

High-temperature wear behaviors of MoSi₂ under different loads

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Abstract: MoSi₂ was prepared by SHS, pressed at room-temperature and then vacuum sintered at 1 500 °C for 1 h. The tribological properties of MoSi₂ against Al₂O₃ were investigated by using an XP-5 type High Temperature Friction and Wear Tester. Micrographs and phases of the worn surface of MoSi₂ were observed by SEM with EDS and X-ray diffraction. The results show that the wearing process of MoSi₂ at high temperature exists three stages: running-in, interim and steady periods. MoSi₂ exhibits preferable wear resistance when the load is lower than 50 N. Adhesion and oxidation wear exists widely at elevated temperature; however besides these, with increasing the load, the main wear mechanisms of MoSi₂ could be changed from adhesion, plastic forming to fatigue fracture in turn.

Key words: MoSi₂; tribological property; wear mechanism

1 Introduction

Molybdenum disilicide (MoSi₂) is one of the intermetallic compounds that have the potential in being used as advanced high temperature structural materials[1]. It is well recognized that MoSi₂ is an attractive wear-resistant material for application at room or high temperature corrosive and oxidative environments because of its high hardness and elastic modulus[2-4]. HAWK et al[4] have compared the wear resistance of MoSi₂ with Nb/MoSi₂, Nb, aluminide (Fe₃Al and TiAl) and oxide ceramics (Al₂O₃ and PS-ZrO₂). They have found that the wear resistance of MoSi₂ is improved greatly after adding Nb, which wear rate is near Al₂O₃ and PS-ZrO₂. After analyzing abrasion property of SiC/MoSi₂ composite, PAN et al[5] have found the wear rate of MoSi₂ is decreased by about 90% with the addition of SiC. The authors[6-13] have ever studied the tribological property of MoSi₂ and its composites (such as adding WSi₂, Mo₅Si₃, La₂O₃, B₄C and Ag/ZrO₂) against carbon steel. All above researches are limited to the range of room temperature. The high

temperature friction and wear properties of MoSi₂ are also important due to its application in high temperature structural parts such as gas turbines in aerospace and automotive, which are relative movement components. However it has no report about high-temperature wear property of MoSi₂. This paper will chiefly discuss the wear behaviors of MoSi₂ against Al₂O₃ at 1 000 °C under different loads, and also accumulated some fundamental data for optimizing wear-resistant design of MoSi₂ at elevated temperature.

2 Experimental

The wear tests were carried out by a type of XP-5 type High Temperature Friction and Wear Tester. MoSi₂ was prepared by SHS, and then pressed under 100 MPa for 2 min at room temperature and vacuum sintered at 1 500 °C for 1 h. MoSi₂ acted as the friction pin, and Al₂O₃ acted as the friction disk. The properties of the friction pair materials are listed in Table 1. Every wear test was done at the sliding speed of 0.126 m/s. Test loads were selected to be 10, 20, 30, 40, 50 and 60 N. The qualities of specimens were determined before and after

tests with an analytical balance having an accuracy of 0.1 mg. Wear rate was calculated according the volume loss of mass for unit wear area. And friction coefficient was given automatically by the calculating module of the machine. Every factor and wear test data was the average of five measure values. Micrographs of worn surface were observed by KYKY—2800 SEM with EDS. Phase identification was done by a SIEMENS-500 X-ray diffractometer with monochromated Cu K_{α} radiation.

Table 1 Properties of friction pair materials

Material	Hardness (HRA)	Toughness/(MPa·m ^{1/2})	Relative density/%	Roughness/R _a	Size/mm
MoSi ₂	81.12	6.67	95.9	0.4	φ8×18
Al ₂ O ₃	82.20	3.10	97.2	0.8	φ54×8

3 Results and discussion

3.1 Wear behaviors

Fig.1 shows the variation of friction coefficient of MoSi₂ against Al₂O₃ with time under 50 N. It can be seen that the friction coefficient is relatively stable (about 0.65) in this wear test. Friction coefficient variation with load is shown in Fig.2. It indicates that load has obvious effect on the friction coefficient. The friction coefficient increases with the increase of load between 10 N and 20 N and then decreases in the range of 20–40 N. When the load is between 40 N and 60 N, however it increases with the increase of load.

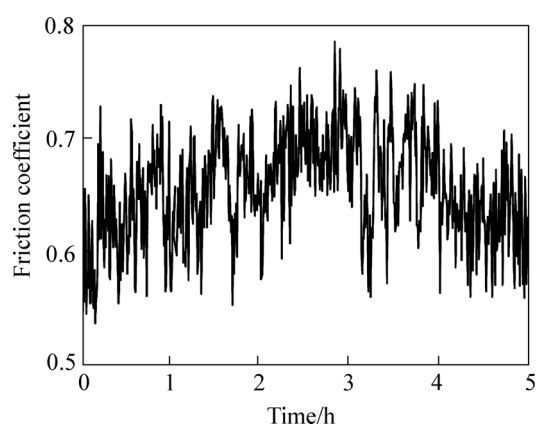


Fig.1 Variation of friction coefficient with time

Fig.3 shows the wear rate of MoSi₂ against Al₂O₃ changed with time under 50 N. It can be seen that its high-temperature wear process has general attribute as same as room temperature wear process. There also exist three stages: running-in, interim and steady period. In 1 h, it is a severe wear process, in which mass loss almost occupies one-half of the total loss. From 2 h to 4 h, the

wear rate increases slowly, and this process is an interim period. From 4 h to 5 h, the wear rate is almost stable, which indicates that the wear process is a steady period. Effect of loads on wear rate of MoSi₂ against Al₂O₃ is shown in Fig.4. The mass wear rate increases slowly at first in the range of 10–50 N, but then it increases rapidly when the load is above 50 N. This means MoSi₂ has good wear-resistance under 50 N.

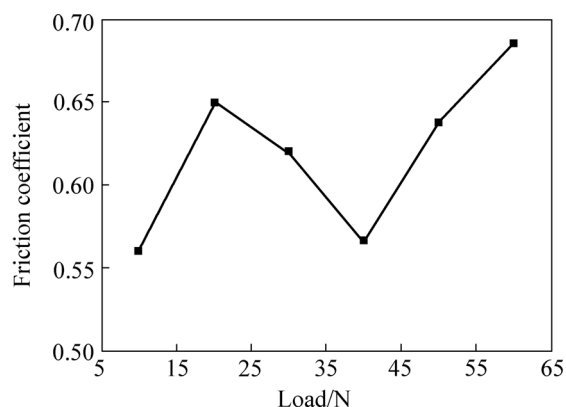


Fig.2 Variation of friction coefficient with load

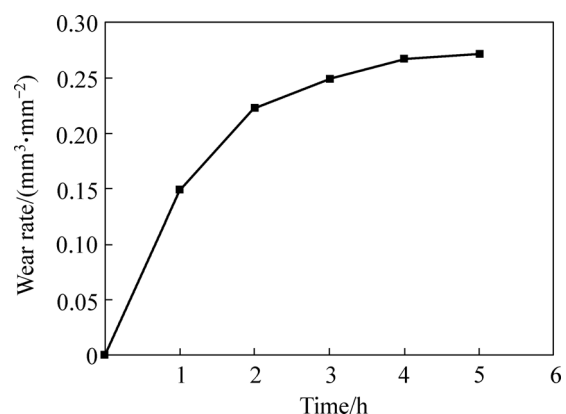


Fig.3 Variation of wear rate with time

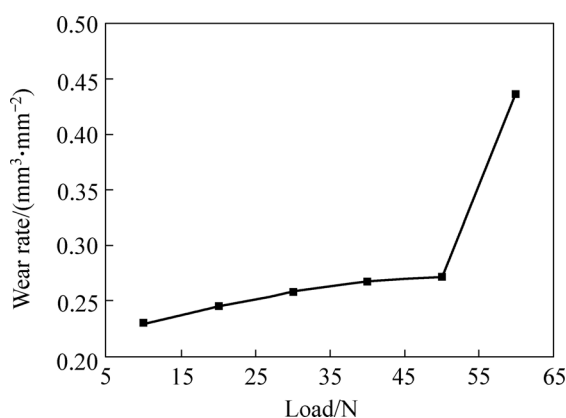


Fig.4 Variation of wear rate with load

3.2 Wear mechanism

Worn surface micrographs of MoSi₂ under different loads are shown in Fig.5. There are white and gray areas

on all of the surfaces. Results from EDS are listed in Table 2. It can be seen that Al element is rich in the white area, and the mole ratio of Si and Mo in gray area is about 2:1. Al is from the opponent, which indicates Al_2O_3 has been transmitted to the surface of MoSi_2 . This is accordant with the XRD patterns of worn surface of MoSi_2 in Fig.6. Fig.6 shows that MoSi_2 , Mo_5Si_3 , SiO_2 and Al_2O_3 phases exist on the worn surface of MoSi_2 . Al_2O_3 phase is the result of adhesion. Mo_5Si_3 and SiO_2 phases indicate that the following oxidation reaction happens[14]: $5\text{MoSi}_2+7\text{O}_2 \rightarrow \text{Mo}_5\text{Si}_3+7\text{SiO}_2$. Because of this experiment in air, MoSi_2 oxidation is unavoidable. Therefore, adhesion and oxidation phenomenon exist widely in this experiment.

Table 2 EDS analytical results of worn surfaces

Area	x/%		
	Mo	Si	Al
Dot <i>a</i> in Fig.5(a)	11.11	23.68	65.21
Dot <i>b</i> in Fig.5(a)	4.90	9.11	85.99
Dot <i>b</i> in Fig.5(c)	29.25	64.79	5.96
Dot <i>a</i> in Fig.5(c)	10.48	27.67	61.85
Dot <i>a</i> in Fig.5(e)	20.30	46.58	33.12
Dot <i>c</i> in Fig.5(e)	8.47	7.20	84.33

From Figs.5(a) and (b), it can be seen that the adhesion and oxidation track is clearly found on worn surface of MoSi_2 . And with the increase of load, the adhesion phenomenon is more serious, which leads to the friction coefficient and wear rate rising. When under 30 N and 40 N, worn surface is changed to be smooth. This is the result of plastic deformation. MoSi_2 is brittle at room temperature, however because of its ductile-brittle transition characteristic (DBTT is about $1\ 000\ ^\circ\text{C}$ [1]), the material exhibits some plasticity when the temperature is near $1\ 000\ ^\circ\text{C}$ under above 30 N. Its surface is planished in Figs.5(c) and (d). These result in friction coefficient decreasing and wear rate rising slowly with the increase of load. Fig.5(e) shows the obvious deforming trace along the motion direction and some crack, which is vertical to the motion direction, on the worn surface. This means that fatigue fracture appears on the surface of MoSi_2 when the load is over 50 N at $1\ 000\ ^\circ\text{C}$. When the load rises to 60 N, a large mass falling resulted from crack spreading at cycle stress is found on the worn surface in Fig.5(f), which causes MoSi_2 to have very high wear rate. Meantime, its worn surface becomes rougher, friction coefficient increases in Fig.2.

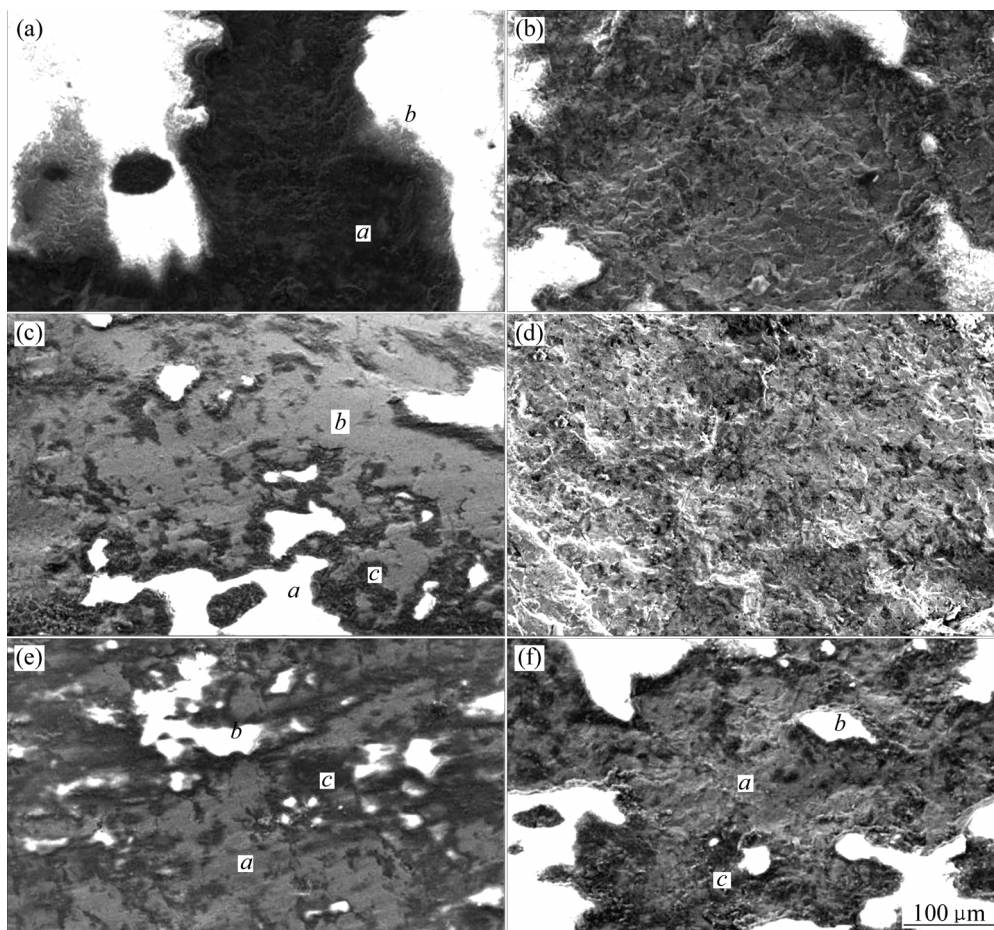


Fig.5 SEM images of worn surfaces of MoSi_2 under different loads: (a) 10 N; (b) 20 N; (c) 30 N; (d) 40 N; (e) 50 N; (f) 60 N

4 Conclusions

1) The wearing process of MoSi₂ at high temperature has the same general attribute as at room temperature wear process, which can be divided into three stages: running-in, interim and steady periods. MoSi₂ has well wear-resistance when the load is lower than 50 N.

2) When against Al₂O₃ at 1 000 °C, adhesion and oxidation wear of MoSi₂ is found widely. Meantime, load has obvious effect on the wear mechanism of MoSi₂ at high-temperature too. When the load is below 20 N, adhesion and oxidation is its main wear mode. Under 30 N and 40 N, plastic deformation happens. When the load is above 50 N, fatigue fracture becomes the main wear mechanism of MoSi₂.

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