Sliding Wear Behavior of Stir Cast AZ91/ SiC$_p$ Composites*

Prasanth SUJAYAKUMAR**, Abhilash VISWANATH**, Kumaraswamy Kaliyamma Ajith KUMAR**, Thazhvailai Ponnu Deva RAJAN**, Uma Thanu Subramonia PILLAI** and Bellambettu Chandrasekhara PAI**

**Material Science and Technology Division, CSIR-National Institute for Interdisciplinary Science and Technology (NIIST), Thiruvananthapuram – 695019, India
E-mail: utspillai@gmail.com

Abstract

Tribological attributes of Mg-alloy (AZ91D) based composites reinforced with 5, 10, 15, 20 and 25 wt% of silicon carbide particle (SiC$_p$) synthesized by stir casting technique are being investigated. The composites show uniform distribution of SiC$_p$ and possess refined grains in comparison with the monolithic alloy. The cleaner interface depicts splendid interfacial bonding. The dry sliding wear behavior of the composites has been characterized using a pin on disc wear testing machine at two different normal loads of 19.6 and 39.4N. The volumetric wear rate, wear resistance and coefficient of friction for the composites shows phenomenal variations with fluctuations in load and SiC$_p$ content. Scanning electron micrographs of wear surface and wear debris provide excellent insight of the type of wear involved.

Key words: SiC$_p$/AZ91 Composite, Stir Casting, Sliding Wear Behavior

1. Introduction

The urgency to address increase in fuel price has made weight reduction an essential need in the aerospace and automotive sectors. The highest specific strength of magnesium and its alloys among structural materials have considerably attracted interest towards magnesium based metal matrix composites (MMCs) with attractive mechanical properties over monolithic alloy $(1)$. This is due to the fact that the limitation of low elastic modulus of monolithic alloys can be circumvented by incorporation of harder and stiffer ceramic particulates in the matrix. However, optimum properties of these composite materials depend upon the selection of the type, size and volume fraction of the reinforcements.

In spite of these attributes, research and development of Mg based MMCs is less in comparison with Al based MMCs. This is basically due to difficulty in the synthesis of Mg MMCs due to high reactivity of Mg, leading to significant problem in its production. Improper fabrication process can cause degradation rather than improvement in mechanical properties of the composite $(2)$. The incorporation of thermally stable SiC$_p$ ceramic particles into the magnesium matrix are being done by stir casting, powder metallurgy, squeeze casting, and spray forming $(3, 4)$. Among these methods, stir casting is considered to be easily adaptable and economically viable due to its low processing cost and high production rate. The near-net shape formation of the composites is an additional benefit of this process $(5)$.

Investigations on tribological properties of Mg-MMCs are even scarcer. Alahelistent et al. $(6)$ are among the earliest to study tribological attributes of magnesium and Mg–9Al–1Zn alloys reinforced with alumina-fibers using sliding, abrasion and erosion tests. They noted
that there is an optimum amount of fibre content for sliding wear resistance and it does not always improve with the increase in alumina fibre. However, two-body abrasion resistance increases with increase in amount of fibre. Later on, studies carried out by Sharma et al (7) on the sliding wear behavior of AZ91 Mg alloy reinforced with feldspar particles inferred that wear rates decreased with increase in reinforcement content. A wear transition from mild to severe has been noted with increase in load, but the presence of the feldspar particles is able to delay this transition. The influence of the spatial distribution of SiC<sub>p</sub> reinforcements in magnesium matrix composite on the tribological properties during abrasive sliding has been described by Thakur et al (8). They have reported about better microhardness, lower coefficient of friction and higher wear resistance of well-dispersed SiC<sub>p</sub>. The dry sliding wear test carried out on SiC<sub>p</sub> reinforced AZ91 alloys synthesized via powder metallurgy by Lim et al (9) reveals five different wear mechanisms involved. They are abrasion, oxidation, delamination, adhesion, thermal softening and melting.

However, investigations into tribological attributes of SiC<sub>p</sub> reinforced AZ91 composites synthesized via stir cast route have not been reported so far as per the authors. The present study is hence, a novel attempt to understand the wear behavior of SiC<sub>p</sub>/AZ91 stir cast composite using dry sliding against a steel counter face.

2. Experimental Details

The materials chosen for this investigation were AZ91 (Mg-9.3Al-0.8Zn-0.18Mn) alloy as matrix and SiC<sub>p</sub> having the size ~ 23µm as reinforcement. The synthesis was done by melting the AZ91 alloy under argon atmosphere in a steel crucible using a resistance heating furnace at 750ºC. The SiC<sub>p</sub> preheated to 300ºC were then added into the melt being stirred at 750 rpm. After completion of the addition, the stirring was continued for another 5 minutes to ensure the blending of the particles with the matrix. Subsequent to the stirring process the melt was poured into the mild steel mould preheated to 350ºC to obtain the castings. The polished metallographic samples were viewed under LeicaDMRX microscope to obtain the microstructure. Samples were heat treated at 400ºC for 24 h (T4 condition) to visualize the grain refinement. The dry sliding wear tests of AZ91/SiC<sub>p</sub> alloys were conducted on a pin on disc wear testing machine (TR-20, DUCOM). The pin specimens having 6mm diameter and 25mm length machined out from the castings were used as test samples. Hardened chromium steel disc (Rc 64) was used as the counter face material. Before the test, the contact surfaces of the specimens prepared by grinding with 600-grit silicon carbide paper were subsequently cleaned with acetone. The wear tests were carried out with two different normal loads of 19.6 and 39.4N. For all the tests, the sliding speed and sliding distance were maintained at 1m/s and 1800m respectively. Since the wear testing was carried out on a microprocessor controlled machine, the height loss and frictional force were monitored simultaneously. Wear surfaces and wear debris of selected samples were characterised using scanning electron microscope (SEM) (JSM-5800, JEOL).

3. Results and Discussion

3.1 Microstructural Characteristics

The optical micrographs shown in figure 1 endorse that the ceramic particles have wetted well with the matrix and are evenly distributed throughout with very less agglomeration. The increase in amount of dark phases in the microstructure signifies lesser rejection of the particles and highlights the soundness of the casting process. As per the microstructure of the samples given in figure 2, α-Mg grains have a reduced size in AZ91-10wt%SiC<sub>p</sub> (fig 2b) when compared with the monolithic alloy (fig 2a). Moreover, the SiC<sub>p</sub> particles are present not only along the grain boundary but also inside the grains. Hence, the presence of thermally stable ceramic particles along the grain boundary impedes grain boundary sliding, improving the mechanical attributes at both room and
elevated temperatures.

Fig 1: Optical micrographs of AZ91 alloy with a) 0, b) 5, c) 10, d) 15 and e) 25 wt% SiCₚ additions.

The presence of particles within the grain boundary also signifies the heterogeneous nucleation mechanism which leads to the reduction in grain size.

Fig 2: Microstructures of (a) AZ91 alloy and (b) AZ91/10 wt% SiCₚ composite

The scanning electron micrographs of AZ91/10wt% SiCₚ composite (fig 3) depicts that the ceramic reinforcements have cleaner interface and no unwanted chemical reactions occurred at the interface during the casting process. Better interfacial bonding is hence
obtained.

![Fig 3: SEM micrographs of a) AZ91/10SiC_p composite b) High magnification SEM](image)

### 3.2 Wear Behavior

The volumetric wear rates, wear resistance and coefficient of friction for the SiC_p reinforced AZ91 composite are plotted against the SiC_p content in Fig. 4. The progressive increase in wear rate with increase in load can be easily identified from figure 4a. Decrease of wear rate with increase in the SiC_p content of the composite can also be noted and is attributed to the strengthening by SiC_p reinforcements. The wear behavior of the composite is affected by various parameters such as type, size and volume fraction of reinforcement (9).

![Fig 4: Graphs showing a) Wear rate v/s SiC_p content, b) Wear rate as a function of reinforcement and c) Variations in coefficient of friction with respect to the amount of SiC_p present.](image)

The reduction in wear resistance at higher normal load, as observed in fig 4b, is attributed to the more eminent stress induced on the wear surface. Furthermore, increase in wear resistance with SiC_p addition is also evident. The COF is also changed noticeably from one test condition to another, especially for the lower loads applied which is shown in Fig.
clarifies that COF decreases with increase in load and increases with SiC\textsubscript{p} content. The abrupt change in COF at 19.6N for variation in SiC\textsubscript{p} from 5 to 10wt% might be due to the increase in tangential load attributed by the delamination mechanism. However, the specific wear rate and wear coefficient decreases are also found reducing with increase in SiC\textsubscript{p} in the matrix irrespective of the loads.

The scanning electron micrograph of worn surfaces of AZ91-10wt% SiC\textsubscript{p} and AZ91-25wt% SiC\textsubscript{p} samples tested at two different load conditions (19.6N and 39.2N) are shown Fig. 5. Delaminated material pickup on most of the wear surface is evident for samples tested at 19.6N for AZ91/10 wt% SiC\textsubscript{p} composite (fig 5 a). Figs 5b-d also reveal the traces of parallel grooves on the wear surface. These distinct patterns of grooves and ridges running parallel to one another are the typical characteristic of delaminated and sliding wear. These scratches may be attributed to hard asperities of counter face or detached particles removed from disc or pin when placed in surface contact.

Fig 5: SEM of worn surfaces: a) AZ91/10 wt% SiC\textsubscript{p} tested at 19.6N, b) AZ91/10 wt% SiC\textsubscript{p} tested at 39.2N, c) AZ91/25 wt% SiC\textsubscript{p} tested at 19.6N and d) AZ91/25 wt% SiC\textsubscript{p} tested at 39.2N

SEM images of wear debris of AZ91-10wt% SiC\textsubscript{p} and AZ91-25wt% SiC\textsubscript{p} samples tested at two different loads are depicted in Fig. 6(a-d). The types of wear debris are numerous flakes or sheet, which are delaminated from the worn surfaces. The delamination involves subsurface deformation, crack nucleation and crack propagation.
Fig 6: Scanning images of wear debris: a) AZ91/10 wt% SiC<sub>p</sub> tested at 19.6N, b) AZ91/10 wt% SiC<sub>p</sub> tested at 39.2N. c) AZ91/25 wt% SiC<sub>p</sub> tested at 19.6N and d) AZ91/25 wt% SiC<sub>p</sub> tested at 39.2N

The dominant wear mechanism is abrasion which is facilitated by the wear process where hard reinforcing materials become the load bearing constituent (10). However, the decrease in size of debris is more significant in case of high SiC<sub>p</sub> added matrix (11). The oxidation type of wear can be visualized as white patches shown in fig 6 b and d. Hence, in the present study abrasion, delamination and oxidation are the main wear mechanisms involved.

4. Conclusions

The investigations on sliding wear behaviour of stir cast AZ91/SiC<sub>p</sub> composites using pin-on-disk apparatus leads to the following conclusions:

1. Stir casting is an effective technique to synthesize AZ91/SiC<sub>p</sub> composite as the particles are uniformly distributed with very less agglomeration even at as high as 25wt% SiC<sub>p</sub>.
2. SiC<sub>p</sub> reinforcements strengthen the soft magnesium matrix by decreasing the wear rate and increasing the wear resistance and coefficient of friction of the composite as a function of reinforcement content.
3. Abrasion, delamination and oxidation are the predominant wear mechanisms in the composites under the prescribed testing conditions.

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