Characterization of Minerals, Metals, and Materials 2015
Edited by: John S. Carpenter, Chenguang Bai, Juan Pablo Escobedo, Jiann-Yang Hwang, Shadia Ikhmayies,
Bowen Li, Jian Li, Sergio Neves Monteiro, Zhiwei Peng, and Mingming Zhang
TMS (The Minerals, Metals & Materials Society), 2015

EFFECT OF APPLIED PRESSURE ON THE TRIBOLOGICAL BEHAVIOUR OF DUAL PARTICLE SIZE RUTILE REINFORCED LM13 ALLOY COMPOSITE

Rama Arora[1], Suresh Kumar[2], Gurmel Singh[1] and O.P. Pandey[2]

[1]Department of Physics, Punjabi University, Patiala, India
[2]School of Physics and Materials Science, Thapar University, Patiala, India

Keywords: DPS, Aluminium,Rutile

Abstract

The tribological behavior of Dual Particles Size (DPS) rutile reinforced LM13 alloy composite was investigated under varying applied pressure from 125 kPa to 625 kPa at a constant sliding speed of 1.6 m/s. In the present studies, 15 wt.% of rutile particles of different sizes (50-75 μm and 106-125 μm) are reinforced in the Al-12Si alloy (LM13) by liquid metallurgy route. Micro-hardness of the prepared samples was measured in different phases. Microstructure, wear mechanism and surface morphology of the wear surfaces and debris was observed under optical and scanning electron microscope. The change in wear behavior has been explained with reference to the observed EDS analysis of the wear track and debris. However, an interesting change in wear feature, mild to severe wear transition at critical pressure was noticed in wear behavior of the composite. The Al-DPS composite has immense potential to be used as a component material for tribological applications.

Introduction

Materials for many light weight applications can be developed by the incorporation of a ceramic phase in the soft aluminum alloy matrix. The addition of ceramic particles can significantly improve the mechanical and wear properties of the composites [1]. The degree of property enhancement depends upon the choice of the reinforcement which is dictated by several factors like intended application, availability and cost effectiveness. The volume fraction, shape, size, type of the reinforcement and processing technique employed for the fabrication of the composite play significant role in determining the mechanical and tribological properties [2-4]. In recent years, numerous research work have been reported on the composites reinforced with various type of ceramics like SiC, Al_2O_3, B, C, flyash, etc. Minerals like zircon, sillimanite, rutile, garnet etc. [5-9] as reinforcement material has been used because of low cost, availability and their environment friendly nature. Arora et al. [10] found that fine rutile particle size reinforced AMCs offers better wear resistance as compared to the coarse particle reinforced composites. Singh et al. [6] found that the wear rate of the composites and the matrix alloy increased with the increase in applied load and abrasive size of the sillimanite particles. Das et al. [11] used stir casting route for incorporating zircon sand particles of different sizes. The abrasion resistance of the composite increased with increase in the amount of reinforced particles. The increase in particle size of the reinforcement decreases the wear resistance of the aluminium rutile composite [7]. Suresh et al. [9] studied the change in microstructural feature of zircon

reinforced DPS composites containing 75% fine and 25% coarse particles and found that the composite to be better wear resistant material at all temperatures for both low and high loads.
In the present study, 15 wt.% of rutile particles of different sizes (50-75 μm and 106-125 μm) were reinforced in the Al-12Si alloy (LM13) by liquid metallurgy route. The developed samples were subjected to wear tests under the varying applied pressure from 125 kPa to 625 kPa at a constant sliding speed of 1.6 m/s. Microstructure and wear studies of the wear surfaces and debris was observed. It has been found that DPS composites offer great potential of developing materials with better mechanical properties and enhanced wear resistance.

Fabrication of Composites

A well known LM13 alloy was used as base material for the fabrication of the single particle size (SPS) and dual particle size (DPS) composites. Single and dual particle size composites containing 15wt.% rutile particles of different sizes (50-75 μm and 106-125 μm) of fine and coarse size in a defined proportion were prepared by a conventional stir casting process. This process involves the mixing of preheated rutile particles at 350 ºC in the vortex created by the melt at 800 ºC. The constant stirring of the melt by moving the impellar up and down during mixing ensured the uniform distribution of the rutile particles in the matrix. Further details on the fabrication of these composites are given elsewhere [7].

Experimental Techniques Used for the Characterization

The surface morphology of each sample was studied with the help of optical and scanning electron microscope at different magnifications. Elemental analysis of the composite at different phases was done with SEM-EDS. Micro hardness of the different phases of the composite was measured by using Vickers Hardness Testing Machine. Dry sliding wear test using pin-on-disc method was done to study the wear behaviour of the prepared composite. The samples of the cast composite were machined to 10 mm dia. cylindrical pins and the wear tests were performed on pin on disc tribometer under dry sliding conditions in ambient air at controlled temperature. Wear tests were conducted at different pressure of 125, 250, 375, 500 and 625 kPa. A constant sliding velocity of 1.6 $m\ s^{-1}$ was maintained throughout the experiment and sliding distance covered during the experiment was about 3000 meters. To study the wear behaviour, wear rate was calculated by using the formula, [W (mm^3/m) = height change (mm) × pin area (mm^2) / sliding distance (m)]. The worn surface regions (wear tracks) and collected debris after the dry sliding wear tests were also examined under scanning electron microscope. The change in wear behavior with the variation in applied pressure has been explained with reference to the observed EDS analysis of the wear track and debris.

Results and Discussion

Morphological Study of the Cast Composites

The SEM micrographs of composites reinforced with rutile fine size particles (50-75μm) and coarse size particles (106-125μm) and dual size particles illustrate the typical microstructure as shown in Figure 1 (a-d) respectively.

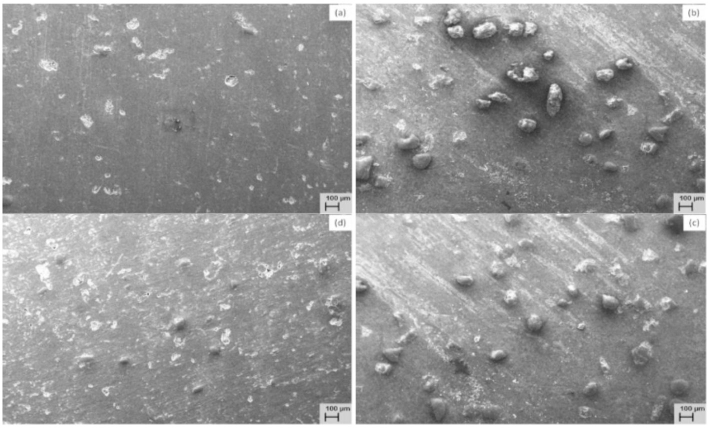


Figure 1 Optical micrograph of composites containing (a) 15wt.% fine (SPS1), (b) 15wt.% coarse (SPS2), (c) 3wt.% fine and 12 wt.% coarse (DPS2) and (d) 12wt.% fine and 3wt.% coarse (DPS1) particles.

The composites have shown the fairly uniform distribution of rutile particles which is achieved by the constant stirring action of the impeller which delays the particle settling tendency [4]. In the composite SPS1 (Fig.1a), the fine rutile particles are well dispersed and embedded in the matrix which confirms the good interfacial bonding between the particle and the matrix. The micrograph of SPS2 (Fig.1b), depicts loose bonding with the matrix owing to the less penetration of coarse particles in the matrix. The addition of 3% coarse size rutile particles as in the DPS1 composite has improved the microstructure as the large protruded rutile particles occupy the space between the fine particles hence lowers the agglomeration tendency of the fine particles during the solidification of the composite (Fig.1d). The inclusion of 3% fine rutile particles in the composite as in DPS2, (Fig.1c), not only enhances the bonding between the particle and the matrix but also hinders the dendritic growth in the particles depleted regions [10], which provides more refinement in the microstructure as compared to the SPS2.

Micro-hardness

Micro-hardness measurement has been carried out on the embedded reinforced particles as well as in the vicinity of particles and matrix shown in Figure 2. Reinforced particles show high hardness which decreases as we move away from particle into the matrix. The high hardness at particle/matrix interface indicates good interfacial bonding between particle and alloy matrix.

Effect of Applied Pressure on the Wear Behaviour

Wear Rate of the Composites: Wear rate of the composites as a function of sliding distance at variable contact pressure from 125kPa to 625 kPa is shown in Figure 3 (a,b). At a particular pressure, two type of wear behaviour are displayed by the composites during the dry sliding. The initial stages of run have shown very heavy wear loss due to the statistical fluctuations in wear as the abrasive wear between the two surfaces in relative motion is dominant. The continuous grinding of the abrasive particles of the two contacting surfaces while sliding reduces the sharpness of the asperities. These blunt shaped smooth abrasives cause fall in wear loss and the steady state is attained [9].

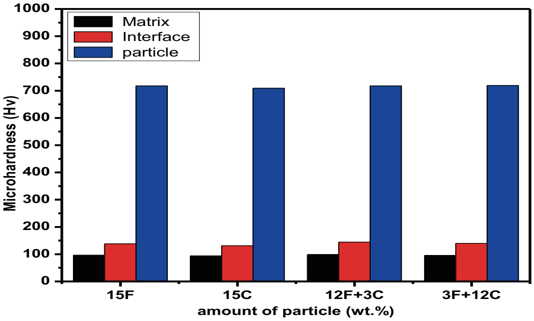


Figure 2. Bar graph of micro-hardness at different amounts ratio of rutile reinforced particle composites.

The difference in wear rates of the initial run in wear and steady state goes on continuously increasing with the applied pressure from 125kPa to 625 kPa. The increased pressure speeds up the crushing and grinding action of the protruded asperities, hence resulting in the increase in the wear loss. Application of high contact pressure of 625kPa causes the abrupt change in the wear rate which is evident from the comparison of the wear rates as shown in Fig 3(a, b). Increase in wear rate with the increase of pressure is on the same pattern as observed by Rao et al. [12]. High pressure during sliding, fractures the oxide film and lead to the exposure of the substrate material thus causing plastic deformation beneath the surfaces. This close contact welds the removed materials which can be transferred to the counterface and some of material may fall out as wear debris.

It may be noted from the Figures 3 (a,b) that the wear rate of the composite SPS1 is lower than that of the SPS2, as the large surface area of fine size rutile particles enhances the hardness of the composite which further lowers the wear rate. Also, the decreased inter-particle distance in the matrix of the composite SPS1 enhances the load bearing capacity of the matrix and hence increases the wear resistance. On comparing the wear rate of the DPS composites as shown in Figure 4 (a, b) it is observed that the DPS1 has shown more improvement in the wear resistance as compared to the DPS2.

The DPS1 has exhibited better wear resistance at all the applied pressures as fine particles provide more hardness to the matrix and subsequent addition of coarse rutile particles safeguard the matrix acting as a load bearing element. At the same time, inclusion of fine particles in the DPS2 has also shown improvement in wear behavior due to modification in the microstructure of the composite but the wear loss is higher as compared to the DPS1. The substitution of a portion of the particles in the SPS composite by fine or coarse particles to produce the DPS composite clearly helps in improving the wear resistance of the DPS composite over that of the SPS composite.

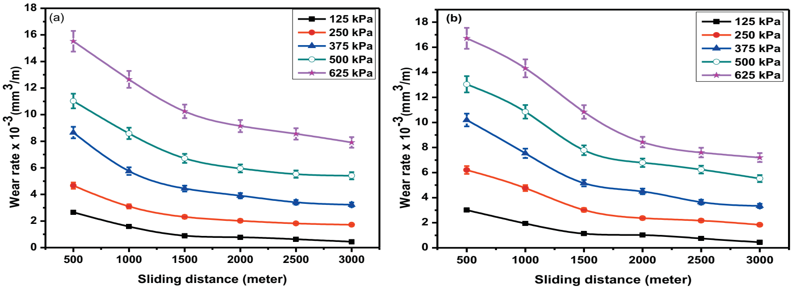


Figure 3.Wear rate of SPS composites against sliding distance at different applied pressure for (a) 15wt.%fine and (b) 15wt.% coarse size reinforced particle

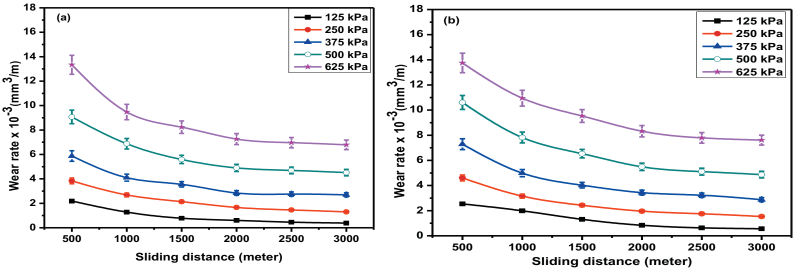


Figure 4.Wear rate of DPS composites against sliding distance at different applied pressure for (a) 4:1 and (b) 1:4 ratio of reinforced particle size.

Morphological Analysis of the Worn Surfaces and Wear Debris: Figure 5(a-d) shows the SEM images of wear tracks of the composites DPS1 and DPS2 tested at 125kPa and 625kPa pressure, respectively. The abrasive grooves on the worn surface of composites at low pressure (125kPa) are due to the abrasive action of the asperities of the steel disc in the matrix. As the hard ceramic particles resisted the deformation of the asperities so the composites wear behaviour lies in the mild wear regime.

At higher contact pressure 625kPa, the material removal is governed by adhesive wear and delamination of matrix material. The material removal is enhanced by adhesive wear mechanism and number of craters is increased showing deep ploughing marks, as shown in Figure 5b. The large craters visible on the surface underneath with the presence of cracks indicate the delamination wear. On increasing the contact pressure to 625kPa, change in wear transition from mild to severe is observed. It is confirmed by heavy damages caused to the specimen surfaces by the delamination wear. At low contact pressure 125kPa, ribbon type morphology in wear debris is more often visible because of the decreased interspacing between the particles in the composite that reduces the abrasive wear of composite (Figure 6a & 6b).

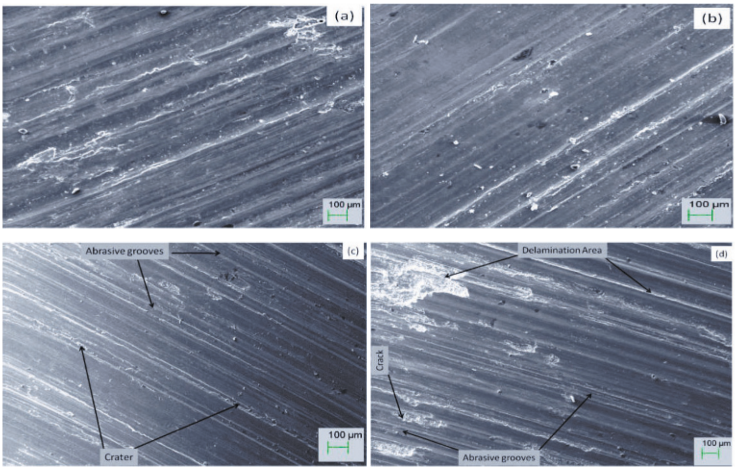
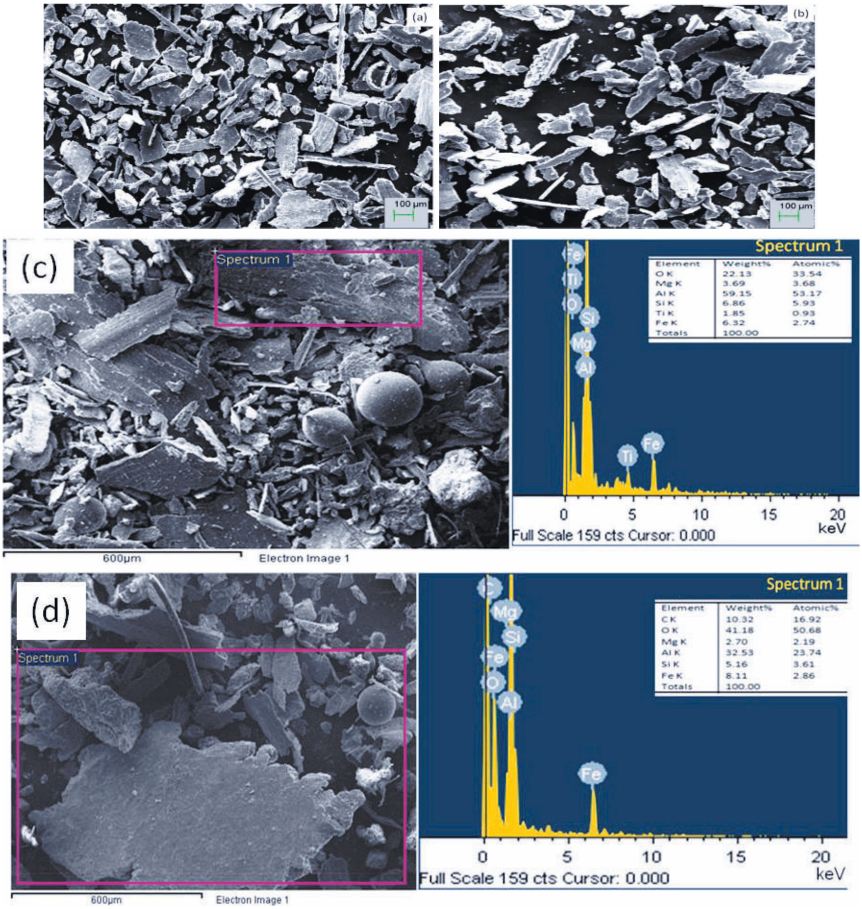


Figure 5. SEM micrographs of wear tracks of composites DPS1 (a) 125 kPa, (b) 625 kPa and DPS2: (c) 125 kPa, and (d) 625 kPa pressure.

Noodles type structure observed on the wear debris is due to the continuous rubbing and crushing of debris between grooves during the wear test of composite SPS1. At higher contact pressure 625kPa, adhesive wear as well as delamination of matrix material resulting from the crack propagation equally contribute towards the loss of material. Rolled delaminated debris depicts that surface has acquired the recrystallization temperature due to the generation of frictional heat during sliding [10]. Molten metal balls are formed by the continuous rubbing of the thread like debris between the two surfaces. Large plate type debris with cracks confirms the dominance of delamination wear which is shown in Fig 6c & d. Shiny and metallic balls as well as corrugated debris are also formed resulting from the adhesive wear. At high contact pressure wear mechanism is governed by the adhesive and delamination wear in the severe wear regime as indicated by the size, shape and the state of the wear debris.

It is observed from EDS spectrum that certain amount of oxide layer has formed and is stably sustained on the contacting asperities. Oxide layer can provide full protection and mild oxidative wear prevailed. EDS analysis (Figure 6c & d) of debris indicate the presence of O, Mg, Al, Si, Ti and Fe elements. This indicates that apart from base metal, rutile is also coming out from the surface. Presence of Fe in the debris may be due to the transfer of steel counterface to the composite surface. The transfer of steel inclusions from counterface surfaces to the composite wear surfaces is another mechanism which contributes to increase in wear resistance of the composites. On comparing the worn surfaces and debris of the composites at high contact pressure, it can be concluded that the DPS1 composite displays the better wear performance at all contact pressures as compared to the other composites as the size of the rutile particles plays dominant role in determining the wear behaviour of the composite.



Spectrum 1

Element	Weight%	Atomic%
O K	22.13	33.54
Mg K	3.69	3.68
Al K	59.15	53.17
Si K	6.86	5.93
Ti K	1.85	0.93
Fe K	6.32	2.74
Totals	100.00	

Spectrum 1

Element	Weight%	Atomic%
C K	10.32	16.92
O K	41.18	50.68
Mg K	2.70	2.19
Al K	32.53	23.74
Si K	5.16	3.61
Fe K	8.11	2.86
Totals	100.00	

Figure 6. SEM micrographs of composites: wear debris at 125 kPa pressure (a) SPS1 (b) SPS2 wear debris and EDS at 625 kPa pressure of (c) SPS1 (d) SPS2 composites.

Conclusions

The size of the rutile particles greatly influences the tribological behavior of the aluminium alloy. Rutile particles inclusion in the matrix modifies the microstructure which in turn improves the wear behavior of the composite. Dual particle size composites turn out to be better wear resistant material under the high contact pressure as compared to single particle composites. At a critical pressure, change in wear feature, mild to severe wear transition takes place which is confirmed from the morphology of the wear tracks and the wear debris.

References

1. G. B. Veeresh Kumar, C. S. P. Rao and N. Selvaraj, “Studies on Mechanical and Dry Sliding Wear of Al6061-Sic composites a review” *Composites*, 43 (2012), 1185-1191.

2. Kamalpreet Kaur,Ramkishor Anant and O. P. Pandey, “Tribological Behaviour of SiC Particle Reinforced Al–Si Alloy”, *Tribol. Lett.,*44(2010), 51-58.

3. S. Kumar, "Effect of Reinforcement Size, and Volume Fraction on the Abrasive Wear of AA7075 Al/SiCp P/M composites-A Statistical Analysis", *Tribol. Inter.*,43 (2010), 414-422

4. J. Hashim, L. Looney and M.S.J. Hashmi, “Metal matrix composites: production by the stir casting method”, *J. Mater. Proces. Technol.*92 (1999), 1-7.

5. S. Kumar, R. S. Panwar, and O. P. Pandey, “Tribological characteristics of Aluminium tri-reinforced particles composites developed by liquid metallurgy route”, *Advd.Mater.Rearch.,*585(2012), 574-578.

6. M. Singh, D.P. Mondal, A.K. Jha, S. Das and A.H. Yegneswaran, “Preparation and properties of Cast Aluminium Alloy–Sillimanite Particle Composite”, *Composites*, 32 (2001), 787-795.

7. Rama Arora**,** Suresh Kumar, Gurmel Singh and O.P. Pandey, “Influence of Particle Size and Temperature on the Wear Properties of Rutile Reinforced Aluminium Metal Matrix Composite”, *Journal of Composite Materials*, DOI: 10.1177/0021998314526079

8. Anju Sharma, Suresh Kumar, Gurmel Singh and O.P. Pandey,“Effect of Particle Size on Wear Behaviour of Al-Garnet Composites,”*Particulate Science and Technology*,(DOI: 10.1080/02726351.2014.954686).

9. S. Kumar, R. S. Panwar, and O. P. Pandey, “Effect of dual reinforced ceramic particles on high temperature tribological properties of aluminum composites”, *Ceramics Inter.*,39(2013), 6333-6342.

10. Rama Arora, Suresh Kumar, Gurmel Singh and O.P. Pandey,“Role of Different Range of Particle Size on Wear Characteristics of Al-Rutile Composites”, *Particulate Science and Technology,* DOI**:** 10.1080/02726351.2014.953648

11. Sanjeev Das., V. Udhayabhanu and S. Das "Synthesis and Characterization of Zircon Sand/Al-4.5 wt% Cu Composite produced by Stir Casting route*., J. Mater. Sci.,* 41 (2006), 4668-4677.

12. R.N. Rao and S. Das, “Effect of Applied Pressure on the Tribological Behaviour of SiCp Reinforced AA2024 Alloy”, *Tribol. Inter.,*8 (2011), 454-462.