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Investigations on Coefficient of Friction and Surface Roughness of AA6061+B_4C Composites Produced by Stir Casting Process

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ABSTRACT
The present work has been carried out in the area of metal matrix composites with the addition of boron carbide (B_4C) to aluminium AA6061 for increasing the strength and wear properties for automotive applications. This work is mainly focuses on the properties like hardness, wear resistance and surface roughness. The aluminium matrix composite (AA6061) is prepared through stir casting with the addition of B_4C. The percentage of B_4C is varied (3%, 6% and 9%) with aluminium metal matrix composite. The resulting composite is tested for hardness, wear rate and surface roughness. Wear tests were carried out with varying loads from 2kg, 3kg and 4kg with a constant sliding speed on a Pin-on-Disc equipment as per ASTM G99 standard. Finally, the quantitative values were observed from AMMCs+B_4C components and the properties were investigated. The analysis of 3D profiles obtained using a non-contact surface roughness tester showed that the surface roughness differs for different loadings.

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Introduction

Metal matrix composites have attracted the interest of researchers for more than a decade due to their unique properties like good strength to weight ratio, stiffness, hardness and wear resistance. The metal matrix composites are potential candidate to replace conventional materials in aerospace and automotive applications. Aluminium alloys possess a number of mechanical and physical properties that make them attractive for automotive applications, but they exhibit extremely poor resistance to seizure and galling. High purity materials were used for the preparation of the metal matrix composites for this work. So far, limited research has been conducted on B_4C reinforced MMCs [1]. Among all the type of MMC's aluminium is widely used because of its low density, good strength to weight ratio, ease of fabrication and good corrosion resistance [2]. Uthayakumar et al. [3] have investigated the effect of boron carbide reinforcement on aluminium matrix composites by stir casting method with different particle sizes. The effect of inclusion of B_4C and glass on EDM of aluminium–SiC composite was studied by Ahamed et al. [4]. The effect of increased reinforcement on the wear behavior of the MMCs is to increase the wear resistance and to reduce the coefficient of friction [5]. Boron carbide (B4C) powder was chosen as reinforcement for the Aluminium-based metal–matrix Composite because of its higher hardness (very close to diamond) than the conventional and routinely used reinforcement such as SiC and Al_2O_3 [6]. The addition of high modulus refractory particles to a ductile metal matrix produces a material whose mechanical properties are intermediate between the matrix alloy and ceramic reinforcement [7].The aging characteristics of aluminium alloy A356 and an aluminium alloy A356 containing hollow spherical fly ash particles were studied by Rohatgi et al. The study reported that the composites have a higher specific strength and specific hardness compared to the matrix since the density of the composite is lower than that of the base alloy due to the presence of hollow particles [8]. The tensile behaviour of composites produced by infiltrating ceramic particle beds with high purity (99.99%) Al is studied as a function of reinforcement size and chemistry (Al_2O_3 and B_4C) by Kouzeli et al. The yield stress is higher in composites containing B_4C particles, increasing with decreasing interparticle distance in both composite systems [9]. Room temperature dry and lubricant sliding wear behaviors of Al_2O_3f and SiCp reinforced aluminum matrix hybrid composites were investigated under both the dry and lubricant conditions by Wang et al. The results of dry sliding tests showed that the F20P0 unhybrid composites with normal (N)-orientation of fibers had better wear behaviors than those with planer-random (PR)-orientation of fibers [10]. Abdel-Azim et al. have described a simple and inexpensive casting method for producing 2024-Al alloy reinforced with different percentages of αAl_2O_3 particles [11]. It was found also that the addition of $A1_2O_3$ particles to the matrix alloy improves the wear resistance and increases the coefficient of friction. A study on the addition of Si to Al–Si/60 vol.% SiC composites, produced by pressure infiltration technique showed that at Si contents higher than 1%, dramatic decrease of toughness was accompanied by a reduction in strength and abrasion resistance [12]. It is well established that introducing a hard particle in an Al-matrix can lead to significant improvements in wear and erosion resistance, stiffness, hardness and strength [13-15].

During the study involving the fabrication and characterization of bulk Al–B4C nanocomposites, Mohammad Sharifi et al. observed that the wear rate is decreased both by increasing the volume fraction of hard phase and the particles size [16]. An experimental work carried out using B_4C powders with different particle sizes to reinforce commercially available aluminium using casting technique showed that B_4C addition with bigger particle size resulted in better microstructure with free of agglomerated particles [17].

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Experimental

Material Selection

Figure1and Fig. 2 show the aluminium 6061 and boron carbide powders respectively which were used to make the composite material for the investigation. Aluminium 6061 was selected as base material for the matrix due to its enormous advantages and applications. Moreover, Table 1 represents for chemical composition of AA6061 materials. Further B4C was selected as the reinforcement material. The aluminium pieces were cut into small strips of 10 cm length. Boron carbide was a granule level powder of 200 - 250 mesh size. Three sets of samples were prepared by adding 3,6 and 9% of B_4C by weight to 1.5 Kg aluminium per sample.

Figure 1: Aluminium 6061

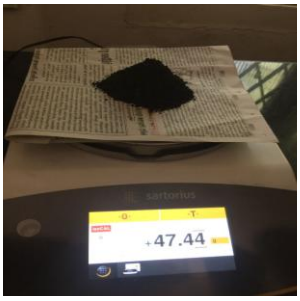

Figure 2: Boron Carbide (B_4C)

Table 1: Chemical composition of AA 6061 materials

Elements	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti
Wt. %	96.7	0.28	0.34	0.5	1.1	0.13	0.55	0.14

Composite Fabrication

The fabrication of the metal matrix composites is of two technological methods such as solid state processing and liquid state processing. In solid state processing, the reinforcements are embedded in the matrix through diffusion and are produced at high temperature and pressure. In this process some special care should be taken to avoid the growth of the undesirable phases or compounds species on interfaces. Some commonly used techniques under this method are diffusion bonding and powder metallurgy. In liquid state processing, the matrix is in liquid form and the reinforcement is either in form of fibers or particles. The uniformity in distribution of reinforcement can be made by means of applying some mechanical actions. This is one of the most used and inexpensive method for fabrication of metal matrix composites. Hot forming, liquid infiltration, squeeze casting and stir casting are most common techniques.

Stir Casting Method

Stir casting method is a liquid metallurgy technique in which the reinforcement particles are introduced into the molten matrix and allowed to solidify. In this work Boron Carbide (B_4C) reinforcements were added to the molten matrix aluminium alloy AA6061. Using this method, the molten matrix material is stirred vigorously to form a vortex at the surface of the melt. The reinforcement material is then introduced at the side of the vortex. Initially, the furnace was preheated for removing the moisture in it. Then aluminium 6061 was placed in the crucible of the apparatus. It was then heated up to 800°C to reach the molten stage. The B_4C powder was preheated by muffle furnace and added to the molten aluminium. This mixture was heated for a period of three hours. The molten material was then poured into mould and allowed to solidify. This procedure was followed for all the three compositions. The mould prepared was on the shape of pins. The pin prepared on different compositions was categorized according to their reinforcement metal (B_4C) percentages. The percentages of B_4C were 3%, 6% and 9%. Pins have been made from this material for a length of 5 cm. For each composition 3 pins were machined using a lathe.

Wear Test

The pin on disc method of testing is used for characterizing the coefficient of friction, frictional force, and rate of wear between two materials. First of all 3 samples of each composition were taken. The weight before test was noted and taken for the test. The wear test is conducted as per ASTM G99 standard. Fig. 3 shows the pin-on disc apparatus. This setup of the experiments gives the output results through an on line monitoring system (data acquisition system) which is integrated to a desktop computer.

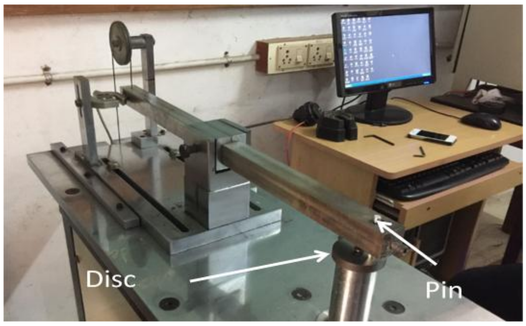

Figure 3: Pin on Disc apparatus

Results and Discussion

Figure 4 shows the different percentages of B_4C added to AA 6061. They are 3%, 6% and 9%. The stircast material was used to make pins for the wear test.

Figure 4: Pins and Disc of raw materials (AA 6061 + B_4C)

The Table 2 indicates the results of wear loss of metal matrix composites (Al6061+B_4C) with different percentages at different loading conditions of B_4C like 3%, 6% and 9% at normal temperature. It is observed that that the value of wear loss is lower at different loading conditions. Especially the composition with 6% and 9% boron carbide produced lower wear rates at loadings of 4 kg and 2 kg. Normally, a composite material produces better results based on the homogeneity of its presence in all the surface. The reinforced matrix materials melted fully and spread over the surface during the casting process.

Table 2: Wear loss

Sample (% B_4C)	After pin on disc Test (weight)	Before Test (g)	After Test (g)	Wear loss (g)
3% sample 1	Load - 2kg	4.840	4.835	0.005
3% sample 2	Load -3kg	4.666	4.660	0.006
3% sample 3	Load -4 kg	4.892	4.868	0.024
6% sample 1	Load - 2kg	5.006	4.998	0.008
6 % sample 2	Load -3kg	5.298	5.292	0.006
6% sample 3	Load -4 kg	5.350	5.346	0.004
9% sample 1	Load - 2kg	5.213	5.209	0.004
9% sample 2	Load -3kg	5.252	5.246	0.006
9% sample 3	Load -4 kg	4.929	4.920	0.009

The hardness value of composites materials were measured by Vickers hardness test with an applied load of 1 kg at ambient condition with a dwell time of 10 seconds. In this experiment an average of 5 values were recorded for each sample. Figure 5 shows the measurement of hardness value in the pin materials fabricated with different composition of B_4C (3%, 6% and 9%) at different places. The hardness of material with 9% B_4C is the highest due to the particles present on the surface.

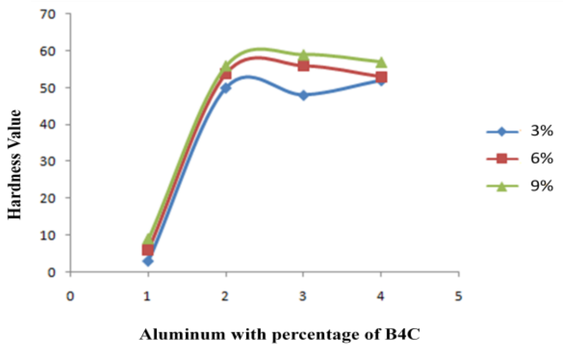

Figure 5: Micrograph of hardness value of AA 6061+B_4C

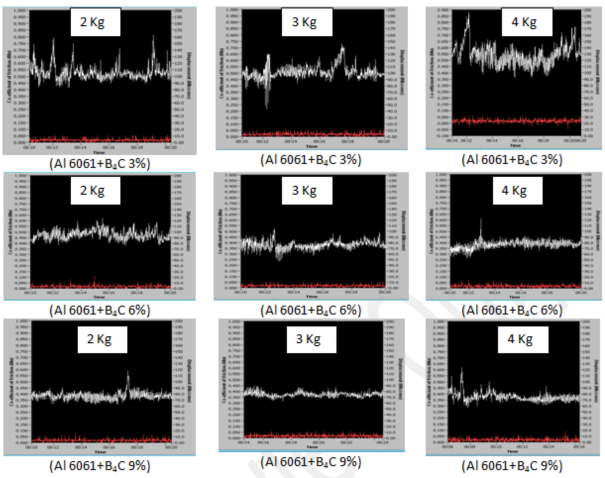

Figure 6: Co-efficient of friction of AA6061+B_4C at 3%, 6% and 9% at various loadings

The images in Fig. 6 show the values of co-efficient of friction of AA 6061-B_4C composite material at different loading conditions. The co-efficient of friction micrographs show the results of friction factor between the pin and disc. The friction test was conducted at different loadings and the co-efficient of friction values were obtained by data acquisition system. Figure 6 reveals that the co-efficient of friction values vary between 0.40 to 0.86 at loadings of 2 kg, 3kg and 4kg.

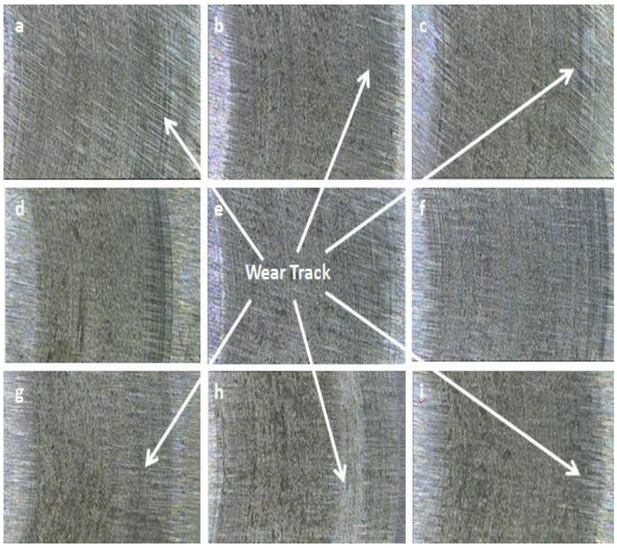

Figure 7: Pin on Disc wear track on AA 6061+B_4C composite materials at different loads

Figure 7 micrograph shows the wear tracks present in the discs for different loadings applied on the surface. The tracks were measured by a video measuring system (VMS). It shows that clear morphology of wear tracks were formed at different loadings on the tested specimen. It is clear from the Fig. 6 that the wear tracks and surface grooves formed due to the surface contact of the pin and disk. The un-melted particles act as debris on material surfaces at loading conditions. The surface may get delaminated depending upon the particle debris. Wear tracks observed in case of AA 6061 indicate the abrasive wear mechanism. Due to high temperate and friction, only oxide wear has taken place. The wear resistance is more in case of (Al6061+ B_4C) composite alloy. The results revealed that the composites with B_4C particulates have better wear resistance than the base alloy.

The surface morphology in Fig. 7 shows evidence for wear when different loadings were applied on the specimen. The wear tracks formed with minimum loading conditions have got low grooving surface. It also shows the deeep groove was formed at higher load of 4 kg at room temperature. A non-contact surface roughness tester was used to obtain the 3D profiles of the worn surfaces at various loads. The surface roughness of AA 6061+B_4C composite material with different compositions is shown in Fig. 8. It shows that the surface roughness differs for different loadings.

Conclusions

The present work on processing and evaluation of AA 6061-B_4C metal matrix composites by varying the percentage of B_4C content using stir casting has led to following conclusions. Lower wear rates were observed for

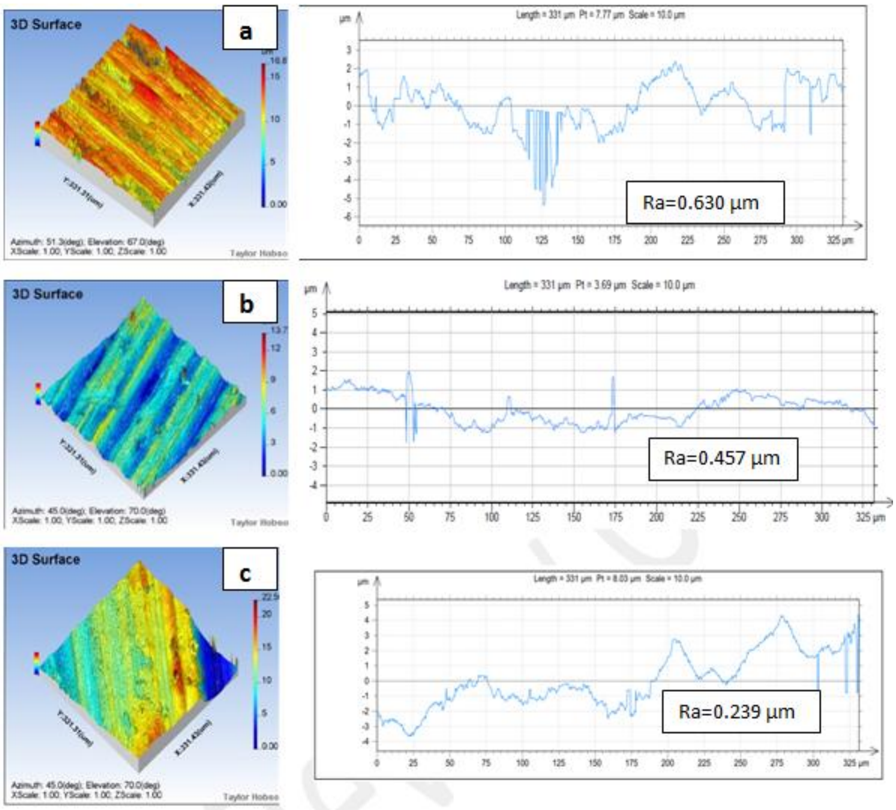

Figure 8: 3D Surface profilograph for: (a) AA 6061+3% B_4C when 4 kg load (b) AA 6061+6% B_4C when 3 kg load (c) AA 6061+9% B_4C when 2 kg load

the composition with 6% and 9% boron carbide at loadings of 4 kg and 2 kg. It was also observed that the hardness of material with 9% B_4C is the highest due to the unmelted particles present on the surface. The values of co-efficient of friction varied between 0.40 to 0.86 at loadings of 2 kg, 3kg and 4kg. The surface morphology showed that the wear tracks formed with minimum loading conditions have got low grooving surface. It also showed that deep groove was formed at a higher load of 4 kg at room temperature. The analysis of 3D profiles obtained using a non-contact surface roughness tester showed that the surface roughness differs for different loadings.

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