from the tests. The coefficient of friction decreased for an increase in the SiCp content at low sliding velocity.

KEYWORDS:

Metal-matrix composites; SiCp reinforcement; Sliding wear; Coefficient of friction

CITATION:

S. Muthukumar, P. Mathiyalagan, R. Mariappan and S. Jayavelu. 2014. Dry Sliding Wear and Friction of Aluminium Alloy Silicon Carbide Particulates Reinforced Composites, *Int. J. Vehicle Structures & Systems*, 6(3), 82-87. doi:10.4273/ijvss.6.3.07.

1. Introduction

The automotive market holds tremendous promise for a number of new applications of aluminium based metal matrix composites (MMC) parts. MMC are composed of a metallic matrix such as aluminium, magnesium, iron, cobalt, copper and a dispersed ceramic like oxides and carbides. Conventional monolithic materials have limitations in achieving good combination of strength, stiffness, toughness and density. To overcome these shortcomings and to meet the ever increasing demand of modern day technology, composites are the most promising materials of recent interest. Due to the attractive properties coupled with their inability to operate at high temperatures, MMC compete with super-alloys and ceramics for re-designing steel components in several aerospace and automotive applications.

Wear of material is very common phenomenon in the service life of aerospace and automotive composite structures. While bringing MMC to working conditions, the hard phases of the counter surface tool are abraded initially due to micro ploughing [1]. This mechanism later changes to micro cutting as the work hardening effect increases for an increase in sliding velocity. This results in groove formation in counterpart and lesser tendency of abrasive particle fracture and their removal. This brings degradation in life of parts and hence product. Wear usually results in the progressive loss of material. The measure used for wear is volume loss. Therefore, wear resistance is not an intrinsic material property like hardness or elastic modulus. Mechanical, chemical and environmental elements can collectively affect the wear and its behaviour. Typical factors that can affect wear behaviour are material properties, nature of the relative motion, nature of the loading, shape, surface roughness and composition of the environment in which the wear occurs.

As a consequence of the widening range of applications of MMC, wear data of these materials has become a very important subject for research. Wear data of composite materials differs significantly in many aspects from that of conventional metals and their alloys. Since MMC is non-homogeneous, anisotropic and reinforced by very abrasive components, it is difficult to characterise their wear data. To minimize the wear due to hard abrasive constituents of the reinforcement phase in the MMC, limitation on the addition of reinforcements for a specific working condition has to be well understood. The choice of specific MMC depends upon the nature of reinforcement, medium employed for lubrication, frictional resistance developed upon applied load and operating velocity. The method of MMC manufacture (i.e. powder or liquid metallurgy) decides the nature and properties of the interface between the particulate and the matrix. Unlike metals and alloys, there are relatively few publications [2] addressing the characteristics and selection of a suitable MMC for a demanding operating condition.

During the last two decades considerable work has been done on the development of Aluminium Alloy Silicon Carbide Particulates (Al-SiCp) reinforced MMC for a number of automotive applications. Eliasson et al. [2] concluded that owing to MMC's outstanding mechanical properties, low density and good wear resistance, Al-SiCp have been widely used as reinforcement material. Deuis et al. [3] discussed that Al-SiCp foam three-dimensional infiltrated composite structure had intermediate mechanical and thermal properties. Madan [4] studied Al6061-SiCp and Al-Al_2O_3 reinforced composite piston and cylinder liners fabricated using powder metallurgy as well as liquid metallurgy routes. Al-SiCp and Al-TiCp composite poppet valves have been fabricated by powder metallurgy by Ramesh et al. [5]. The low cost MMC have been developed for automotive applications by Goni et al. [6]. The locally reinforced components such as brake disc with MMC inserts were produced by gravity casting in a metallic mould. These MMC inserts forms the friction faces of a ventilated brake disc.

Al-SiCp composite cams with different compositions were fabricated using isostatic compaction and subsequent sintering [7]. Further improvement in mechanical properties was achieved using re-compaction of the cam after sintering. They exhibited high hardness, wear resistance, high tensile and compressive strength and low coefficient of thermal expansion compared to conventional metal alloys. A356-Al-SiCp composites with 15% and 25% of SiCp by weight were tested at a sliding speed of 0.5 m/s at different loads using pin on disc machine under dry condition [8]. They exhibited better wear resistance compared with un-reinforced alloy up to a pressure of 26 MPa.

Friction and wear behaviour of four Al-SiCp composites have been investigated over a wide range of sliding conditions by the use of a specially adapted high speed wear tester of the pin on disc configuration [9]. It was reported that at high velocity the size of SiCp rebuilds controls the wear resistance of the composite. Therefore smaller size of SiCp was suggested to be suitable for low speed applications [10]. Suresha et al. [11] discussed that metal-ceramic hybrid composites containing Al-SiCp and graphite particulates have shown improved the wear properties over their monolithic alloys. Chang et al. [12] showed that continuous ceramic reinforcing structures had low wear rates than the base metal alloy. SiCp dissolves in liquid aluminium leading to the precipitation of Al_4C_3, Al_4SiC_4 and Al_8SiC_7 in the temperature range 670-1350 °C [13], 1350-1930 °C [14-15] and above 1930 °C respectively. From an industrial perspective Al-SiCp reinforcement [17] is cost effective. But, their industrial acceptance still needs some more research on the wear behaviour of the Al-SiCp composites [18-20] under different service conditions.

The objective of this work is to study the dry sliding wear behaviour of Al6061-SiCp reinforcement of size 43 µm. The content of SiCp in the alloy was varied from 5% to 35% in steps of 5% weight. MMC were manufactured using stir casting based on liquid metallurgy technique. Al-SiCp specimens have been fabricated in the shape of cylindrical pins. Wear properties of composites were studied using pin on disc wear testing machine. The Al-SiCp composite pins were slided against EN-31 steel disc in dry condition. Sliding velocity and applied load are selected for the analysis along with the varying content of SiCp in the alloy. Microstructure, wear resistance and friction characteristics were studied.

2. Test setup for evaluation of wear rate and coefficient of friction

Al6061-SiCp MMC bars were fabricated using stir casting technique. The wear test specimens were machined from the cast bar as cylindrical pins having diameter of 10 mm and a height of 40 mm. Specimens are polished to a roughness level of 0.82 µm prior to starting the test. Materials are tested under nominally non abrasive conditions. Fig. 1 shows the photograph of Al-SiCp test specimens. The initial weight of the specimen was measured in a single pan electronic weighing machine with least count of 0.01 mg.

Fig. 1: Photograph of Al6061-SiCp MMC wear test specimens

A wear test rig has been designed and fabricated by adapting Ducom pin on disc wear test machine. A schematic of test setup a photograph of fabricated wear test rig is shown in Fig. 2 and Fig. 3 respectively. The test rig consists of a flat circular plate coupled with the shaft of a DC motor whose speed can be varied from 0 to 1500 rpm with an autotransformer. The ground EN-31 steel disc as a counter surface is mounted on the circular plate. The test specimen is clamped in specimen holder. The bottom face of the specimen rests against the ground surface of the disc as shown in Fig. 4.

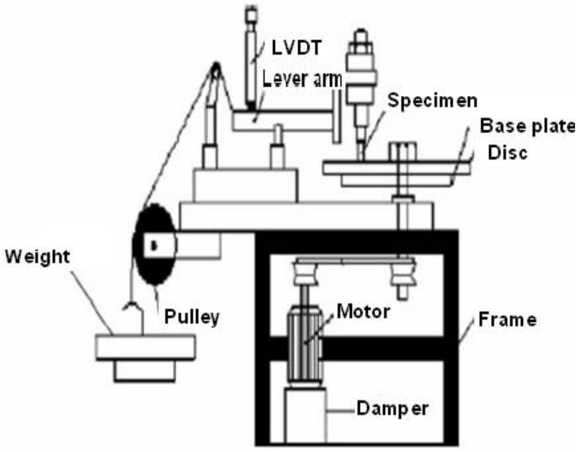
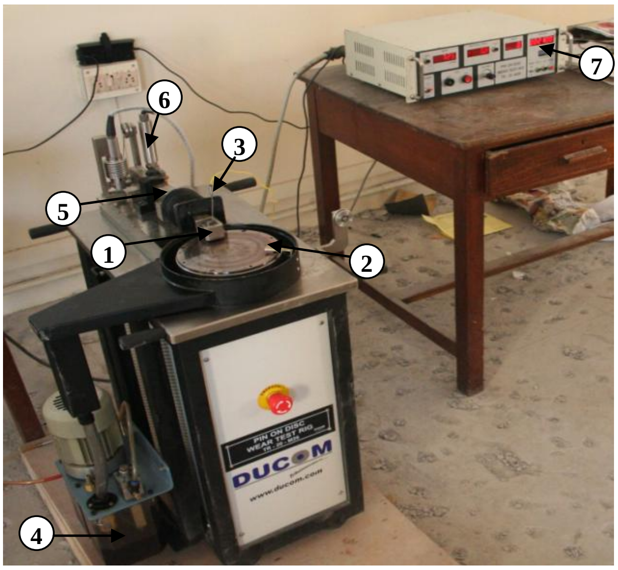


Fig. 2: Schematic of experimental setup for wear test



1. Wear pin; 2. Counter face disc; 3. Thermocouple; 4. Lubricant sump; 5. Cantilever arm; 6. LVDT; 7. Digital readout

Fig. 3: Photograph of fabricated pin on disc wear test rig

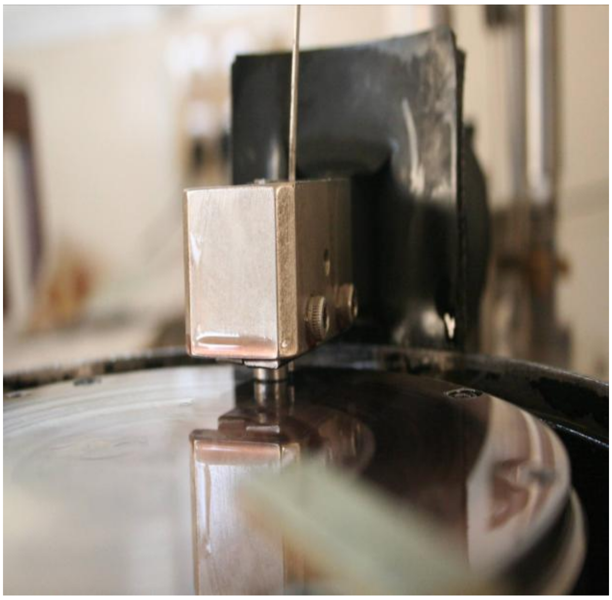


Fig. 4: Photograph showing dry sliding wear contact of pin on disc

A step less variation of sliding velocities from 0 to 8 m/s can be obtained by varying the motor speed and/or the distance of specimen from the center of the rotating disc (i.e. track radius). A control panel has been designed to control and measure various parameters such as sliding speed, test duration and temperature near the contact. The sliding wear test is carried out as per ASTM G99-95 standards. The following wear test parameters can be varied:

- Accumulated sliding distance obtained from the number of revolutions multiplied by track circumference.
- Sliding velocity between the contact surfaces.
- Force at the wearing contact.
- The environment surrounding the wearing contact.

Sliding distance is varied in terms of number of revolutions of the disc, which can be set in the digital read out. Sliding velocity is varied by moving the radial position of the pin from the disc center. Large radial distance results in higher sliding velocity, which can also be controlled by setting desired rpm. Normal load is applied through cantilever arrangement provided in the setup. LVDT measures the worn length of the specimen, which can be converted to wear volume for finding out the wear rate. Thermocouples are available to measure the temperature of the specimen or the disc while experiment is being carried out. Separate pumping units are available for lubricated wear test.

The load cell unit consists of strain gauge sensor unit and an elastic member on the supporting structure. A flat surface machined on the middle portion of the vertical column that acts as an elastic member on which the strain gauges are bonded. The elastic member undergoes deformation when normal load is applied. The strain gauges undergo change in resistance, which is reflected as a small variation in voltage displayed by milli-voltmeter. Bonded-foil strain gauge, that is photo etched out of flat metal foil about 2.5 μm thickness is used such that the electrical resistance of the zigzag portion of the foil parallel to axis is greater than that of the portion perpendicular to axis. The thin foil gauge has more intimate contact with the structure. The gauge length can be from 0.2 to 100 mm. The strain gauge resistance is 1200 ohm. The measurement of the friction force is possible by means of a loading pan on a cantilever arrangement which carries set of load cells whose difference in voltage across the bridge circuit is observed in milli-volts. For known values of potential difference, the friction force is a linear function of the normal load. Coefficients of friction were calculated by dividing the friction force by the corresponding load.

3. Results and discussions

3.1. SEM analysis

Wear tests were conducted, on the MMC specimens for different combinations of SiCp content, sliding distance (3.6 km, 7.6 km and 10.2 km) and applied load 20, 40, 60 and 80 N. Counter face was EN-31 steel disc. Friction force, surface finish, wear volume, wear rate and temperature were measured for each combination of load and sliding distance. A track radius of 3.5 cm was used for all the tests. The specimen was allowed to wear at sliding speed of 1 m/s for 2 hours simulating 7.2 km sliding distance. The machine was stopped at each one-hour interval and the specimen was removed from the specimen holder and washed with acetone and weighed to determine the weight loss. Then the specimen was once again mounted on the wear testing machine for next one hour test. The worn surfaces of the Al-SiCp composite pin specimen are studied using SEM as shown in Fig. 5. It has been established that deep tracks are formed at higher load. A change in the wear mechanism from ploughing to chipping is noticed for an increase in the applied load. It was found that 20% SiCp content being an optimum reinforcement [21].

3.2. Specific wear rate

The specific wear rate can be obtained by dividing the wear rate by applied load. In other words, specific wear rate is the volume lost per unit length per unit force. Table 1 shows the details of the wear test conditions.

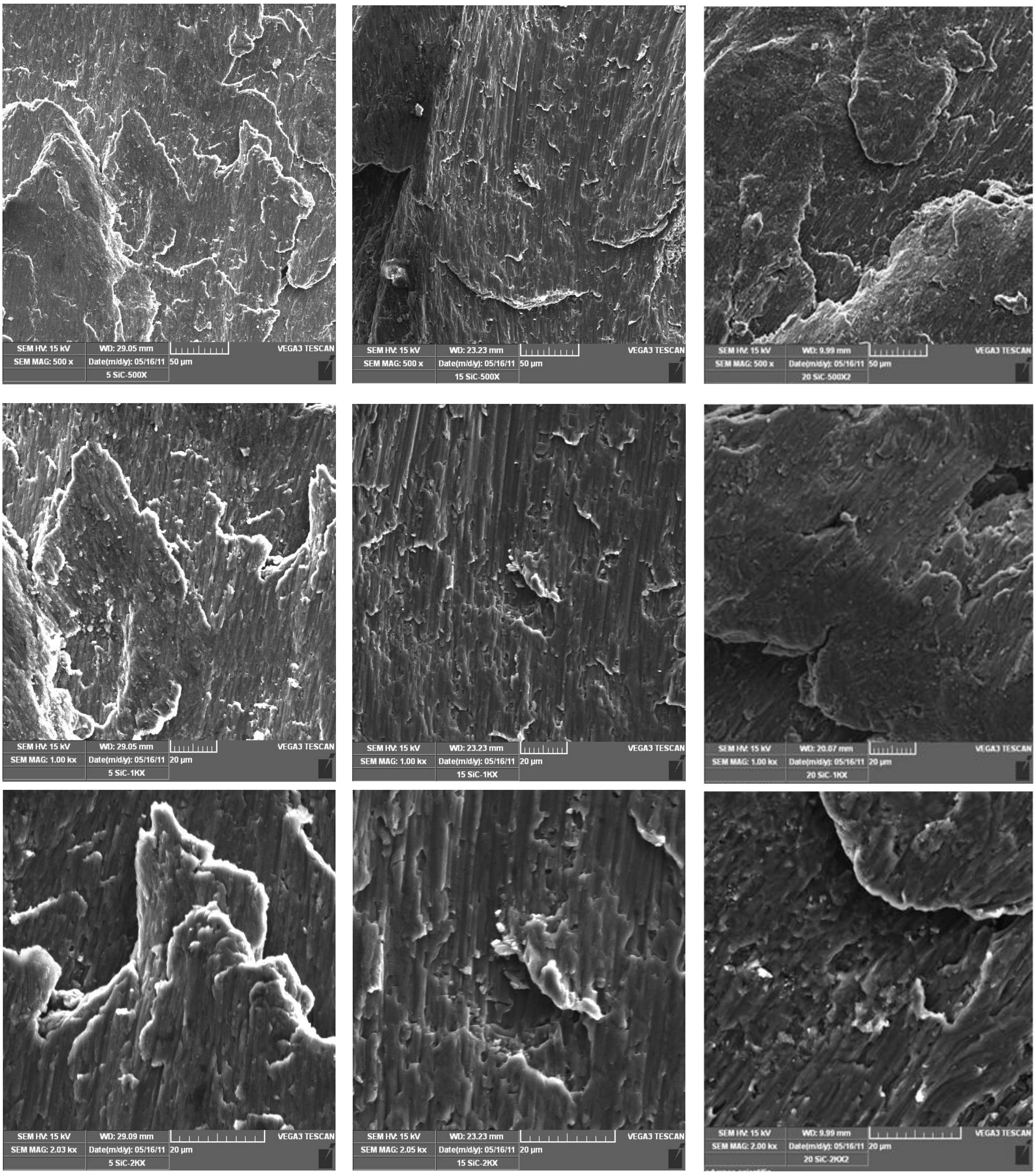


Fig. 5: SEM of worn surfaces of the pin at sliding velocity 1 m/s. Rows - Top 40 N, Middle 60 N and Bottom 80 N; Columns – Left 5% SiCp, Middle 10% SiCp and Right 20%

Table 1: Details of wear test conditions

Parameter	Description/value
Pin material	Al 6061 MMC 20% SiCp by weight
Disc material	EN31 steel with hardness of 65 HRC
Pin dimension	Diameter 10 mm and height 40 mm
Sliding speed	3 m/s
Sliding distance	2500 m
Normal load	20, 40, 60, 80 N

For each experiment, initial and final weights of the specimen are measured with an accuracy of 0.01 mg. The applied load is varied as 20, 40, 60 and 80N. The contact surface temperature increased for an increase in the applied load. The variation of specific wear rate with respect to applied load is shown in Table 2. As the applied load increases the wear rate increased. The wear mechanism reported was oxidation at lower loads and adhesion and delamination at higher loads. Al-alloy easily undergoes thermal softening and re-crystallization at higher temperature compared with the composites because the strength of the composites at higher temperature is greater. As a result, the wear rate of the Al-alloy is increased drastically at higher loads.

Table 2: Sliding wear with varying loads

Load (N)	Initial wt. (g)	Final wt. (g)	Lost wt. (g)	Specific wear rate (10^{-5} mm^3/Nm)
20	8.1229	8.144	0.0211	3.864
40	8.1133	8.1074	0.0059	4.321
60	8.1320	8.1133	0.0187	4.566
80	8.1129	8.0999	0.0132	4.835

At low loads, as particles act as load bearing constituents, the direct involvement of Al-alloy in the wear process is prevented. The transition in wear rate is faster and test temperature dependent as a result of cracking between reinforcement and the matrix both of which lead to fragmentation and delamination of the surface. Thus, the maximum load a composite can support during sliding without excessive wear can be obtained by the fracture toughness of the reinforcement.

3.3. *Coefficient of friction*

The variation of the coefficient of friction for various % of Al-SiCP content at different loads is shown in Fig. 6. The coefficient of friction decreases for an increase in applied load and for an increase in % of SiCp content. The coefficient of friction decreases for an increase in relative velocity from 0.2 to 0.6 m/s at 9 N.

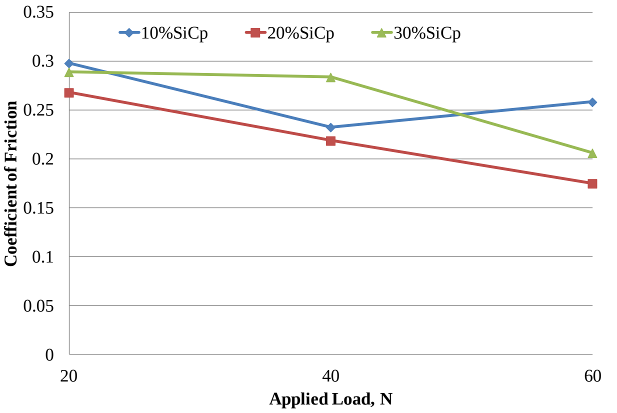


Fig. 6: Variation of coefficient of friction for %SiCp & load

4. Conclusions

Dry sliding wear behaviour and friction characteristics of AL6061-SiCp reinforced composites were studied using pin on disc wear test. SiCp content, sliding velocity and sliding distance were varied during wear testing of a number of Al6061-SiCp composite pin specimens. SEM analysis of Al-SiCp composite pins worn surfaces showed cutting marks on the aluminium matrix caused due to severe abrasion by abrasive particles. SiCp content of 20% showed deep cavitations due to the dislodging of SiCp and found to be optimum. The specific wear rate increased for an increase in the applied load for the specimens with 20% SiCp Content.

The variation of coefficient of friction with % SiCp content was complex. The coefficient of friction decreased for an increase in % SiCp content. The coefficient of friction decreased for an increase in relative velocity.

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