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Short Communication

High-temperature tribological behavior of a nickel alloy matrix solid-lubricating composite under vacuum

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ABSTRACT

In aerospace, some moving parts will meet with simultaneous high temperature and vacuum environments. In this study, the tribological behavior of a nickel alloy matrix solid lubricant composite was contrastively investigated under both air and vacuum conditions from room temperature to 800 °C. Results showed that both the friction coefficient and the wear rate of the composite were highly dependent on testing temperature and atmosphere. The friction coefficient in vacuum was lower than that in ambient air. The compositions of the frictional surfaces were analyzed, based on which, the mechanism of friction and wear was proposed.

1. Introduction

High performance moving system for aerospace encounters the high temperature lubrication issue under both air and vacuum conditions [1,2]. Using solid lubricant materials with excellent lubricity obtained by adding suitable solid lubricants into the metal-matrix or ceramic-matrix composites is an effective way to simplify design and prolong service life of the operating systems under high temperature conditions. It has been documented that combining multiple solid lubricants is a successful way for the composite to exhibit lubricating performance at a wide temperature range [3,4]. Up to now, the best example to provide lubrication at broad range of temperature is PS coatings which developed by NASA. These PS coatings employ Ag and BaF_2/CaF_2 eutectic as solid lubricants and exhibit excellent self-lubricating properties and have been successfully used as the component of aircraft, such as foil bearing and lightly-loaded oscillatory bearing [3,5–7]. The adaptive nanocomposite coatings, which were developed by Air Force Research Laboratory, with Ag and in situ formed double metal oxide as solid lubricants, perform excellent lubricating properties from room temperature (RT) to 1000 °C in air [8–10]. Besides, Yang et al. [11] reported that a nickel-alloy matrix composite containing Ag and fluoride eutectic exhibit both excellent self-lubricity and high strength from RT to 800 °C. Moreover, some works on high performance intermetallic compound (FeAl, TiAl, NiAl and Ni_3Al) [12–15] and structural ceramics (ZrO_2 and Al_2O_3) [16,17] as matrix also had proved that employing low-to-moderate temperature lubricants and moderate-to-high temperature lubricants is the effective way to obtain lubricity at broad range of temperature.

Furthermore, in most cases, materials exhibit distinct tribological properties in vacuum and air conditions at RT [18,19], and it can be speculated that the difference is more noteworthy at high temperatures due to the more obvious effect of oxidation. Therefore, it is vital for aerospace applications to investigate the high-temperature tribological properties of the high-temperature solid lubricant composites under vacuum. To the authors' knowledge, the researches published on the tribological behavior of solid lubricant composite under vacuum and high temperature are very scarce. In our previous work [20,21], a nickel alloy matrix solid lubricant composite with the composition by weight percent, 82.5%nickel-alloy-12.5%Ag-5%BaF_2/CaF_2 was prepared and its tribological properties from RT to 800 °C in air was investigated. In the present work, the tribological behavior of this composite under vacuum and air environments from RT to 800 °C was investigated by comparison, and the transformation of wear mechanism was also discussed.

2. Experimental details

The nickel alloy matrix composite was fabricated by hot pressed sintering method, and the details on processing parameters, microstructures and mechanical properties had been given elsewhere [20]. The tribotests were conducted using a GHT-1000E high-temperature vacuum ball-on-disc rotation tribometer under both vacuum (approx-

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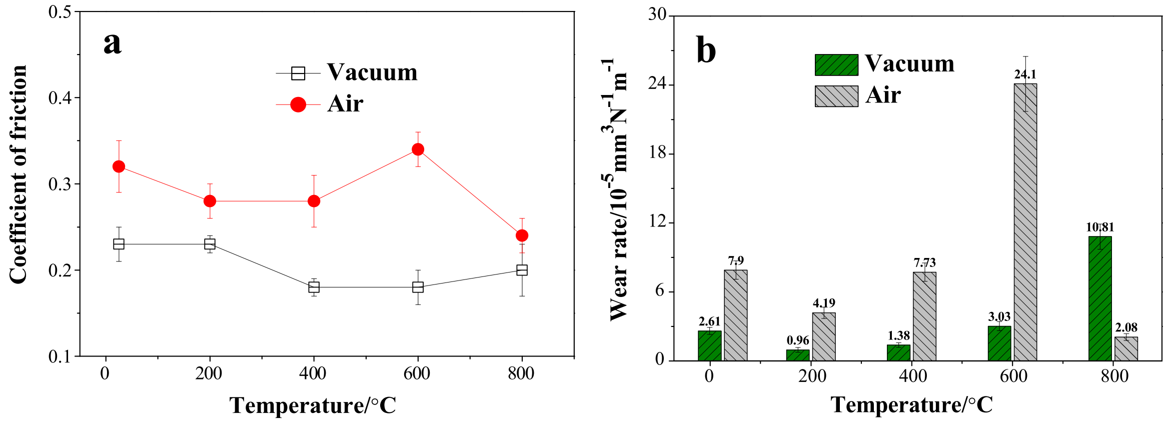

Fig. 1. Friction coefficient and wear rate of the composite at various temperatures under air and vacuum conditions.

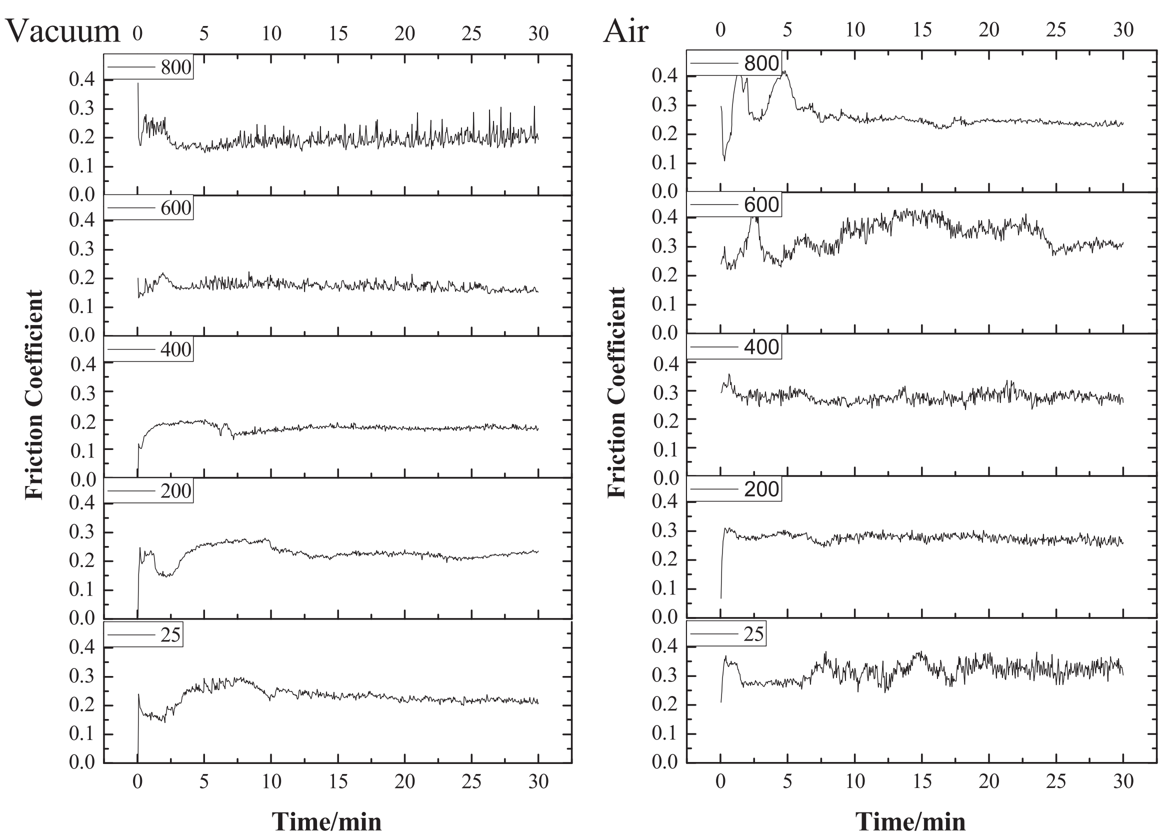

Fig. 2. Friction curves under air and vacuum conditions at various temperatures.

Table. 1
Microhardness of the composite at various temperatures.

Temperature/°C	25	200	400	600	800
Microhardness/Hv	311	288	261	246	182

imate 1×10^{-1} Pa) and lab air. Si_3N_4 ceramic ball with a diameter of 6.35 mm was used to slide against rotating disc made by this composite for that might be a candidate for high temperature hybrid bearing and engine assemblies [22]. The testing temperatures were selected as RT, 200, 400, 600 and 800 °C. The applied load was 5 N and the sliding speed was 0.8 m/s. The friction coefficient was continuously recorded by the computer during the sliding test. The wear volume of the composite was measured using an Alpha-step D-100 contact probe profilemeter, and then the wear rate was obtained as the wear volume divided by normal load and sliding distance, and expressed as $mm^3N^{-1}m^{-1}$.

The worn surface feature of the composite was examined by JSM-5600LV scanning electron microscope (SEM) equipped with an energy dispersive spectroscopy (EDS). The phase compositions of the worn surfaces were identified by a LabRAM HR Evolution Micro-Raman (Horiba Jobin Yvon S.A.S. France) with a laser wave length of 532 nm. The Vickers hardness of the composite at different temperatures was measured by HTV-PHS30 high temperature Vickers hardness tester (Archimedes Industrial Technology Co., Ltd. England) with a load of 1 kg and an endurance time of 10 s.

3. Results and discussion

Fig. 1a shows the friction coefficient (COF) of the composite sliding against Si_3N_4 ball under vacuum and air conditions from RT to 800 °C. The friction pairs exhibit lower COF in vacuum in comparison with that in air at all testing temperatures. In vacuum, the COF is in the range of