

# Technology of self-repairing and reinforcement of metal worn surface

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**Abstract** Researches on self-repairing material (serpentine phyllosilicate) of our team in the past few years, such as ultrafining treatment, surface modification, self-repairing mechanism, the effect of rare metal on the self-repairing performance of serpentine, were introduced summarily. The phyllosilicate of serpentine shows excellent tribological and self-repairing performance for metal worn surface as additive in lubricant.

**Keywords** Self-repairing performance · Self-repairing mechanism · Serpentine

## 1 Introduction

Friction and wear, as one of the main causes of materials failure, has attracted more and more attention all over the world [1, 2]. In recent years, micro-nano scale phyllosilicate composition (the main component is serpentine) developed by Russian researchers exposed favorable self-repairing performance at practical application [3]. Jin et al. [4] studied the tribological performance of serpentine by using the serpentine additive in diesel engine of locomotive, and the results indicated that certain thickness of self-repairing protective layer can be formed on the iron worn surface. Moreover, the self-repairing protective layer possesses

lower surface roughness, higher microhardness and very low frictional coefficient. Zhang et al. [5] indicated that the tribological performance of metallic tribo-couples was improved and the friction temperature was reduced by adding micro-nano scale natural serpentine powder (SP) into base oil. The self-repairing technology for the metal worn surface of mechanical equipments under the running conditions, by using lubricating oil as carrier to transport the micro-nano scale into the interface of tribo-couples, could accelerate the formation of self-repairing protective layer with a dynamical thickness on the worn surface. Thereby, the formation of self-repairing protective layer on worn surface could reduce worn and prolong remarkably the service life of equipments [2]. It is notable that there are numerous research reports on the tribological performance of phyllosilicate self-repairing material, but the self-repairing mechanism in the frictional course did not get to a common view.

Our research team has been hammering at research works about serpentine (a kind of phyllosilicate) in the past few years, such as surface modification, tribological properties, self-repairing mechanism, and so on. In this paper, some research work was introduced summarily.

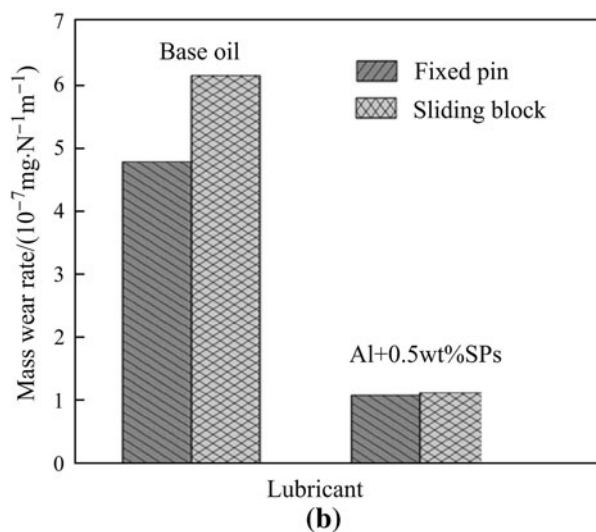
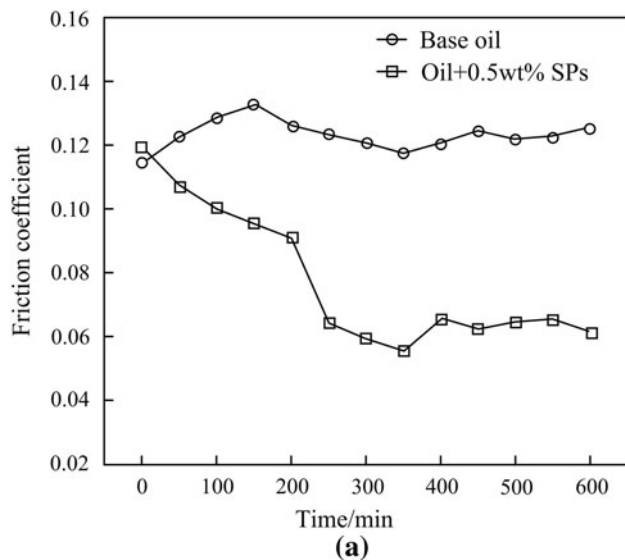
## 2 Experimental

Friction and wear tests were performed on a RFT-III tribometer with a pin-on-block configuration at room temperature [6, 7]. The upper sample was a pin with a diameter of 8 mm and a height of 30 mm, and the lower sample was sectioned into 70 nm × 14 nm × 14 nm block. The pin makes oscillating movement (50 mm in amplitude) on the top of block. Both pin and block were made of 45# steel. The tribological tests were conducted with a load of 50 N and a sliding speed of 1.0 m/s. All the specimens were ultrasonically cleaned in an

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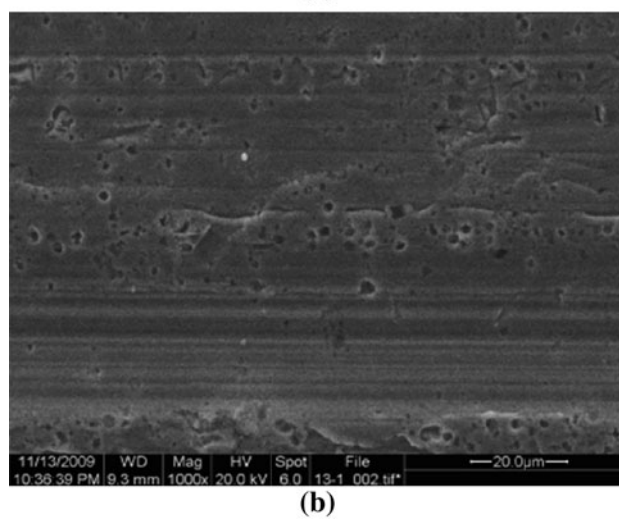
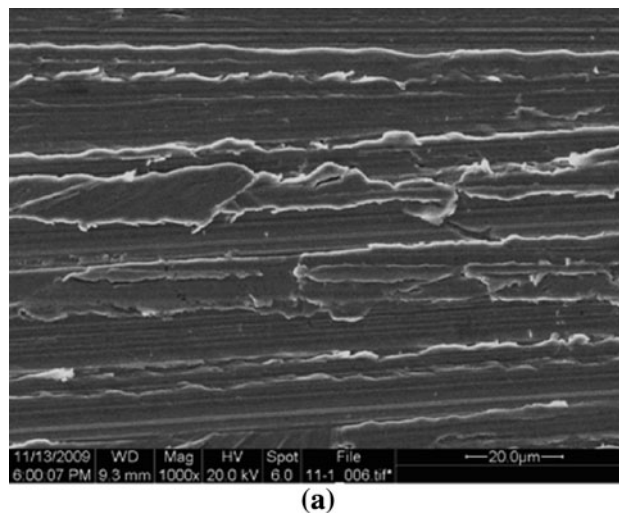
**Fig. 1** **a** Friction coefficient and **b** wear rate of lubricant oil with and without addition of serpentine powder [7]

acetone bath prior to the tribological tests. A MicroXAM 3D profiler was used to measure the worn volumes of the disks after friction and wear testing. All wear rates were calculated based on the worn volumes and the sliding distance. The morphology and composition of worn surfaces were investigated by using scanning electron microscopy (SEM), X-ray energy dispersive spectroscopy (EDS), laser Raman spectroscopy and X-ray photoelectron spectroscopy (XPS).

### 3 Results and discussion

#### 3.1 Tribological properties

The tribological properties of serpentine powder as additive in lubricant oil was investigated. The result shows that

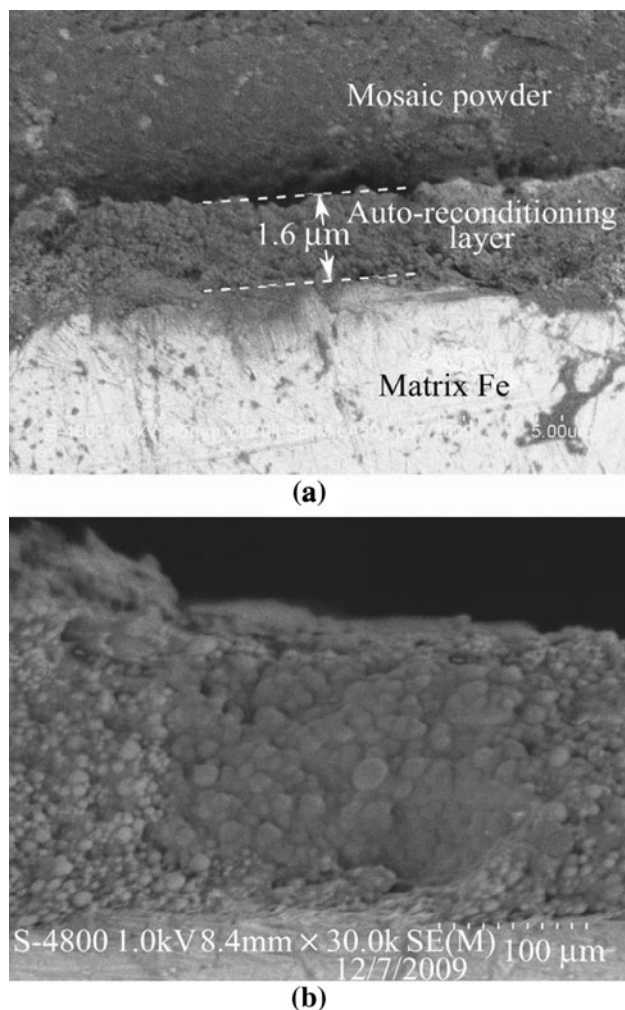


**Fig. 2** Micrograph of worn surface lubricated in **a** base oil, and **b** oil including serpentine powder [7]

the tribological properties of base oil can be remarkably improved by addition of serpentine powder under different sliding conditions [6–12]. Figure 1 shows the tribological properties of lubricant oil before and after addition of serpentine powder [8]. Compared with base oil, friction coefficient of lubricant oil containing 0.5 % serpentine powder by weight was reduced to one-half (see Fig. 1a), and wear rate was reduced by 80 % (see Fig. 1b).

#### 3.2 Self-repairing layer on worn surface

Figure 2 shows the SEM morphologies of worn surface under lubricating condition of base oil and oil including serpentine powder [8]. The typical characteristics of abrasive wear and plastic deformation were exhibited on worn surface in base oil, as shown in Fig. 2a. After adding serpentine powder in base oil, a smooth surface morphology is presented on worn surface shown in Fig. 2b. Moreover,



**Fig. 3** SEM photograph of cross section of worn block surface under lubricating condition of base oil containing serpentine powder [6]

many black dots could be observed on the worn surface. The non-black areas around black dots are analyzed to be made from the elements of C, O, Fe, and Si by using EDS. There is higher content of element Si on black dot area than non-black area.

The SEM photographs of cross section of worn block surface under lubricating condition of base oil containing serpentine powder are shown in Fig. 3 [6]. Upper black mosaic powder, middle auto-reconditioning layer (self-repairing layer) and lower matrix Fe can be observed in Fig. 3a, and the thickness of self-repairing layer is about 1.6  $\mu\text{m}$ . The self-repairing layer was made of an amount of nano-scale particles with different particle sizes (60–180 nm), as shown in Fig. 3b. The self-repairing layer was compacted closely on matrix Fe, which means that there might be a transition layer for structure and composition on the interface between the self-repairing layer and matrix Fe.

The composition of self-repairing layer on worn surface was characterized by using EDS, laser Raman spectroscopy and XPS [6]. The results show that the self-repairing layer was made of Fe,  $\text{Fe}_2\text{O}_3$ , non-crystalline graphite, organic fragment, silicon organic substance and  $\text{SiO}_2$ . The non-crystalline graphite was due to the fracture of carbon chains of lubricant oil, and could reduce friction coefficient of tribo-couples.  $\text{Fe}_2\text{O}_3$  was the oxide of matrix Fe. Organic fragment, silicon organic substance and  $\text{SiO}_2$  might come from decomposition production or secondary reaction production of natural serpentine powder.

By addition of natural serpentine powder in lubricant oil, a self-repairing layer with a certain thickness could be formed on iron worn surface under certain tribological conditions. Due to the formation of self-repairing layer on worn surface, friction coefficient and wear rate of working parts could be decreased obviously. So the service life of machines could be prolonged effectively by using the dynamic self-repairing technology.

#### 4 Conclusions

Serpentine powder as additive in lubricant oil shows the excellent tribological properties and self-repairing performance for metal tribo-couples. The technology of self-repairing and reinforcement of metal worn surface had been used widely in friction fields of gear-box, bearing, gear driving parts, engine. The service life of these mechanical equipments could be prolonged remarkably. However, the self-repairing mechanism of serpentine had not been clear and needs to be studied in further.

In the future research work, the following aspects need to be noticed: (i) self-repairing mechanism of serpentine, (ii) the online detection of worn surface in the sliding process, and (iii) effect of rare earth metal on self-repairing performance of phyllosilicate serpentine.

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