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Tribological behaviour of powder metallurgy-processed aluminium hybrid composites with the addition of graphite solid lubricant

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Abstract

The tribological behaviour of powder metallurgy-processed Al 2024–5 wt% SiC–*x* wt% graphite ($x=0$, 5, and 10) hybrid composites was investigated using a pin-on-disc equipment. An orthogonal array, the signal-to-noise ratio and analysis of variance were employed to study the optimal testing parameters using Taguchi design of experiments. The analysis showed that the wear loss increased with increasing sliding distance and load but was reduced with increased graphite content. The coefficient of friction increased with increasing applied load and sliding speed. The composites with 5 wt% graphite had the lowest wear loss and coefficients of friction because of the self-lubricating effect of graphite. Conversely, due to the effect of the softness of graphite, there was an increase in wear loss and the coefficient of friction in composites with 10 wt% graphite content. The morphology of the worn-out surfaces and wear debris was examined to understand the wear mechanisms. The wear mechanism is dictated by the formation of both a delamination layer and mechanically mixed layer (MML). The overall results indicated that aluminium ceramic composites can be considered as an outstanding material where high strength and wear-resistant components are of major importance, particularly in the aerospace and automotive engineering sectors.

Keywords: B. Composite; C. Friction; C. Wear resistance; D. SiC

1. Introduction

In recent years, aluminium metal matrix composites (AMMCs) have been used in the aerospace, aircraft and automotive industries, particularly for lightweight cylinder liners because AMMCs have many advantages, including higher strength, higher wear resistance, higher thermal conductivity and lower coefficient of friction. [1,3,7,9]. An improvement in the tribological properties of AMMCs has been successfully attained by introducing ceramic particles, such as SiC, B_4C, Al_2O_3, TiC and AlN. Both the mechanical strength and wear resistance of composites increase with the addition of SiC ceramic particulates to the aluminium matrix alloy. These aluminium-based ceramic composites require not only good mechanical strength and high wear resistance but also self-lubrication properties [2,3]. The use of a single reinforcement in an aluminium matrix may sometimes compromise its physical properties [4]. However, the consequent increase in SiC content in composites makes machining difficult [4,5]. Thus, it is essential to identify ways to retain the advantageous influence of SiC while simultaneously addressing the problems of machining SiC-reinforced composites.

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Graphite particulates are well suited to this application, and their addition improves the machinability and wear resistance of Al–SiC composites. Al–SiC composites reinforced with graphite particulates are known as Al–SiC–Gr hybrid composites [6,7].

A number of studies have reported on the dry sliding wear behaviour of aluminium composites reinforced with various ceramic particles [1–14]. An investigation of machining Al–Gr composites by Krisnamurthy et al. showed a considerable reduction of cutting forces, which has been attributed to a possible reduction of friction due to the solid lubrication of Gr particulates [8]. Thus, graphite can be advantageously used as a second reinforcement to overcome the problem of machining brittle SiC-reinforced composites [6–8]. The combined effect of aluminium alloy reinforced with ceramics and graphite imparts good wear properties to the composite [7–9]. Mahdavi and Akhlaghi investigated the effect of SiC content on the processing, compaction behaviour, and properties of Al6061/SiC/Gr hybrid composites using an in-situ powder metallurgy (IPM) technique [6]. Basavarajappa et al. reported on the influence of sliding speed on the dry sliding wear behaviour and subsurface deformation of hybrid metal matrix composites using a liquid metallurgy technique [9]. TedGuo and Tsao reported the tribological behaviour of self-lubricating aluminium/SiC/graphite hybrid composites synthesised by the semi-solid powder-densification method [10]. There are many articles focused on the synthesis of silicon carbide/Gr aluminium composites using different routes [2,5,11–17], such as stir-casting, squeeze casting, in-situ, semi-solid powder densification and spray co-deposition. However, the powder metallurgy route is rarely found in the literature. The powder metallurgy route to manufacturing metal matrix composites offers advantages compared with ingot metallurgy, stir-casting, and squeeze casting because of its low manufacturing temperature, which avoids strong interfacial reactions, minimising undesired reactions between the matrix and the reinforcement. An additional advantage of powder metallurgy is the uniformity in the reinforcement distribution. This uniformity improves not only the structural properties but also the mechanical strength as well as imparts high wear resistance. Based on literature sources, studies on the tribological behaviour of hybrid composite are very limited. However, most of the reported research focuses on the effect of either one or two factors on the dry sliding wear behaviour of hybrid composites. There is no systematic study reported thus far that investigates the various factors that influence the tribological behaviour of hybrid composites. The principal objective of this investigation was to fabricate hybrid aluminium matrix composites by powder metallurgy and evaluate their basic tribological properties. Furthermore, an attempt was made to study the effect of applied load, sliding speed and sliding distance on the friction and wear behaviour of the hybrid composites using Taguchi design of experiments. Analysis of variance was employed to find the percentage of influence of various factors and their interactions. Furthermore, the SEM morphology of the worn surfaces, wear debris and the EDX of worn surfaces were analysed to understand the wear mechanisms.

2. Experimental setup and procedures

2.1. Specimen preparation

The composites were fabricated through the P/M process route. Aluminium 2024 was used as the matrix material in the present investigation, and details of its composition are given in Table 1. This matrix was chosen because it provides an excellent combination of strength and damage tolerance at elevated and cryogenic temperatures. To perform the study, three types of composites were prepared

(i) Al/5 wt% of SiC composite.
(ii) Al/5 wt% of SiC/5 wt% of Gr hybrid composite.
(iii) Al/5 wt% of SiC/10 wt% of Gr hybrid composite.

Fig. 1 shows typical SEM micrographs of the as-received aluminium, SiC and graphite powder particles. SEM observations confirmed that the mean diameter of Al powder (Fig. 1a) was approximately 30 μm, and the mean diameters of both the SiC and graphite particulates were approximately 50 μm (Figs. 1b and c). Table 2 provides details about the SiC and graphite particulates, which were used as reinforcements. Table 3 lists details about the hybrid composites. Powders used in this study were elemental powders of aluminium, copper, magnesium, manganese, iron, silicon, chromium, zinc, silicon carbide and graphite. All of the metal powders were supplied by M/s Metal Powder Company Ltd., Madurai, Tamil Nadu, India. Silicon carbide was obtained from M/s Grindwell Norton, Bangalore, India. Al 2024 was prepared by mechanical alloying. First, the elemental powders were dried at 110 °C in an oven for 1 h. Mixing of the powder was performed in a planetary tumbler mixer using stainless steel balls with a diameter of 8 mm and a ball to powder weight ratio of 10:1, with a mixing time up to

Table 1
Chemical composition of the matrix alloy.

Element	Cu	Mg	Fe	Mn	Si	Cr	Zn	Al
Content%	4.0	1.8	0.5	0.25	0.5	0.25	0.2	Balance