

Effect of B₄C Particles on Dry Sliding Wear Behavior of LM-13 Metal Matrix Composite

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ABSTRACT

LM-13 aluminium alloys reinforced with B₄C particles (5, 10, 15 wt. %) were prepared by gravity die casting. The samples were characterized on the basis of microstructure, microhardness, XRD and SEM. The micro hardness tests indicated increased hardness values of the metal matrix composite (MMC) as B₄C percentage increased. Optical microscopic observation revealed presence of rhomboidal hard B₄C particles distributed randomly in the LM-13 matrix. Presence of B₄C was also confirmed with XRD Analysis. The dry sliding wear behavior of this LM-13 - B₄C composite was investigated by means of the pin-on-disc technique. The results showed that as the B₄C % increased, the volumetric wear decreased proportionately - indicating the active role of the B₄C particles in wear reduction. Study of the worn surfaces of the composite using the SEM suggests presence of adhesive and abrasive wear mechanisms with evidence of transfer films. The improvement in wear resistance points to the presence of hard B₄C particles which acts as a positive reinforcement in the LM-13 matrix. The wear and hardness results suggest that the material could be a suitable candidate for brakes disc/drum application in light automotive vehicles.

KEYWORDS: B4C particle, Dry sliding wear, MMC, Aluminium Alloys, LM-13

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INTRODUCTION

Metal matrix composites utilize the advantages of both the metal matrix as well as that of the particulate reinforcements thereby giving improvement in mechanical and tribological properties. Since early nineties aluminum metal matrix composites (Al MMC's) have been used in wear resistance applications in automotive and space industry, due to its mechanical properties like light weight, high strength, low co-efficient of thermal expansion and good wear resistance [1]. The combination of wear resistant ceramic reinforcement with the ductile metals has found many applications in the field of tribology [2, 3]. Al MMC's exhibits a considerable improvement in wear resistance depending on the reinforced metal and the percentage of

reinforcement [4, 5]. The most commonly used reinforced particles are SiC, Al₂O₃, TiB₂, B₄C etc [6].

Boron Carbide (B₄C) is suitable for particulate reinforcement as it has a relatively low density (2.52 g/cm³) [7] as compared to other reinforcements like SiC (3.1 g/cm³) and Al₂O₃ (3.9 g/cm³) [8] while being harder than both [9]. A combination of high stiffness and ductility of Al matrix and high hardness of B₄C is obtained in Al-B₄C composites while retaining the advantages of a low density material [7]. The Al MMC's especially with ceramic reinforcement have a significant effect in improving the wear resistance, indicating a good bonding existence between Al matrix and reinforcement particle [4, 10, 11].

The sliding wear behavior of B₄C reinforced Al matrix is examined by measuring the reduction in pin length and by

studying the topography of wear track of Al MMC's after the wear test. The objective of this paper is to study the effect on dry sliding wear behavior with increasing percent weight of B₄C reinforced particle, and involves studying of significant trends in wear behavior.

LITERATURE REVIEW

Many researchers have studied the effect of particulate reinforcements of various functional properties of materials. Shorowordi, Haseeb et al. [12] studied the tribo-surface characteristics of Al-13 vol. % B₄C and Al-13 vol. % SiC MMC's worn against a commercial phenolic brake pad. Different contact pressures in the range of 0.75-3.00MPa have been investigated at a constant sliding speed 1.62ms^{-1} . It was observed that the wear rate and friction coefficient of Al-B₄C are found to be lower than those of Al-SiC. Shorowordi, Laoui et al. [13] also prepared three aluminium metal matrix composites containing reinforcing particles of B₄C, SiC and Al₂O₃ (0-20 vol. %) by stir-casting manufacturing route followed by hot extrusion. It was observed from fracture surface analysis that the particle distribution as well as the interfacial bonding in Al-B₄C was better than Al-SiC and Al-Al₂O₃ composites.

Miyajima and Iwai [14] performed dry sliding wear tests using a pin on disc wear tester in which the discs were made from Al 2024 and ADC12 aluminum alloys reinforced with 5 - 29 vol. % SiC whiskers, 3 - 26 vol. % Al₂O₃ fibers and 2-10 vol. % SiC particles. The Discs were rubbed against a carbon steel pin under a load of 10N at 0.1m/s sliding velocity. It was observed that the particle reinforcements were beneficial in improving the wear resistance of the MMC as compared to the whisker and fiber reinforcements. Also the wear rate decreased as the volume fraction of the particulates increased.

Chapman et al. [15] studied the wear resistance of aluminium boron carbide (Al - B - C) cermets for automotive brake applications. The paper stated that Al - B - C cermets displayed a high wear resistance as compared to current asbestos and semimetallic materials while producing no increase in rotor wear.

M. B Karamış et al. [16] studied the tribological properties of AA2124 reinforced by SiC, B₄C and Al₂O₃ (10, 20, 30 vol. %) for purpose of automobile cam material which were prepared by powder metallurgy. From the paper it was observed that the specific wear rates of the composite reinforced with 10% vol. fraction of B₄C or SiC were each lower than that of the GGG40 cam material and the sample with 10 % B₄C addition shows the best wear performance.

Tang et al. [17] studied dry sliding friction and wear properties of 5% and 10% B₄C particulate - reinforced Al-5083 matrix composites which were fabricated by cryomilling and consolidating process. It was observed in his study that wear rate of 10% B₄C reinforcement was approximately 40% lower than that of 5% reinforcement. The wear was observed in two stages abrasive and adhesive wear,

with the former occurring first and giving a lesser coefficient of friction then that of the latter. The author concluded that the decrease in wear rate was due to incorporation of increased amount of B₄C. Ipek [18] compared the adhesive wear characteristics under dry sliding conditions of 4147 Al/B₄C, 10, 15 and 20 wt. % B₄C particle with Al/SiC metal matrix composites 20 wt. % SiC. The samples were produced by liquid metallurgy and the results showed that the adhesive wear resistance was dependant on volume fraction of B₄C reinforcement. Also no changes in wear values were observed in samples with B₄C reinforcement over 15%.

EXPERIMENTAL PROCEDURE

The LM13 - B₄C MMC's were prepared by adding 5, 10 and 15 % B₄C powder, by weight, and of 80 mesh size, in molten LM 13 alloy and gravity die casted to produce cylindrical samples of 20 mm diameter. Wear test samples of 10 mm diameter and were machined out of the castings, taking care that porosity was minimal. The samples were polished and then etched using Keller's reagent (HF, HCL, HNO₃ and distilled water). An Image Analyzer with inverted microscope (Make-CARL ZEISS Germany, Model-Axiovert40Mat) with image analyzer was used to take images of the microstructure.

Dry Sliding wear tests were conducted using a digitally interfaced pin on disc wear and friction testing machine (Make - Industrial Engineering Instruments, Bengaluru, India, Model - IWFT-DD). The Al MMC pin samples were held stationary and were rotated against an 8mm thick SAE 52100 (HRC 55) steel disc, maintaining a wear track diameter of 60mm. A sliding speed of 1.8 m/s at 60N load was maintained for a distance of 3000mm. A schematic representation of pin on disc test is shown in Figure 1. During sliding, a load was maintained using cantilever mechanism to keep the pin in contact with the rotating disc. Before beginning a new wear test, the steel disc was fine polished to remove the previous wear track.

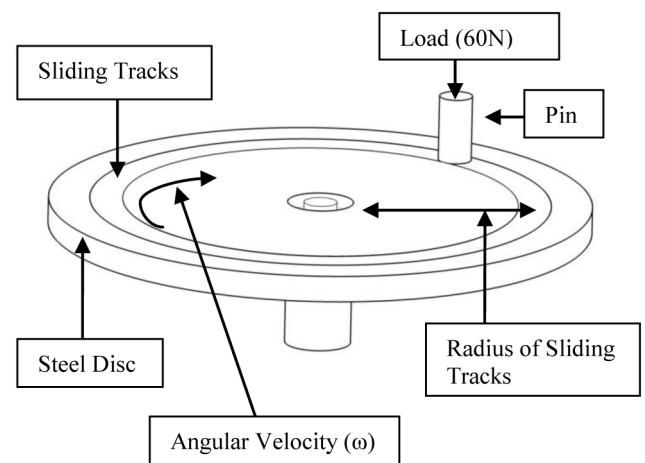


Figure 1. Schematic diagram of pin on disc test.

The post wear characterization of the Al MMC samples was done using optical microscope, SEM, microhardness and XRD analysis. The quantitative analysis of the samples with B₄C additions was done to determine the area fraction of the B₄C particles in the LM13 matrix. The analysis was done using the Mpower-Image Analyzer software in which the microstructure images were fed to the software which computed the area fractions of B₄C particles. The microhardness test was conducted on Vickers micro-hardness testing machine with an applied load of 100gm for dwell time of 15 seconds. The indent size was of the order of 50 μ m. The SEM test was performed on Philips XL30 machine to capture the wear track images.

RESULTS AND DISCUSSION

Microhardness Test

The B₄C particles being the harder phase in the matrix resulted in the increased average hardness of the MMC. As the dent size was higher than the average B₄C particle the average hardness of the matrix increased as compared to the pure alloy. The indentation size was higher than the size of the B₄C particle. Averages of five readings are reported as hardness of a material.

The variations of hardness of the composites are shown in [Figure 2](#). The hardness of the Al MMC's increased more or less linearly with the percentage of particulates in the alloy matrix due increasing ceramic phase (B₄C) of the matrix alloy. The hardness variation is in the range of 68 to 115 HV indicating the direct relation of B₄C addition to the hardness values.

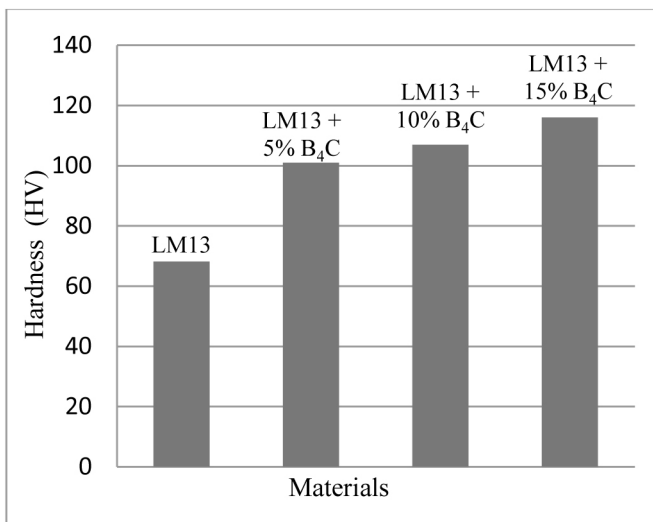


Figure 2. Microhardness variation with increase in B₄C % in LM13.

The increase in hardness is due to the physical obstruction of the moving dislocations by the hard particles occurring during deformation. This hard B₄C phase acts as a positive

reinforcement to the composite which thereby increases hardness and also shows an increase in wear resistance. It is also seen that the percentage rise in hardness values are proportional to the increase percentage additions of B₄C.

Microstructure

Quantitative analysis

The area fraction of the B₄C particles in the LM13 matrix for 5, 10, 15% B₄C additions are shown in [Table 1](#).

Table 1.

Materials	Reinforcement during casting	Reinforcement in analysis
LM13 + 5%	5 %	4.210 %
LM13+10%B ₄ C	10 %	3.779 %
LM13+15%B ₄ C	15 %	10.317 %

It can be seen that the area fraction of B₄C particles in the LM13 matrix is less than the weight percent of B₄C particles added to the matrix during casting operation. The 10 % B₄C showed an area fraction of only 3.799%. This indicates that the distribution of particles in the matrix is not perfectly uniform because of limitations imposed by stir casting. However the 5 and 15 % samples showed predictable trends. The area fraction of the particulate matter sheds light on tribological trends as the ratio of the hard and soft phases are key parameters in deciding the wear rates.

XRD analysis

[Figure 3](#) shows X-ray diffraction (XRD) pattern of LM13+5% B₄C composites. The graph shows the diffraction pattern belonging to LM13 matrix and B₄C particle. The XRD analysis showed the presence Al, Si, B₄C. There is no presence of any intermediate phase in the analysis.

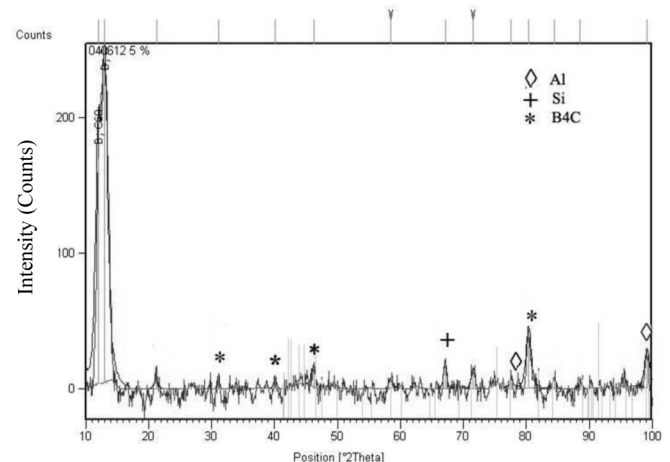


Figure 3. XRD analysis of 5% B₄C reinforced LM13.