DEVELOPMENT OF MoS_2-CONTAINING Ni-Cr BASED ALLOYS AND THEIR HIGH-TEMPERATURE TRIBOLOGICAL PROPERTIES①

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ABSTRACT B- and MoS_2-containing Ni-Cr based self-lubricating materials were prepared by P/M hot-pressing the mixture of alloyed Ni-Cr powder, elemental Mo and B powders and MoS_2 powder. The phase constituents were analysed using an X-ray diffractometer, and the hardness was measured using a Brinell's machine. The friction coefficients and wear rates of the studied materials were determined by means of pin-on-disc tribometer. The results showed that the studied materials are mainly composed of Ni-based solid solution, Cr_3S_4 and MoB; the wear debris are mainly composed of NiO, CrO, $x NiO \cdot MoO_3 \cdot y H_2O$, Cr_2O_3 and nickel-based solid solution at 700 ℃; the Ni-Cr-Mo-B-4MoS_2 alloy has the best tribological properties, over a wide range of temperature from 20 ℃ to 700 ℃, its friction coefficient is 0.14~0.26 and its wear rate is 1.6×10^{-14}~$1.2\times10^{-13} m^3/N\cdot m$.

Key words Ni-Cr based alloy self-lubricating tribological properties high-temperature

1 INTRODUCTION

With the development of heat engines, their working temperatures become higher and higher. The new-type heat engines in the future are needed to be lubricated at 800 ℃ or above. Therefore, the development of materials with good self-lubricating and wear resistant properties from room temperature to high temperature (above 800 ℃) draws much attention from scientists in the field of tribological materials[1-5].

The Ni-based alloys possess excellent high-temperature comprehensive properties and have found wide applications in various combustion turbines. Recently, some efforts have been devoted to the self-lubricating MoS_2-based meterials with Ni-Cr, Ni-Cr-Ag, Ni-Co or Ni-Mo alloys as strengthening phases[6-10]. Because the amount of MoS_2 is over high, although they are antifrictional, they are not wearing-resistant and their mechanical properties decrease with increasing MoS_2 content. Furthermore, no systematic research has been made on their wearing behaviors at high temperatures. In this paper, the wearing behaviors from room temperature to 700 ℃ of eight Ni-Cr based alloys prepared by P/M hot-pressing the mixture of alloyed Ni-Cr powder, elemental Mo and B powders and MoS_2 powder were examined with Al_2O_3 ceramics as wearing pairs.

2 EXPERIMENTAL

Minus 44 μm (−320 mesh) Ni-20% Cr alloy powder, elemental Mo and B powders and MoS_2 powder of chemical purity were mixed in certain

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proportions, then loaded in graphite moulds and rapidly heated in a hot-presser. The pressure was 40~ 60 MPa, the temperature was 1 000~ 1 100 ℃, and the holding time was 5~ 10 min. The blanks with a dimension of d 9 mm × 20 mm were machined to d 6 mm × 15 mm cylindrical pin samples. The material number, composition and HB value are listed in Table 1.

Table 1 Alloy number, composition and HB value

Alloy No.	Composition	HB
1	Ni-Cr-Mo	153
2	Ni-Cr-Mo-1B	184
3	Ni-Cr-Mo-3B	340
4	Ni-Cr-Mo-6B	401
5	Ni-Cr-Mo-10B	404
6	Ni-Cr-Mo-3B-2MoS_2	361
7	Ni-Cr-Mo-3B-4MoS_2	340
8	Ni-Cr-Mo-3B-6MoS_2	350

The wearing behaviors were measured with an MG- 200 high-temperature tribometer. The pin samples made of studied materials were weared with d 50 mm × 8 mm Al_2O_3 ceramics disks (Before each test, the pin samples and the disc samples were polished by $400^{\#}$ abrasive paper). The test conditions were: load= 49 N, velocity= 2.0 m/s, sliding distance at each temperature= 2.5 km. The friction coefficients were continuously detected using an X-Y recorder and the average values were taken as the corresponding frictional coefficients. The wearing amounts were measured by mass method (the oxidation mass gain was ignored), then the wear rate was calculated using the following equation:

$$W = \Delta V / (L \cdot S) \qquad (1)$$

where ΔV is wear volume (= mass loss/density), L is load, and S is slide distance.

3 RESULTS AND DISCUSSION

3.1 Effect of B addition on high-temperature friction behavior

It can be seen from Table 2 that the friction coefficients show a decreasing tendency with increasing B addition at relatively low temperatures (20~ 300 ℃), while the friction coefficients increase with increasing B addition at relatively high temperatures (400~ 700 ℃), especially. Alloy No. 4 and No. 5 with high contents of boron, show great fluctuations in friction coefficients at high temperatures (500~ 700 ℃).

3.2 Effects of temperature on friction coefficient and wear rate

Fig. 1(a), (b) and (c) show the variations of friction coefficients and wear rates with temperature for Alloy No. 6, 7 and 8. It can be known by comparison that when the MoS_2 addition increases from 2% (Fig. 1(a)) to 4% (Fig. 1(b)), the friction coefficient obviously decreases in the temperature range from 20 ℃ to 700 ℃, but does not show significant decrease when the MoS_2 addition is raised to 6% (Fig. 1(c)), or even increases a little at 600~ 700 ℃. When the temperature is raised from 600 ℃ to 700 ℃, the wear rates of Alloy No. 6 and 8 are increased by 30 and 90 times respectively, while that of Alloy 7 is increased only by 3 times, and in the whole testing temperature range Alloy No. 7 shows the lowest wear rate. By considering the results of friction and wear simultaneously, Alloy No. 7 containing 4% MoS_2 additive is selected as the best material.

Table 2 Variation of friction coefficient with temperature

Alloy No.	Friction Coefficient							
	20 ℃	100 ℃	200 ℃	300 ℃	400 ℃	500 ℃	600 ℃	700 ℃
1	0.51	0.45	0.52	0.49	0.32	0.29	0.28	0.28
2	0.38	0.31	0.40	0.42	0.38	0.44	0.42	0.46
3	0.37	0.30	0.37	0.39	0.40	0.44	0.51	0.63
4	0.34	0.29	0.36	0.38	0.43	0.46	0.56	0.72
5	0.35	0.27	0.34	0.31	0.42	0.61	0.71	0.78

3.3 Examinations of morphologies of wear scars and analyses of X-ray diffraction

Fig. 2(a) and (b) show the optical micrographs of the wear scars of Alloy No. 7 after friction tests at 200 ℃ with the lowest wear rate and at 700 ℃ with the highest wear rate. It can be seen that, after 200 ℃ friction test, there is an integrated bright film on the friction surface and

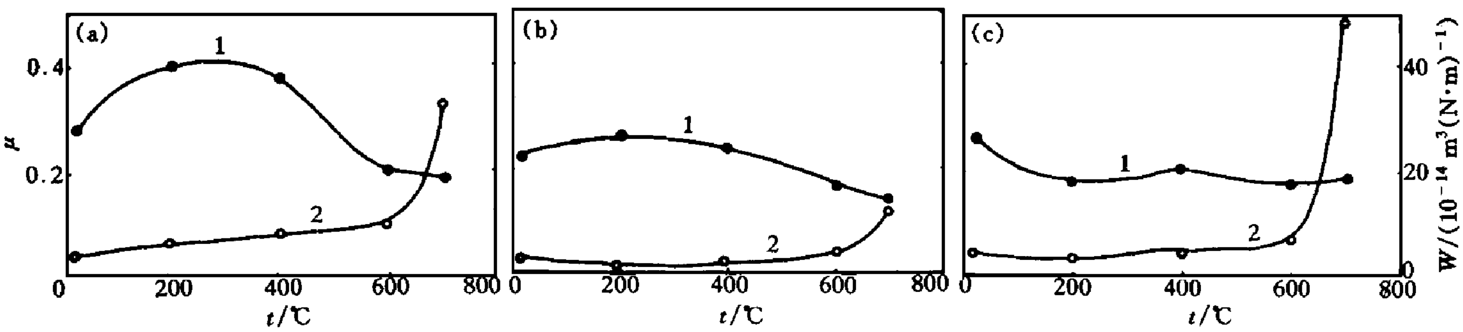

Fig. 1 Variation of friction coefficients and wear rates with temperature
1 —Friction coefficient; 2 —Wear rate

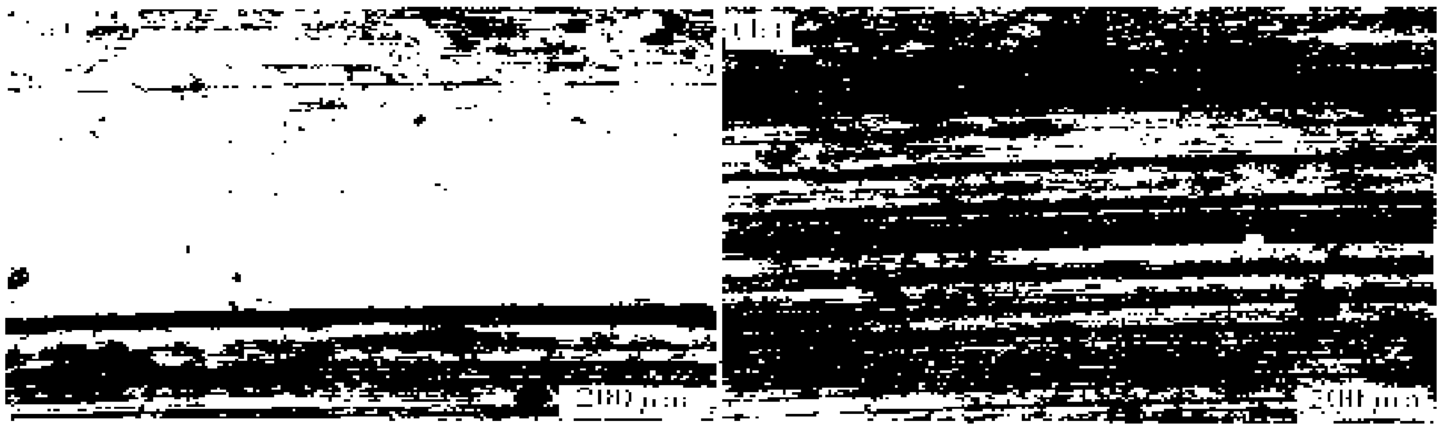

Fig. 2 Optical micrographs of wear tracks of Alloy No. 7
(a) —200 ℃; (b) —700 ℃

there are deep plow grooves under the bright film; while after 700 ℃ friction test, the friction surface is gray which indicates that the friction surface is seriously oxidized, and the plow grooves are further deepened and widened, therefore the wear rate is larger.

XRD analyses demonstrated that Alloy No. 7 is mainly composed of Ni-based solid solution, Cr_3S_4, MoB and Mo (Fig. 3(a)). In the process of friction, the Cr_3S_4 etc transfer to the opposite pair and forms a relatively integrated lubricating film, and this film in turn coats the pin material surface and adheres to its friction surface to form a bright lubricating layer. Fig. 3(b) is the XRD patterns for the worn surface of Alloy No. 7 at 700 ℃. Comparing Fig. 3(a) with Fig. 3(b), we can find that the peaks of Cr_3S_4 and Mo decrease and small peaks of MoO_2 appear, which indicates that Cr_3S_4 and Mo in the worn surface of the alloy at high-temperature were oxidized. The wear debris and transfer films of Alloy No. 7 on the Al_2O_3 disc were collected and identified by XRD after 700 ℃ friction test (Fig. 3(c)). The results show that it is mainly composed of NiO (hexagonal), CrO (cubic), nickel-based solid solution, Cr_2O_3 (hexagonal) and a large quantity of composite oxide $x NiO \cdot MoO_3 \cdot y H_2O$. Thus the friction coefficient of the Alloy No. 7 is further decreased at 700 ℃.

4 CONCLUSIONS

(1) Eight Ni-Cr based alloys were prepared by P/M hot-pressing. When the B content increases, the value of HB increases and the high-temperature friction coefficient also increases.

(2) The friction coefficient decreases with MoS_2 addition in general. But in the light of the

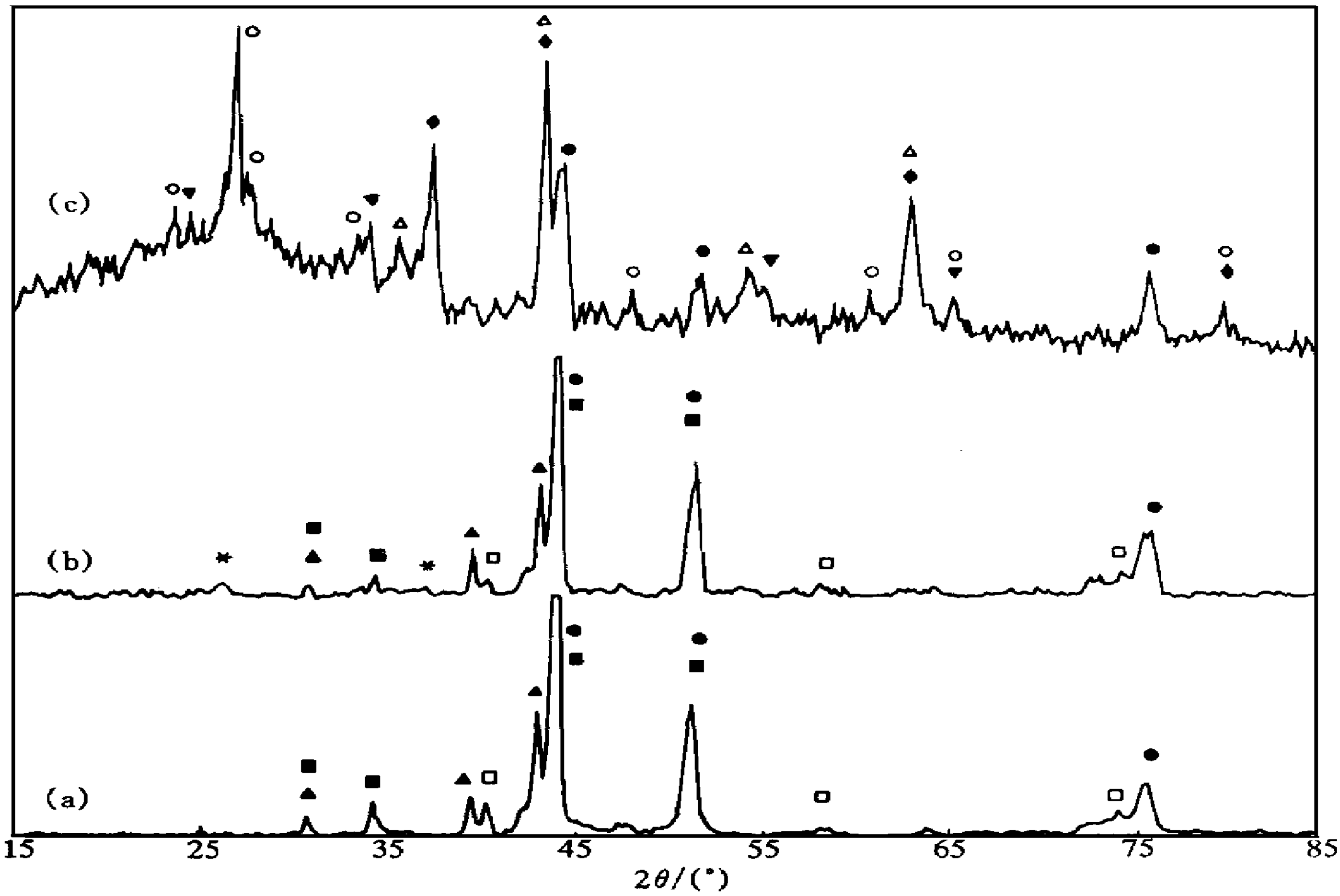

Fig. 3 XRD patterns, (a) Alloy No. 7, (b) worn surface of Alloy No. 7 at 700 ℃ and (c) wear debris of Alloy No. 7 at 700 ℃

● —Ni-based solid solution; ■ —Cr_3S_4; ▲ —MoB; □ —Mo; * —MoO_2;
○—xNiO·MoO_3·$y H_2O$; △ —CrO; ◆—NiO; ▼ —Cr_2O_3

wearing behavior, the optimum addition amount of MoS_2 is 4% (Alloy No. 7). Alloy No. 7 shows the best antifrictional and wear-resistant ability in the temperature range from 20 ℃ to 700 ℃.

(3) Cr_3S_4 is responsible for the self-lubrication of the studied materials in the low temperature range. The synergetic actions of NiO, CrO, Cr_2O_3 and composite oxide of Ni and Mo and the residual Cr_3S_4 at high temperatures are responsible for the further reduction of the friction coefficient.

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