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A Comparative Study on Wear Behavior of Al6061-6% SiC and Al6061-6% Graphite Composites

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Abstract

This work investigated the influence of SiC and graphite on the microstructure and wear behavior of Al6061- SiC and Al6061-Graphite composites. The investigation reveals the effectiveness of incorporation of SiC and Graphite in the Al6061 alloy for studying wear properties. The composites were fabricated using liquid metallurgy route. The Al6061- SiC and Al6061-Graphite composites were fabricated separately by introducing 6 wt. % of SiC and graphite particulates by two stage melt stirring process. In this reinforcement particulates were added in two steps to increase the wettability. The characterization was performed through Scanning Electron Microscope and Energy Dispersive Spectrum. The particle distribution was uniform in these composites. Pin on disc apparatus was used to conduct the dry sliding wear tests. The experiments were conducted by varying loads and sliding speeds for sliding distance of 2000 m. The results revealed that Al6061-6% SiC and Al6061-6% Graphite composites were shown more resistance to wear. Al6061-6% Graphite composites were shown more resistance to wear as compared to Al6061-6% SiC composites. Further, the volumetric wear loss was found to increase with the load and sliding speed for all materials. Worn surface analysis made by using scanning electron micrographs to know various mechanisms involved in the wear process.

Keywords: Al6061 Alloy; SiC Particulates; Graphite; Wear; Stir casting

Introduction

The metal matrix composites (MMCs) are very attractive materials for several applications. For many researches the term MMCs is often equated with the term light metal matrix composites. Substantial progress in the development of light metal matrix composites has been achieved in recent decades, so that they could be introduced into the most important applications [1]. Aluminum matrix composites (AMCs) are the competent material in the industrial world. Efforts have been made to develop aluminium metal matrix composites in recent years due to their low density, high strength, superior creep resistance and have great potential in automotive and aerospace applications [2,3].

Aluminium (Al) is the second most widely used metal in the world today after iron. It has a low density (2.7 g/cc), superior malleability, excellent corrosion resistance, good thermal conductivity (237 W/mK), very low electrical resistivity ($2.65*10^{-8}\Omega m$) and good formability. It's Young's modulus is 70 GPa and its Vickers hardness is 60 to 70 VHN. Al has a melting point of 660.32°C and at high temperatures, the strength of Al decreases. However, the demand for Al and its alloys having a much higher strength is increasing. Al-matrix composites (AMCs) have been widely used in automobile and aerospace industries due to their excellent physical and mechanical properties. To overcome these shortcomings and to meet the ever increasing demand of modern day technology, composites are one of the most promising materials [4,5].

Many techniques are currently available to fabricate the metal matrix composites (MMCs), such as mechanical alloying, high-energy ball milling, spray deposition, powder metallurgy, sintering and various casting techniques. The powder metallurgy processing method cannot be used for bulk production of large and complex structural MMCs components. The fabrication of MMCs by powder metallurgy route is time-consuming, expensive and energy intensive. The liquid metallurgy route or stir casting process is most commonly used method to fabricate aluminium composites. This technique is the simplest and can able to produce more complex castings by this method. It is economical for bulk production.

Aluminium-based metal matrix composites (AMCs) have been widely used in automotive and aircraft applications due to their low density and concurrent high wear resistance, strength, corrosion resistance, stiffness and thermal conductivity [6]. Ceramic particulates like SiC, B_4C, TiC, WC, ZrO_2 and Al_2O_3 are the most commonly used reinforcements to fabricate composites.

In industrial applications maximum components are subjected to sliding motion, where wear resistance plays important role. Several researchers investigated wear behaviour ceramic particulates reinforced aluminium alloy matrix composites [7,8]. Suresh et al. [9] studied wear prediction of stir cast Al-TiB_2 composites. The wear mechanism of the specimen was studied through scanning electron microscope images. Umanath [10] and co-authors investigated the wear properties of Al6061-SiC-Al_2O_3 reinforced metal matrix composites. The 15% hybrid composite shown better wear resistance compared to 5% composites. The fracture surface of composites shows the ductile tear ridges and cracked SiC and Al_2O_3 particles indicating both ductile and brittle fracture mechanism.

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In the present investigation, an attempt is made to develop Al6061-6 wt. % SiC and Al6061-6 wt. % Graphite composites by stir casting technique. Further, a comparative study on wear behaviour of Al6061 alloy, Al6061-SiC and Al6061-Graphite composites has been made at varying loads and sliding speeds.

Experimental Work

Aluminium 6061 alloy with theoretical density of 2.7 g/cm^3 was used as the matrix material. Table 1 tabulates the chemical composition used. In the table, the amount of Mg and Si is maximum, which is required for Al6061 alloy matrix.

Micron sized SiC and particulates of Graphite with an average particle size of 90-125 µm were selected as the reinforcements for metal matrix composites. The theoretical density of SiC is 3.10 g/cm^3 and graphite is 2.20 g/cm^3.

In this present work, stir casting technique was used to fabricate Al6061-6 wt. % SiC and Al6061-6 wt. % Graphite particulate composites. Initially the required amount of Al6061 alloy was placed into graphite crucible and heated to a temperature of 750^{0}C in an furnace. The temperature of furnace was controlled to an accuracy of ±10°C using a thermocouple. Preheated reinforcement particles were added in novel two step addition method. Ceramic SiC and Graphite particulates were preheated to a temperature of 300°C in an oven to remove the gases from the surface of particles and to avoid temperature drop in molten metal after addition of reinforcements. After degassing of molten Al alloy by using solid hexachloroethane (C_2Cl_6), preheated SiC and Graphite particles were poured into the vortex of the molten Al6061alloy. Vortex was generated with the help of a zirconia coated steel impeller. The extent of incorporation of SiC and Graphite particles in the matrix alloy was achieved in steps of 2. i.e., Total amount of reinforcement required was calculated and is being introduced into the melt 2 times rather than introducing all at once. At every stage before and after introduction of reinforcement, mechanical stirring was carried out for a period of 5 min. The stirrer was preheated before immersing into the melt, and was located approximately to a depth of 2/3 height of the molten metal from the bottom and run at a speed of 300 rpm. Composite mixture was poured into cast iron moulds having diameter 15 mm and length of 125 mm and 710°C was the temperature at the time of pouring.

Element	Wt. Percentage
Magnesium	0.82
Silicon	0.64
Iron	0.23
Copper	0.17
Zinc	0.031
Manganese	0.072
Titanium	0.015
Chromium	0.014
Others	0.15
Aluminium	Bal

Table 1: Chemical composition of Al6061 alloy.

Figure 1: Pin on disc wear testing machine.

Figure 2: Wear test specimens.

The prepared composites were machined for microstructure and wear studies as per required dimensions. Samples for SEM/EDS were prepared by diamond grinding and final polishing was done by using 1µm diamond paste. SEM was carried out on HR-SEM (Hitachi S-4800, Japan).

Pin on disc machine (DUCOM, TR-20LE) was used to carry wear tests as per ASTM G99 standard [11-13]. Dry sliding wear tests were performed on specimens of diameter 8 mm and 25 mm height. The counter disc material was of EN31 steel. Prior to testing, the pin and disc surface were cleaned with acetone. The experiments were conducted at a constant sliding speed of 400 rpm and sliding distance of 2000 m over a varying load of 10 N, 30 N and 50 N. Similarly experiments were conducted at a constant load of 50 N and sliding distance of 2000 m over a varying sliding speed of 100 rpm, 200 rpm, 400 rpm and 600 rpm. During testing the pin specimen was kept stationary and perpendicular to the disc while the circular disc was rotated. Electronic weighing machine with the precision of 0.0001 g was used to weigh the initial weight of the specimens. After each test, the counter face disc was cleaned with acetone. The pin was weighed before and after testing to determine the amount of wear loss. The data in the form of weight loss was converted into volumetric wear loss with respect to their corresponding density and from the wear volume. Figure 1 showing the DUCOM made pin on disc wear testing machine used for the experiments. Figure 2 shows the wear test specimens used in the study.

Results and Discussion

Microstructural analysis

Representative SEM micrographs of the synthesized as cast Al6061 alloy and micro SiC and Graphite particulate reinforced aluminium matrix composites are presented in Figures 3a-3c. The dispersion of the reinforcement particles (SiC and Graphite) within the Al6061 alloy matrix is visible and can be considered as homogeneous in the composite.

Figures 3b-3c clearly show and even distribution of SiC and Graphite particles in the Al6061 alloy matrix. In other words, no

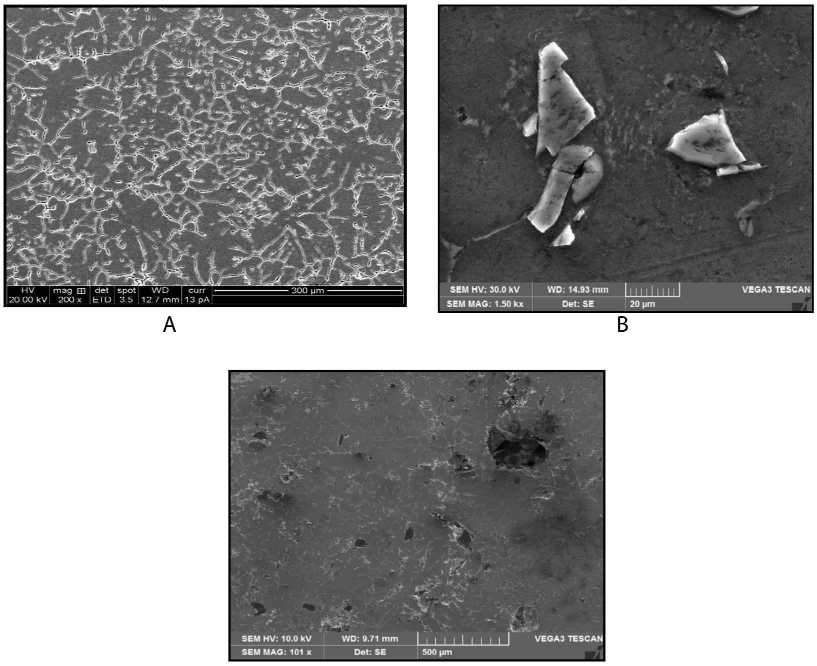

Figure 3: Scanning electron micro photographs of (a) as cast Al6061 alloy (b) Al6061- 6 wt. % SiC (c) Al6061- 6 wt. % Graphite composites.

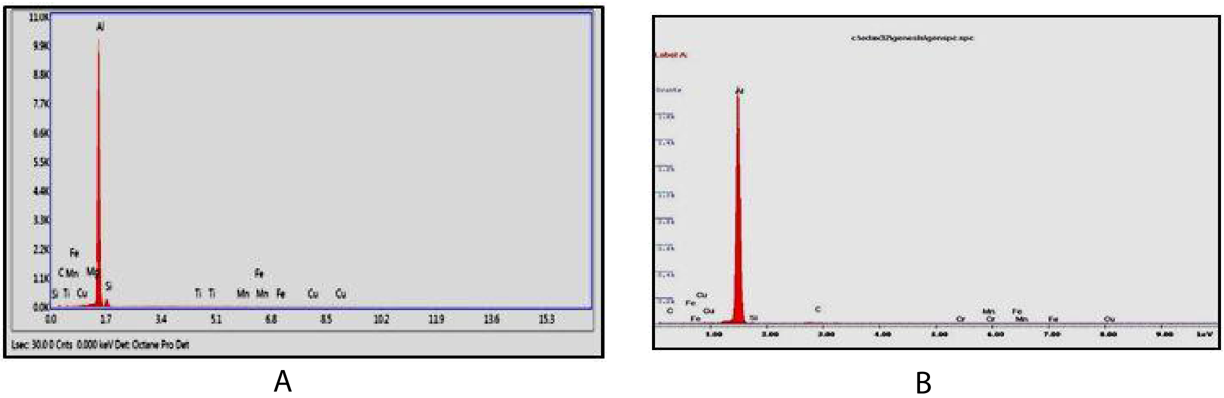

Figure 4: EDS analysis of (a) Al6061- 6 wt. % SiC (b) Al6061- 6 wt. % Graphite composites.

clustering of SiC and Graphite particles are evident. There is no evidence of casting defects such as porosity, shrinkages, slag inclusion and cracks which is indicative of sound castings. This is difficult to achieve in the aluminium matrix by conventional casting process. Two step mixing technique is an ideal process for synthesizing ceramic particulate reinforced composites [14]. In this, wetting effect between particles and molten Al6061 alloy matrix also retards the movement of the SiC and Graphite particles, thus, the particles can remain suspended for a long time in the melt leading to uniform distribution.

Figures 4a and 4b show energy dispersive X-Ray spectrographs of Al6061-6wt. of SiC and Al6061-6 wt. % of Graphite composites respectively. The EDS analysis confirmed the presence of SiC and Graphite in the Al matrix alloy. The presence of SiC shows in the form of Si (Silicon) and Carbon (C), which is evident from the EDS graph (Figure 4a). The presence of graphite shows in the form of Carbon (C), which is evident from the EDS graph (Figure 4b).

Wear studies

The volumetric wear loss of Al6061 alloy and its composites is as shown in Figure 5. The effect of applied load on the wear behavior of Al6061 alloy and its composites is shown in the Figure 5. The volumetric wear loss is increased as the normal load increases from 10 N to 50 N and is y lower in case of SiC and Graphite reinforced composites.

Higher volumetric wear loss is observed for matrix alloy and the composites at higher loads. At maximum loads the temperature of sliding surface and pin exceeds the critical value. So as load increases on the pin ultimately there is an increase in the volumetric wear loss of both the matrix alloy and SiC-Graphite composites.

The variation of volumetric wear loss of the matrix alloy 6061 and its composites with 6 wt. % SiC and 6 wt. % Graphite reinforcement contain are shown in Figure 5. It is observed that the volumetric wear loss of the composites decreases with 6 wt. % SiC reinforcements in the matrix alloy. The improvement in the wear resistance of the composites with 6 wt. % of SiC reinforcements can be attributed to the high hardness of SiC particulates which acts as the barrier for the material loss. There was significant decrease in volumetric wear loss in 6 wt. % Graphite reinforced composites. The volumetric wear loss of Al6061-6 wt. % Graphite composite is lesser than Al6061-6 wt. % SiC and as cast

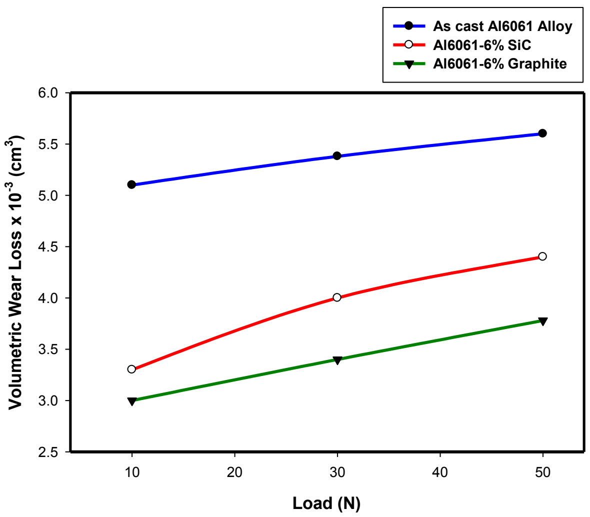

Figure 5: Volumetric wear loss of Al6061 alloy and SiC and Graphite composites at varying loads and 400 rpm constant sliding speed.

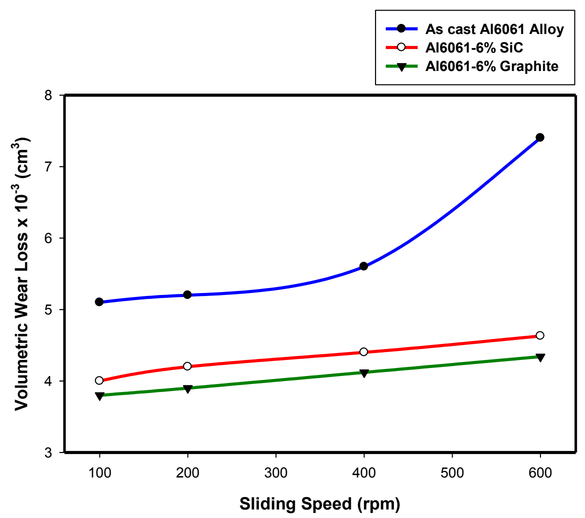

Figure 6: Volumetric wear loss of Al6061 alloy and SiC and Graphite composites at varying sliding speeds and 50 N constant load.

Al6061 alloy matrix. A6061-Graphite composites shown superior wear resistance compared to SiC reinforced composites.

Good lubricating property of graphite makes Al6061-6 wt. % Graphite composites more resistance to wear. When the Graphite content is low, mating parts is largely not covered by a film of graphite and the tri-biological properties are almost similar to or only slightly better than those of the matrix materials. When Graphite content is high, acts as a lubricant in the solid form and smears on the surface of the disc [15,16].

Figure 6 shows the dependence of all the volumetric wear loss of Al-6061 matrix alloy and Al6061-6 wt. % SiC and 6 wt. % graphite composites on sliding speed. With an increasing speed from 100 rpm to 600 rpm, the volumetric wear loss is increased for both Al6061 matrix alloy and fabricated composites. However for all sliding speeds, the wear rate of the composites were much lower, when compared with the Al6061 matrix alloy and is much lesser in the case of Al6061-6 wt. % Graphite composites compared to Al6061 alloy matrix and 6 wt. % SiC composites. Further, as sliding speed increases there is increase in wear due to softening of the composite at high temperature. The increased temperature causes the severe plastic deformation in the specimen at higher sliding speeds can leading to form high strain rate sub-surface deformation. Therefore this leads to enhanced delamination contributing to enhance wear rate.

Worn surface study

Wear surface analysis of Al6061 alloy and SiC-Graphite reinforced composites are studied by using scanning electron micro-photographs. Figure 7 represents the wear worn surfaces of matrix material Al6061 alloy and its composites 6 wt. % of SiC and 6 wt. % of Graphite particles reinforced composite at 50 N load and 400 rpm sliding speed.

Figure 7a shows the wear worn surface of the matrix alloy as cast Al6061 reveals more patches of smashed portions and yawning grooves due to heavy deformation in the plastic form. It can be seen that the wider and deeper grooves in the case of Al6061 alloy compared to its composites.

Figures 7b and 7c show the SEM photographs of the worn surface of Al6061-6 wt. % SiC and Al6061-6wt. % Graphite composites tested at applied load of 50 N and 400 rpm speed. Due to presence of hard SiC particulates in Al alloy wear loss is less and small patches can be seen.

Worn surface shows very minor flaws and cracks mainly due to the presence of SiC particulates (Figure 7b). The smeared particles of graphite from the worn surface of composites form a thin layer between sliding surfaces, which prevents direct metal contact. This acts as tribo-layer between pin and disc, avoids the direct contact between the two surfaces, and causes less volumetric wear loss in graphite composites (Figure 7c).

Conclusion

The investigation made on fabrication and evaluation of wear behavior Al6061-6 wt. % SiC and Al6061-6 wt. % Graphite metal matrix composite by vortex method has led to following conclusions. Al6061 alloy and its composites have been effectively fabricated by stir casting method using two step additions of particulates in the melt. The scanning electron microphotographs of Al6061-SiC and Al6061-Graphite composites were shown uniform distribution of reinforcement particulates in the base matrix material. The wear resistance of Al6061 alloy increased after addition of SiC and graphite particles. The volumetric wear loss is affected by load and sliding speed. There is significant increase in volumetric wear loss as applied load and sliding speed increases. The Al6061-6 wt. % graphite composites have shown lower rate of volumetric wear loss as compared to that observed in as cast Al6061 alloy matrix and Al6061-6 wt. % SiC composites. SEM micrographs of wear worn surfaces indicated the presence of

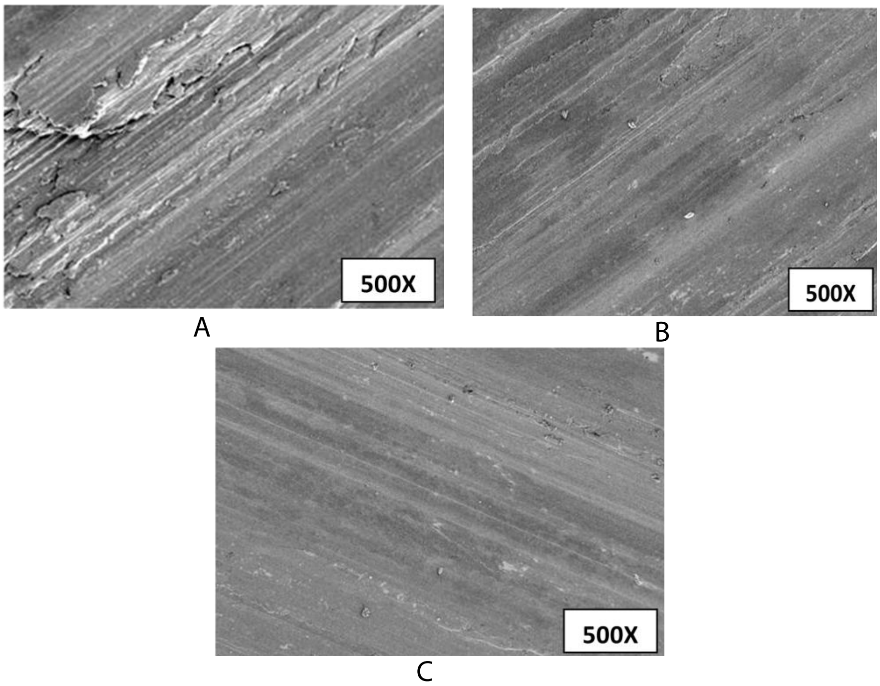

Figure 7: Shows the SEM microphotographs of worn surfaces of (a) as cast Al6061 alloy (b) Al6061-6% SiC (c) Al6061- 6% Graphite composites at 5 kg load and 400 rpm.

soft grooves in the Al6061-SiC and Al6061-graphite composites as observed in the base alloy Al6061.

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