Wear 270 (2011) 423–430

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Effect of load and sliding speed on friction and wear behavior of silver/h-BN containing Ni-base P/M composites

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ARTICLE INFO

Article history:
Received 26 April 2010
Received in revised form 3 August 2010
Accepted 12 August 2010
Available online 19 August 2010

Keywords:
Ni-base composites
Solid lubricants
Silver lubrication
Sliding wear
Friction and wear
Self-lubrication

ABSTRACT

Sliding wear of behavior of Ni-based composites, prepared by powder metallurgy route and containing different (0, 8, 12, 16 and 20 wt.%) amounts of silver, was investigated under different loads and speeds by conducting wear tests against a counterface of AISI 52100 ring using a ring-on-disk set up. One composite containing 12 wt.% silver and 4 wt.% h-BN was also prepared and tested under same conditions to investigate the synergistic action of Ag and h-BN. The friction coefficients and the wear rates are significantly reduced by addition of silver and h-BN. The friction coefficient reduced from 0.36 to 0.21 by addition of solid lubricants whereas the reduction was 3–5 times in the wear rates. The friction coefficients of composites decreased with increasing load and sliding speed whereas the wear rates increased marginally. No noticeable synergy could be observed between silver and h-BN because h-BN fails to form strongly adherent transfer film on counterface surface.

1. Introduction

Ni-based alloys are widely used in several industrial applications like gas turbine parts, medical applications and nuclear systems to solve wear resistance, corrosion and thermal fatigue problems [1–4]. Self-lubricating nickel based composites are used in new generation high-performance gas turbine engines due to their excellent self-lubricating characteristics over an extreme range of operating temperatures [5]. Molybdenum disulfide, graphite, rare earth compounds and soft noble metals (Ag, Au, Pt) have been utilized as solid lubricants [6–9]. However, molybdenum disulfide and graphite begin to loose their lubricating characteristics at temperatures above 350 °C [10] while the rare earth compounds are ineffective at room temperature [11,12]. Several studies have been conducted on the tribological behavior of self-lubricating Ni-base composites since the early work pioneered by Sliney [13,14], who utilized a combination of Ag/CaF_2–BaF_2 to achieve self-lubricating function over a wide range of temperatures. Xiong [15] observed that the addition of MoS_2 brings about an enhancement in the tribological performance of composite over a temperature range from 25 to 600 °C. Recently, Li et al. [7,16] investigated the high-temperature friction and wear properties of Ni-based P/M composites containing a combination of lubricants like MoS_2/graphite, Ag/CeO_2 and reported that friction coefficients as low as 0.2 can be achieved up to 600 °C. Silver has been used as a solid lubricant to lubricate bearings, seals, fasteners and other components and exhibits good thermo-chemical stability over a wide range of temperatures [17] at the same time it provides low shearing interface. It has been used in conjunction with other lubricants in composite coatings to obtain the self-lubricating features at elevated temperatures. However, all the above-mentioned investigations were focused on enhancing the regime of temperatures in which these composites provide effective lubrication. The room temperature friction and wear behavior of composites containing silver as the only solid lubricant has not been studied in detail under different conditions of load and speeds.

The mechanism of lubrication of various solid lubricants highlighted above is very well understood. However, solid lubricants having similar structure possess different lubrication roles and their lubrication degree is not identical in a way. Realizing lubrication mechanism of each solid lubricant and optimizing them as lubricant additives could provide an effective way to enhance the self-lubricating characteristics of Ni-based P/M composites. Hexagonal boron nitride (h-BN) is one such solid lubricant which has a lamellar crystalline structure in which the bonding among molecules within each layer is covalent, whereas the bonding between adjacent layers is weak van der Waals forces. This kind of structural property of h-BN make it suitable to used as solid lubricant additive as it could be easily sheared along the basal plane. It

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doi:10.1016/j.wear.2010.08.013

Table 1
Composition and designation of composites.

Alloys (designation)	Composition (wt.%)						
	Ni–20Cr	W	Mo	Al	Ti	Ag	h-BN
Ni–Cr–W–Mo–Al–Ti (S0)	Balance	10	6	5	4	–	–
Ni–Cr–W–Mo–Al–Ti–12Ag–4 BN (S4)	Balance	10	6	5	4	12	4
Ni–Cr–W–Mo–Al–Ti–8Ag (S8)	Balance	10	6	5	4	8	–
Ni–Cr–W–Mo–Al–Ti–12 Ag (S12)	Balance	10	6	5	4	12	–
Ni–Cr–W–Mo–Al–Ti–16Ag (S16)	Balance	10	6	5	4	16	–
Ni–Cr–W–Mo–Al–Ti–20Ag (S20)	Balance	10	6	5	4	20	–

has been used in different anti-wear applications [18–20]. Although h-BN is a well-known solid lubricant additive, hardly any literature reported on addition of h-BN in Ni-based P/M composites, especially no investigation using silver in conjunction with h-BN is available.

In this work, we present a more detailed study on the influence of load and sliding speed on Ni-based P/M composites under dry sliding conditions against AISI 52100. Ni-based P/M composites with the addition of four different amounts of silver were prepared using hot pressing techniques. A small amount of h-BN was added in one of the specimens to investigate the effect of h-BN on the friction and wear behavior of these composites. The combination of silver and h-BN is somewhat novel, which is primarily directed towards acquiring an understanding of any synergistic mechanism of these two solid lubricants.

2. Experimental methods

2.1. Material preparation

Ni–20Cr alloy powder (80 μm), W (20 μm), Mo (60 μm), Al (20 μm), Ti (20 μm) powder, Ag powder (80 μm), h-BN powder (200 nm, supplied by Momentive Performance Materials Inc., USA) were mixed together and pressed as disks (45 mm × 6 mm) in a steel mould. The pressed samples were processed in vacuum by a FVPHP-R-10 FUJI vacuum-hot-pressing furnace (Japan). The furnace was drawn to a vacuum of 10^{-6} Pa and protected by nitrogen gas. The furnace temperature was increased 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. The compositions and designations of the composites prepared for the study are presented in Table 1.

2.2. Friction and wear tests

The friction and wear tests were carried out on a MG-2000 high-temperature ring-on-disk tribometer (Beilun Cop.). The lower rotating specimens were made of Ni-based composites disks (45 mm × 6 mm). The counterface was a ring (outer diameter 46 mm and inner diameter 32 mm) made of AISI 52100 (containing around 1% carbon and 1.5% chromium by weight, hardened to 61–63 HRC). Fig. 1 shows the schematic diagram of contact geometry. Dry sliding wear tests were conducted at room temperature at three different normal loads of 100, 150 and 200 N corresponding to geometric contact pressures of 0.116, 0.175, 0.23 MPa, respectively, and three sliding speeds of 0.5, 1.0, 1.5 m/s. Both the disk and the counterface were polished up to # 400 emery paper and cleaned with acetone before each test. All the tests were conducted at a relative humidity of 35–55%. All the tests were run for 5000 cycles corresponding to a sliding distance of 625 m. The frictional torque was recorded by a computer consistently. The wear mass losses of disks and counterface were measured by an analytical balance having an accuracy of 1×10^{-7} kg. Each test at a particular load and sliding velocity was repeated at least twice and the average data for volume loss after each test were used for the analysis of wear rate.

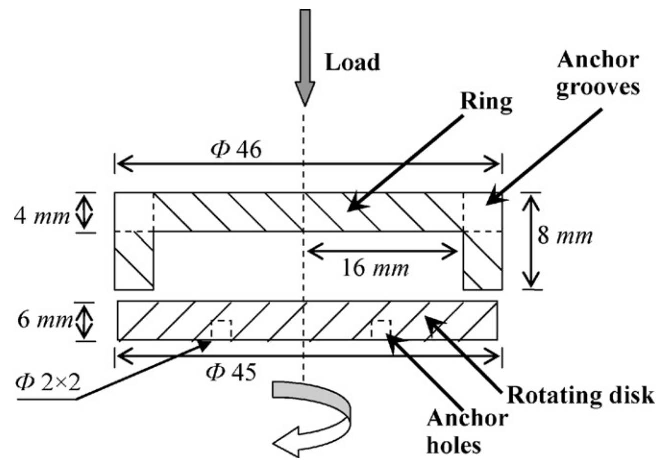

Fig. 1. Contact schematic diagram of ring-on-disk set up.

Wear rate was calculated by the following formula:

$$W = \frac{V}{LS} \quad (1)$$

where W is the wear rate, V is the worn volume of the specimen, L is the applied normal load and S is the sliding distance.

The microstructure, worn surfaces and the wear debris of the composites were analyzed using optical microscope and scanning electron microscope (JOEL, JSM-6380 LV) attached with EDS. X-ray diffraction studies were carried out on the prepared composites to

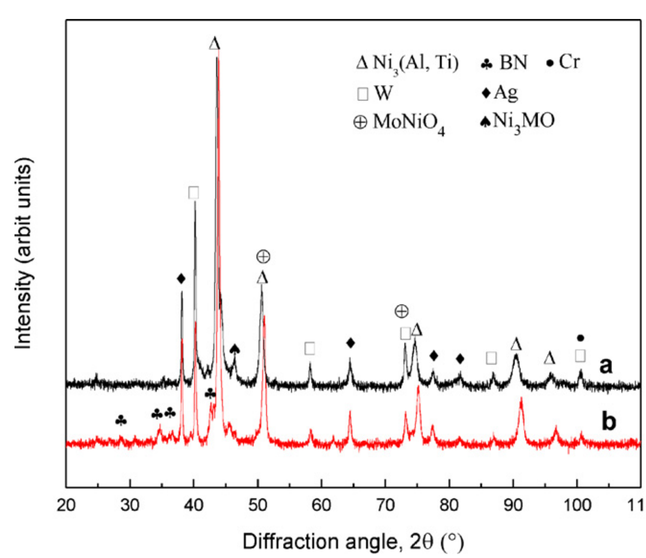

Fig. 2. XRD pattern of composites. (a) S20, containing 20 wt.% Ag and (b) S4 containing 12 wt.