Dry sliding wear of heat treated hybrid metal matrix composites

Mohammed Naveed1 and A R Anwar Khan 2

1 Department of Mechanical Engineering, Ghousia College of Engineering, Ramanagaram, Visveswaraya Technological University, Karnataka, India- 562159 / naveed.gce1980@gmail.com/ 
2 Department of Mechanical Engineering, Ghousia College of Engineering, Ramanagaram, Visveswaraya Technological University, Karnataka, India- 562159 / drarak_gce@rediffmail.com

Abstract. In recent years, there has been an ever-increasing demand for enhancing mechanical properties of Aluminium Matrix Composites (AMCs), which are finding wide applications in the field of aerospace, automobile, defence etc., Among all available aluminium alloys, Al6061 is extensively used owing to its excellent wear resistance and ease of processing. Newer techniques of improving the hardness and wear resistance of Al6061 by dispersing an appropriate mixture of hard ceramic powder and whiskers in the aluminium alloy are gaining popularity. The conventional aluminium based composites possess only one type of reinforcements. Addition of hard reinforcements such as silicon carbide, alumina, titanium carbide, improves hardness, strength and wear resistance of the composites. However, these composites possessing hard reinforcement do possess several problems during their machining operation. AMCs reinforced with particles of Gr have been reported to be possessing better wear characteristics owing to the reduced wear because of formation of a thin layer of Gr particles, which prevents metal to metal contact of the sliding surfaces. Further, heat treatment has a profound influence on mechanical properties of heat treatable aluminium alloys and its composites. For a solutionising temperature of 550°C, solutionising duration of 1hr, ageing temperature of 175°C, quenching media and ageing duration significantly alters mechanical properties of both aluminium alloy and its composites. In the light of the above, the present paper aims at developing aluminium based hybrid metal matrix composites containing both silicon carbide and graphite and characterize their mechanical properties by subjecting it to heat treatment. Results indicate that increase of graphite content increases wear resistance of hybrid composites reinforced with constant SiC reinforcement. Further heat treatment has a profound influence on the wear resistance of the matrix alloy as well as its hybrid composites. For all the heat treatment processes studied ice quenching with ageing duration of 6hrs resulted in improved wear resistance of both the unreinforced matrix alloy and its hybrid composites.

1. Introduction
In recent years aluminium matrix composites (AMCs) are gaining widespread popularity in several technological sectors owing to their excellent corrosion and wear resistance, higher fatigue life, good high temperature oxidation resistance in addition to being light in weight when compared with conventional alloys. At present AMCs are attractive alternatives for aerospace and automotive applications because of their high stiffness-to-weight characteristics. Currently, focus on development of aluminium, copper, magnesium, titanium based metal matrix composites is carried out to explore their possible applications in several high-tech areas. The various reinforcements that have been tried out to develop AMCs are graphite, silicon carbide, titanium carbide, tungsten, boron, Al2O3, flyash, Zr, Si3N4, TiB2. The conventional aluminium based composites possess only one type of reinforcements. Addition of hard reinforcements such as silicon carbide, alumina, titanium carbide, improves hardness, strength and wear...
resistance of the composites. However, these composites possessing hard reinforcement do possess several problems during their machining operation. AMCs reinforced with particles of Gr have been reported to be possessing better wear characteristics owing to the reduced wear because of formation of a thin layer of Gr particles, which prevents metal to metal contact of the sliding surfaces. AMCs reinforced with SiC particulates are known for higher modulus, strength and wear resistance compared to conventional alloys. Addition of SiC particulates increases both mechanical strength and wear resistance of Al alloy. But the consequent increase in hardness makes the machining difficult. On the other hand, addition of Gr particulates facilitates easy machining and results in reduced wear of Al–Gr composites compared to Al alloy [1]. It is reported that the surface finish of the hard reinforced metal matrix composites are inferior when compared with the matrix alloy. Further it is absorbed that during turning, the hard reinforced metal matrix composites resulted in higher flank wear with increased content of the reinforcement. It is reported that composites possessing softer reinforcement possess good machinability index.

Hence the current interest is to produce Hybrid Metal Matrix Composites (HMMCs) were in more than one type, shape and size of the reinforcement are used to obtain synergistic properties of the reinforcement and the matrix chosen. It is reported that hybridization of reinforcement has enhanced structural, physical, mechanical and tribological behavior of HMMC’s when compared with metal matrix alloy. Hence attempts are made to develop aluminum based hybrid metal matrix composites consisting of both hard reinforcement (SiC) and soft reinforcement (Gr) in the present paper. Further to enhance the mechanical properties, the specimens are subjected to heat treatment processes.

2. Experimental details

2.1 Composite preparation
Al6061 based composites were prepared by vortex method of liquid metallurgy route. A quantity of 3kgs of Al6061 alloy was used each time in an electric melting furnace with graphite crucible for melting with furnace temperature set at 710°C. Silicon carbide particles of 10 micron size and graphite particles of 60 micron size were used. The permanent molds of cast iron along with the reinforcements were heated in order to reduce the effect of chilling during solidification. Degassing of the melt was done with commercially available tablets of hexachloroethane (C₂Cl₆). After degassing, the preheated SiC and Gr were added slowly into the vortex while continuing the stirring process up to 10 minutes. The amount of reinforcement was varied from 1wt% to 4wt% in steps of 1wt% of Gr keeping constant 7wt%SiC.

2.2 Heat treatment
Heat treatment was carried out in an electric furnace. The specimens were heat treated for a solutionising temperature of 550°C, for duration of 1hr. After that they were cooled in air, water and ice medium respectively. They were further subjected to secondary heat treatment at ageing temperature of 175°C for duration of upto 6 hrs for ice and water quenched specimen while about 8 hrs for air quenched specimen. They were further cooled in air under normal room temperature.

2.3 Evaluation of dry sliding wear.
Friction and wear test of both Al6061 and its hybrid composites were studied using standard pin on disc wear test rig of diameter 10mm and height 23mm. Finely ground samples were used. Hardened steel disc of Rc 60 was used as counter disc. Before loading the samples on the test rig the surface of the hardened steel disc was thoroughly cleaned with acetone. The loss of height of the samples was recorded at different intervals of time ranging from 5mins to 30mins by use of LVDT of accuracy of 1μm. On wearing of the pin surface during rubbing with counter disc, the pin continuously moves down to re-establish the contact with the disc surface. This linear downward motion of the pin is thus a measure of wear loss of the
pin material. Friction and wear studies were conducted at constant load of 10N and track radius of 50mm. The sliding velocity was set at 15.7 m/sec.

3. Results and discussion

3.1 Effect of reinforcements without heat treatment.
The effect of reinforcements on wear resistance of AL6061 alloy and its composites with sliding distance is as shown in figure 1.

![Figure 1. Effect of reinforcements on wear resistance of AL6061 alloy and its composites](image)

It is observed from figure 1 that there is decrease in material loss with an increase in graphite reinforcement with constant SiC. However, at all the reinforcements studied, the material loss of the hybrid composites were much lower when compared with the matrix alloy and reduced with increased content of reinforcement of graphite in the composites.

3.2 Effect of reinforcements with heat treatment.
The effect of reinforcements on wear resistance of heat treated AL6061 alloy and its composites for different quenching medium is shown in figure 2.
It is observed from figure 2 that there is improvement in wear resistance of specimen subjected to heat treatment. Heat treatment has a profound influence on the wear resistance of the matrix alloy as well as its hybrid composites. For a solutionising temperature of 550°C, for duration of 1hr, quenching media significantly enhances the wear resistance of both the matrix alloy and its composites. The lowest material loss was observed for both the matrix alloy and its composites when quenching medium was ice. In all the quenching media studied, composites exhibited lower material loss compared to the matrix alloy. Among the quenching media, ice quenched specimen showed the best result followed by water and air.

3.3 Effect of sliding velocity without heat treatment.

The effect of sliding velocity on wear resistance of AL6061 alloy and its composites is as shown in figure 3.
It is observed from the figure 3 that the wear resistance of Al6061 alloy and its hybrid composite decreases with increase in sliding velocity. At all the sliding velocity studied an increase in the content of Gr in the matrix alloy results in improved wear resistance. Increased sliding velocity will result in higher relative motions leading to rise in surface temperatures of the sliding members. An increase in surface temperature promotes oxidation of the transformed iron layers from the counter disc on the pin surface. Further the extent of grooving on the pin surfaces will be reduced because of the formation of the beneficial tribological film as a consequence of which the size of the debris tends to be smaller in size at larger sliding velocity.

3.4 Effect of sliding velocity on quenching media.
The effect of sliding velocity on wear resistance of heat treated AL6061 alloy and its composites for different quenching media is shown in figure 4

![Figure 4](image)

**Figure 4.** Effect of sliding speed on wear resistance of heat treated AL6061 alloy and its composites.

It is observed from the figure 4 that the wear loss of Al6061 alloy and its hybrid composites decreases with increase in sliding velocity. At all the sliding velocity studied an increase in the content of Gr in the matrix alloy results in improved wear resistance. Further it is observed that there is improvement in wear resistance of specimen subjected to heat treatment. Heat treatment has a profound influence on the wear resistance of the matrix alloy as well as its hybrid composites. For a solutionising temperature of 550°C, for duration of 1hr, ageing temperature of 175°C, quenching media and ageing duration significantly enhances the wear resistance of both the matrix alloy and its composites. The lowest material loss was observed for both the matrix alloy and its composites for ageing duration of 6hrs when quenching medium was ice.

3.5 Effect of load without heat treatment.
The effect of load on wear resistance of AL6061 alloy and its composites is as shown in figure 5.
Figure 5. Effect of load on wear resistance of AL6061 alloy and its composites

Figure 5 shows the variation of wear loss with increase in loads. With the increase in load there is a higher wear loss for both the matrix alloy and the composite. However at all the loads studied, the wear loss of the hybrid composites were lower when compared with the Al6061-SiC composites and matrix alloy. Increased loads will result in onset of delamination leading to higher wear loss of both matrix alloy and its composites. A higher wear loss of the composites at higher loads can be mainly attributed to particle damage or particle pull out.

3.6 Effect of load on quenching media.
The effect of load on wear resistance of heat treated AL6061 alloy and its composites for different quenching medium is shown in figure 6
Figure 6. Effect of load on wear resistance of heat treated AL6061 alloy and its composites.

Figure 6 shows the variation of wear loss with increase in loads. With the increase in load there is a higher wear loss for both the matrix alloy and the composite. However at all the loads studied, the wear loss of the hybrid composites was less when compared with the Al6061-SiC composites and matrix alloy as stated earlier. Further it is observed that there is improvement in wear resistance of specimen subjected to heat treatment with increase in load. Heat treatment has a profound influence on the wear resistance of the matrix alloy as well as its hybrid composites. For a solutionising temperature of 550°C, for duration of 1hr, ageing temperature of 175°C, quenching media and ageing duration significantly enhances the wear resistance of both the matrix alloy and its composites. The lowest material loss was observed for both the matrix alloy and its composites for ageing duration of 6hrs when quenching medium was ice.

4. Fractography

Scanning electron micrographs of tested specimen for AL 6061 alloy and its composites not subjected to heat treatment and subjected to heat treatment (ice quenched) is shown in figure 7.
Figure 7. Scanning electron micrographs of Al6061 and its composites
From the figure 7, it can be observed that the surface morphology has changed significantly on heat treatment. It is observed that on use of ice as quenching media, the surface morphology appears to be fine in size. This observation leads one to conclude that wear rates will be significantly lower on ice quenching.

**Conclusion**

Al6061-SiC-Gr hybrid composites have been successfully produced by vortex method upto 4wt% Gr with constant 7wt% SiC. Fabrication of hybrid composites with more than 4wt% of Gr with constant 7wt% SiC was not achieved successfully due to low density of graphite. Wear resistance of Al6061 increases with presence of SiC. Wear resistance of Al6061 increases with increase in graphite content. Presence of hard silicon carbide reinforcement in the hybrid composites leads to enhancement in wear resistance of hybrid composites reinforced with graphite. Further heat treatment has a profound influence on the wear resistance of the matrix alloy as well as its hybrid composites. For all the heat treatment processes studied ice quenching with ageing duration of 6hrs resulted in improved wear resistance of both the unreinforced matrix alloy and its hybrid composites.

**References**

[1] Surappa M K, Prasad SV and Rohatgi P K 1982 *Wear* **77** 295.
[2] Surappa M K and Rohatgi P K 1978 *Met Technol* **5** 358.
[3] Son H T, Kim T S, Suryanarayana C and Chun BS 2003 *Mater Sci Eng* A **163**.
[4] Lin C B, Chang R J and Weng W P 1998 *Wear* **167**.
[5] Ted Guo M L and T sao C Y A 2000 *Compos Sci Technol* **60** 65.
[6] Pai B C and Rohatgi P K 1978 *J Mater Sci* **13** 329.
[7] Yen B K and Ishihara T 1996 *Wear* **198** 169.
[8] Jha A K, Prasad S V and Upadhyaya G S 1989 *Powder Metall* **32** 309.
[9] Ted Guo M L and T sao C YA 2002 *Mater Sci Eng* A **134**.
[10] Akhlaghi F and ZareBidaki A 2009 *Wear* 37.
[11] M Babic , Stojanovic, Mitrovic , Bobic B, Miloradovic, M Pantic and D zunic 2013 *Tribology in industry* **35** 148
[12] A Muniaraj, Sushilal Das and K Palanikumar 2013 *Indian journal of science and technology* **6** 5002
[13] T Rajmohan, S Ranganathan and T S A Suryakumari 2014 *International journal of advanced engineering applications* **7** 11
[14] Vinod Kumar, Surender Sharma and Anup Verma 2014 *International journal of engineering trends and technology* **8** 181