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# Friction and wear behavior of Ni–P coated $Si_3N_4$ reinforced Al6061 composites

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ABSTRACT

Al6061 matrix composite reinforced with nickel coated silicon nitride particles were manufactured by liquid metallurgy route. Microstructure and tribological properties of both matrix alloy and developed composites have been evaluated. Dry sliding friction and wear tests were carried out using pin on disk type machine over a load range of 20–100 N and sliding velocities of range 0.31–1.57 m/s. Results revealed that, nickel coated silicon nitride particles are uniformly distributed through out the matrix alloy. Al6061–Ni–P–$Si_3N_4$ composite exhibited lower coefficient of friction and wear rate compared to matrix alloy. The coefficient of friction of both matrix alloy and developed composite decreased with increase in load up to 80 N. Beyond this, with further increase in the load, the coefficient of friction increased slightly. However, with increase in sliding velocity coefficient of friction of both matrix alloy and developed composite increases continuously. Wear rates of both matrix alloy and developed composites increased with increase in both load and sliding velocity. Worn surfaces and wear debris was examined using scanning electron microscopy (SEM) for possible wear mechanisms. Energy dispersive spectroscope (EDS), X-ray diffraction (XRD) and X-ray photoelectron spectroscope (XPS) techniques were used to identify the oxides formed on the worn surfaces and wear debris.

## 1. Introduction

In last two decades, discontinuously reinforced aluminum (DRAs) matrix composites have emerged as most promising materials on account of its several advantages. They include processing flexibility, wide range of application, low density, high thermal conductivity, heat treatment capability, improved elastic modulus and strength [1]. They also possess excellent wear and seizure resistance which has led to several studies on DRA composites focusing on its tribological behavior. Venkataraman et al. [2] have studied the sliding wear behavior of Al/SiC composite and have reported that, composite exhibits superior wear resistance when compared with aluminum matrix and their wear resistance increases with increase in volume fraction of SiC. De et al. [3] have reported the effect of addition of graphite particulate on wear characteristics of aluminum alloy. They have observed that the formation of graphite layer at the interface acts as a solid lubricant thereby reducing the wear rate. Shorowordi et al. [4] have investigated tribological characteristics of Al–$B_4C$ and Al–SiC composites sliding against phenolic brake pad and have reported that phenolic transfer layer formed at the interface protects the composite surface and helps to reduce both wear and friction coefficient.

Various techniques such as powder metallurgy [5], liquid metallurgy route [5,6], infiltration technique [7], spray deposition [7], squeeze casting [3], etc. have been tried out to synthesis the DRA composites. Among all these, liquid metallurgy route is one of the most effective method, in view of its simplicity, easy adaptability, mass production, and applicability to large quantity production [7,8]. However, composites prepared by these techniques experience certain limitations in terms of:

(a) Non-uniform distribution and poor wettability of ceramic particles in molten metal [9,10].
(b) Absence of sound interface between matrix and reinforcement/formation of interfacial products [11].
(c) Generation of inherent casting defects due to incomplete adhesion of ceramic particles to matrix [12,13].

Many researchers [14,15] have studied and reported that these problems can be minimized/eliminated by providing a thin metallic coating on ceramic particles before adding into the molten metal. It is also reported that metallic coated ceramic particles reinforced composite exhibits superior mechanical and tribological properties when compared with uncoated ones.

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A comparative study on tribological properties of uncoated and metallic coated graphite reinforced copper composites has been carried out by Moustafa et al. [16]. They have reported that, metallic coated graphite reinforced composites exhibit lower wear rate and coefficient of friction when compared with uncoated ones. The transition in wear has been changed to higher loads with increased content of copper coated graphite composite as compared with uncoated ones. Davidson et al. [17] have reported on the beneficial effect of copper coating on SiC particles reinforced in aluminum matrix composites, they have observed that metallic coating on reinforcement has improved the interfacial bonding and resulted in large failure strain.

Yongxhong et al. [18] have studied the mechanical and wear properties of uncoated and nickel coated reinforced copper composites, they have observed nickel coated SiCp–Cu composites exhibit better combination of flexural strength and ductility than the uncoated SiCp–Cu composites. They have also noticed that nickel coated SiCp particles reinforced composites possessed improved wear resistance.

A wide range of ceramic particles such as SiC [4], $B_4C$ [4], $Al_2O_3$ [7], $TiO_2$ [19], $TiB_2$ [20], and fly ash [21] have already been tried out as reinforcement in aluminum based composites. Their mechanical and tribological properties have been found superior than that of unreinforced alloys. Among all the available engineering ceramics, silicon nitride appears to be most promising material as a reinforcement, because of its several advantages like low density, high hardness, high fracture toughness and excellent strength over a wide range of temperature, good thermal shock and chemical resistance [22,23]. In addition to this, it also possess excellent wear resistance and antifriction properties [24,25].

However, meager information is available in the literature as regards the tribological properties of metallic coated silicon nitride reinforced aluminum based composites processed by liquid metallurgy route.

In the light of the above, the present investigation focuses on friction and wear behavior of Ni–P coated $Si_3N_4$ reinforced Al6061 composites.

## 2. Experimental details

Al6061 alloy with the chemical composition given in Table 1 were procured from Fen Fee Metallurgicals, Bangalore, in the form of ingots.

Alpha type silicon nitride particles of size 2–20 μm (supplied by Johnson Matthey Company, USA) are used as reinforcement. The particles are nickel coated using electroless plating technique [10,11]. Detailed coating procedure is described in our earlier work [26].

### 2.1. Composite preparation

Aluminum 6061 alloy was melted using 6 kW electrical resistance furnace. The melt was degassed by commercially available chlorine based tablet (hexachloroethane). The molten metal was agitated by using mechanical stirrer rotating at a speed of 300 rpm to create fine vortex. Ni–P coated $Si_3N_4$ particles were slowly added into the vortex while continuing the stirring process. Stirring duration was 10 min. The percentage of Ni–P coated $Si_3N_4$ particles was varied from 4 to 10 wt% in steps of 2 wt%. The composite melt maintained at a temperature of 710 °C was then poured into preheated metallic molds. After casting, the test specimens were prepared by machining from both Al6061 alloy and Al6061–Ni–P–$Si_3N_4$ composite for characterizing its microstructure, frictional and wear properties.

### 2.2. Friction and wear test

Dry sliding friction and wear tests were performed using Pin-on-disk apparatus, manufactured by Magnum Engineers, Bangalore as per ASTM G99-95. Cylindrical specimens (both alloy and composites) of 8 mm diameter and 20 mm height were used as test samples. The specimen end surfaces were flat and polished metallographically. Counterface disk was made of EN-31 steel and hardened to 60HRC. The initial surface finish (Ra) of the steel disk was 1 μm. A track radius of 30 mm has been used for all the experiments. All the tests were conducted in air at room temperature. Test duration of 30 min was adopted for all the tests. The loads and sliding velocities were varied from 20 to 100 N and 0.314 to 1.574 m/s respectively. Frictional force was measured using load cell of accuracy 0.1 N while the wear loss was measured in the steady state regime at using linear variable differential transducer (LVDT) of accuracy 1 μm at the end of 30 min. The coefficient of friction was calculated using frictional load and normal load data. The wear rates were calculated from height loss data in terms of volumetric wear loss per unit sliding distance.

JEOL 840A JSM scanning electron microscope with EDAX attachment is used to characterize microstructure, worn surfaces and wear debris. X-ray diffraction (XRD) patterns were taken using Philips X'Pert Pro X-ray diffractometer using Cu-Kα radiation.

X-ray photoelectron spectra (XPS) of worn surfaces were recorded on a ESCA-III Mark 2 spectrometer using AlKα radiation with a photon energy of 1486.6 eV.

## 3. Results and discussion

### 3.1. Nickel coating of silicon nitride particles

Fig. 1 shows the SEM photographs of uncoated and nickel coated silicon nitride particles. It is observed from the microphotograph that uncoated silicon nitride particles (Fig. 1a) are irregular in shape, bright and smooth, where as nickel coated silicon nitride particles (Fig. 1b) are dark and rough in nature indicating the thin deposition of Ni–P coating on the surface. Further, the presence of Ni–P coating on silicon nitride particles is confirmed by carrying out EDAX analysis on both coated and uncoated silicon nitride particles which are shown in Fig. 1(c and d). EDAX analysis of nickel coated $Si_3N_4$ indicates the presence of both nickel and phosphorous.

### 3.2. Microstructure

SEM microphotographs of Al6061 matrix alloy and Al6061–Ni–P–$Si_3N_4$ composites with different percentage of reinforcement are shown in Fig. 2(a–d). From the microphotographs it is

**Table 1**
Chemical composition of Al6061 alloy.

| Elements | Si | Fe | Cu | Mn | Ni | Pb | Zn | Ti | Sn | Mg | Cr | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percentage | 0.43 | 0.43 | 0.24 | 0.139 | < 0.05 | 0.024 | 0.006 | 0.022 | 0.001 | 0.802 | 0.184 | Balance |