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Short communication

Effect of Ag and CeO_2 on friction and wear properties of Ni-base composite at high temperature

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ABSTRACT

The molybdenum disulfide and metal silver are commonly used solid lubricants at the temperature below 500 °C, while the rare earth compound is useful at high temperature but ineffective at room temperature. These solid lubricants are limited in special temperature ranges. When they are combined in the nickel-base alloy, a self-lubrication over a wide temperature range is reached. The nickel-base composites containing silver, MoS_2 and CeO_2 were prepared by powder metallurgy (P/M) method. The friction and wear properties of composite were tested from room temperature to 600 °C by a pin-on-disk tribometer with alumina, high speed steel, and Ti2AlNb alloy as counterfaces. The microstructure and morphology of composites were analyzed by X-ray diffraction (XRD) and scanning electron microscope (SEM). The worn surfaces were observed by optical microscope and SEM. The composite is mainly consisted of free phase of Cr_3S_4, CeS, silver and a little amount of MoS_2. The friction coefficient at room temperature is decreased after adding silver in the composite. Meanwhile, the wear rates at high temperature are reduced by adding cerium oxide. The friction coefficients of silver and CeO_2 containing Ni-base composite from room temperature to 600 °C are in the range of 0.16–0.26. The wear rates are reduced by more than one order of magnitude after adding silver and CeO_2, especially the wear rates at 600 °C are even two orders of magnitude lower. The SEM analysis of worn surface after rubbing at 600 °C shows that the rare earth compound is helpful for the formation of smooth 'glaze' layer, which improves the wear resistance at high temperature.

1. Introduction

Nickel-base composites containing solid lubricant are effectively used in new generation high-performance gas turbine engines due to its excellent self-lubricating properties over an extreme range of operating temperatures [1]. Molybdenum disulfide, graphite and rare earth compound are widely used solid lubricants [2–4]. However, the application of solid lubricant is limited by the temperature and most lubricants are oxidized at high temperature [5]. For example, molybdenum disulfide are oxidized at the temperature higher than 500 °C; graphite loses its lubricating role at the temperature above 450 °C while the rare earth compounds are ineffective at room temperature [6,7]. Because it was hard for single lubricant to realize the lubrication over a wide temperature range, the study of synthesis effect of more than two lubricants became attractive. The lubricants included $Ag/CaF_2/BaF_2$, MoS_2/LaF_3, graphite/CeF_3, Ag/CeF_3, etc., presented the synthesis lubricating effects [8–11]. However, there were few explanations of the synthesis lubricating mechanism in detail.

Silver is attractive because of its large diffusion coefficient, which allows the metal to rapidly provide lubrication with increasing temperature. However, silver is less effective in providing lubrication in the case of above 500 °C, because of excessive softening [12]. One approach for obtaining low friction at high temperature (>500 °C) is to incorporate with soft oxide compounds that are deformed by plastic flow [13]. This mechanism has been observed previously for $ZnO–WS_2$ adaptive coatings, where $ZnWO_4$ was formed during wear at 500 °C [14]. Voevodin investigated the lubrication of silver and molybdenum from room temperature to 700 °C and described the synthesis lubrication of silver and MoO_3 [12].

In this paper, the silver, MoS_2 and CeO_2 were incorporated in the nickel-base composite by powder metallurgy (P/M) in order to reach the lubrication over a wide temperature range. The frictional properties of composite from room temperature to 600 °C were tested by a pin-on-disc high-temperature tribometer. The worn surfaces were analyzed by scanning electron microscope (SEM) and X-ray diffraction (XRD).

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Table 1
Composition of Ni-base self-lubricating composite.

Alloys	Composition (wt.%)						
	Ni–20Cr	W	Al	Ti	Ag	MoS_2	CeO_2
Ni–Cr–W–Al–Ti–5Ag	Balance	10	3.8	5.5	5	–	2
Ni–Cr–W–Al–Ti–10Ag	Balance	10	3.8	5.5	10	–	2
Ni–Cr–W–Al–Ti–Ag–MoS_2	Balance	10	3.8	5.5	5	10	–
Ni–Cr–W–Al–Ti–Ag–MoS_2–4CeO_2	Balance	10	3.8	5.5	5	10	4
Ni–Cr–W–Al–Ti–Ag–MoS_2–8CeO_2	Balance	10	3.8	5.5	5	10	8

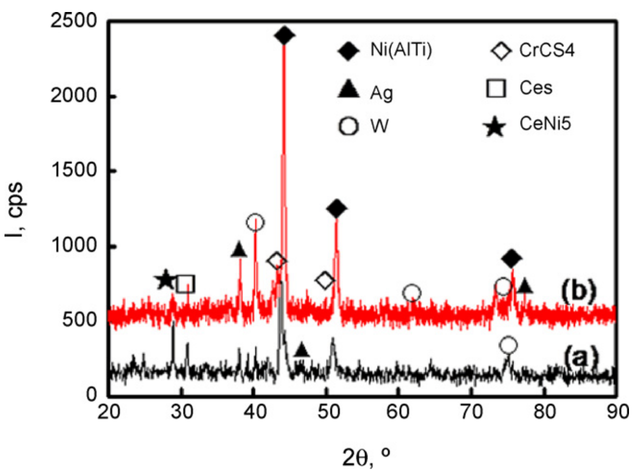

Fig. 1. X-ray diffraction pattern of Ni–Cr–W–Al–Ti–Ag (a) and Ni–Cr–W–Al–Ti–Ag–MoS_2–CeO_2 composite (b).

2. Experiment

2.1. Material preparation

Ni–20Cr alloy powder (~60 μm), tungsten (20 μm), aluminium, titanium powder, silver powder (60 μm), MoS_2 (20 μm) and CeO_2 powder (shown in Table 1) were mixed together and pressed as disks (Φ 45 mm × 8 mm) in a steel mould. Then they were hot pressed in vacuum by a FVPHP-R-10 FUJI vacuum-hot-pressing furnace (Japan). The furnace was draw to a vacuum of 10^{-6} Pa and protected by nitrogen gas. The furnace temperature was elevated to 1200 °C at a rate of 20 °C/min and hot-pressed for 20 min under a loading pressure of 16 MPa in the nitrogen atmosphere.

2.2. Properties testing

The friction and wear tests were carried out by a MG-2000 high-temperature pin-on-disk tribometer (Beilun Cop.). The upper samples of alumina ball (Φ 12.7 mm, roughness (Ra) 0.05 μm), flat-ended high speed steel (W6Mo5Cr4V2) pin (Φ 5 mm × 12 mm, Ra 0.1 μm, Hardness 63 HRC) and Ti2AlNb pins (Φ 5 mm × 12 mm, Ra 0.1 μm, Hardness 45 HRC) were kept still, while counterface Ni-base composite disks (Φ 45 mm × 7 mm, hardness HRC 30-40, Ra 0.5 μm) were rotated. The tests were conducted under the load of 20 N, sliding velocity of 0.4 m/s, environment temperature of RT ~600 °C and average wear track of Φ 31 mm. The sliding distance in each test was 600 m. The frictional moment was recorded by a computer consistently. The samples were cleaned by ethanol before and after each test. The wear mass losses of pins and disks were weighed by an analytical balance with accuracy of 0.1 mg. The microstructure was analyzed by SEM and XRD and the worn surfaces were observed by optical microscope.

3. Results and discussion

3.1. Microstructure and organization

XRD results indicates that there are silver and tungsten phases in the Ni–Cr–W–Al–Ti–Ag alloy (Fig. 1(a)). After adding MoS_2 and CeO_2, the new phases, such as Cr_3S_4, CeS and $CeNi_5$, are formed in Ni–Cr–W–Al–Ti–Ag–MoS_2–CeO_2 during hot-pressing [15]. Besides, there are the free phases of W and MoS_2 in the composite (Fig. 1(b)).

Fig. 2 shows the optical morphology of Ni–Cr–W–Al–Ti–Ag alloy. The black phases in Fig. 2(a) and (b) are the un-reacted tungsten inclusions, whose oxide (WO_3) is lubricious [16]. The grey phase dispersed at the grain boundary is silver inclusion. There is little amount of CeO_2 in the composite.

Fig. 3 shows the morphology of Ni–Cr–W–Al–Ti–Ag– MoS_2–CeO_2 composite. The dark phases are CeO_2 in the

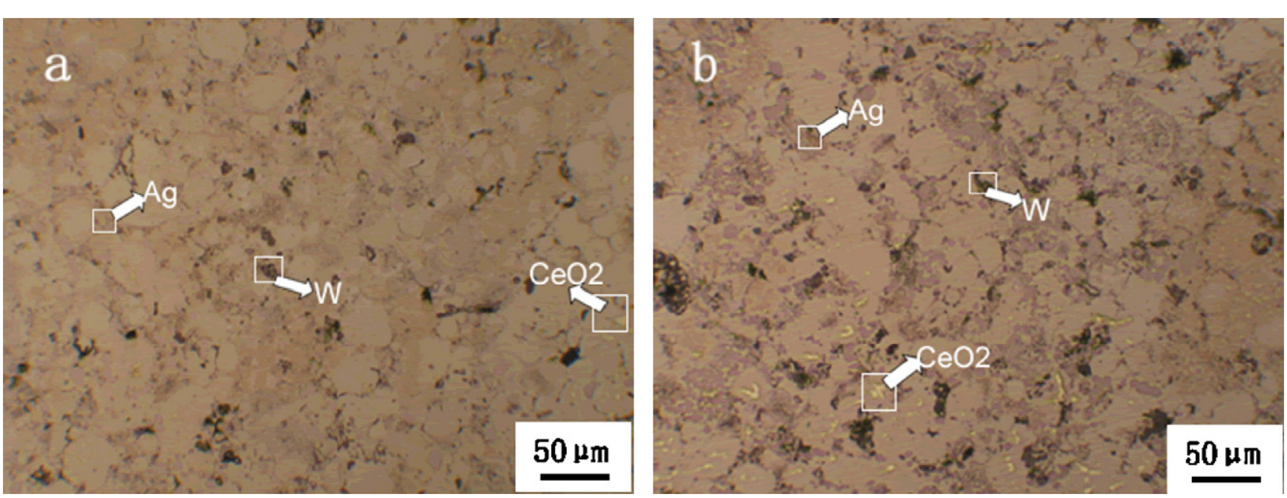

Fig. 2. Optical morphology of Ni-base composite: (a) Ni–Cr–W–Al–Ti–5Ag; (b) Ni–Cr–W–Al–Ti–10Ag.