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# Friction and wear behaviors of $B_4C$/6061Al composite

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ABSTRACT

The friction and wear behaviors of $B_4C$/6061Al composite were studied by considering the effect of sliding time, applied load, sliding velocity and heat treatment. The results show that, when the sliding time, applied load and sliding velocity reach critical values (namely 120 min, 30 N and 240 r min$^{-1}$, respectively), the mass loss and friction coefficient (COF) increase significantly. Severe delamination wear is the main wear mechanism after sliding for 120 min and under an applied load of 30 N. While fretting wear happens at a sliding velocity of 240 r min$^{-1}$. After solution-treated at 550 °C for 1 h and then aged at 180 °C for 15 h, the composite shows the highest wear resistance owing to the precipitation of β″ ($Mg_2Si$) phases in the matrix and the strong interface bonding between $B_4C$ particles and the matrix alloy.



## 1. Introduction

Aluminum matrix composites (AMCs) reinforced with ceramic particles have been widely used in aeronautical and aerospace industries due to their high specific strength and modulus, readily fabrication and low cost [1–3]. They are also applied in the automobile industry, such as pistons and cylinder liners in automotive engines, owing to their superior wear resistance [4–6].

SiC and $Al_2O_3$ are the most commonly used reinforcements for AMCs due to their high hardness, chemical and thermal stabilities [7,8]. While as a new reinforcement, $B_4C$ has a better interfacial bonding with the aluminum matrix than that of SiC and $Al_2O_3$ which can lead to higher wear resistance [9]. Besides, $B_4C$ has excellent neutron absorber properties which can endow AMC more potential applications in nuclear industry [10,11].

Recently, tribological properties of $B_4C$ particulate-reinforced AMCs have been investigated by varying internal factors (e.g. $B_4C$ content [6,12], microstructure [9,13]) and external factors (e.g. sliding time [14], applied load [15], sliding velocity [16]). For instance, Ipek studied the effect of $B_4C$ content on adhesive wear behavior of adhesive $B_4C$/4147Al composite [12]. With increasing wt.% $B_4C$ particle content, the wear resistance of the composite increased considerably and the wear mechanism changed from adhesive-abrasive regime to the soft-mild adhesive regime. Lashgari et al. investigated the heat treatment effect on the microstructure and dry sliding wear behavior of 10% $B_4C$/A356 cast composites [9]. The result showed that, T6 treatment can contribute to the strong bonding between $B_4C$ and matrix alloy, and consequently, leading to higher wear resistance. Canakci investigated the effect of sliding time on the abrasive wear properties of $B_4C$/2014Al composites [14]. The specific wear rate of samples swiftly decreased with increasing sliding time until a steady-state value of 670 s. The effects of sliding speed and applied load on dry sliding friction and wear properties of $B_4C$/5083Al were also studied by Tang et al. [16]. Two stages were observed in the wear process. The transition from the first stage to the second stage is attributed to the change in the wear mechanism from abrasive wear to adhesive wear. Despite these investigations, none of them illustrated a comprehensive study of these influence factors under the same experimental conditions. What is more, most of the research did not show the critical values of the influence factors causing severe wear, which is very important measurement of failure when used as machinery component. Herein, the effects of sliding time, applied load, sliding velocity and heat treatment on tribological properties of $B_4C$/6061Al were studied in our present work. Severe wear was detected when the sliding time, applied load and sliding velocity reached a critical value. Superior wear resistance was also realized after peak aging treatment. The wear behaviors and wear mechanisms were investigated and discussed in details.

## 2. Experimental details

### 2.1. Material preparation

20 wt.% $B_4C$ reinforced 6061Al (nominal chemical composition: Table 1) was prepared by a stir casting method. 8 kg 6061Al alloy

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**Table 1**
Nominal chemical composition of Al6061 alloy.

| Elements | Si | Fe | Cu | Mn | Mg | Pb | Zn | Cr | Ti | Ni | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Percentage | 0.43 | 0.70 | 0.24 | 0.14 | 0.82 | 0.24 | 0.25 | 0.25 | 0.15 | 0.05 | Balance |

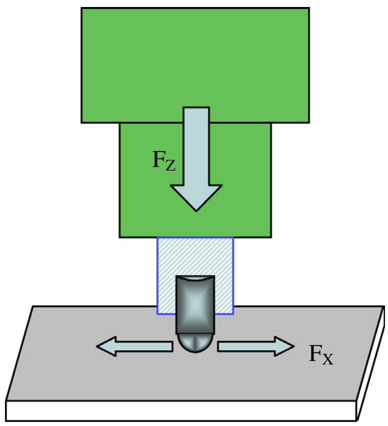


**Fig. 1.** Assembly drawing of the friction test in reciprocating movement Fz, the load in vertical direction; Fx, the load in horizontal direction.

was melted at 725 °C in an electric furnace. A mechanical stirrer was used at a speed of 600 r min$^{-1}$ to form a fine vortex. Then 2 kg preheated $B_4C$ particles at 600 °C were added into the vortex under Ar gas atmosphere. After being stirred for 10 min, the molten mixture was poured into the preheated permanent steel mould (250 °C), cooled and solidified. Finally, hot forging was carried out at 500 °C under 200 MPa to make a more compact composite. The test samples were cut from the ingot and some were subjected to solution treatment at 550 °C for 1 h followed by water quenching, and aging at 180 °C for different times.

### 2.2. Microstructure characterization and hardness test

The microstructure of the as-forged composite was observed by a Nova NanoSEM 230 Field Emission Scanning Electron Microscope. The hardness of specimens with different aging times was measured using a HB-3000 brinell hardness tester. The reported

**Table 2**
Wear plan at room temperature.

| Variables (invariables) | Values and states | | | |
|---|---|---|---|---|
| Sliding time (20 N, 120 r min$^{-1}$) | 30 min | 60 min | 90 min | 120 min |
| Load (120 r min$^{-1}$, 60 min) | 10 N | 20 N | 30 N | 40 N |
| Sliding velocity (20 N, 60 min) | 60 r min$^{-1}$ | 120 r min$^{-1}$ | 180 r min$^{-1}$ | 240 r min$^{-1}$ |
| Heat treatment (20 N, 120 r min$^{-1}$, 60 min) | As-forged | As-solutionized | Peak-aging | |

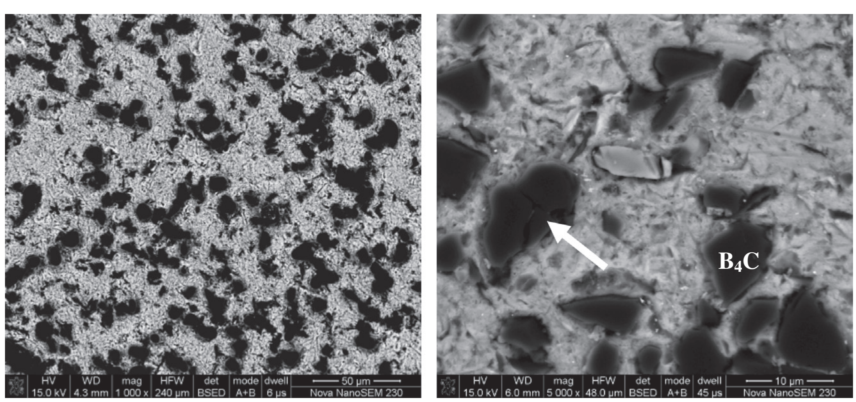


**Fig. 2.** Microstructures of as-forged $B_4C$/6061Al composite.

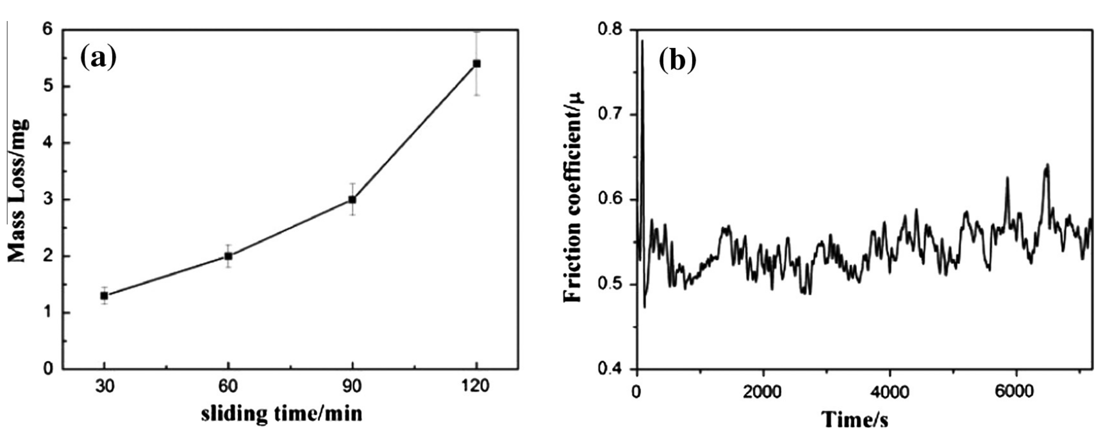


**Fig. 3.** Variation of mass loss and COF with the sliding time (20 N, 120 r min$^{-1}$) (a) mass loss and (b) COF.