Middle-East Journal of Scientific Research 22 (1): 128-133, 2014
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2014.22.01.21833

# A Study on Wear Behaviour of Aluminium Matrix Composites with Ceramic Reinforcements

*M. Manikandan and A. Karthikeyan*

Department of Mechanical Engineering,
Sathyabama University, Chennai, Tamilnadu, India, Pincode: 600119

**Abstract:** Aluminium Alloys (AA) are highly used in many engineering applications because of its weight light property. But, these alloys are lack to resist wear and become ailing for tribological applications. This phenomenon raises the need for Aluminium Matrix Composites (AMCs) for high performance tribological applications. Generally, the reinforcements are added with the AA to form AMCs through liquid casting technique. The influence of reinforcements in AMCs samples are tested to find the improvement in mechanical and tribological properties. The mechanical properties like hardness and tensile strength are tested. The wear mechanism involved in the improvement of tribological property is studied using the microscopic images. The results of various reinforcements in AMCs are consolidated and the superior reinforcement is identified for tribological applications.

**Key words:** Wear · Aluminium Matrix Composites · Reinforcements · Casting

## INTRODUCTION

Aluminium alloys (AA) play a vital role in various engineering fields owing to their superiority in strength to weight ratio and other mechanical properties [1]. However the difficulty of AA is that they exhibit low resistance to wear in tribological applications. Among the AA, AA 7075 exhibits good mechanical properties so it is heavily used in many engineering applications [2].

To improve their tribological properties, Aluminium Matrix Composites (AMCs) with graphite particulate composites are being explored. These self-lubricating composites have accentuated due to their excellent anti-seizure effect [3-6], low thermal expansion, high damping capacity [7, 8], low friction and wear [9-12] and reduced temperature rise [13] at the wearing contact surface.

The addition graphite particle with the AA through liquid casting reduces the mechanical properties so it becomes weak in engineering applications [14]. But with an addition of ceramic particles like SiC, $Al_2O_3$, $B_4C$, TiC, $TiB_2$, MgO, $TiO_2$ and BN will improve both the mechanical and wear properties [15].

Mostly, the ceramic reinforcements in AMCs are SiC, $Al_2O_3$ and $B_4C$. Many researchers did their work separately with these reinforcements and stated the optimum level of reinforcement addition in the AMCs. The addition of $Al_2O_3$ (Alumina) with the AA results in good improvement of mechanical and wear properties. The optimal level of $Al_2O_3$ was identified as 6wt. % in the AMCs [16].

Baradeswaran and Elaya Perumal stated that the addition of hard $B_4C$ particle with 10wt. % in AMCs will increase the wear resistance and also it improves the mechanical property [17]. The SiC particle addition in AMCs exhibits good tribological applications due to its improved wear resistance and hardness. The better SiC addition was identified with 5wt. % in AMCs [18].

From the literature survey, it was inferred that the addition of ceramic particles with AA will improve the mechanical and wear properties [19]. But the superior reinforcement addition with AA is yet being a research gap. This attempt aims to evaluate the various ceramic reinforcements in AMCs and to identify the superior wear behaviour influencing reinforcement.

## MATERIALS AND METHODS

**Material Selection:** Commercial grade aluminium AA 7075 was used as the matrix material and the reinforcements are SiC, $Al_2O_3$ and $B_4C$ with the size ranging from 16µm to 20µm. The chemical composition of the AA 7075 is shown in Table 1.

**Corresponding Author:** M. Manikandan, Department of Mechanical Engineering, Sathyabama University, Chennai, Tamilnadu, India, Pincode: 600119.

Table 1: Chemical Composition of AA 7075

| Zn | Cu | Mn | Mg | Fe | Cr | Ti | Si | Al |
|---|---|---|---|---|---|---|---|---|
| 5.4 | 1.42 | 0.12 | 2.42 | 0.42 | 0.21 | 0.11 | 0.13 | 89.77 |

**Sample Preparation:** For composite preparation, the simplest and cost effective route used to cast is stir casting method (liquid casting method) [20]. Aluminium metal matrix (AA 7075) is melted at 850°C in a graphite crucible. When the temperature of the melt is about 30°C above the pouring temperature, the preheated stirrer is introduced in the melt. The agitation of the melt is started and the preheated $Al_2O_3$ particle of 6wt. % is introduced. The stirring is continued to ensure a proper mixing and slurry. It is subsequently stirred at 300rpm, by using an impeller attached to the variable speed motor. The slurry of the composites is prepared and poured into the steel moulds to solidify to form AA 7075/ Alumina composite.

The same way other composites are prepared by varying the reinforcement and its percentage. For AA 7075/ SiC composite preparation, use 5wt. % of SiC particle instead of $Al_2O_3$ particle. For AA 7075/BC composite preparation, use 10wt. % of $B_4C$ along with 10wt. % of $K_2TiF_6$ flux to over wettability [21]. The solidified composites undergo a T6 heat treatment and the samples are prepared as per the requirements of the testing methods.

The commercial OHNS stainless steel disc with 62HRc hardness was prepared to act as the counter body in the wear test.

**Testing Methods**

**Hardness Test:** Hardness tests were carried out on the matrix aluminium alloy and composite material specimens on a Brinell hardness testing machine. The specimens were metallographically polished for conducting the hardness test. A define force is mechanically applied on the specimen for about 30 seconds with five trails.

AMCs are tested using the steel ball indenter of 10mm Diameter (D) under a load 500Kg (P) into the specimen for 30s and the mean diameter (d) of the impression left on the surface after the removal of the load is measured. The Brinell Hardness Number (BHN) is then calculated using the equations (1) and (2).

Depth of indentation (h) is given by,

$$h = \frac{D}{2(D^2 - d^2)} \tag{1}$$

$$BHN = \frac{P}{\prod Dh} \tag{2}$$

**Tensile Strength Test:** Tensile strength test is conducted as per ASTM E08-8 on the samples in computerized ultimate tensile testing machine (UTE40). Since it is a computerized machine, the break-point and results are recorded accurately.

**Wear Test:** A pin on disc apparatus is used to investigate the dry sliding wear characteristics of the aluminium alloy and the composites under different load conditions. The applied load is varied from 20N to 60N with sliding velocity of 1-3m/s for 2000m sliding distance. Wear specimens of 6mm diameter and 15mm height were machined from the cast samples and polished metallographically for the wear test. Before each test, the disc surface was polished with grade 220 SiC paper to a Central Line Average (CLA) value of 2µm. A digital weighing balance machine is used for determining the weight of the pins before and after the wear test and the corresponding coefficient of friction (COF) are recorded. The worn surfaces were analyzed by using the JEOL-MODEL 6390 Scanning electron microscope. The wear rate is calculated from the equation (3).

$$\text{Wear Rate} = \frac{\text{Wear Mass Loss}}{\text{Sliding Distance}} \text{ (mg/m)} \tag{3}$$

## RESULTS AND DISCUSSION

**Hardness:** From the Figure 1, it is inferred that the hardness of the AMCs are higher compared to AA 7075. This effect is due to the influence of hard ceramic particles into the soft surface [22]. Among the various AMCs, the AA 7075/BC composite exhibits higher hardness. This is due to the fact that aluminium is a soft material and the reinforced particle, especially ceramics, being hard, contributes positively to the hardness of the composites.

**Tensile Strength:** The Figure 2 shows the variation of tensile strength of the AMCs with the influence of various reinforcements. This result is similar with the Figure 1. The peak is obtained at the same AA 7075/BC composite. This phenomenon is due to the indention of higher strength in to the matrix alloy which offers more resistance to the tensile stress. In the process of load transfer, the matrix transfers the load to the $B_4C$ particles, so if the boundary is assumed to be strong, $B_4C$ particles prevent plastic deformation of the matrix and this lead to the direct strengthening of the composites.

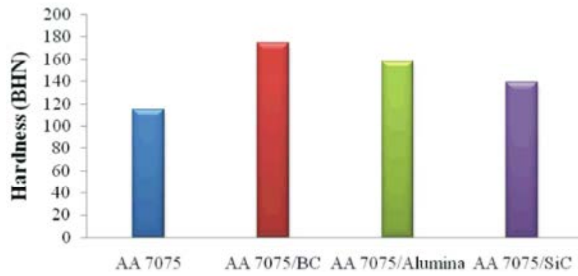


Fig. 1: Comparison of hardness

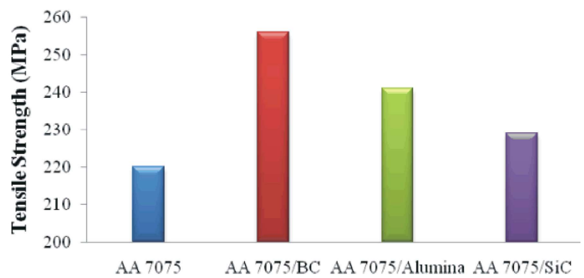


Fig. 2: Comparison of tensile strength

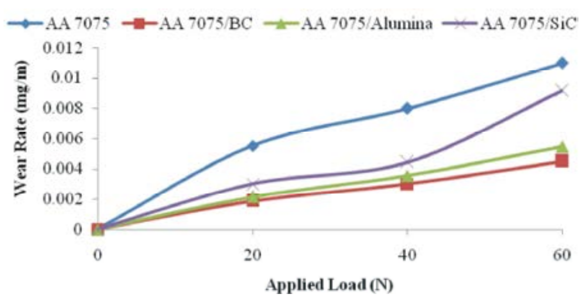


Fig. 3: Effect of applied load

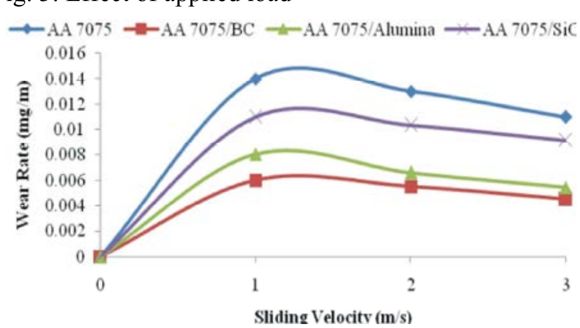


Fig. 4: Effect of sliding velocity

**Wear Behaviour**

**Effect of Applied Load:** The wear test was conducted at constant sliding velocity of 3m/s and 2000m sliding distance by varying the applied load from 20-60N for various AMCs was shown in Figure 3. From this figure it is infer that the wear rate increases with increasing the applied load but in all load conditions the AMCs remains less compared to AA 7075 matrix. This effect is because of the greater pressure on the hard ceramic, which is distributed over the AA 7075 and tends to the wear mass loss of the composite [23].

The AA 7075/BC composite exhibits the superior wear resistance compared to others. This is because of excellent wear and heat resistances due to superior hardness and heat resistance characteristics of the particles that are dispersed in the matrix. The higher wear resistance of composite materials can be attributed to the presence of $B_4C$ particles that can be act as the load-bearing elements.

**Effect of Sliding Velocity:** The wear test was conducted at constant applied load of 60N and 2000m sliding distance by varying the sliding distance from 1-3m/s for various AMCs was shown in Figure 4. From this figure it is infer that the wear rate decreases with increasing the sliding distance and in all conditions, the AMCs remains less compared to AA 7075 matrix. This is due to the metal to metal conduct is high at low sliding velocity and it tends to plough the surface and cause high wear. The $B_4C$ in the AA 7075/BC composite influence the wear resistance and helps in preventing wear.

**Sem Analysis:** The SEM micrographs (Figure 5) show the formation of grooves, patches and deformation on the worn surfaces of the various composites at 60N applied load, 3m/s sliding distance for 2000m sliding distance. The heavy plastic deformation is visible in AA 7075, which confirms the wear results of Figure 3 & 4.

The less wear is noticed in Figure 5(b), it helps to infer that the AA 7075/BC composite exhibits the superior wear resistance compared to other AMCs and base alloy. This effect is due to the formation of mechanically mixed layer (MML), which is shown in figure 6. This band acts as a preventive layer for wear mechanism.

**COF:** The COF is inferred from Figure 7, shows the minimum COF about 0.3 is noticed at AA 7075/BC. Since $B_4C$ acts as a solid lubricant and prevents the sliding wear by forming smooth surface. This improves the tribological behaviour of the composite, far better than that of the matrix alloy and properties such as the wear rate and coefficient of friction decrease considerably for this composite [24].

The SiC composite exhibits better wear resistance compared to AA 7075 but its tribological properties resembles the base alloy. This result agrees with the results of wear test [25].

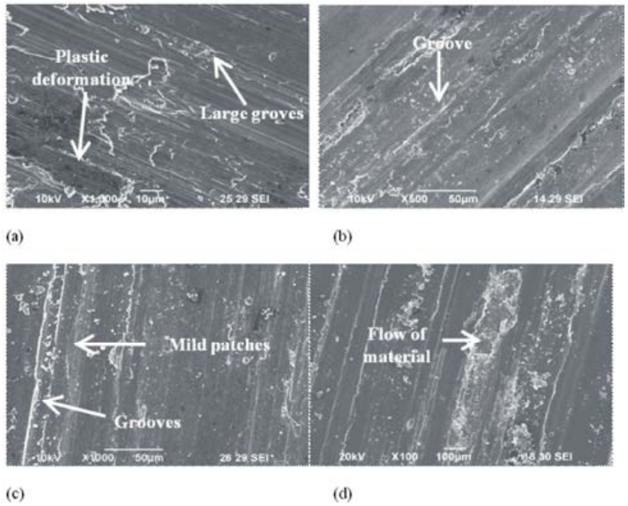


Fig. 5: SEM images of worn surfaces (a) AA 7075 (b) AA 7075/BC composite (c) AA 7075/ Alumina composite and (d) AA 7075/ SiC composite

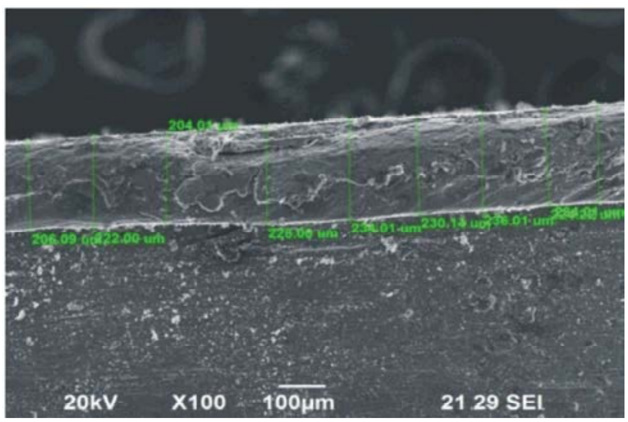


Fig. 6: MML layer of AA 7075/BC composite

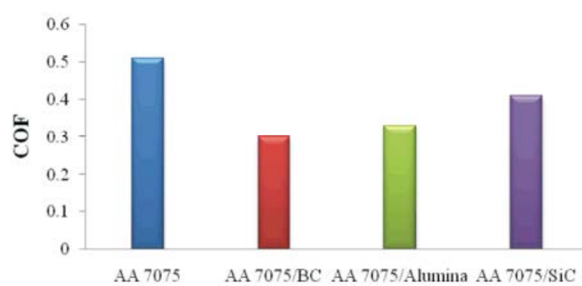


Fig. 7: Comparison of COF

## CONCLUSION

- The attempt made to prepare the AMCs for tribological applications was done using liquid casting technique. The AMCs were manufactured with AA 7075 and hard ceramic $B_4C$/ SiC/ $Al_2O_3$ with optimal level of wt. %.
- The mechanical properties like hardness and tensile strength were improved to the influence of hard ceramic particles. The $B_4C$ in the AA 7075/BC composite results the peak of hardness and tensile strength. This is due to the higher strength, strong interfacial bond and hard particles.
- The wear test was conducted using pin-on-disc apparatus by varying applied load and sliding distance for a constant sliding distance. The results evidence that the wear rate increases with increasing applied load and decreasing sliding velocity.
- At all conditions the AMCs exhibits better wear resistance compared to base alloy, among AMCs, the AA 7075/BC composite exhibits the superior wear resistance. It was confirmed through the microscopic analysis.

- The similar results were observed with the COF results. By this it confirms that the superior AMC's reinforcement was $B_4C$ for high performance tribological applications.

## REFERENCES


1. Baradeswaran, A., 2011. A. Elayaperumal, Effect of Graphite Content on Tribological behaviour of Aluminium alloy - Graphite Composite, European Journal of Scientific, 53(2): 163-170.
2. Baradeswaran, A. and A. Elaya Perumal, 2014. Study on mechanical and wear properties of Al 7075/$Al_2O_3$/graphite hybrid composites, Composites: Part B, 56: 464-471.
3. Chu, H.S., K.S. Liu and J.W. Yeh, 2010. An insitu composite of Al (graphite, $Al_4C_3$) produced by reciprocating extrusion. Materials Science and Engineering, 277: 25-32.
4. Ted Guo, M.L. and C.Y.A. Tsao, 2002. Tribological behavior of aluminum/SiC/nickel-coated graphite hybrid composites, Materials Science and Engineering, 333: 134-145.
5. Akhlaghi, F. and A. Zare Bidaki, 2009. Influence of graphite content on the dry sliding and oil impregnated sliding wear behavior of aluminium 2024 – graphite composites produced by in situ powder metallurgy method, Wear, 266: 37-45.
6. Rohatgi, P.K. and B.C. Pai, 1980. Seizure resistance of cast aluminum alloys containing dispersed graphite particles of various sizes, Wear, 59: 323-332.
7. Bermudez, M.D., G. Martinez-Nicolas, F.J. Carrion, I. Martinez-Mateo, J.A. Rodriguez and E.J. Herrera, 2001. Dry and lubricated wear resistance of mechanically-alloyed aluminium-base sintered composites, Wear, 248: 178-186.
8. Wei, J.N., H.F. Cheng, Y.F. Zhang, F.S. Han, Z.C. Zhou and J.P. Shui, 2002. Effects of macroscopic graphite particulates on the damping behavior of commercially pure aluminium, Materials Science and Engineering, 325: 444-453.
9. Rohatgi, P.K., S. Ray and Y.Liu, 1992. Tribological properties of metal matrix–graphite particle composites, International Materials Review, 37(3): 129-149.
10. Hocheng, H., S.B. Yen, T. Ishihara and B.K. Yen, 1997. Fundamental turning characteristics of a tribology-favoured graphite/aluminum alloy composite material, Composites A, 28: 883-890.
11. Ted Guo, M.L. and C.Y.A. Tsao, 2000. Tribological behavior of self-lubricating aluminum/SiC/graphite hybrid composites synthesized by the semi-solid powder-densification method, Composites Science and Technology, 60: 65-74.
12. Riahi, A.R. and A.T. Alpas, 2001. The role of tribo-layers on the sliding wear behaviour of graphite aluminium matrix composites, Wear, 251: 1396-1407.
13. Rohatgi, P.K., R. Asthana and S. Das, 1986. Solidification, structures and properties of cast metal-ceramic particle composites, International Metals Reviews, 31(3): 115-139.
14. Baradeswaran, A., 2013. A. Elayaperumal, Mechanical And Tribological Behaviour Of Graphite Reinforced Aluminium Matrix Composites, Journal of the Balkan Tribological Association, 19(3): 354-364.
15. Toptan, F., A. Kilicarslan and I. Kertil, 2010. The effect of Ti addition on the properties of Al–$B_4C$ interface: a microstructural study, Mater Sci Forum, 636-637: 192-7.
16. Baradeswaran, A., A. Elayaperumal and R. Franklin Issac, 2013. A Statistical Analysis of Optimization of Wear Behaviour of Al-$Al_2O_3$ Composites Using Taguchi Technique, Procedia Engineering, 64: 973-982.
17. Baradeswaran, A. and A. Elaya Perumal, 2013. Influence of $B_4C$ on the tribological and mechanical properties of Al 7075–$B_4C$ composites, Composites: Part B, 54: 146-152.
18. Uthayakumar, M., S. Aravindan and K. Rajkumar, 2013. Wear performance of Al–SiC–$B_4C$ hybrid composites under dry sliding conditions, Materials and Design, 47: 456-464.
19. Miyajima. T. and Y. Iwai, 2003. Effects of reinforcements on sliding wear behaviour of aluminium matrix composites, Wear, 255: 606-616.
20. Rosenberger, M.R., C.E. Schvezov and E. Forlerer, 2004. Wear of different aluminium matrix composites under conditions that generate a mechanically mixed layer, Wear, 259: 590-601.
21. Baradeswaran, A., A. Elaya Perumal and J.P. Davim, 2013. Effect of $B_4C$ on Mechanical properties and Tribological behaviour of AA 6061 - $B_4C$ Composites, Journal of the Balkan Tribology Association, 19(2): 230-239.
22. Joel Hemanth, 2005. Tribological behavior of cryogenically treated $B_4C_p$/Al–12% Si composites, Wear, 258: 1732-1744.

23. Das, S., D.P. Mondal, S. Sawla and N. Ramakrishnan, 2008. Synergic effect of reinforcement and heat treatment on the two body abrasive wear of an Al–Si alloy under varying loads and abrasive sizes, Wear, 264: 47-59.
24. Prasada Rao, A.K., K. Das, B.S. Murty and M. Chakraborty, 2008. Microstructure and the wear mechanism of grain-refined aluminium during dry sliding against steel disc, Wear, 264: 638-647.
25. Chen, M.Y. and M.C. Breslin, 2002.Friction behavior of co-continuous alumina/aluminium composites with and without SiC reinforcement, Wear, 249: 868-876.