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## Dry friction and wear properties of intermetallics MoSi<sub>2</sub><sup>①</sup>

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**[Abstract]** The dry friction and wear properties of intermetallics MoSi<sub>2</sub> against 45 steel under different loads were investigated with M-2 type friction and wear tester. Scanning electric microscope (SEM) equipment with microprobe was employed to analyze the morphology of the friction surface. Results show that the dry friction and wear properties are deeply affected by load. The wear rate of MoSi<sub>2</sub> at the load of 80 N is the maximum which is 36.1 μg/m. On the condition of the load of 150 N, MoSi<sub>2</sub> material has the better friction and wear properties: friction coefficient is 0.28 and wear rate is 10.6 μg/m. With the load increasing, the main friction mechanisms change from microslip and plastic deformation to adhesive effect, and the main wear mechanisms change from plough groove wear and oxidation-fatigue wear to adhesive wear.

**[Key words]** molybdenum disilicide; friction and wear mechanism; dry friction

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### 1 INTRODUCTION

The study on friction and wear properties of ceramic materials has become one of the hot topics in the field of material science and tribology<sup>[1,2]</sup>. Intermetallics molybdenum disilicide (MoSi<sub>2</sub>) has double characteristics of metal and ceramics, for example, it's high hardness (8~10 GPa) and elastic modulus (about 400 GPa), excellent high-temperature oxidation resistance and corrosion resistance, especially, and other characteristics better than ceramic materials, such as ductile-brittle transition properties and high electric conductivity which make it can be machined using electro-discharge machining<sup>[3]</sup>. At present, there are more studies concentrated on its preparation and mechanical properties<sup>[4~6]</sup>, but less on its wear resistance. Hawk et al<sup>[7~10]</sup> preliminarily reported that MoSi<sub>2</sub> can act as the wear resistant materials or the additive of ceramic materials to improve its wear resistance. Whereas the friction and wear properties has not been systematically and deeply studied. Author aims at investigating the dry friction and wear properties of MoSi<sub>2</sub>-45 steel friction pair, and explaining the friction and wear mechanism.

### 2 EXPERIMENTAL

#### 2.1 Experimental specimen

MoSi<sub>2</sub> material powder was first synthesized by mechanical alloying (MA), and then shaped by IP

and high-temperature sintering<sup>[11]</sup>. The size of the ring-shaped specimen was  $d$  16 mm × 40 mm × 10 mm, and the surface roughness ( $R_a$ ) was 0.4 and the Vickers hardness was 7.47 GPa. The counterpart was the quenched and tempered 45 steel, and size,  $R_a$  and hardness of 45 steel were  $d$  16 mm × 44 mm × 10 mm, 0.32 and HRC 22, respectively.

#### 2.2 Wear test

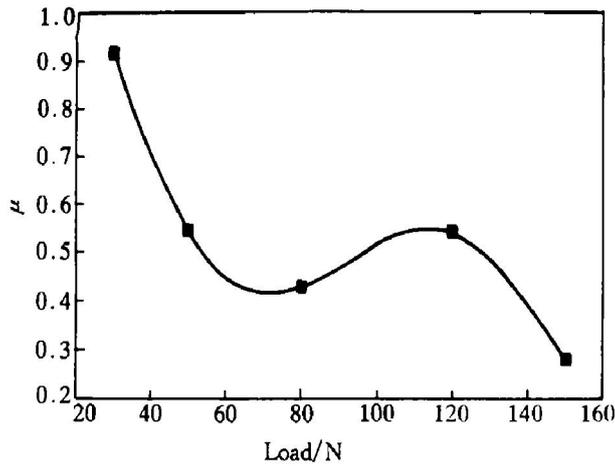
The dry friction tests were run on the M-2 type friction and wear tester by a way of ring-ring rolling contact under the loads of 30 N, 50 N, 80 N, 120 N and 150 N at room temperature, respectively. The whole friction distance was 36 km. The below specimen was MoSi<sub>2</sub> rotated at 200 r/min, and the above specimen was 45 steel rotated at 180 r/min. The rolling and gliding complex friction was achieved. The qualities of specimens were determined at intervals by an analytical balance (the precision is 0.1 mg) to calculate their wear rate. The friction coefficient can be calculated out according its friction moment. The wear surface of specimens was observed and analyzed by KY-2800 type SEM equipment with microprobe.

### 3 RESULTS

#### 3.1 Tribological behavior

The friction coefficients of MoSi<sub>2</sub>-45 steel friction pair are shown in Fig. 1 under dry friction and different loads. It can be seen that loads significantly

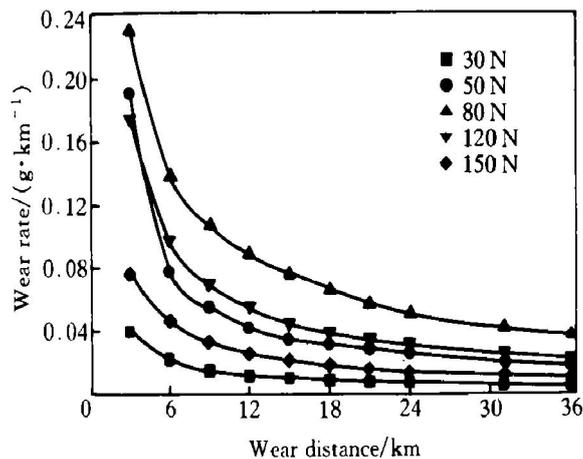
affect the friction coefficients. In the range of 30 N to 80 N, the friction coefficients decrease from 0.917 to 0.427 with the increase of load. But it is increased to 0.54 again under 120 N. The lowest value 0.28 is found under 150 N.



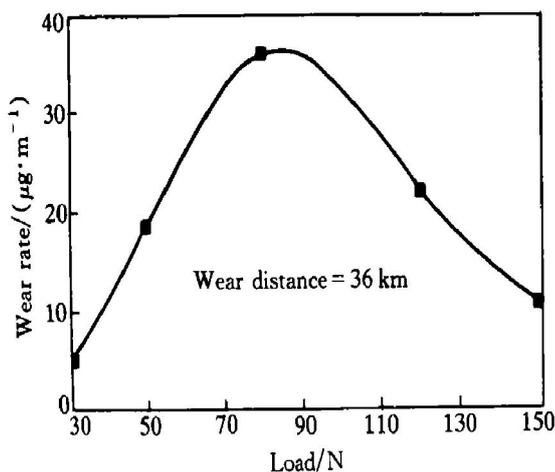
**Fig. 1** Friction coefficient curve under dry friction condition

### 3.2 Wear behavior

The relationship between MoSi<sub>2</sub> wear rate and friction distance is described in Fig. 2. It can be seen that the wear process includes three stages: run-in, transition and stable state. Fig. 3 shows the relation-



**Fig. 2** Variations of wear rate of MoSi<sub>2</sub> with distance

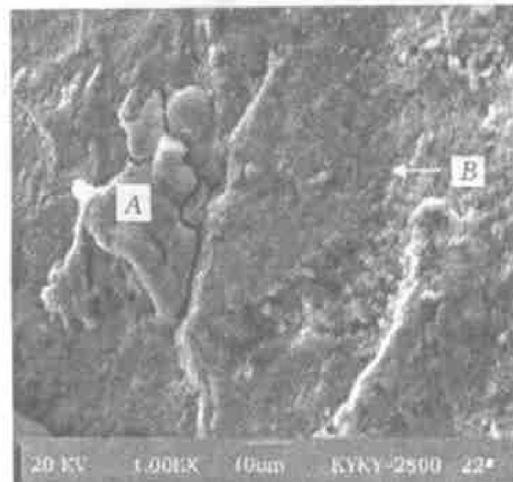


**Fig. 3** Variations of wear rate of MoSi<sub>2</sub> with loads

ship that obeys parabola regularity between the wear rate of MoSi<sub>2</sub> material and load when the friction distance is 36 km. When the vertical pressure is 80 N, the wear rate is the maximum 36 μg/m. More or less than 80 N, the wear rate is obviously decreased.

## 4 DISCUSSION

When MoSi<sub>2</sub> material is frictionized with 45 steel under low loads, plough-cutting occurs (Fig. 4). Because the hardness of MoSi<sub>2</sub> is far higher than that of 45 steel, the micro-bulge of MoSi<sub>2</sub> can be easily pressed into the surface of 45 steel, and surface material of 45 steel is pushed in the vertical both sides to the movement direction. The extrusion-deforming layer is found around plough-cutting, as shown *B* in Fig. 4. *A* in Fig. 4 shows the drop of 45 steel material because of deforming, hardening and fracturing. Friction resistance mainly comes from the micro-slip and plastic deformation<sup>[12,13]</sup>. The brittle fracture of micro-bulge of MoSi<sub>2</sub> results in crumbs. So the higher friction coefficients and lower wear rate are seen in Fig. 1 and Fig. 2, respectively.

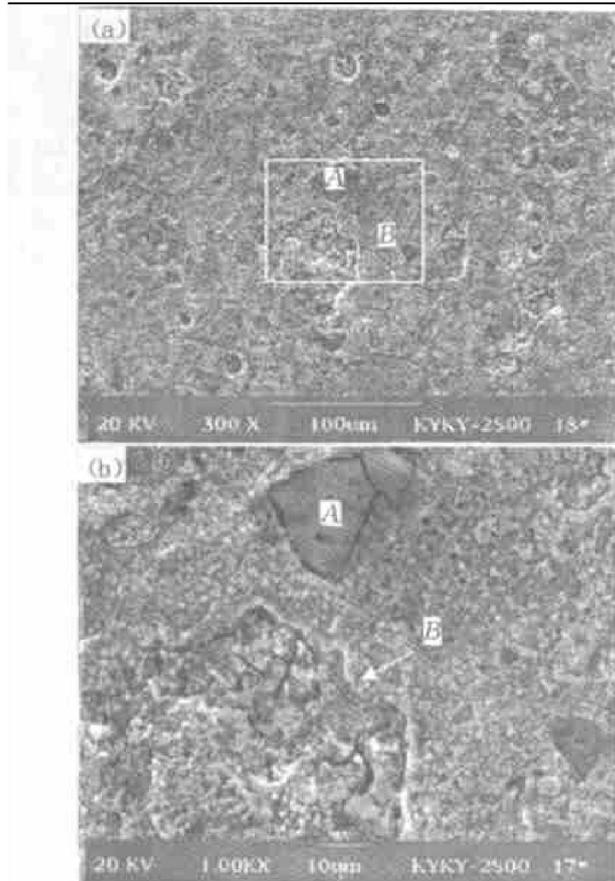


**Fig. 4** SEM micrograph of wear surface of 45 steel under 30 N

With the increase of load, the change of surface character of material is aroused because of friction thermal effect. Fig. 5 is the SEM micrographs of wear surface of MoSi<sub>2</sub> under 80 N. Fig. 5(b) is the magnifying area of the pane in Fig. 5(a). The formation of black blocks is shown on the surface of MoSi<sub>2</sub>, which can be proved to be a rich Si phase by micro-probe (see Table 1). The [Si] decomposed from silicide is very active. It combines easily with oxygen to form SiO<sub>2</sub>. According to the results reported in Ref. [14, 15], SiO<sub>2</sub> exists in a amorphous solid at room temperature, which improves the frictional contact statue and reduces the contact between fresh surfaces of MoSi<sub>2</sub> and 45 steel. Therefore, the friction coefficient decreases, as shown in Fig. 1. The high wear rate of MoSi<sub>2</sub> material can be attributed to as follows: first, the low combining strength between SiO<sub>2</sub>

**Table 1** Results of electron microprobe analysis (%)

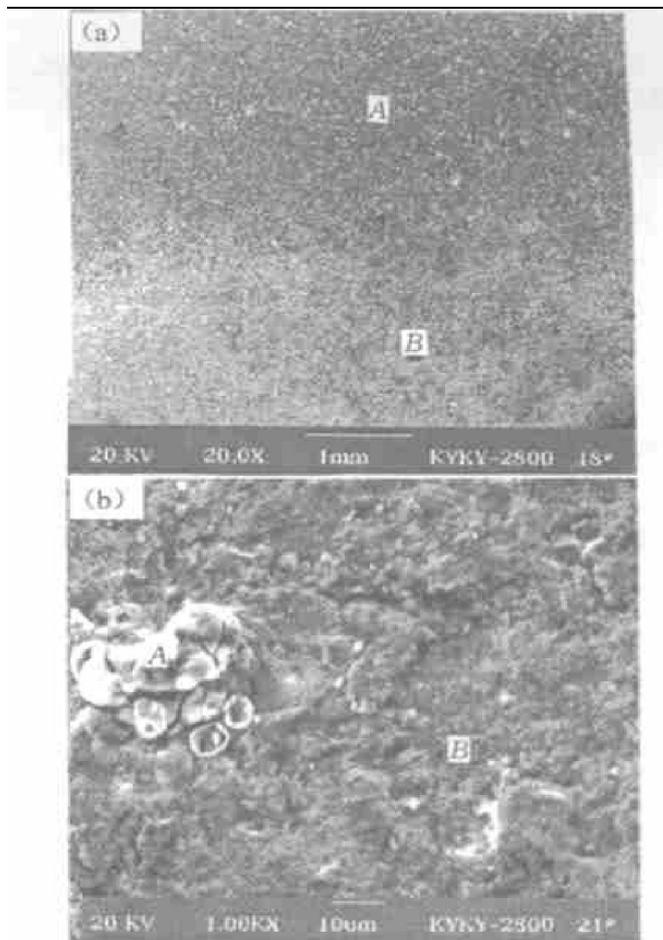
Area	$x(\text{Mo})$	$x(\text{Si})$	$x(\text{Fe})$	$x(\text{O})$
A dot in Fig. 5(b)	3.22	96.78		
A dot in Fig. 6(a)	2.72	6.07	91.21	
A dot in Fig. 6(b)			40.00	60.00



**Fig. 5** SEM micrographs of wear surface of MoSi<sub>2</sub> at 80 N

and the matrix makes SiO<sub>2</sub> easily drop from the surface of the matrix (see Fig. 5(a)); second, with the increase of load, the cycle stress rising arouses the buds of crack in inferior surface, as shown B in Fig. 5(b), and when crack develops to surface, the surface material of MoSi<sub>2</sub> will wear out because of fatigue; third, dropping oxide and MoSi<sub>2</sub> granule may be the crocus to accelerate the abrasive wear of MoSi<sub>2</sub><sup>[12]</sup>.

When load is raised to 120 N, the silver-white bright strip is formed on the surface of MoSi<sub>2</sub> (Fig. 6(a)). The A zone is proved to be the rich Fe phase by microprobe. This indicates the part-adherence occurring. The reason is that 45 steel material on the part contact peak is transformed to MoSi<sub>2</sub> material surface because of weld at instantaneous high-temperature under high stress. By the collective action of adherence and the mutual insert of micro-bulge, the friction coefficient increases again and the wear rate of MoSi<sub>2</sub> decreases. Fig. 6(b) is the SEM



**Fig. 6** SEM micrographs of wear surface of MoSi<sub>2</sub> at 120 N (a) and 45 steel at 150 N (b)

micrograph of 45 steel surface under 150 N. Tearing mark (B) and Fe<sub>2</sub>O<sub>3</sub> oxide (A) can be obviously found. This indicates that with the load increasing, the temperature of friction surface increases, which is beneficial to decreasing shearing strength and mutual inset effect and forming oxide. All of these make the friction coefficient reduce<sup>[16]</sup>.

### 5 CONCLUSIONS

1) The dry friction and wear properties are deeply affected by loads. The wear rate of MoSi<sub>2</sub> under 80 N is the maximum, which is 36.1 μg/m. On the condition of 150 N, MoSi<sub>2</sub> material has the better friction and wear properties: friction coefficient is 0.28 and wear rate is 10.6 μg/m.

2) With the load increasing, the main friction mechanisms change from microslip and plastic deformation to adhesive effect, and the main wear mechanisms change from plough-groove wear and oxidation-fatigue wear to adhesive wear.

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