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Wear rate behavior of As-cast and heat treated hybrid Aluminum Metal Matrix Composites

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Abstract

In the present study the effect of sliding speed on wear behaviour of as-cast and heat treated Aluminum alloy / composites has been investigated. Aluminum alloy series A356 is used as matrix, Silicon Carbide particles (SiC_p) and graphite (Gr) particles are used as reinforcements. The proposed Aluminum Metal Matrix Composites (AMMCs) were fabricated by stir-casting. In the Aluminum A356 matrix, the reinforcement SiC_p was varied from 0 to 9% by weights in steps of 3%, in addition to it 3% by weight Gr particles was also added. The castings were machined as per ASTM standard and T6-heat-treatment was carried out. Specimens were aged at different durations of 3, 6, 9, and 12 hrs at a temperature of 155º C. The pin-on-disc wear testing machine was used to evaluate the wear rate of the composites. The results revealed that by increasing the reinforcement and ageing at T6-9 hrs showed a maximum wear resistance in all the sliding tests. The reinforcements were restricted to 9% by weight due to the formation of agglomeration. The increase in sliding speed showed an increase of wear rate. The wear tested samples were examined for microstructure using scanning electron microscope (SEM) and the composition of worn out surface was confirmed using energy dispersive spectrum (EDS).

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Keywords: Sliding speed, Hybrid MMC, Ageing, SEM, EDS, Wear rate

1. Introduction

Metal Matrix Composites (MMCs) are attractive, as they offer to attain the property of combinations that are not obtained in monolithic materials and resulting in a number of service benefits. These could include increased strength, decreased weight, higher operating temperature, improved wear resistance, high elastic modulus and controlled coefficients of thermal expansions. The particles employed to make the composites have typically high melting point and they are not expected to modify significantly on overall chemistry of the matrix alloy. The particulate reinforced metal matrix composites are preferred since they offer a number of advantages. In particular, particulate reinforced composites exhibit near isotropic properties (Rohatgi, 1993). The good number of work is carried out on hard SiC_p, Al_2O_3, soft graphite particles etc. The wear resistance increased with increasing of hard ceramic particles in matrix material but decreasing the machining property (Basavarajappa, 2006). To maintain good

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wear and machining property, both hard and soft particles are added to matrix. Tjong et al., (1997) reported that the addition of SiC_p from 2-8 vol. % to the Al-silicon alloys, significant increase in wear resistance was observed with the increase in reinforcement (Tjong et al.,1997). Sahin reported that the combined effect was observed using orthogonal arrays and analysis of variance to study the Tribological behaviour of 10 wt. % of SiC_p with average particle size of 100 µm reinforced with Al 2014 alloy. The results indicate that the SiC_p into matrix alloy exerted a greatest effect on abrasive wear, followed by applied load, lower effect was observed for sliding distance (Sahin, 2007). Zhang and Wang (2007) investigated the friction and wear behaviour of two different brake drum materials such as Aluminum matrix composites reinforced with different sizes of 3.5 and 34 µm of 25 vol. % of SiC_p. The following conclusion were drawn, Al-MMCs containing small size of SiC_p were not suitable for the fabrication of the brake rotors and drums. As friction parameter strongly depends on size of SiC_p, and small size of SiC_p are easily pulled out from matrix material which forms thin tribofilms. This results in abrading of brake material. But in large size of SiC_p forms thick tribofilm, that protects the brake material from abrasion, hence reducing the specific wear rate (Zhang and Wang, 2007). Constantin et al.,(1999) worked on dry sliding wear of Aluminum matrix composites, reinforced with different volume fraction of particles. They reported that even for small volume fraction of reinforcement, wear resistance of the composites was increased. Bindumadavan et al., (2001) reported that the porosity was increased with increasing the reinforcement percentage of SiC_p. However for lower SiC_p increase the particle porosity interaction was greater, when compared with higher SiC_p (Bindumadavan et al., 2001). Surappa et al., (1982) investigated on wear rate of cast Aluminum and Al-Si alloys containing up to 5 wt. % of Al_2O_3 particles with 100 µm size under conditions of adhesive and abrasive wear. The wear rate of Al-Si alloy decreases with addition of Al_2O_3 particles (Surappa et al., 1982). Equal effort has been carried out on soft graphite (Gr) reinforced with matrix material that increases the machining property and with a loss of mechanical property. To maintain high mechanical, wear and machining property by addition of graphite in Al/SiC_p composite, it forms Al/SiC_p/Gr hybrid composites.

There has been significant amount of work on A356 composites but there are not many research work pertaining to A356 hybrid composite containing SiC_p and Gr. The study of this kind of hybrid composites opens up whole new areas of research. The aim of the present investigation is to observe the structure and wear behavior of A356 hybrid composite in as-cast and heat treated condition so that a specific recommendation is being put forward for its tribological use in automotive brake discs.

2. Experimental Procedures

2.1Materials and processing

A356 alloy billets are placed inside the crucible and the induction furnace temperature was set at 750^0C. Specimens of varying percentage of SiC_p were prepared which contained SiC_p of 3%, 6% and 9% by weight and additional Graphite particles 3% by weight to each specimen. As the A356 matrix melts in the crucible at a temperature of 740^0C, SiC_p and graphite particles were added on the weight basis. An electrical stirrer is used to stir the entire mixture, during stirring scum powder was added to remove the flux. After removal of flux a degasification agent hexachloroethane is added to remove the gas from molten mixture. The mold box is preheated to attain good solidification and is placed on sand bed in order to avoid spilling of molten metal while pouring into mold box. It solidified after around 1.5 to 2 hrs. After solidification, the composite billets were removed from mold box.

The castings were turned to ASTM standard and T6 heat treatment was carried out at 540^0 C±5^0C for 12 hrs and quenched at 60^0C. Specimens were artificially aged at different durations such as 3, 6, 9, and 12 hrs, at a temperature of 155^0 C. Microstructure of the base alloy and composites obtained through SEM shown in Fig 1.

The composition of the base alloy is shown in Table 1. The wear tests were performed on all the samples and the base alloy by varying the sliding speed using a pin on disc wear testing apparatus.

Table 1 Composition of A356 Aluminum alloy

Elements	Cu	Mg	Mn	Si	Fe	Zn	Ti	Others	Al
Weight %	0.1	0.4	0.06	7.0	0.1	0.04	0.1	Traces	Balance

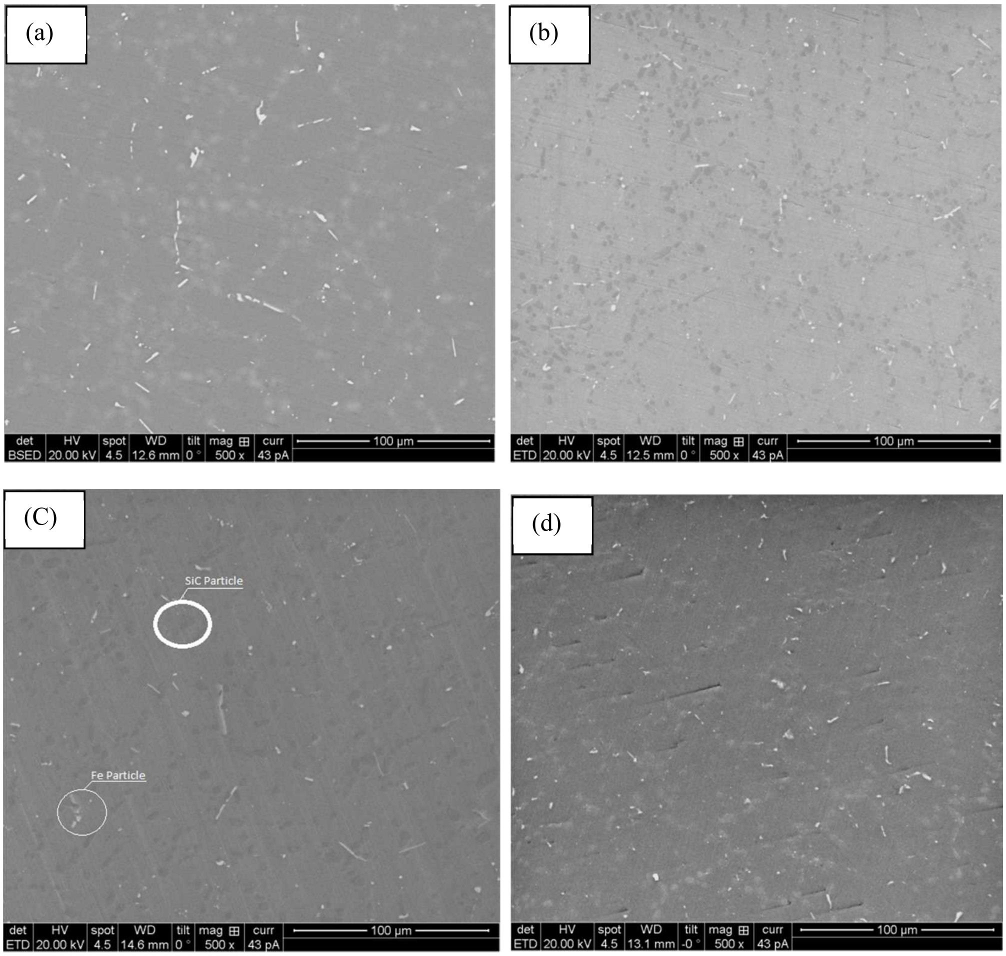


Fig 1 SEM of (a) A356-3SiC_p-3Gr-T6-3 hrs (b) A356-6SiC_p-3Gr-T6-6 hrs (c) A356-9SiC_p-3Gr-T6-9 hrs (d) A356-9SiC_p-3Gr-T6-12 hrs.

The darker SiC_p and bright iron particles are clearly visible in the SEM image of the composites with different percentages of SiC_P and different ageing durations. Confirmation of these assumptions is obtained by EDS analysis, as shown below by the two spectrums. The first spectrum shows the presence of SiC particles, and the particles of iron and its oxides can be seen on second spectrum. The A356-9SiC_p-3Gr-T6-12 hrs shows some degree of agglomeration compared to the other images.

2.2 Plan of Experiment

The wear tests were carried out on the pin-on-disc wear monitor (DUCOM; TL-20) with data acquisition system. It was used to evaluate the wear behaviour of the composite, against hardened ground steel disc (En-32) having hardness 62 HRC and surface roughness (R_a) 0.5μm. It is versatile equipment designed to study wear under sliding condition. Sliding generally occurs between a stationary pin and a rotating disc. The disc rotates with the help of a D.C. motor having speed range 0-2000 rev/min with wear track diameter of 50 mm-180 mm, which could yield sliding speed 0 to 10 m/sec. The system has a maximum loading capacity of 200 N.

The tests were carried out as per ASTM standard under ambient conditions. The tests were conducted with varying sliding speed of 1.25, 2.51, 3.77, 5.03, and 6.28 m/s with constant sliding distance of 4500 m and applied load of 30 N. After every test, the specimen and disc were cleaned with acetone to remove the debris and dried. The difference of weight before and after the test gives the wear rate of the specimens.

3. Results and Discussion

3.1 Effect of Sliding Speed on Wear Rate

The wear rate of base alloy as well as composites increases with increasing of sliding speed as shown in Fig 2. The wear rate of base alloy and composite increases linearly with sliding speed. The wear rate was maximum for base alloy compared to the composite. The maximum wear resistance is attained for A356-9%SiC_p-3%Gr composites aged at T6-9 hrs compared with different aged composites and the base alloy. The wear rate increases with increasing the sliding speed and decreases with T6 ageing. Among all heat treated composites, T6-9 hrs exhibits a better wear resistance. The wear resistance of base alloy and composites increases with increasing of weight percentage of SiC_p. The specimens aged at T6-12 hrs exhibit less wear resistance in all the cases, due to failure to form a precipitation to get good hardening phase formation. It is observed that base alloy showed a maximum wear rate followed by composites aged at 3 hrs. The lower wear rate was observed for composites aged at T6-3 hrs, T6-6 hrs, T6-9 and T6-12 hrs compared to base alloy. The composites with less ageing duration showed the formation of precipitation when compared to ageing of 12 hrs and beyond . When the sliding speed was increased beyond 3.77 m/s, ceasing was observed for the base alloy, but increasing of SiC_p percentage in the alloy reduces the ceasing effect. The SiC_p is more effective element compared with other ceramic reinforcement element like Al_2O_3 (1998), as SiC_p is having higher hardness and fracture resistance, thus provides more resistance to ceasing.

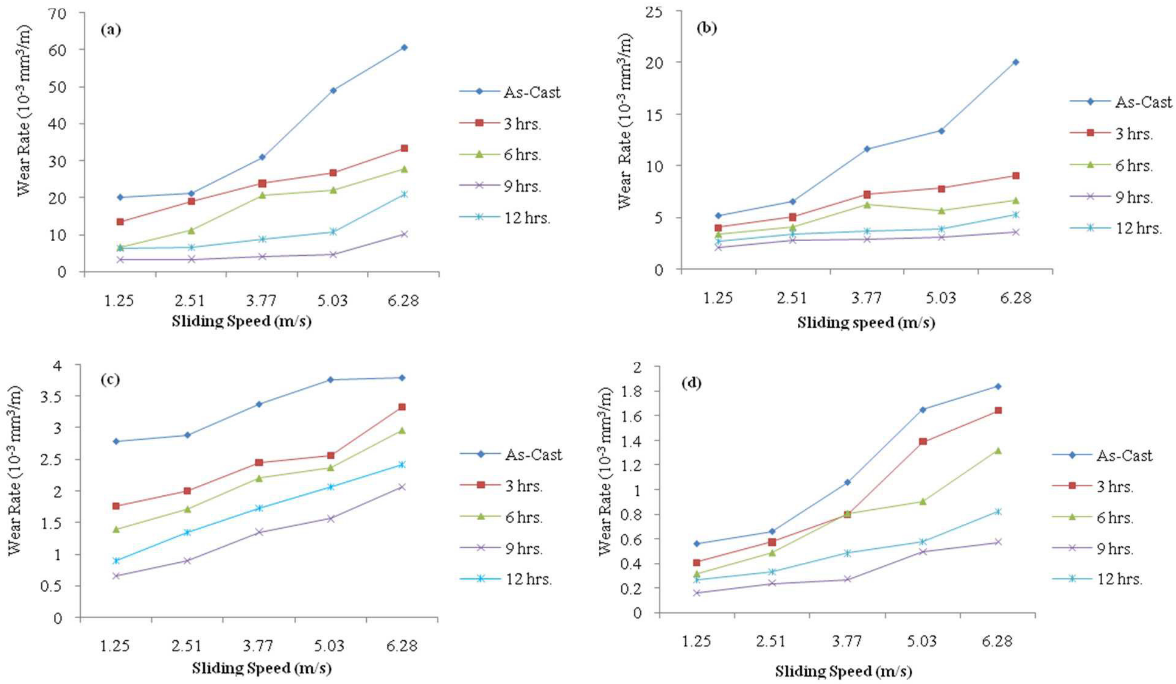


Fig. 2 Cumulative wear rate of base alloy and different ageing composites as a function of sliding speed at constant sliding distance of 4500 m and applied load of 30 N. (a). A356 alloy (b). A356-3SiC_p-3Gr (c). A356-6SiC_p-3Gr (d). A356-9SiC_p-3Gr.

The function of the graphite particles is to decreases the diffusion and adhesion effect. Hence it decreases the wear rate with increase in the sliding speed, due to quick formation of lubricating layer which avoids the direct contact between specimens and disc that avoids the ceasing, it improves wear behaviour of the composites. The main function of the SiC_p is to carry the load.

The increasing of SiC_p in A356-3Gr composites increases the wear resistance, it enhances the tribological property of the composite. As SiC particles come in contact with sliding disc, that avoids further wear and graphite particles which helps to run smoothly on disc. It helps avoid cease of the material that occur during test periods. The SiC_p acts as load bearing member and graphite acts as a solid lubricant in A356 matrix material. The addition of SiC_p to A356 matrix material, leads mild wear regime at higher speeds their by inhibiting severe wear. The SiC_p assist with retention of oxide transfer layer on composite sliding surface. It prevents metal-metal contact and keeps wear behaviour within the mild wear regime.

3.2 Analysis of Worn surfaces

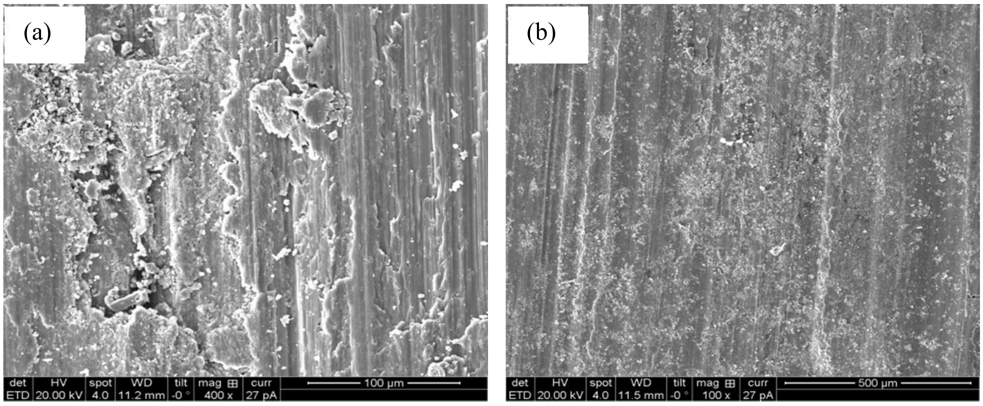
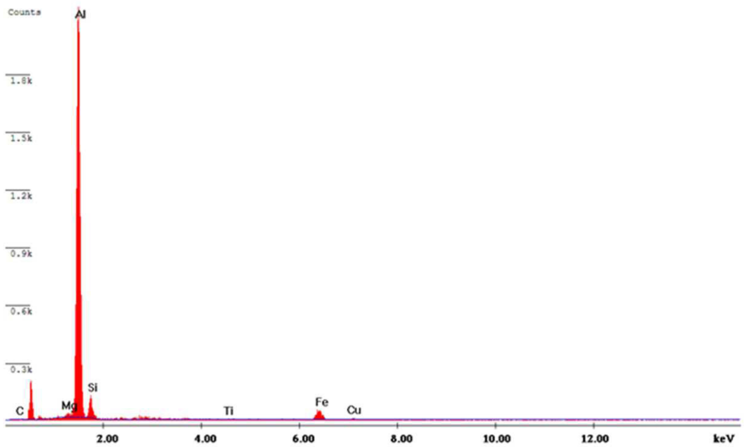


Fig 3 SEM of worn surfaces of (a) base alloy and (b)Composites

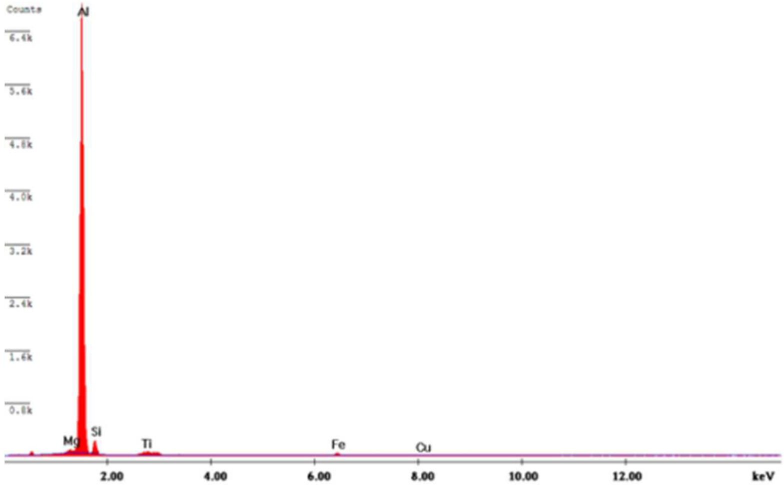
The SEM image of the worn surface of the base alloy and the composites specimens at sliding speed of 3.77 m/s is shown in Fig 3. The figure shows two micrographs at the same speed, sliding distance and load with different materials. However the other samples also shows similar microstructures. The microstructures of the base alloy Figure 3-a, shows large amount of plastic deformation on the surface. Whereas the hybrid composites microstructure reveals grooves formed by the hard SiC_p. The graphitic particle clearly shows interactions with SiC_p and also with surface of the disc and it forms the lubricant layer. After wear of matrix, SiC_p are projected out from the material which is observed in Fig 3-b.

3.3 EDS Analysis

This is confirmed by EDS analysis of worn surfaces of the base alloy and composites (Fig 4). Compared with EDS profile of base alloy (Fig 4a) it is clear that, Fe peaks is observed. The Fig 4b clearly shows Si and C peaks, which indicates that SiC and Gr particles are available for being pulled out from the Al matrix while sliding. However, a noticeable Fe peaks are also observed because, the steel counter surface is abraded by the reinforcements. This is due to iron and its oxide formed during the sliding. This concludes that the maximum hardness of the composites gives the stronger wear resistance. Due to the above said reasons, the use of hybrid composites in high speed, friction and high temperature applications, would result in enhanced life.



(a)



(b)

Fig 4 EDS Analysis of worn surfaces of (a) base alloy (b) composite

4. Conclusion

Wear tests of hybrid composites A356-SiC_p-Gr show their superior performance in relation to the base material A356. In the Stir cast technique, uniform distribution of SiC and Gr particles were observed, which is confirmed by SEM microscopy analysis. The Wear rate of A356-9SiC_p-3Gr T6 – 9hrs was found to be optimal for lower wear rate compared to other ageing durations and base alloy. The test also confirms that wear rate is low at the low sliding rate. Wear rate decreases with decrease of normal load and increase of sliding speed. At higher sliding speed, composites shows stable mechanical mixed layer and produces less wear rate when compared with base alloy. The Composites aged at T6-12 hrs exhibits less wear resistance, due to improper precipitation and failure to form good hardening surface of the specimens. The increase of SiC_p in composite material acts as load bearing and graphite particles acts as solid lubricant, combined it improves the tribological properties of the composites. These properties of the hybrid composite, low wear rate and good thermal conductivity makes it a fascinating material for its use in automotive disc brakes.

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