IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 14, Issue 1 Ver. IV (Jan. - Feb. 2017), PP 04-09
www.iosrjournals.org

Microstructure and Wear Behavior of B_4C Particulates Reinforced Al-4.5%Cu Alloy Composites

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Abstract: *The work is carried out to investigate the microstructure and wear behavior of B_4C reinforced Al-4.5% Cu alloy metal matrix composites. In the present work Al-4.5% Cu alloy was taken as the base matrix and B_4C particulates as reinforcement material to prepare metal matrix composites by stir casting method. For metal matrix composites the reinforcement material was varied from 0 to 4 wt. % in steps of 2 wt. %. The wear resistance of metal matrix composites was studied by performing dry sliding wear test using a pin on disc apparatus. The experiments were conducted at a constant sliding speed of 300rpm and sliding distance of 4000m over a varying load of 0.5, 1 and 1.5Kg. Similarly experiments were conducted at a constant load of 1.5Kg and sliding distance of 4000m over a varying sliding speed of 200, 300 and 400rpm. The results showed that the wear resistance of Al-Cu-2%B_4C and 4% B_4C composites were better than the unreinforced alloy. The wear in terms of height loss found to increase with the load and sliding speed. To study the dominant sliding wear mechanism for various test conditions, the worn surfaces were analyzed using optical microscopy.*

Keywords: *Al-4.5%Cu alloy, B_4C, Microstructure, Wear, Worn Surface*

I. Introduction

Metal matrix composites are a class of materials with potential for a wide variety of structural and thermal management applications. Metal matrix composites are capable of providing higher temperature operating limits than their base metal counterparts, and can be tailored to give improved strength, stiffness, thermal conductivity, abrasion resistance, creep resistance or dimensional stability [1-2]. Unlike resin matrix composites, MMCs are nonflammable, do not outgas in a vacuum and suffer minimal attack by organic fluids such as fuels and solvents.

The principle of incorporating high performance second phase into a conventional engineering material to produce a combination with features not obtainable from the individual constituents is well known. In MMC, the continuous or matrix phase is a monolithic alloy, and the reinforcement consists of high performance carbon, metallic or ceramic additions.

Most of the commercial work on MMCs has focused on aluminium as the matrix metal. The melting point of aluminium is high enough to satisfy many application requirements, yet low enough to render composite processing reasonably convenient. Also, aluminium can accommodate a variety of reinforcing agents [3]. Reinforcements, characterized as either continuous or discontinuous, may constitute from 10 to 40 vol. % of the composite. Continuous fiber or filament reinforcements for aluminium include graphite, silicon carbide, boron and aluminium oxide. Discontinuous reinforcements consist mainly of SiC in whiskers form, particle types of SiC or Al_2O_3 and short or chopped fibers of Al_2O_3 or graphite. Incorporation of particulates improves the wear resistance, damping properties, hardness and stiffness [4].

Wear resistance is an important function in the balance of properties provided by MMCs. The addition of hard reinforcements intrinsically improves the wear resistance of the host metal [5, 6]. Further, additions such as graphite along with SiC, B_4C, and Al_2O_3 provide intrinsic lubricity. MMC materials have been engineered to provide exceptional wear resistance and represent an important family of applications.

Although much of the early work on Al-MMCs concentrated on continuous fiber types, most of the present work focused on discontinuously reinforced Al-MMCs because of their greater ease of manufacturing, lower production costs, and relatively isotropic properties. Hard ceramic particulates such as zirconia, alumina and SiC have been introduced into aluminium based matrix in order to increase the strength, stiffness, wear resistance, fatigue resistance. Among these reinforcements B_4C is compatible with aluminium and forms good bond with the matrix.

In this study, an attempt has been made to prepare Al-4.5%Cu alloy composites by adding 2 & 4 wt. % of B_4C particulates into matrix by using a novel two stage reinforcement addition method. Further, the prepared Al-4.5%Cu – B_4C composites were studied for effect of load and sliding speed on the wear properties by using pin-on-disc wear testing machine.

II. Experimental Details

2.1 Materials Used

Metal matrix composites containing 2 and 4 weight percentages of B_4C particles were produced by liquid metallurgy route. For the production of MMCs, an Al-4.5% Cu alloy was used as the matrix material while B_4C were used as the reinforcements. The theoretical density of matrix material Al-4.5% Cu alloy is 2.80g/cm^3 and reinforcement particulates B_4C density is 2.52g/cm^3.

2.2 Synthesis of Composites

The B_4C particle reinforced Al-4.5% Cu alloy metal matrix composites have been produced by using a vortex method. Initially calculated amount of Al-4.5% Cu alloy was charged into SiC crucible and superheated to a temperature 750˚C in an electrical resistance furnace. The furnace temperature was controlled to an accuracy of ±20 degree Celsius using a digital temperature controller. Once the required temperature is achieved, degassing is carried out using solid hexachloroethane (C_2Cl_6) to expel all the absorbed gases [7]. The melt is agitated with the help of a zirconia coated mechanical stirrer to form a fine vortex. A spindle speed of 300 rpm and stirring time 3-5 min. were adopted. The B_4C particulates were preheated to a temperature of 500 degree Celsius in a pre-heater to increase the wettability. The pre-heated B_4C particles introduced into melt in steps of two at constant feed rate of 1.2-1.4 g/sec. After holding the melt for a period of 5 min., the melt was poured from 720 degree Celsius into a preheated cast iron mould having dimensions of 125mm length x 15mm diameter.

2.3 Testing

Metallographic test samples of 5mm thickness were obtained by cutting the as cast and B_4C reinforced Al-4.5% Cu alloy composites. Samples were polished as per the standard metallographic procedure and etched with Keller's reagent. The microstructure was observed using a scanning electron microscope.

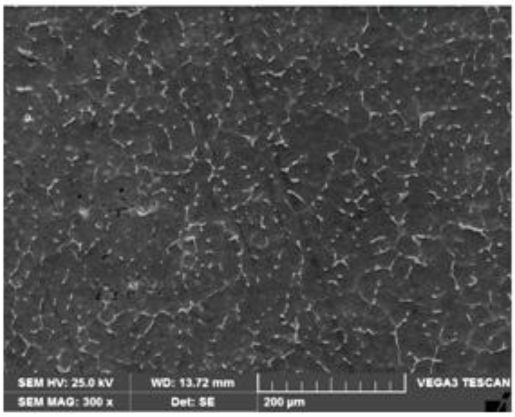
The dry sliding wear behavior of as cast Al-4.5% Cu alloy and Al-Cu-B_4C composites were evaluated using a pin-on-disc wear apparatus at room temperature according to ASTM G99 standard. Pins of length 25mm and diameter 8mm were prepared from the cast samples. The experiments were conducted at a constant sliding speed of 300rpm and sliding distance of 4000m over a varying load of 0.5Kg, 1.0Kg, and 1.5Kg. Similarly experiments were conducted at a constant load of 1.5Kg and sliding distance of 4000m over a varying sliding speed of 200, 300 and 400rpm. The polished surface of the pin was slide on a hardened chromium steel disc. A computer aided data acquisition system was used to monitor the loss of height. Wear value is presented in terms of volumetric wear loss.

III. Results And Discussion

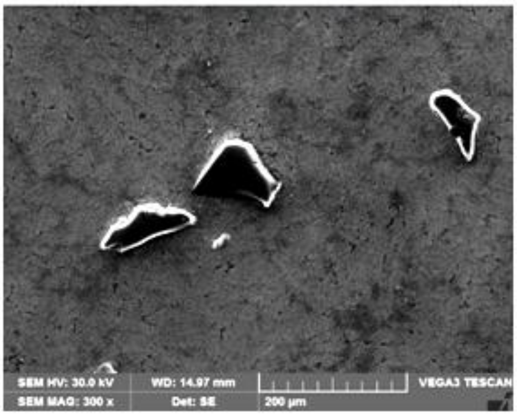
3.1 Microstructural Studies

Figure 1 (a-c) shows the SEM microphotographs of Al-4.5% Cu alloy as cast and Al-4.5Cu with 2 and 4 wt. % of B_4C particulate composites. This reveals the uniform distribution of B_4C particles and very low agglomeration and segregation of particles, and porosity.

Figure 1 b-c clearly show and even distribution of B_4C particles in the Al-4.5% Cu alloy matrix. In other words, no clustering of B_4C particle is evident. There is no evidence of casting defects such as porosity, shrinkages, slag inclusion and cracks which is indicative of sound castings. In this, wetting effect between particles and molten Al-Cu alloy matrix also retards the movement of the B_4C particles, thus, the particles can remain suspended for a long time in the melt leading to uniform distribution.



(a)



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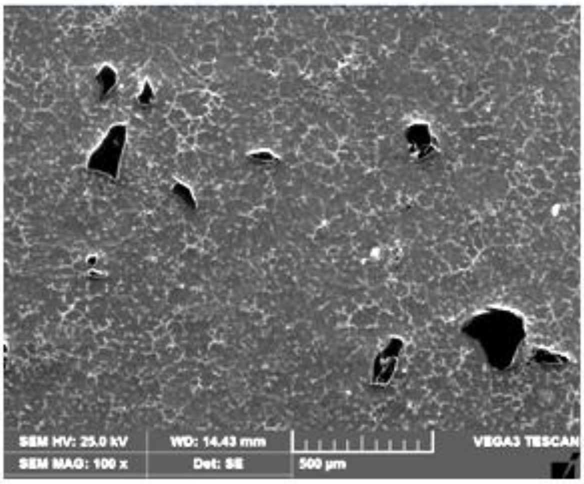


(c)

Figure 1: Showing the SEM microphotograph of (a) as cast Al-4.5% Cu alloy (b) Al-4.5% Cu Alloy -2 wt. % B_4C (c) Al-4.5% Cu Alloy -4 wt. % B_4C

Figure 2 show energy dispersive X-Ray spectrograph of Al-4.5% Cu alloy – 4 wt. % of B_4C composite. The EDS analysis confirmed the presence of B_4C particulates in the Al matrix alloy. The presence of B_4C shows in the form of B (Boron) and C (Carbon), which is evident from the EDS spectrum.

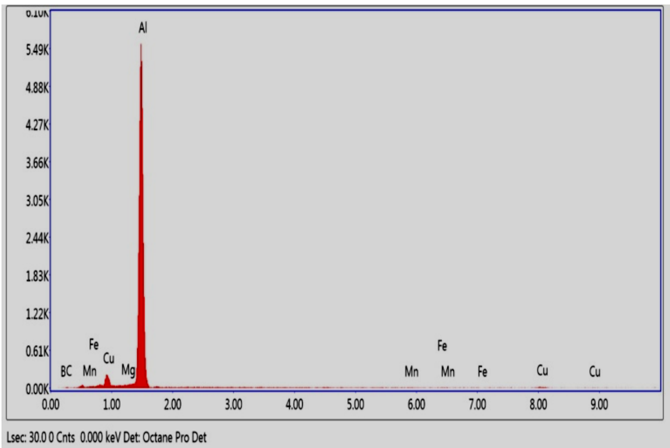


Figure 2: EDS analysis of Al-4.5% Cu alloy – 4 w_t. % B_4C composite

3.2 Effect load on wear

The variation of volumetric wear loss at constant 300rpm sliding speed and varying loads of 0.5Kg, 1.0Kg and 1.5Kg is as shown in figure 3. Applied load affects the wear of Al-Alloy and the composites significantly and is the most dominating factor controlling the wear behavior. The wear loss varies with the normal load and is significantly lower in case of composites.

With increase in loads there is higher volumetric wear loss for matrix alloy and the composites. However at all the loads considering wear resistance of the composites is superior to the matrix alloy. At higher loads and the transition to sever wear the surface temperature exceeds a critical value. So as applied load increases ultimately there is an increase in the wear loss for both the reinforced and unreinforced composite materials. The variation of wear loss of the matrix alloy and its composites with 2 and 4 wt. % of B_4C content is shown in figure 3.

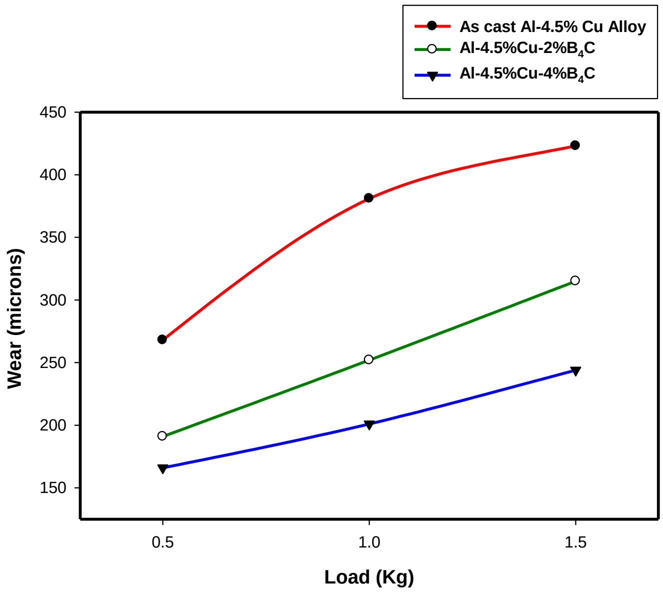


Figure 3: Showing wear of Al-Cu alloy and its composites at varying loads and sliding speed of 300rpm and 4000m sliding distance

The improvement in the wear resistance of the composites with B_4C reinforcement can be attributed to the improvement in the hardness of the composites and improved hardness results in the decrease in the wear loss of the composites [8].

3.4 Effect speed on wear

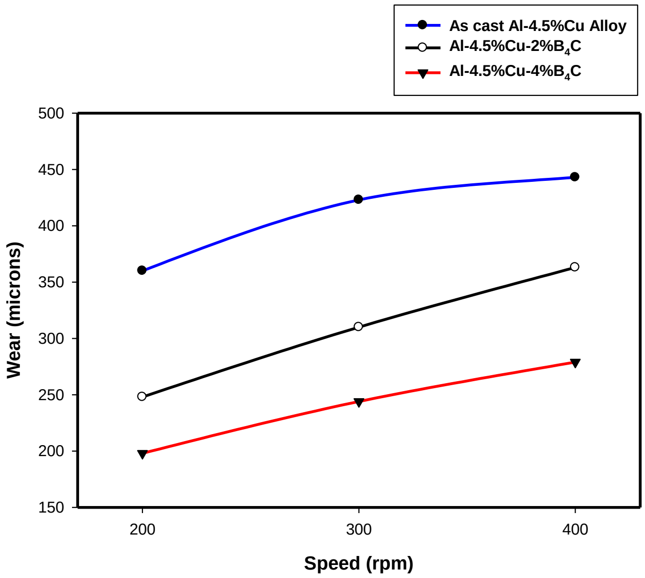
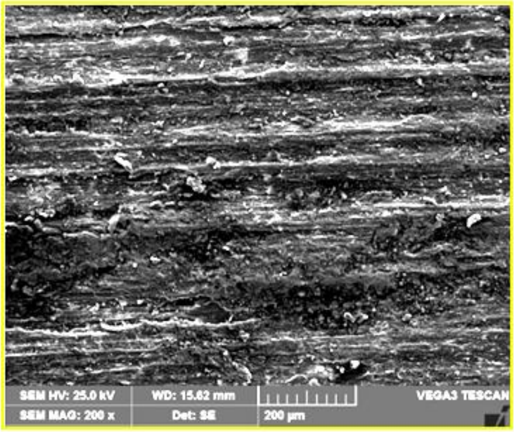


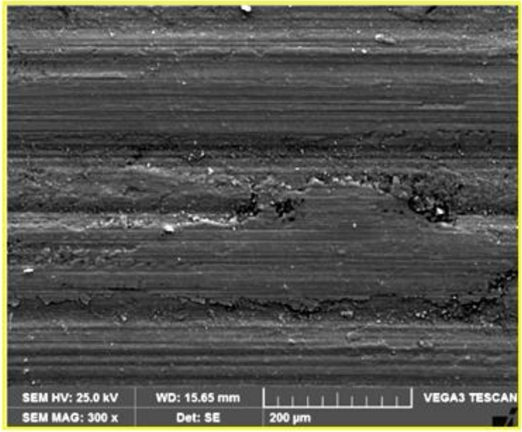
Figure 4: Showing wear of Al-Cu alloy and its composites at varying sliding speed, constant load of 1.5kg and 4000m sliding distance

Figure 4 shows the variation of wear loss of Al-4.5% Cu matrix alloy and Al-4.5%Cu-2% & 4% B_4C composites at constant 1.5kg load and varying sliding speeds. With an increasing speed i.e. 200, 300, and 400 rpm, there is an increase in the wear loss for both matrix alloy and its composites. However at all the sliding speeds studied, the wear loss of the composite was much lower when compared with the matrix alloy. Further increased wear rate with increased sliding speed is due to thermal softening of the composite [9, 10]. On the other hand the increased temperature at higher sliding speeds can cause severe plastic deformation of the mating surfaces leading to form high strain rate sub-surface deformation. The increased rate of sub-surface deformation increases the contact area by fracture, and fragmentation of asperities. Therefore this leads to enhanced delamination contributing to enhance wear rate. Further, 4wt.% of B_4C particulates reinforced Al-4.5% Cu alloy composites shown more resistance to wear.

3.5 Worn surface morphology



(a)



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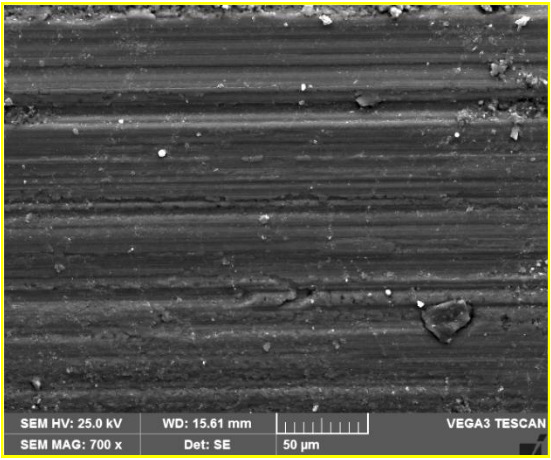

(c)

Figure 5: Shows the SEM microphotographs of worn surfaces of (a) as cast Al-4.5%Cu alloy (b) Al-4.5%Cu – 2wt.% B_4C (c) Al-4.5%Cu – 4wt.% B_4C composites at 1.5kg load and 300rpm.

Wear surface analysis of composites were examined by scanning electron microscope. Fig.5a-c represents the wear surface of as cast Al-4.5% Cu alloy and specimens containing 2 & 4 wt. % of B_4C particles reinforced composite at 1.5 kg load and 300rpm sliding speed.

The examination of worn as showed in figure 5a, that the worn surfaces of base alloy are much rougher than composites. Cavities and large grooved surfaces are found on worn surface of Al-4.5%Cu alloy. The indication of cavities and grooves supports the fact that soft Al alloy deformed at higher load of 1.5kg and at 300rpm speed and pulled out from the surface. The wear track observation shows that adhesion and delamination are dominant wear mechanisms observed at higher loads. This is supported by the large sized delamination flakes and severe adhesion resulting in bulk removal of material at higher loads.

Figure 5b & c shows the SEM image of the worn surface of Al-4.5%Cu-2 & 4 wt.% of B_4C composite tested at applied load of 1.5kg and 300rpm speed. The grooves are very small due to the hard nature of B_4C reinforcement and poor wear losses. As the ceramic particles resist the delamination process, composites are found to have greater wear resistance. Worn surface shows less cracks and grooves mainly due to the presence of hard particulates.

IV. Conclusions

The present work on processing and evaluation of Al-4.5%Cu-B_4C metal matrix composite by melt stirring has led to following conclusions. Al-4.5%Cu alloy based composites have been successfully fabricated by melt stirring method using two stage addition method of reinforcement combined with preheating of particles. The SEM microphotographs of composites revealed fairly uniform distribution of reinforcement particulates in the Al-4.5%Cu metal matrix. The addition of B_4C particles to Al alloy matrix improves the wear resistance of the composite. The wear loss is dominated by load factor and sliding speed. The increase of loads and sliding speeds leads to a significant increase in the wear loss. The Al-4.5%Cu-4% B_4C composites have shown lower wear loss as compared to that observed in as cast Al-Cu alloy and 2 wt.% B_4C reinforced composites matrix. Worn morphology showed the effect of hard ceramic particulates addition on wear behavior of Al alloy and its composites.

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