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Effect of short carbon fiber/SiC on tribological properties of aluminium matrix hybrid composites

Tanmay Vivek Joshi and Akash Mohanty

School of Mechanical Engineering, Vellore Institute of Technology, Vellore-632014, India

E-mail: mohanty@vit.ac.in

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Abstract

This research study was carried out to combine the beneficial properties of Silicon Carbide (SiC) and carbon fiber (CF) as reinforcements in the aluminum matrix to develop the composites for automotive and aerospace applications. Powder metallurgy was used to fabricate five samples with different compositions. Optical microscopy was used to visualize the microstructure and the phases of the composite. Linear wear, coefficient of friction, density, and Vickers hardness of the samples were determined and were compared. The sample with 6 wt.% CF and 10 wt.% SiC was found to have the optimal properties for the application. The linear wear was 52.32% less and the hardness was 14.58% more than the base.

1. Introduction

Metal Matrix Composite (MMC) is a term including a wide range of composites that have a metallic matrix and non-metal or a metallic reinforcement. MMC's have the advantage of properties that can be tailored according to the application [1]. Properties such as a low density, high hardness, wear resistance, tensile/compressive strengths and good thermal conductivity can be achieved which are of great importance especially for the automotive and aerospace industries. This study aims to combine the beneficial properties of the Al matrix and the SiC, CF reinforcements in a hybrid MMC for automotive and aerospace applications. Aluminium is widely used as a matrix material due to its low cost and density, high strength, corrosion resistance and good conductivity [1]. SiC reinforced Al MMC's have considerable advantages. Increasing the wt.% of SiC increases the stiffness, wear-resistance and high-temperature strength of the composite. Based on the literature review conducted, it was observed that Aluminum matrix composites with 10 wt.% SiC gave optimal results [2–4]. Hence, the same composition has been selected in this study. Addition of carbon fibres (CF) as reinforcement improves mechanical properties and acts as a lubricant. Powder metallurgy method is used for fabricating the composites in this study due to its advantages such as good distribution of reinforcing particles, low process temperatures, no wettability issues and ability to produce intricate components [5].

Shirvanimoghaddam, *et al* published a review paper giving detailed information about the types of carbon fibers, their production and their properties. It illustrates the various methods of fabricating CF reinforced metal matrix composites [6]. **Umasankar** *et al* conducted a study that intends to understand the influence of processing parameters on the mechanical properties [7]. **Ravindran** *et al* investigated powder metallurgy processed Al_20_3, SiC and graphite using a pin-on-disc wear test. The composites with 5 wt.% graphite had the lowest wear loss and coefficients of friction because of the self-lubricating effect of graphite [8]. **Miyajima**, *et al* investigated the effects of SiC and Al_2O_3 reinforcements on the wear behaviour of aluminium matrix composites by pin-on-disk tests. It was concluded that particle reinforcements are the most effective in improving the wear resistance of MMC [4]. **Islam**, *et al* described the available raw material, various fabrication techniques along with their effects on the properties of the composites produced and the manufacturing problems encountered in detail [9]. **Lei**, *et al* studied the influences of the fiber volume fraction, the load applied, rotating speed, and wear mechanism on the friction and wear properties of the composite. The results indicate that SCFs/Al composite had better tribological properties than Al alloy.

Figure 1. Sintered samples.

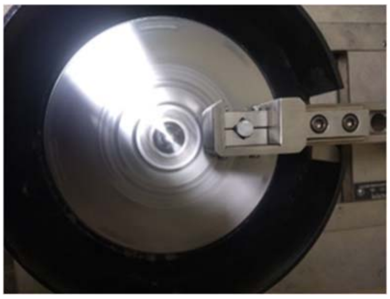

Figure 2. Pin on Disc wear test setup.

Table 1. Constituents of the MMC.

Samples	Wt.% of short CF	Wt.% of SiC
A	0	10
B	2	
C	4	
D	6	
E	8	

2. Experimental

2.1. Sample preparation

Aluminum powder of 99% purity and 60 μm size was purchased from Nice Chemicals, India. SiC powder of 65 μm was obtained from Otto chemicals, India. CF (PAN) was procured from ZOLTEK. The fibres were cut to 0.5–2 mm length and then heated at 200 °C for 2 h to remove the saline coating. The constituents were weighed using a digital weighing scale with 0.0001 g accuracy and five compositions were prepared with 10% SiC and 0%, 2%, 4%, 6%, 8% CF, by wt. [table 1].

The mixed constituents were consolidated using ball milling. The ball to powder ratio used was 3:1 and a duration of 2 h at 200 rpm for each composition. 1 wt.% of Stearic acid was used as a process control agent to prevent fibre agglomeration and to facilitate easy removal from the compaction mold. 0.1 ml of PVA binder was added and then the samples were then compacted in a custom made mold under 100 MPa pressure in a hydraulic press compaction machine. The green compacts were sintered at 550 °C in an Argon atmosphere to produce the final samples. The dwell time was 1 h and the heating rate was 5 °C per minute [figure 1].

2.2. Characterisation

The samples were machined to 10 mm diameter and 10 mm height blanks for the purpose of mounting the specimens in the test setup. The mounted samples were grinded using emery sheets and polished to obtain a mirror finish on the surface. The etching was performed using Keller's reagent and the microstructure was viewed using an optical microscope with a magnification of 500×.

The density test was performed using the Archimedes principle. The samples were weighed on a digital weighing scale and then immersed in water to obtain the volume. The theoretical density was calculated using

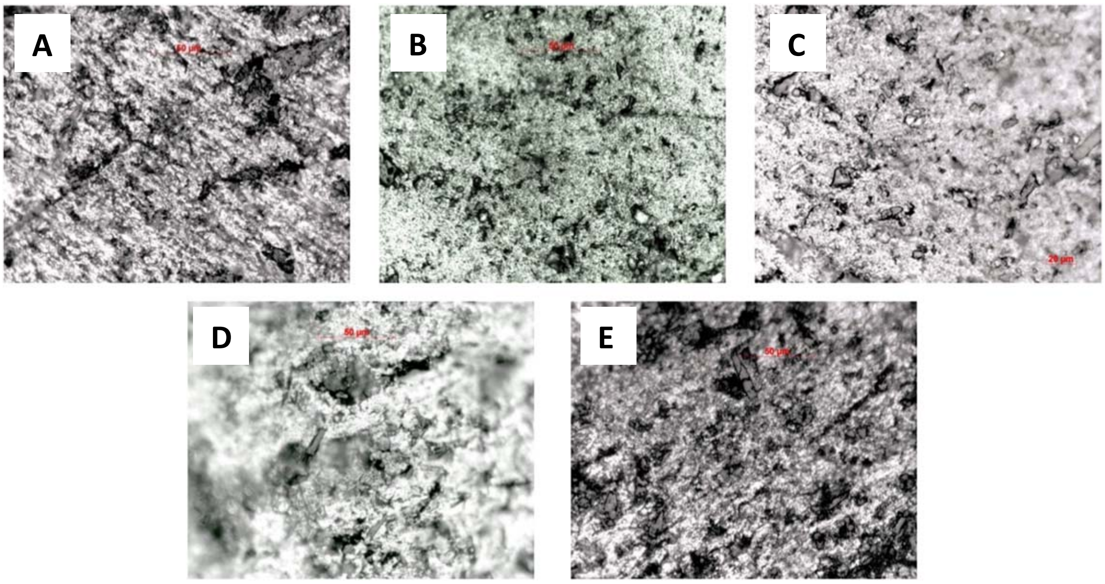

Figure 3. The microstructure of (A) 0%, (B) 2%, (C) 4%, (D) 6% and (E) 8% CF reinforced aluminium matrix composites.

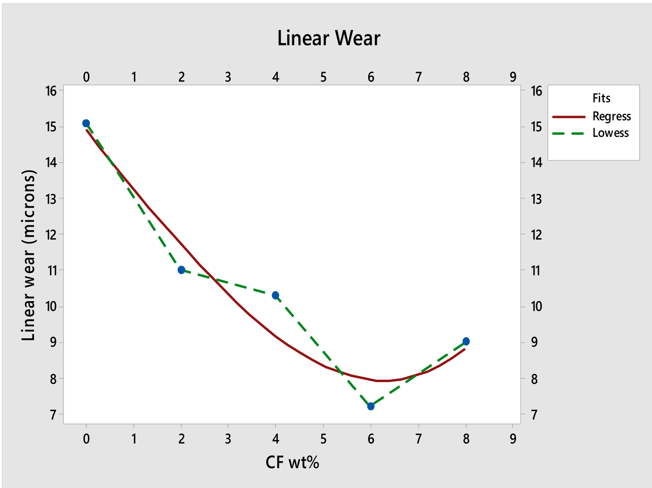

Figure 4. Plot of linear wear against wt.% of CF.

the law of mixtures and the difference between the theoretical and true values of density was visualized and the error percentage was calculated.

The wear test was performed on a DUCOM tribometer to obtain the linear wear loss and the frictional force exerted by each sample [figure 2]. The MMCs were fabricated into pins of 10 mm diameter and 30 mm length and the metallic disc used was EN31 steel. The load applied was 10 N with the sliding velocity as 0.5 m s^{-1}. All samples were compared after a sliding distance of 500 m.

The Vickers hardness test was conducted on a Matsuzawa testing machine. The mounted samples were used with the variation of filler content as shown in the table 1. The load applied during the indentation was 200 g for a time duration of 15 s.

3. Results and discussions

3.1. Microstructure

Figure 3 shows the microstructure for the samples with the variation of the fillers contain. The grey region in this figure is the Aluminum matrix. The dark narrow regions can be identified as carbon fibers while the rounded black spots are the SiC particles. Some pores can be seen as small dark circles in the images. It was observed that the reinforcements have more or less achieved the uniform distribution of the reinforcements in the matrix.

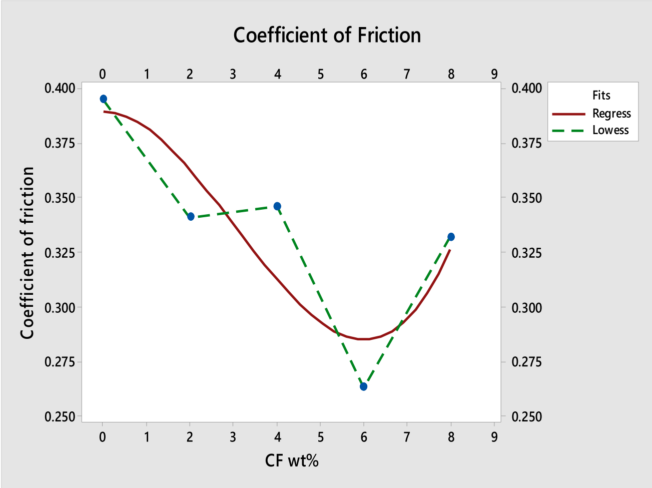

Figure 5. Plot of coefficient of friction against wt.% of CF.

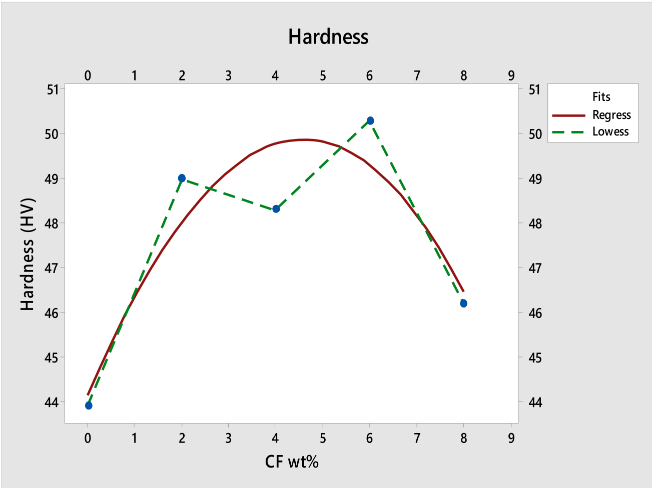

Figure 6. Plot of Vicker's hardness against wt.% CF.

Table 2. Density of the MMC samples.

Sample	Theoretical density	True density	Relative density (%)
A	2.751	2.479	90.113
B	2.733	2.448	89.572
C	2.715	2.392	88.103
D	2.697	2.359	87.468
E	2.679	2.343	87.458

However, some agglomeration of carbon fibers can be observed in figure 3(E) i.e. 8 wt.% CF. The good bonding between the matrix and the reinforcement can be seen in all the samples.

3.2. Density

The true density observed for all the samples was less than their theoretical densities [table 2]. This is an expected result while following the powder metallurgy route due to porosities after compaction and sintering of the powders [10]. It is observed that the relative density decreases with increasing percentage of CF in the sample. This can be explained by the agglomeration of fibers and the resulting porosities in the samples having high wt.% of CF reinforcements [11, 12].

3.3. Pin and Disc Wear test

The values of linear wear and friction coefficient were obtained from a Pin and Disc wear test. It is observed that the wear rate is proportional to the sliding distance [figure 4], while the friction coefficient [figure 5] remains constant with respect to sliding distance.

It can be inferred that the linear wear decreases linearly with the increasing percentage of CF up to 6 wt.% at which it is minimum and a 52.32% reduction over the base sample. The suspected cause for this result is the lubrication and hardness offered by the CF particles. The reinforcement helps in hindering dislocation of the matrix resulting in better wear resistance [13]. The linear wear increases again for 8 wt.% of CF, which can be explained by the agglomeration and non-uniform distribution of the reinforcement.

The Coefficient of Friction result shows a similar trend to the linear wear. The largest value obtained is for the 0 wt.% CF sample, while the smallest value is given by the 6 wt.% CF sample. The explanation for the result is the same as the wear test i.e. probable lubrication due to the carbon component. The wear and friction coefficient results are in agreement with previous studies conducted on similar composites [13–15].

3.4. Hardness

The Vickers hardness test results for all the samples were analysed. The highest value is obtained for the 6 wt.% CF sample with the increase being of 14.58% over the base sample [figure 6]. The increasing concentration of CF helps in hindering the movement of dislocation and hence dispersion hardening takes place in the composite [16]. Similar results are obtained in previous studies [16, 17]. However, the agglomeration of fibers observed in the 8 wt.% sample may inhibit this phenomenon resulting in reduced hardness for the sample.

4. Conclusions

The CF and SiC reinforced Aluminum matrix hybrid composite was successfully fabricated using PM. Using five samples with different compositions helped in comparison and visualizing trends in the properties. The microstructure shows a uniform distribution of reinforcements except for the 8 wt.% sample in which fiber agglomeration occurred. Adding the reinforcements improved the physical properties of the matrix due to precipitation and dislocation hardening and grain refinement [15]. Density analyses of the samples showed that the true densities of all samples were lesser than the calculated densities due to porosities, with the maximum variation being 12.54%. The tribological properties of linear wear and coefficient of friction were successfully tested. The linear wear decreased with increasing concentration of CF up to 6 wt.%, giving a maximum reduction of 52.32%. The coefficient of friction showed a similar trend with values ranging from 0.392 to 0.262. The Vickers hardness result showed an increase of 14.58% at 6 wt.% over the base sample.

Based on the analyses of all the tests conducted, it can be inferred that Sample D (6 wt.% CF) gives the best results among the samples tested. It is potentially a replacement material for products in aerospace and automobile sectors such as pistons, bearings and brakes due to its low density, good wear resistance and hardness.

Data availability statement

No new data were created or analysed in this study.

ORCID iDs

Akash Mohanty https://orcid.org/0000-0002-1215-0642

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