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Tribological properties of molybdenized silver-containing nickel base alloy at elevated temperatures

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ABSTRACT

The lubricious naturally occurring oxide of molybdenum combines with silver in order to reach lubrication over a wide temperature range. The silver-containing nickel base alloys prepared by powder metallurgy were molybdenized by a double-glow plasma alloying method. The friction properties of molybdenized silver-containing nickel base alloys rubbing against alumina ceramic ball from room temperature to 600 °C were tested by a ball-on-disk tribometer. The morphologies and worn surfaces were observed by optical microscope and scanning electron microscope. The microstructures and wear scars of silver-containing nickel base alloys were analyzed by X-ray diffraction. The results indicate that the molybdenized layer on nickel base alloy is about 20–30 μm in thickness. The content of molybdenum on the surface of molybdenized layer reaches 57% and the hardness is improved by molybdenizing. The friction coefficient of nickel base alloy at room temperature decreases from 0.8 to 0.2 after adding the silver. After molybdenizing, the friction coefficient of silver-containing nickel base alloy is decreased more than 30% and its high-temperature wear rate is also reduced. The diffusion of sliver and the forming of trioxide of molybdenum affected by temperature are responsible for the friction reduction at elevated temperatures.

1. Introduction

Solid lubrication over a wide range of temperature is a challenge for decades and has yet to overcome [1–3]. Most common lubricant performs only within a narrow temperature range, such as graphite, molybdenum disulfide, and PTFE are effective below 250–400 °C in air, above which they will oxidize or decompose and lose their lubricious nature [4]. Some oxides lubricate well above 600–800 °C, but are abrasive at lower temperature [5].

In recent years, a novel adaptive coating was fabricated by embedding nanoscopic lubricant phase in a tough, hard matrix [6]. Nano gold and silver inclusions were usually employed as lubricant in temperature-adaptive nanocomposite [7]. Several researchers have investigated hard coatings containing noble metal. Voevodin et al. have investigated the lubrication of silver by diffusion from an YSZ–Ag–Mo coating [8]. In order to hinder the silver diffusion, a porous TiN mask was introduced [9]. However, at elevated temperature, the short-lived tribo-film in the contact is limited its application. In our previous study, nickel-based composites containing MoS_2 were prepared and the self-consumption phenomenon of sulfide at high temperature was discussed [10]. The lubricous glaze layer formed by oxidizing of metals was observed and counter face material was properly selected [11–13]. The silver was used as lubricious additive in the nickel-based matrix. The silver element diffuses to the friction surface by a strong reduction in surface energy and provides a low-shear interface between counterfaces.

In order to reach the lubrication over a wide range of temperature, the molybdenum alloyed layer was prepared on the silver-containing nickel base alloy by double glow plasma alloy technology. The oxidizing of molybdenum plays the role of lubrication at high temperature, which offsets the limited lubrication properties of silver. During friction, the diffusion of silver and oxidizing of molybdenum are responsible for the friction reduction at moderate and high temperature, respectively.

2. Experimental procedures

2.1. Materials preparation

Ni–20Cr alloy powder (~60 μm), tungsten (20 μm), aluminum, titanium powder, and 0–10 wt% silver (20 μm) and 2% CeO_2 were mixed together and pressed as disks (∅45 mm × 7 mm) in a steel mould (Table 1). Then they were hot pressed in vacuum. The processing parameters were as follows: pressure 16 MPa, temperature 1200 °C, temperature increasing by 20 °C/min, holding 20 min, draw vacuum to 10^{-5} Pa and protected by nitrogen gas.

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Molybdenizing of Ni–Cr–W–Al–Ti–Ag alloy was conducted in a multi-function double glow plasma surface alloying furnace. The pure molybdenum plate (∅100 mm × 5 mm, purity 99.9%) was used as source target, the silver-containing nickel base alloy (∅45 mm × 7 mm) was used as cathode. The distance between poles was 20 mm. The furnace vacuum was drawn below 1.0×10^{-2} Pa, then supplied high purity argon gas until its pressure reached 45 Pa. The voltage of source pole was 900–950 V and the voltage of cathode (substrate material) was 400–550 V. The temperature of substrate material was measured by infrared detector. The substrate temperature was kept at 950 °C for 4 h.

Table 1
Composition of Ni–Cr–W–Al–Ti–Ag alloy.

Alloy	Composition (wt%)						Vickers hardness ($HV_{0.1}$)
	Ni–20Cr	W	Al	Ti	Ag	CeO_2	
Ni–Cr–W–Al–Ti	Bal.	10	3.8	5.5	0	2	449
Ni–Cr–W–Al–Ti–Ag	Bal.	10	3.8	5.5	10	2	388

The thickness and morphology of alloyed layer were observed by Olympus optical microscope. The content of alloy element varied with alloyed layer was detected by SEM attached with energy dispersive spectroscopy (EDS).

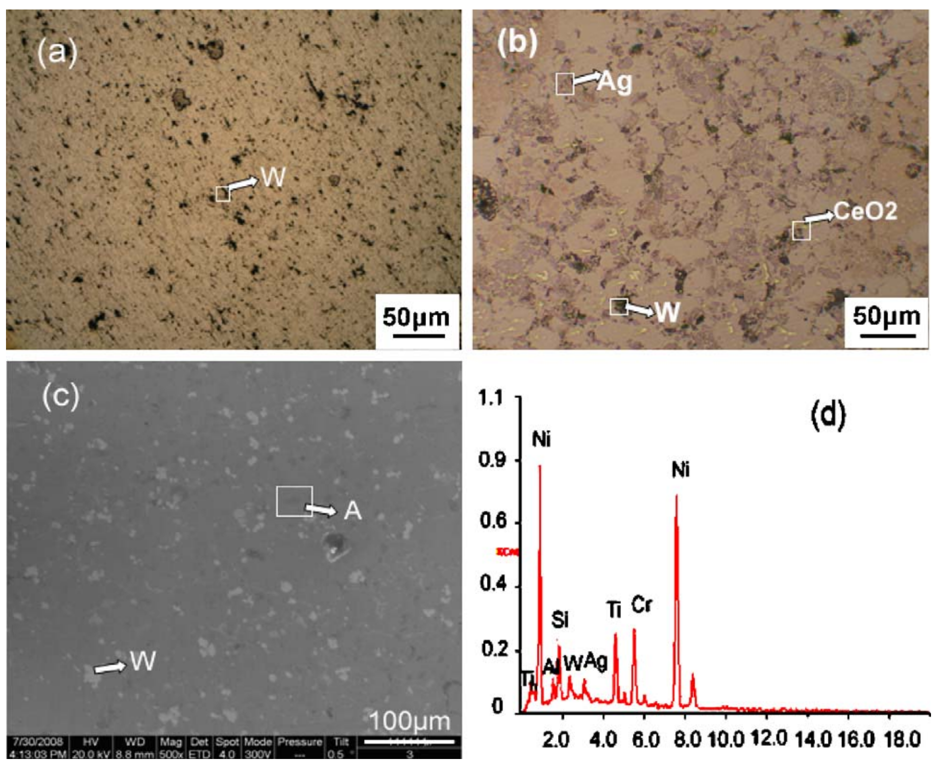

Fig. 1. Morphologies of silver-containing nickel base alloy: (a) 0% Ag; (b) 10% Ag; (c) SEM morphologies; and (d) EDS analysis of mark A.

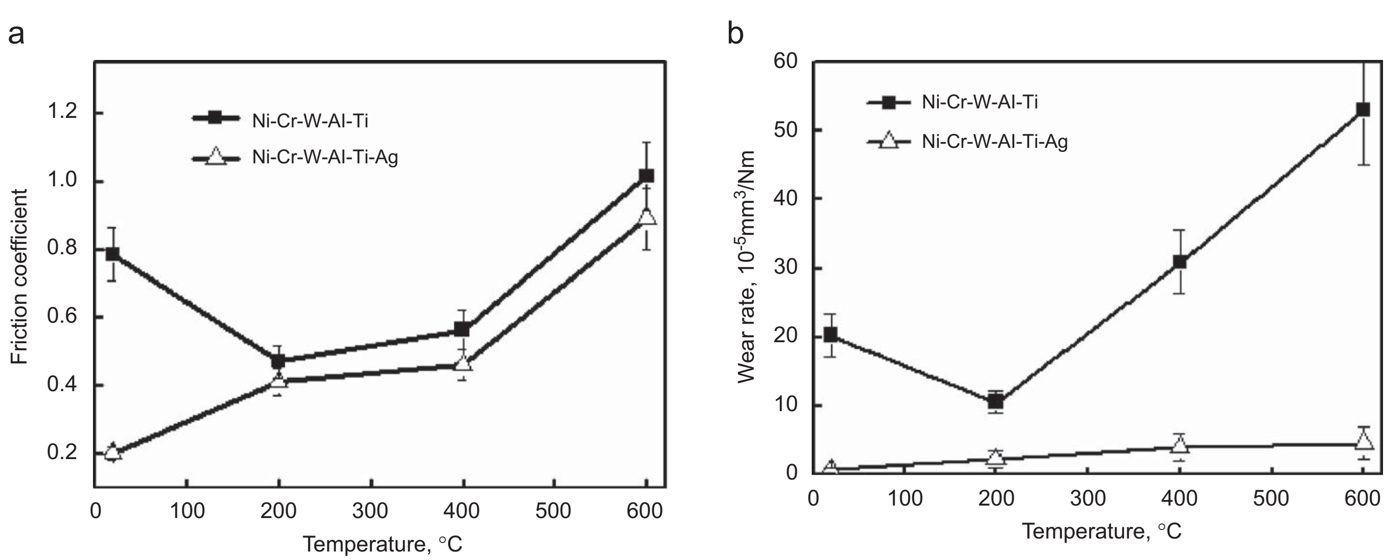

Fig. 2. Friction coefficient (a) and wear rate (b) of Ni–Cr–W–Al–Ti–Ag against Al_2O_3 ball vs. temperature.