ABSTRACT

In the present study, AA2014 composites dispersed with 5 and 10 wt% TiC particles were synthesized by SHS in-situ technique. The base alloy was also synthesized under identical conditions for comparative studies. The matrix alloy and composites were synthesized in an electrical resistance furnace in argon atmosphere. The melt was solidified in cast iron die in the form of 14 mm diameter and 170 mm long rods. Samples were sectioned and polished for density and hardness measurements. Table 1 shows the density and hardness of the matrix alloy and composites. The hardness and density both increased with the increasing TiC content; the density of the composite was close to their theoretical density. The abrasive wear performance of improved by 2-3 times in the presence of TiC particles in the alloy. Also, increasing concentration of TiC led to a further improvement in the wear resistance. Also the wear resistance was found to be better in case of testing the samples up to the specified sliding distance of 500 m in one go compared testing intervals of 100 m.

Keywords: Abrasive wear, 2014Al-TiC, In-situ technique; TiC particulate; Metal matrix Composite

1. INTRODUCTION

Poor strength and other relevant characteristics of pure Al limit its wide usage especially at high temperatures. Addition of non-metallic second phase particles such as oxides, carbides and borides dramatically improve mechanical and tribological properties. Metal-matrix composites (MMCs) have received substantial attention from the aerospace and automotive industries during the last decade because of their improved strength, high elastic modulus and increased wear resistance over conventional monolithic base alloys. The composites are being developed as a cost-effective alternative to conventional materials for making piston, engine
poppet valves, rotor brake, bearing sleeves, cylinder liners, cylinder heads, connecting rods etc. There are several techniques available for making metal matrix composites (MMCs) ranging from powder metallurgy method to casting. For most applications, a homogeneous distribution of the reinforcing phase is desirable in order to attain isotropic characteristics. Self-propagating high-temperature synthesis (SHS) process is useful to achieve good particle dispersion. This is imparted since the dispersoid phase forms from within the matrix thus making the dispersoid/matrix bonding sound. In addition, the surface is free of contamination such as gas absorption and oxidation. This also helps to minimize the degree of segregation of the reinforcement phase ultimately leading to improved properties. The mentioned problems become quite severe during external addition of the dispersoid particles to the alloy matrix. Moreover, fine grained and thermodynamically stable ceramic phases are formed during in-situ technique responsible for improved characteristics. Because of its high melting point, hardness, modulus and strength, and good thermal and chemical stabilities titanium carbide (TiC) is an attractive ceramic material for application as a reinforcing phase in Al-matrix composites.

1.1 Formulation of the Problem

Available information suggests that there exist a variety of techniques to synthesize MMCs in general. They include liquid and powder metallurgy routes and a combination of the two processes, spray co-deposition technique, rheocasting, compocasting, gravity and pressurized solidification techniques. Two methods of incorporating the reinforcement phase in the alloy matrix include ex-situ and in-situ techniques. Out of the two processes, in-situ generation of the reinforcement phase offers a number of advantages (over the ex-situ process involving the external addition of the dispersoid phase in to the matrix). They include good dispersoid-matrix bonding, more uniform distribution of the dispersoid phase in the matrix, better control over the morphology of the reinforcement phase and ability to disperse ultrafine particles of the second phase usually not possible through the external addition process. Accordingly, the in-situ composites attain superior characteristics and properties compared to the ex-situ composites. As far as wear response of materials is concerned, there are a number of material and test parameters that control the wear characteristics of the alloys. Material related parameters include alloy chemistry, microstructural features, material processing steps and parameters. In the case of composites, additional parameters governing wear response include the shape, size, properties, and the mode of distribution of the dispersoid phase and nature of matrix/particle interfacial bonding. Test parameters pertaining to the case of abrasive wear include the characteristics and shape and size of the abrasive particles, applied load, traversal speed and distance. Another factor of importance is the mode of testing the material even for the same sliding distance. Interestingly, no definite trend exists as far as the influence of the material and test parameters on wear behaviour is concerned. This amounts to saying that the wear performance of materials needs to be examined on a case-to-case basis to assess their response in more realistic terms. In view of the above observations, an attempt has been made in this study to examine the influence of applied load, traversal distance, abrasive size and test mode on the wear characteristics of Al alloy and its composites containing ultrafine 5 and 10% TiC dispersoid particles. The effects of TiC reinforcement and its content on the wear behaviour have also been investigated. Wear parameters evaluated include wear rate, frictional heating and friction coefficient. The observations made have been discussed in terms of the nature of damage caused to the abrasive medium and the resistance offered by
the reinforced TiC particles against the penetrating action of the abrasive particles into the material (alloy and composites) system.

2. EXPERIMENT DETAIL

2.1 Materials preparation

Aluminum based alloy and in-situ composites were prepared by liquid metallurgy route using graphite crucibles for melting. Electric resistance furnace was used for melting. Melting was done under protective argon environment. The base alloy was synthesized by melting pure commercial aluminum ingot and adding Mn, Mg, Cu and Fe chips (purity 99.5 %) to meet the 2014 al alloy designation. The nominal composition of alloy and composites so synthesized was shown in the following table 1.

Table 1: compositions of alloy and Composites

<table>
<thead>
<tr>
<th>Materials</th>
<th>Al</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Fe</th>
<th>TiC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium alloy</td>
<td>92.5 %</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
<td>---</td>
</tr>
<tr>
<td>(Al alloy)-5TiC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>(Al alloy)-10TiC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

After adding required wt % of alloying elements the melt was steered thoroughly and degassed. The aluminum alloy melt was poured into the pre heated permanent cast iron mold and allowed to solidify. The Al-TiC composites of two different volume fraction of TiC have been fabricated by in-situ SHS technique. The casted piece is cut into small pieces for re-melting and metal matrix composite Synthesization. The pre heated elemental powders of Ti and C were added into the alloy melt according to 5 and 10 wt% TiC to be formed into the melt. Immediate after five seconds of adding elemental powder in to the melt the exothermic reaction was taken place, after completion of reaction the melt was stirred with the help of mechanical stirrer rotating at a speed of 500 ± 10 rpm than poured into the permanent die mold. The pouring temperature of Al alloy and composites was 800± 5 0C. All the castings made were in the form of 14 mm diameter and 170 mm cylindrical rods.

2.2Density and bulk hardness measurement:

Densities of the samples were measured by water displacement technique with the help of a Mettler microbalance. A microbalance capable of recording the weight of the samples to as small as 10-5g with a range of variation of ±2 x 10-5g was used for weighing the samples for the purpose. Bulk hardness of the specimens was determined using Vickers hardness testing machine with an applied load 5 kg. Diamond pyramid indenter was used for measuring hardness of the alloy and composites. The samples were polished metallographically prior to measuring their properties. An average of 10 readings was considered in each specimen.

2.3 Wear Test

A pin-on disc with emery paper apparatus was employed to evaluate the wear characteristics of composites and aluminium matrix alloy. SiC papers with two different size of 46 (320 grit) and20 (600) grit fixed on a rotating disc. Test specimen cut from 2014 alloy and composites
(5TiC and 10TiC), and shaped in the form of cylinder 10 mm in diameter and 30 mm length. Before the abrasion tests, each sample was making surface with the help of 240 grit abrasive paper for wear surface was in complete contact with the surface of the abrasive paper. Sample for wear testing were loaded against the abrasive mediums by a cantilever mechanism. The wear tests were carried out at room temperature. The test parameters were: normal load on the pin, 5 N, 10 N, 15 N and 20 N, sliding velocity of 1 m/s and 2 m/s and total distance 500 m. The composites and aluminium matrix alloy were tested and each test was performed with a 320 and 600 grit abrasive papers, one load and 100 to 500 m sliding distance. Before and after every test, the pins were cleaned in an ultrasonic bath with an acetone and then dried. The wear loses were obtained from the differences in weight of the pin specimens measured before and after the tests using an electronic balance.

3. RESULTS

This chapter presents description of the observations made in this investigation. This includes hardness, density, and abrasive wear properties. Abrasive wear response has been investigated under the influence of varying load, sliding distance and abrasive size. Wear performance parameters studied include wear rate, frictional heating and friction coefficient.

3.1 Density and Hardness

Table 5.1 shows the hardness and density of the samples. The incorporation of TiC particles led to higher hardness and density that increased further with the increasing concentration of TiC.

5.1 Properties of the matrix alloy and composites

<table>
<thead>
<tr>
<th>Materials</th>
<th>Load (kg)</th>
<th>Dwell time (sec)</th>
<th>Hardness (HV)</th>
<th>Density g/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al2014 alloy</td>
<td>5</td>
<td>15</td>
<td>85± 1</td>
<td>2.802</td>
</tr>
<tr>
<td>Al2014-5wt % TiC</td>
<td>5</td>
<td>15</td>
<td>90± 1.5</td>
<td>2.786</td>
</tr>
<tr>
<td>Al2014-10wt% TiC</td>
<td>5</td>
<td>15</td>
<td>92± 1.5</td>
<td>2.904</td>
</tr>
</tbody>
</table>

3.2 Abrasive Wear Response

3.2.1 Wear Rate

Figure 5.2 shows the wear rate of the matrix Al alloy and its composites containing 5 and 10% TiC particles plotted as a function of sliding distance. In this case, the wear loss measurements were made in intervals of 100 m while abrasive and specimen surface remained unchanged during the tests (referred to as test mode A). The influence applied load and abrasive size on the wear behaviour is also evident in the figure. The wear rate of the samples decreased with increasing sliding distance. The rate of reduction in the wear rate was high initially. This was followed by a lower rate of decrease in the wear rate ultimately
attaining a steady state condition at still longer distances. The same trend was observed for all the material types and test conditions (applied load and abrasive size). The wear rate increased with the rising abrasive size and load. A comparison of the wear rate of the Al-TiC composites with that of the matrix alloy at a typical load of 10 N is shown in Fig. 5.3. Maximum wear rate was observed in case of the matrix Al alloy followed by that of the composites containing 5 and 10%TiC. It may also be noted that the influence of load, sliding distance and TiC reinforcement in the alloy became more prevalent in the case of testing the samples against the coarser (320 grit) size abrasive medium compared to that of the finer one (600 grit). Figure 5.4 represents the wear rate of the samples tested for the sliding distance of 500 m continuously (referred to as test mode B) and corresponding to the last (5th) test interval in the case of test mode A. It may be noted that the presence of TiC particles led to reduced wear rate compared to that of the matrix alloy. Increasing TiC content resulted into a higher extent of decrease in the wear rate. Further, increasing load brought about higher wear rate of the samples whereas the wear rate decreased in test mode B compared to that of mode A. Same trend was observed in both 320 and 600 grit size abrasive media while finer abrasive caused less wear rate.

3.2.2 Frictional Heating

Temperature near the specimen surface for the matrix Al alloy, and Al-5%TiC and Al-10TiC composites test in test mode A has been plotted in Fig. 5.5 as a function of intermediate sliding distance corresponding to the 1st and 5th(last) test intervals. The rate of temperature increase was high initially followed by a lower rate of increase finally attaining a steady state condition. This was more predominantly noted at higher loads and/or coarser abrasive medium. In some cases, a decrease in temperature was also observed after attaining the peak. The severity of heating increased with increasing applied load and abrasive particle size irrespective of the specimen material type. The influence of TiC reinforcement on the frictional heating of the matrix alloy is shown in Fig. 6&7. Presence of the TiC particles led to reduced severity of frictional heating while their rising concentration brought about a further decrease in the severity of frictional heating. The degree of heating also became less during the last test interval compared to that of the 1st one. Same trend was noticed for the matrix alloy as well composites at all load against both abrasive sizes.

3.2.3 Friction Coefficient

Figure 5.8 reveals the friction coefficient of the samples plotted as a function of intermediate sliding distance in test mode A. The friction coefficient increased with the sliding distance initially at a higher rate, attained the peak and decreased there after leading to the attainment of steady state condition. In some cases, the steady state condition was experienced after attaining the peak value. The friction coefficient became lower for the Al-TiC composites compared to that of the matrix Al alloy irrespective of the abrasive size (Fig. 5.9 and 5.10). However, less friction coefficient was recorded for the finer abrasive and lower load (Fig. 5.9 b versus a and 5.10 b versus a).

An appraisal of the observations made in this investigation suggests the wear response of the samples to be affected by intermediate sliding distance, applied load, abrasive size and the test mode. The presence of TiC particles in the matrix alloy significantly influenced the wear properties like wear rate, frictional heating and friction coefficient. Broadly speaking, increasing load led to higher wear rate and frictional heating while friction coefficient followed a reverse trend. The increasing (intermediate) sliding distance brought about reduced wear rate where in the rate of decrease was high initially followed by a lower rate of
decrease ultimately attaining steady state condition. In the case of frictional heating and friction coefficient, an initially high rate of increase was recorded with the increasing sliding distance followed by a reduction in the slope of the plots and finally the attainment of steady state condition. Increasing abrasive size caused the samples to experience higher wear rate, frictional heating and friction coefficient. Talking about the role of the reinforced TiC particles in the alloy matrix, the TiC particles significantly improved the wear response of the sample by decreasing the wear rate, frictional heating and friction coefficient.

Fig.5.2 Wear rate plotted as a function of sliding distance for the (a) matrix Al alloy and (b) Al-5%TiC and (c) Al-10%TiC composites tested at different applied loads against different abrasive particle sizes
5.3 Comparison of the wear behavior of the matrix Al alloy and Al-5&10%TiC composites tested against different abrasive particle sizes at a typical applied load of 10N.

Fig. 5.4 Comparison of the wear rate of the matrix Al alloy and Al-5&10%TiC composites tested for the sliding distance of 500 m run directly and in intervals of 100 m at typical applied loads of 5 & 20N against (a) 320 and (b) 600 grit abrasive particles.

(a)

(b)
Fig. 5.5 Comparison of frictional heating plotted as a function of (intermediate) sliding distance in test mode A for the sliding distances of 100 and 500 m (1st and last test intervals) at typical applied loads of 5 & 20N against 320 and 600 grit abrasive particles in case of the (a) matrix Al alloy, and (b) Al-5%TiC and (c) Al-10%TiC composites.

Fig. 5.6 Comparison of frictional heating of the matrix Al alloy and Al-5&10%TiC composites plotted as a function of (intermediate) sliding distance for the samples tested for the 1st and last (5th) test intervals (test mode A) at a typical applied load of 5 N against (a) 320 and (b) 600 grit abrasive particles.
Fig. 5.7 Comparison of frictional heating of the matrix Al alloy and Al-5&10%TiC composites plotted as a function of (intermediate) sliding distance for the samples tested for the 1st and last (5th) test intervals (test mode A) at a typical applied load of 20 N against (a) 320 and (b) 600 grit abrasive particles.
Fig. 5.8 Comparison of friction coefficient plotted as a function of (intermediate) sliding distance for the sliding distances of 100 and 500 m (1st and last test intervals) in test mode A at typical applied loads of 5 and 20N against 320 and 600 grit abrasive particles in case of the (a) matrix Al alloy, and (b) Al-5%TiC and (c) Al-10%TiC composites.

Fig. 5.9 Comparison of frictional heating of the matrix Al alloy and Al-5&10%TiC composites plotted as a function of (intermediate) sliding distance for the samples tested for the 1st and last (5th) test intervals (test mode A) at a typical applied load of 5 N against (a) 320 and (b) 600 grit abrasive particles.
4. DISCUSSION

This chapter presents discussion of observations made in this investigation and Decreasing wear rate of the samples with increasing sliding distance (Fig.) could be attributed to the predominant effect of capping, clogging and attrition of the abrasive particles and subsurface work hardening of the specimen material. An increase in the wear rate of the specimens with increasing abrasive size and load could be attributed to the higher degree of penetration realized by the abrasive particles into the specimen surface. Greater severity of wear in test mode B than that of A (Fig.) may be a result of a relatively higher extent of material (matrix) softening in the former case, thus allowing increased depth of penetration by the abrasive particles. A reduction in the wear rate of the samples in the presence of TiC particle reinforcement was due to the resistance offered by the phase against the destructive action of abrasive particles. Initially high rate of temperature increase with the increasing (intermediate) sliding distance could be owing to high rate of work hardening and abrasive action caused to the initially few contacting asperities that protrude high and fragment in the due course of abrasion. It may be mentioned that initial contact between the contacting surfaces takes place at only a few (highly protruding) asperities which have to carry the entire load. This leads the asperities to deform, work harden, fragment and caused severe abrasion leading high rate of frictional heating initially. With the progress of time, more and more asperities establish contact and load is shared by them, thus making the wear condition relatively mild. Accordingly, the rate of frictional heat generation reduces with a further increase in the sliding distance. Attainment of the steady state condition in this case suggests maintenance of identical conditions of abrasion. Less frictional heat generation in the case of composites compared to that of the matrix alloy was a result of the resistance offered by the reinforcement TiC particles against the penetrating action of the abrasive particles. An identical effect of sliding distance and abrasive size on friction coefficient indicates that same parameters govern the two (i.e. friction coefficient and frictional heating) as far as their effect is concerned. Reduction in the friction coefficient with increasing load despite higher wear rate suggests that the two parameters cannot be correlated directly. It may be possible that while a higher depth of cut at higher load was responsible for higher wear rate, a relatively higher extent of material softening as a result of the consequently generated higher frictional heat could have led to a reduction in friction coefficient. An appraisal of the observation made in this investigation strongly suggests that a large number of material and test related parameters controlled the overall wear performance of the samples and that it is very difficult to establish a direct correlation between the affecting parameters and wear behaviour in view.
of the synergism existing therein. This further strengthens the view that one needs to understand the wear behaviour of materials on a case-to-case basis to assess their suitability in real terms.

5. CONCLUSIONS

Observations made in this investigation lead us to draw the following conclusions:

1. The presence of dispersed TiC particles in the matrix led to higher hardness and density.
2. Abrasive wear resistance of the samples decreased with increasing sliding distance while abrasive size and applied load produced a reverse influence. Also the test mode B led to higher wear rate than that of A.
3. Frictional heating increased with sliding distance at a high rate initially. This was followed by a lower rate of increase ultimately attaining steady state condition. Higher applied load and abrasive size brought about a greater severity of frictional heating. Moreover, the test mode B caused increased frictional heating compared to A.
4. Friction coefficient was affected by sliding distance, abrasive size and test mode in a manner to that of frictional heating while load produced a reverse influence.
5. There exist a large number and types of material and test related factors controlling the overall wear behaviour of materials. However, the predominant effect of one set of parameters over the other (producing a counteracting influence) actually dictates the wear response in real terms. These parameters produce synergistic effect in view of the complexity involved in the process of wear. Accordingly, it becomes imperative to develop a systematic understanding pertaining to the wear response of materials on a case-to-case basis to judge their suitability from technical as well as application point of view.

REFERENCE