Journal of Manufacturing Engineering, 2009, Vol.4, Issue.2, pp 93-97

TRIBOLOGICAL PROPERTIES OF SILICON CARBIDE REINFORCED ALUMINIUM COMPOSITES

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ABSTRACT

Metal matrix composites (MMCs) represent a new generation of engineering materials in which a strong ceramic reinforcement is incorporated into a metal matrix to improve its properties including specific strength, specific stiffness, wear resistance, excellent corrosion resistance and high elastic modulus. In the present work, aluminum alloy – silicon carbide composites were developed using vortex method and pressure die casting technique. The dry sliding wear properties on aluminum alloy – silicon carbide metal matrix composite were carried out using a pin-on-disc wear testing apparatus at room temperature. The effects of normal load and sliding speed on tribological properties of the MMC pin on sliding with En 36 steel disc was evaluated. The wear rate increases with normal load and sliding speed. The specific wear rate marginally decreases with normal load. The coefficient of friction decreases with normal load and sliding speed. The wear and friction coefficient of the aluminum alloy–silicon carbide MMC is lower than the plain aluminum alloy.

Key words: *Metal matrix composites, friction, wear, aluminum, silicon carbide*

1. Introduction

The application of silicon carbide (SiC) reinforced aluminum alloy matrix composites in the automotive and aircraft industries are gradually increasing for pistons, cylinder heads, etc., where the tribological properties of the material are very important. Therefore, the development of aluminum matrix composites is receiving considerable emphasis in meeting the requirements of various industries. Incorporation of hard second phase particles in the alloy matrix to produce metal matrix composites (MMCs) has also been reported to be more beneficial and economical. To widen the application range of MMCs in the automotive industry, it is necessary to establish low cost manufacturing process. The die casting technique seems to be most suitable to obtain economic parts of near net shape MMCs compared to other manufacturing processes. The main benefit of high pressure die casting is to obtain a fine microstructure casting part as it solidifies within the precision-machined mold cavity. There is a substantial progress been made during the past decade in the development of pressure die casting alloys and processing technology. High pressure die casting components made of aluminum or magnesium alloys offer various advantages in automotive applications. In particular, the cost efficiency of the casting process and the possibility to cast thin walled components of complex geometries led to the use of this class of materials in modern light weight vehicles.

Metal matrix composites (MMC) appeared about few decades ago and have received significant attention for automotive, aeronautical, electronic and military fields (Bertin, 1990 and Odorico 1990) [1,2]. Aluminum based MMCs offer potential for advanced structural applications when high specific strength and modulus, as well as good elevated temperature resistance are important. Most of the commercial work on MMCs has been focused on aluminum as the matrix metal because of its light weight. Also, aluminum can accommodate a variety of reinforcing agents. When an alloy is used as the matrix instead of pure metal, mechanical properties of composites can be improved by performing different heat treatment operations. Among the various metal-ceramic combinations, some aluminum-based metal matrix composites reinforced with silicon carbide (SiC), aluminum oxide (Al_2O_3), titanium carbide (TiC) and graphite are referred to as heat treatable materials (Albiter et al, 2000) [3].

Hosking et al. [4] reported that, SiC particles were more effective than Al_2O_3 particles for the improvement of wear resistance of aluminum matrix composites due to the high hardness. Gurcan et al. [5] and Lee et al. [6] have also stated better wear resistance of SiC reinforced composites than that of Al_2O_3 reinforced composites. Deuis et al. [7] have comprehensively reviewed the status of research in the area of dry sliding wear of discontinuously reinforced

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aluminum alloy MMCs. However, almost all the MMCs investigated had an aluminum alloy as the matrix material. It is known that particulate reinforcement strengthening and precipitation hardening act in a synergistic fashion (Rack, 1988) [8]. The friction and wear behavior of aluminum - SiC composites improves with SiC particle reinforcement (Venkataraman and Sundararajan, 1996) [9,10]. Wear loss of particle reinforced aluminum specimens decreased about 1.5 – 2 times. Optical and scanning electron microscope revealed that surfaces of pure aluminum specimens were rougher than those of particle reinforced aluminum specimens. Abrasive and adhesive wear tracks decreased for particle reinforced aluminum specimens due to particle addition and better wear resistance property. Consequently, tribological properties of particle reinforced aluminum composite specimens were improved by these methods. In addition, tribological and mechanical properties of casting specimens were about 1.5–2 times better than those of powder metallurgy specimens (Bekir Sadık Ünlü, 2008) [11]. The wear results showed that the wear resistance of composites increased with increase of the reinforcement weight fraction due to the strong particulate matrix bonding and high hardness of the Al_2O_3 particulates [12]. The mechanical properties of the bronze–alumina composite are improved by the addition of alumina in the metal matrix [13].

2. Experimental Work

In the present work, the aluminum alloy - 3 % weight silicon carbide was die cast, using LM24 aluminum alloy as the matrix material and silicon carbide particles of average particle size of 16 microns as a reinforcement material. The aluminum alloy was melted in a graphite crucible at a controlled temperature protected with an argon gas atmosphere. The graphite stirrer was introduced into the crucible to perform mixing process when the molten temperature reached 850 ^{0}C. The stirring was carried out for 45 minutes at the rate of 200 rpm. Silicon carbide particles were preheated to 200 ^{0}C and introduced into the vortex created in the molten alloy. The internal surface of the die is applied with a water based die coat before each casting which acts as a lubricant between the molten metal and die, and also prevents the adhesion between the die cast metal and die. A 420 ton cold chamber hydraulic type die casting machine was used for making the castings. The pouring temperature of molten mixture was 850 ^{0}C and molten metal was injected into the runner of the closed die with the initial velocity of 0.23 m/sec up to runner gate. Then the ram movement is given with 1.8 m/sec for injection and simultaneously shot in the die. The molten mixture is poured into the plunger sleeve and forced into the die cavity with pressure of 100 MPa. The shot accumulation force of 420 tons is applied at the end of injection and the die is simultaneously cooled with demineralized water. Then the MMC is ejected from the die with at a temperature of 150 ^{0}C and it is allowed to cool in air.

2.1 Friction and wear tests

The pin-on-disc set up is a standard test for studying the friction and wear characteristics [14]. In the present work the friction and wear characteristics of the aluminum alloy– silicon carbide composite was assessed using a pin-on-disc set up**;** the test specimen 8 mm diameter cylindrical specimens of aluminum alloy–silicon carbide composite were mated against hardened En 36 steel disc of 65 HRC . The tests were conducted with normal loads of 9.8, 29.4 and 49 N and sliding speeds of 3, 4 and 5 m/s for a sliding distance of 5000 m. The frictional load and the wear were measured at regular intervals of sliding distance.

3. Results and Discussion

The microstructure of the plain LM24 aluminum alloy is presented in figure 1. The microstructure shows the interdendritic particles of eutectic silicon and $CuAl_2$ in a matrix of aluminum solid solution. The X-ray diffraction pattern of the plain LM24 aluminum alloy is given in figure 2. The 28.6, 47.6 and 56.5 degrees represent the silicon peaks and the other peaks (38.4, 44.7, 65.7 and 78.2 degrees) are aluminum peaks. The hardness of the aluminum alloy-silicon carbide composite is higher than that of the plain LM24 aluminum alloy. The hardness of the aluminum alloy-silicon carbide composite of 107 BHN is higher than that of the plain LM24 aluminum alloy of 96 BHN due to particulate hardening.

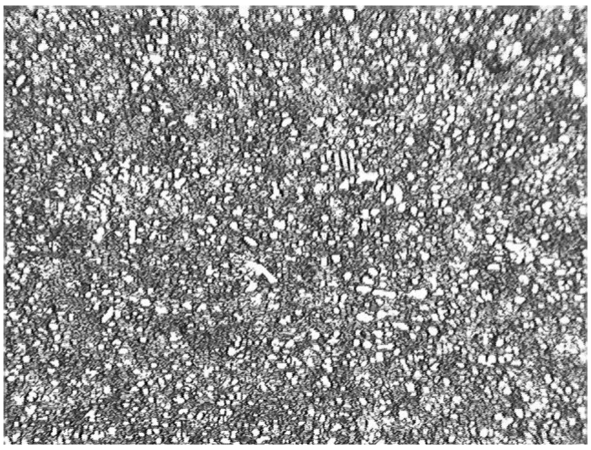

Fig. 1 Microstructure of the plain LM24 aluminum alloy

3.1 Influence of normal load on wear

The wear rate increases significantly when the load was increased from 9.8 to 49 N as shown in figures 3, 4 and 5. At higher normal loads, due to excessive frictional heat generated the pin surfaces become quite soft and plastic enough to deform and finally fracture such that the wear debris formed and dislodged consists of large shining metallic particles. It was also observed that there was a gross material transfer from pin to the steel disc, at these high loads. The wear rate of the plain LM24 aluminum alloy are higher than aluminum alloy–silicon carbide composite.

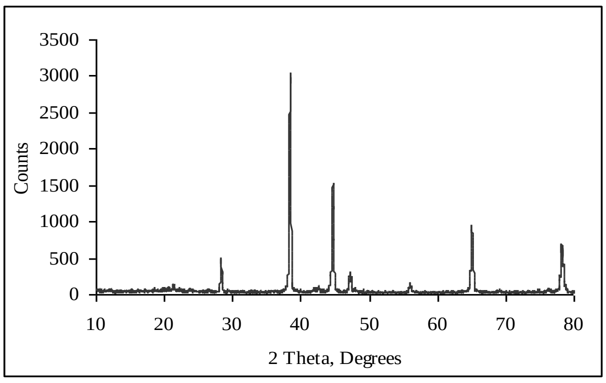

Fig. 2 XRD Pattern of plain LM 24 aluminum alloy

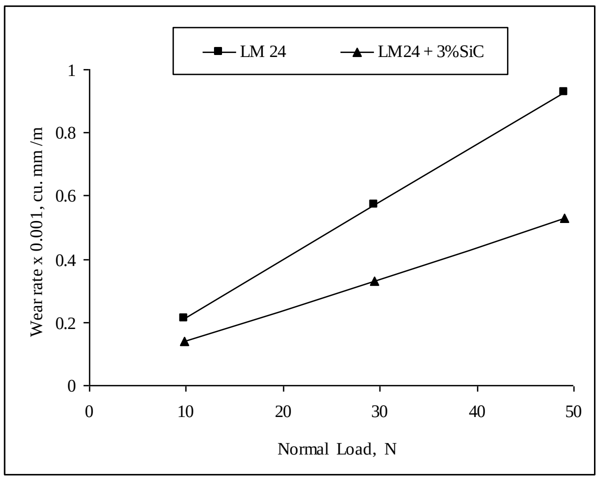

Fig. 3 Wear rate vs normal load at 3 m/s

The specific wear rate marginally decreases with increasing normal load, suggesting that significant plastic deformation and work hardening occur at higher loads as shown in figures 6, 7 and 8. The specific wear rate of the plain LM24 aluminum alloy is higher than aluminum alloy–silicon carbide composite.

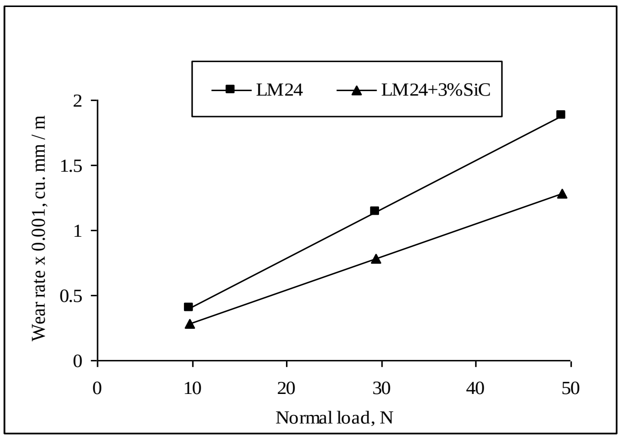

Fig. 4 Wear rate vs normal load at 4 m/s

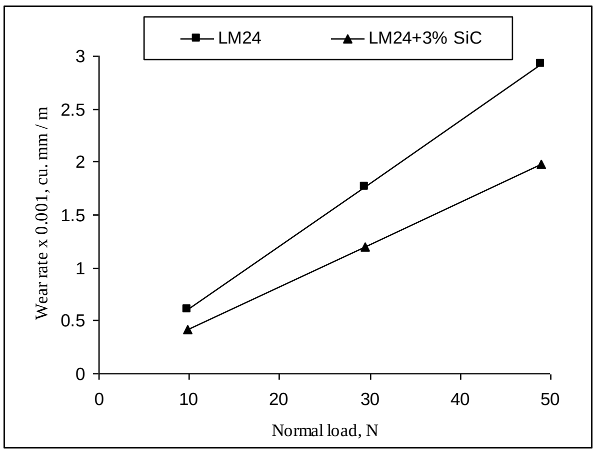

Fig. 5 Wear rate vs normal load at 5 m/s

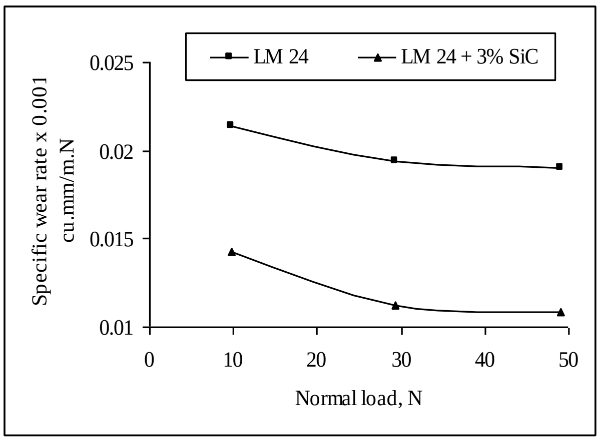

Fig. 6 Specific wear rate vs normal load at 3 m/s

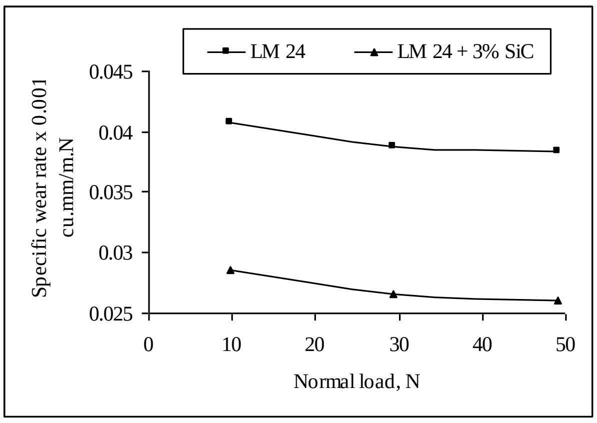

Fig. 7 Specific wear rate vs normal load at 4 m/s

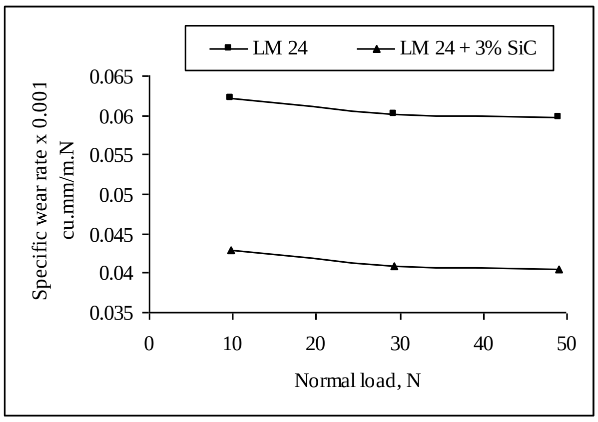

Fig. 8 Specific wear rate vs normal load at 5 m/s

3.2 Influence of sliding speed on wear

At higher sliding speed, the temperature rise is considerably high and there is a tendency of softening of surface materials and a greater degree of penetration by the relatively harder asperities. At higher sliding speed there is also increased tendency of fracture and fragmentation of asperities due to high strain rate subsurface deformation. There is also an increased contact area and contributing to enhanced wear.

3.3 Influence of normal load on coefficient of friction

The variation of coefficient of friction with normal load is shown in figures 9, 10 and 11. At lower normal loads the contact of the asperities is less and results in more plowing action, increasing the coefficient of friction. As the normal load increases, it results in better conformity of the contacting surfaces resulting in the reduced plowing action and coefficient of friction.

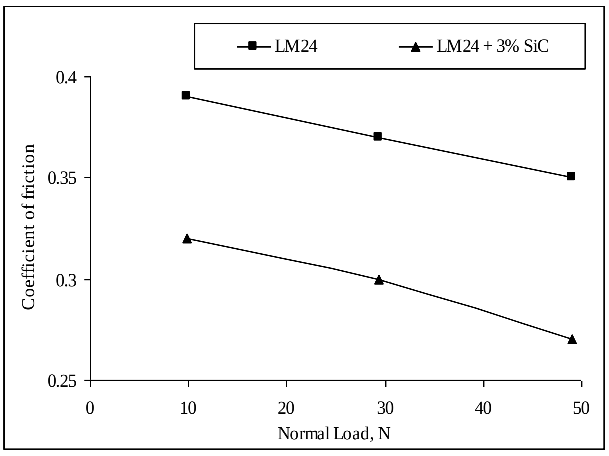

Fig. 9 Coefficient of friction vs normal load at 3m/s

Friction coefficient of the plain LM24 alloy and the aluminum alloy–silicon carbide composite shows a decreasing trend with increasing load. At higher normal loads an oxide layer form on the pin surface and reduce the friction. Friction coefficient of aluminum alloy–silicon carbide composites are lesser than the unreinforced alloy due to the higher hardness of the composite, which is attributed to the presence of hard SiC particles.

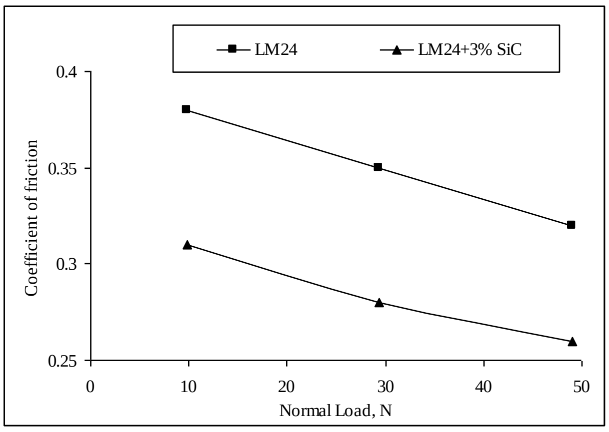

Fig. 10 Coefficient of friction vs normal load at 4m/s

3.4 Influence of sliding speed on the coefficient of friction

The increase in temperature can induce a thermal softening beneath the worn surface and even result in the change of wear mechanism at higher sliding speeds. At higher sliding speeds oxide layer forms on the pin surface and reduce the coefficient of friction.

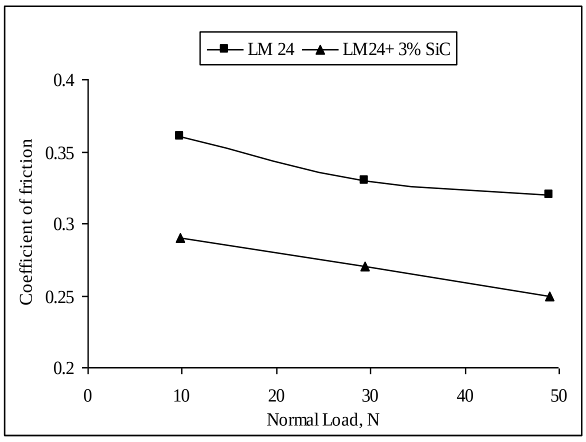

Fig. 11 Coefficient of friction vs normal load at 5m/s

3.5 Wear behavior

The microscopy studies of the wear surfaces of these samples revealed that less abrasive and adhesive wear tracks occurred for the aluminum alloy–silicon carbide composites than the plain LM24 alloys due to harder SiC particles resulting in better wear resistance property. The figure 12 shows the wear surface of the aluminum alloy – silicon carbide composite at normal load of 49 N and sliding speed of 3m/s.

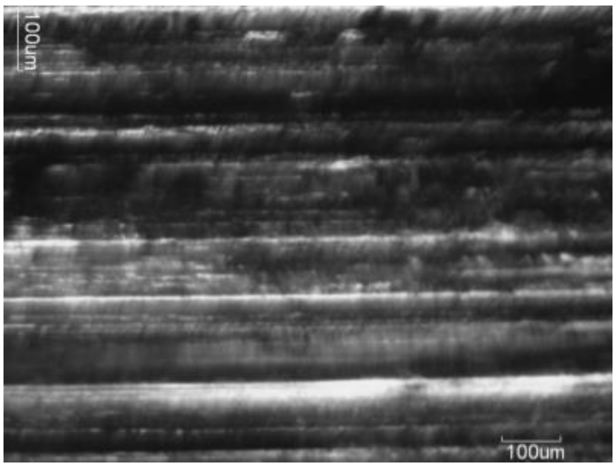

Fig. 12 The wear surface of the aluminum alloy-aluminum oxide composite

4. Conclusion

Aluminum alloy–silicon carbide composite was developed using vortex method and pressure die-casting technique. The wear resistance of aluminum alloy–silicon carbide composite improved compared to the plain LM24 aluminum alloy. As normal load and sliding speed increases the wear rate increases. The specific wear rate marginally decreases with normal load. The coefficient of friction with the aluminum alloy–silicon carbide composite is lesser compared to plain LM24 aluminum alloy. The coefficient of friction decreases with increasing normal load and sliding speed.

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