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Effect of natural attapulgite powders as lubrication additive on the friction and wear performance of a steel tribo-pair

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ABSTRACT

Tribological properties of the surface-modified attapulgite powders as additive to lubricating oil for mated steel contact were investigated. The results indicated that the attapulgite powders exhibit good performance in reducing wear and friction coefficient. Such effect can be attributed to the formation of a smooth and compact tribo-film composed of multiple oxides on the worn surface.

1. Introduction

Abrasion induced by friction, as one of the main causes of materials failure, has caused huge pecuniary loss each year all over the world. During the last few years, nanomaterials have attracted great attention in tribology. Some researches have reported that plentiful of nanoparticles, such as elementary substance [1,2], metallic oxide [3], metallic sulfide [4], borate [5], carbonate [6], rare-earth compound [7,8] and macromolecular compound [9] can be used as lubricating additives to reduce friction and wear. Recent researches indicate that phyllosilicate mineral powders can improve the tribological properties of lubricating oil, such as serpentine and attapulgite. It is founded that the oils containing serpentine powders exhibit excellent friction reducing and anti-wear properties. This excellent tribological performance is attributed to the formation of a multi-apertured oxide tribo-film with excellent mechanical properties on the worn surface [10,11]. As another phyllosilicate mineral powders, attapulgite has a structure similar to that of serpentine. But the cost of attapulgite is much lower than serpentine. Some researches indicate that attapulgite can also decrease friction coefficient and wear loss of carbon steel friction couples [12,13]. So it is reasonable to confirm that attapulgite powders may be a potential lubricant additive for mechanical components. However, the mechanism that how attapulgite powders present friction reducing and anti-wear properties have not been penetratingly analyzed. In the study reported here, an Optimal SRV oscillating friction and wear tester was used to investigate the tribological properties of the natural attapulgite nanoparticles as lubricant additive. The tribo-film formed on the worn surfaces were characterized to disclose the friction reducing and anti-wear mechanism.

2. Materials and methods

2.1. Materials

The attapulgite powders (AP) were purchased from Jiuchuan Scientific and Technical Corporation (Jiangsu Province, China). Table 1 shows the chemical composition of AP, which indicated that the attapulgite is a kind of silicate composed of some oxide. The X-ray pattern of the attapulgite powders shown in Fig. 1 indicates that the chemical formula of the AP is $(Mg,Al,Fe)_5Si_8O_{20}(OH_2)_4{\cdot}4H_2O$ (JCPDS No. 21-0957). A few attapulgite powders were added into alcohol and then dispersed by ultrasonic to prepare suspension. Then a little suspension was dropped onto copper mesh and observed by TEM to get the microstructure of AP. The TEM morphology of the AP is shown in Fig. 2. It can be seen that the AP keeps a fibrous shape mostly with 1 μm in length and 50 nm in width. The mineral lubricating oil (150SN) was employed as the

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Table 1
Chemical composition of attapulgite.

Component	Content (wt%)
SiO_2	58.88
MgO	12.10
Al_2O_3	9.50
Fe_2O_3	5.20
K_2O	1.04
CaO	0.4
TiO_2	0.55
P_2O_5	0.18
MnO	0.05
Cr_2O_3	0.04
H_2O	12.06

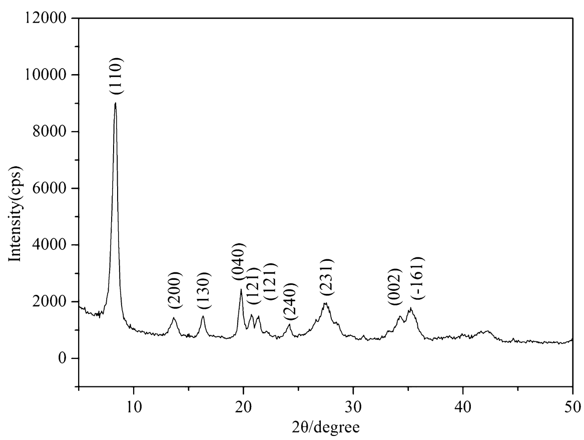

Fig. 1. XRD pattern of the attapulgite powders.

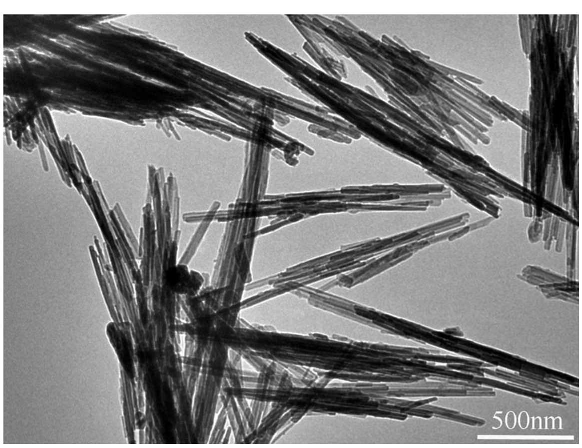

Fig. 2. TEM micrographs of the attapulgite powders.

base lubricant with basic physicochemical properties presented in Table 2 and chemical constituent shown in Table 3. In order to obtain good dispersity in the oil, the AP was modified with a 5.0 wt% oleic acid (percent of AP).

Table 3
Chemical composition of 150SN.

Base oil	Chemical constituent
150SN	Paraffin hydrocarbon
	Naphthenic hydrocarbon
	Alkyl naphthalene
	Alkyl benzene
	Polycyclic aromatic hydrocarbons
	Sulfide
	Nitride
	Oxide

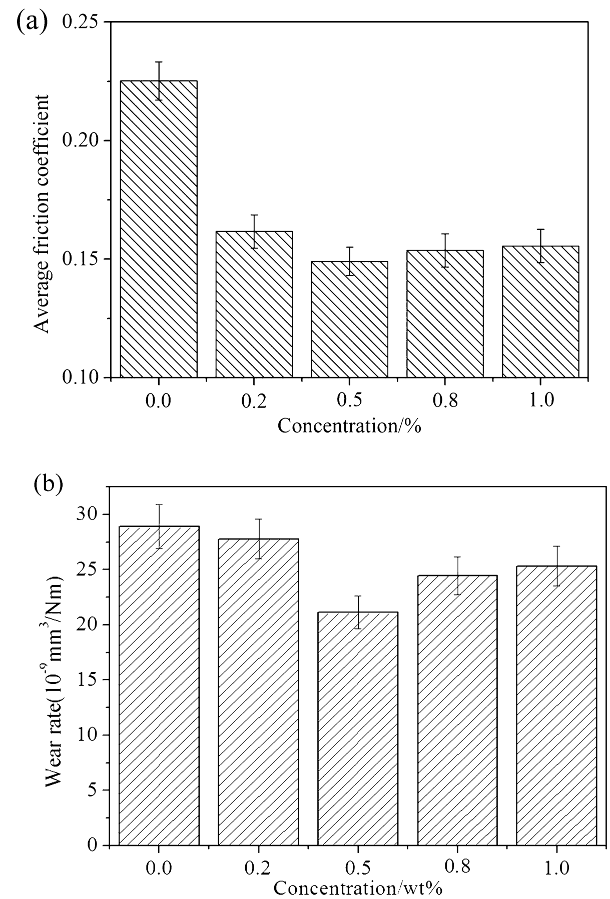

Fig. 3. Effect of AP concentration on (a) friction coefficient and (b) wear rate of the disk (50 N, 10 Hz, 30 min).

2.2. Friction and wear test

An Optimal SRV-IV oscillating friction and wear tester was used to evaluate the tribological properties of the lubricants. The upper ball, with a diameter 10 mm, was made of AISI 52100 steel (hardness 59–62 HRC). In all the tests, the ball slides reciprocally at an amplitude of 1 mm and a frequency of 10 Hz against the stationary disks (AISI 1045 steel, hardness 27–30 HRC) for 30 min. The chemical compositions of the ball and disk are shown in Table 4. Each test was repeated 3 times to minimize data scatter. The friction coefficient was recorded by a computer connected to the SRV

Table 2
Typical physicochemical properties of the lubricating oil.

	Item value (ASTM)				
	Density ($g\,cm^{-3}$)	Kinematic viscosity ($mm^2\,s^{-1}$)	Viscosity index	Pour point (°C)	Flash point (°C)
150SN	0.877	5.32, 100 °C/31.7, 40 °C	118	−15.5	220