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Dry sliding wear behavior of aluminum based hybrid composites with graphite nanofiber–alumina fiber

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ABSTRACT

The wear behavior of aluminum based hybrid composites reinforced with graphite nanofiber (GNF) and alumina short fiber (Al_2O_{3sf}) in different volume fraction of fibers (10%, 15% and 20%) was studied under dry sliding conditions. The Taguchi approach to experimental design was used to identify those testing parameters that have the largest effects on wear loss and coefficient of friction of the composites. Sliding distance was found to be the prominent parameter affecting wear loss; applied load affected coefficient of friction most significantly. The results of Taguchi analysis indicate that wear loss increases with increasing load and sliding distance, but it is reduced with increasing sliding speed. Coefficient of friction decreases with increasing applied load and sliding speed whereas it increases with increasing sliding distance. The composites with 10 vol.% and 15 vol.% of fiber had the lowest wear loss and friction because of the mixture effect of GNFs and Al_2O_{3sf}. However, due to the effect of agglomerated GNFs, there was an increase in wear loss and friction at 20 vol.%.

1. Introduction

In recent years, hybridization of reinforcements has gained significant importance in enhancing the properties of Metal matrix composites (MMCs) [1]. Moreover, mechanical properties of MMCs are improved by the reduced formation of intermetallic compounds at the interface between fibers and the matrix metal that results from the increase in interfacial area between fibers. Currently, aluminum matrix composites with micro–nano hybrid reinforcements are recognized as promising materials. The MMCs can show significantly lower wear rates than unreinforced alloys over wider ranges of load and sliding speeds. The wear resistances of MMCs have been found to be improved by hybridization with fibers, particles, whiskers and nanoparticles in different combinations [2]. Previously, a few studies on the wear behavior of hybrid MMCs have been reported. Ames and Alpas [3] studied on wear mechanisms in hybrid composites of graphite$_p$–SiC$_p$/A356 aluminum alloy. They highlighted that wear resistance was improved by hybridization. Zhang et al. [4] found a higher wear resistance for Al/(Al_2O_{3sf} + SiC_w) hybrid composites than for Al/SiC_w and Al/Al_2O_{3sf} composites. Du and Li [5] studied the improvement on the wear properties of Al matrix by hybridization with the Al_2O_{3sf}/SiC_p system. Ahlatci et al. [6] investigated wear behaviors of Al/(Al_2O_3p–SiCp) hybrid composites produced by pressure infiltration. These composites, reinforced with 37 vol.% of Al_2O_3 and 25 vol.% of SiC particles also contained Mg up to 8%. Metal–metal and metal–abrasive wear resistance were found to increase with an increase in the Mg content. Tjong et al. [7] found out that the addition of BN into the Al/SiC_p composite system improved the wear resistance of the latter. Jun et al. [8] developed Al_2O_{3p} and carbon short fiber reinforced Al alloy (Al–Si–Cu–Mg–Ni) hybrid composites, by squeeze infiltrated route. Fiber normal-orientation was found to contribute to an improvement in the wear properties. Long et al. [9] highlighted that composites reinforced with a hybrid of SiC whisker, SiC particulate, and carbon fiber exhibited excellent wear resistance. Guo et al. [10] studied the tribological behavior of aluminum/graphite$_p$/SiC_p hybrid composites and found that the wear rate increased as the amount of graphite was increased up to a threshold value of 5%. Chen et al. [11] found a higher wear resistance for Cu/CNT composites than for pure Cu matrix, and that Ni–P–CNT electroless coating exhibited higher wear resistance and low coefficient than that of the Ni–graphite and Ni–P–SiC composites. Choi et al. [12] studied the wear behavior of aluminum based composites containing CNTs. They found that wear resistance is enhanced and the coefficient of friction is reduced. Kim et al. [13] observed that the incorporation of CNTs in the matrix resulted in a lower coefficient of friction and higher wear resistance.

It may be seen from the above discussions that the composites have been studied from different combinations of reinforcements

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Table 1
Properties of Saffil alumina fibers (ICI, UK) and GNF (Polyfield Korea Co. Ltd.).

Materials	Density (g/cm^3)	Melting point (°C)	Mean diameter (μm)	Mean length (μm)	Tensile strength (MPa)	Young's modulus (GPa)
Al_2O_{3sf}	3.3	2000	3	120	2000	300
GNF	0.2	2800	0.05	10	3500	550

Table 2
Factors and levels for Taguchi method.

Testing parameters	Label	Level 1	Level 2	Level 3
Volume fraction of fibers (%)	VF	10	15	20
Applied load (N)	AL	10	30	50
Sliding speed (rpm)	SP	240	360	480
Sliding distance (m)	SD	1000	3000	5000

Table 3
Taguchi L9 orthogonal array design.

Exp. No.	Parameters			
	Vol.%	Load (N)	Sliding speed (rpm)	Sliding distance (m)
1	10	10	240	1000
2	10	30	360	3000
3	10	50	480	5000
4	15	10	360	5000
5	15	30	480	1000
6	15	50	240	3000
7	20	10	480	3000
8	20	30	360	5000
9	20	50	240	1000

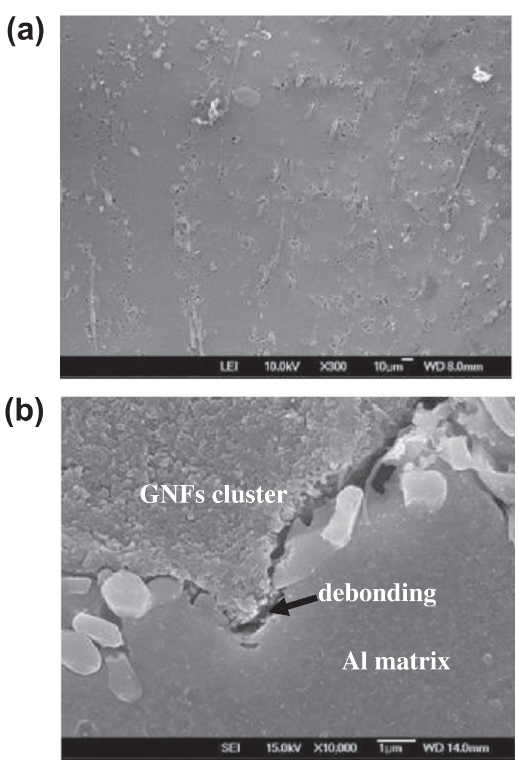

Fig. 1. SEM micrographs of Al hybrid MMCs: (a) Al_2O_{3sf} dispersed within the Al matrix and (b) debonding of GNFs cluster and Al matrix.

and matrix on their wear properties. The authors have previously described the mechanical properties of the Al/GNFs/Al_2O_{3sf} hybrid composites [14], but no systematic attempt has been made to study the influence of the hybridization of GNFs and Al_2O_{3sf} on the tribological properties of aluminum based composites. Therefore, in the present work, the wear behavior of Al/GNF/Al_2O_{3sf} hybrid composites was analyzed under dry sliding conditions. Scanning electron microscope (SEM) was used to examine the microstructures of the worn surfaces, whereas electron dispersive spectroscope (EDS) was used to analyze the compositions in the worn surface after being wear tested.

2. Experimental details

2.1. Materials and fabrication of Al based hybrid MMCs

GNFs and Al_2O_{3sf} were used as reinforcements for developing a hybrid preform. Table 1 lists the properties of these fibers. A commercial casting-grade aluminum alloy (A356) was used as the matrix material. The experimental set up details of the fabrication of preform and composites were the same as described elsewhere [14]. Initially, hybrid preforms were fabricated from GNFs and Al_2O_{3sf} with varying volume fraction of fibers such as 10%, 15%, and 20%. In the first stage, Al_2O_{3sf} and GNFs were mixed in the selected ratio with water and the required amount of binder. The level of mechanical agitation was carefully controlled to avoid the damage for the short fibers and GNFs. Then, cationic polyacrylamide, NaDDBs and starch were fixed as (5% each of the total weight of fibers) were added. Subsequently, ultrasonic agitation was employed for a proper mixing of the additives in the water medium. The slurry containing fibers, binder, flocking agent, surfactant, flocculant and water was poured into a rectangular mold. Water was removed by a vacuum pump. The cakes formed were pressed by a punch to the desired height. The preforms so formed were removed from the mold and baked at 100 °C. Laboratory scale hybrid-fiber preforms, with dimensions of 55 mm length, 20 mm width, and 15 mm thickness were thus developed.

The hybrid composite system based on an aluminum alloy (A356) as the matrix metal using GNFs/Al_2O_{3sf} hybrid preform

Table 4
Experimental results.

Exp. No.	Wear loss (mg)	Coefficient of friction (avg)
1	0.03	0.60
2	0.05	0.58
3	0.06	0.56
4	0.04	0.60
5	0.03	0.56
6	0.06	0.52
7	0.05	0.60
8	0.06	0.62
9	0.05	0.54

Table 5
ANOVA for wear.

Factor	DF	*S*	*V*	*F*	*S′*	*P*
VF	2	0.0002	0.0001	7.0	0.0001	11.54
AL	2	0.0004	0.0002	19.0	0.0004	34.62
SP	2	0.0000	0.0000	Pooled	Pooled	
SD	2	0.0006	0.0003	25.0	0.0005	46.15
Error	2	0.0000	0.0000		0.0001	7.69
Total	10	0.0012	0.0006			100

DF – degree of freedom, *S* – sum of squares, *V* – variance, and *P* – percentage of contribution.