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The tribological performances of modified magnesium silicate hydroxide as lubricant additive

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ABSTRACT

Modified magnesium silicate hydroxide (MSH) was synthesized by hydrothermal method with magnesium oxide and silica as raw materials, and oleic acid (OA) as the modified agent. The tribological properties of MSH as lubricant additive were studied by the four-ball tests. The tests results show that the MSH-containing oil exhibits better anti-wear properties than the base oil, with the highest rate of wear reduction reaching 55%. In addition, different test conditions, such as load and rotation speed, have an influence on the anti-wear properties of MSH. It is assumed that both physical effects and tribochemistry reactions could contribute to the anti-wear properties of MSH.

1. Introduction

As the main anti-wear additive in engine oils, Zinc Dialkyl Dithiophosphate (ZDDP) has been invented 70 years ago and once was seen as the most successful lubricant [1]. With the development of technology, people have higher expectations for the anti-wear additive. They hope that it can be applied under more severe working conditions, and have a better performance in anti-wear. Meanwhile, it should not pollute the environment. Against this background, ZDDP is faced with a series of challenges. For example, the anti-wear performance of ZDDP in some severe conditions including the high pressure (over 90 MPa) and the high temperature (over 200 °C) is negligible [2]. Besides, with the encouragement of clean and environmentally friendly additives, ZDDP is constantly being replaced because of its environmental hazards. The researchers turn to more clean and efficient anti-wear additives [3,4].

The focus of our research is on the anti-wear properties of MSH which is the main component of serpentine mineral. Serpentine, as a natural mineral, has been widely studied since it was found to be used as lubricant additive. For example, Qi [5,6] dispersed serpentine nano-powders into the LAN46 mineral oil to test its tribological performances. The test showed that a self-heal protect layer was formed on the worn surface at 400 °C. Yu [7–9] dispersed the surface-modified serpentine ultrafine powders into liquid paraffin, engine oil and mineral base oil. The results showed that a multi-apertured oxide layer was formed on the worn surface, which presented excellent tribological performance. However, the complex composition of natural minerals brings difficulties to explain its specific anti-wear mechanism. As the main component of serpentine, MSH is synthesized and used as the lubricant additive, which is of great significance. Currently, MSH is synthesized mainly by hydrothermal methods. For example, in a neutral environment, Huang [10] synthesized the MSH nanotubes with the use of MgO and SiO_2. Jancar [11] used $Mg(OH)_2$ and SiO_2 to synthesize MSH nanotubes and they also clarified the reaction parameters' effect on the diameter and length of MSH nanotubes. Besides the hydrothermal method, other methods were also used to prepare MSH nano-powders. Fei [12,13] used MgO and SiO_2 at room temperature to synthesize MSH and studied the effect of reaction activity and concentration of raw materials on the hydration process.

Although the synthesis is widely studied, there are not many researchers that study the tribological performances of synthetic MSH used as lubricant additive. Chang [14] studied the diamond-like carbon (DLC) films formed on the worn surface with the addition of synthetic MSH nanoparticles, which showed excellent tribological performances. In our earlier studies, it was found that when magnesium oxide and silica were used to synthesize MSH, magnesium hydroxide impurities were generated under certain conditions. The addition of OA during synthesis would inhibit the formation of magnesium hydroxide impurities. Explanations for this mechanism involved are in progress. In this work, we add OA as the modified agent in the synthetic process to prepare the modified MSH and mainly study the tribological performances of modified MSH as lubricant additive under different experimental conditions, such as load

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Table 1
Physical properties of the PAO base oil.

Property	PAO 10
Dynamic viscosity 100 °C (mm^2/s)	10.12
Dynamic viscosity 40 °C (mm^2/s)	68.1
Viscosity index (VI)	133
Pour point (°C)	−45
Open flash point (°C)	260

and rotation speed. The paper is organized as follows: Section 2 describes the experiments including samples preparation and tribological tests. In Section 3, we describe MSH characterization, results of tribological test etc. The results are discussed in Section 4 followed by conclusions in Section 5.

2. Experiment

2.1. Samples preparation

We blended MgO and SiO_2 with a special ratio (mass ratio, 1:1) into distilled water. After that, 0.63 wt% OA as the modified agent was added to the mixture. Finally, the pH of the mixture was adjusted to 13 by NaOH titration solution. The mixture was put into the reactor and heated to 200 °C for 12 h. The stirring speed was kept at 450 r/min. After completion of the reaction, the resulting product was washed with deionized water and dried in a drying oven at 80 °C, then MSH powders were prepared.

The morphologies of synthetic MSH nanoparticles were characterized by scanning electron microscopy (SEM). X-ray diffraction (XRD) patterns showed the composition of MSH.

We chose the poly-alpha-olefin (PAO) oil [16] as the base oil. The physical properties of the PAO base oil were listed in Table 1. The MSH powders were added into ploy-alpha-olefin (PAO) at a specific ratio (1 wt %), meanwhile, 4 wt % organic dispersant was added for the sake of improving the powders' stability in oil. After that, we stirred and ultrasonically vibrated the mixture for 20 min to obtain uniformly dispersed oil samples.

2.2. Test and characterization

The tribological properties of MSH as lubricant additive are tested by MRS-10A four-ball machine. The schematic diagram of four-ball machine friction test is shown in Fig. 1. Four-ball machine friction test means that the three standard steel balls under the test head are fixed as bearing parts, which are submerged in the lubricating oil. The load is applied to the standard steel balls below by the hydraulic transmission and the ball above rotates with a given speed. Upon completion of the test, wear scar appears on the contact areas of the fixed steel ball below. We measure the wear scar diameter of the three fixed balls and take the average as the test result. In our studies, tribological tests are carried out at room temperature for 2 h. The load is set to 200 N, 300 N, 400 N, 500 N and 600 N, respectively, corresponding to the maximum Hertz contact stress 2.77, 3.17, 3.49, 3.76 and 3.99 GPa. We set the experimental speed to 400RPM, 600RPM and 800RPM, corresponding to linear speed 0.153, 0.230 and 0.307 m/s. The test ball is E52100 (ASTM/AISI) with a diameter of 12.7 mm and a hardness of 62 ~ 64 HRC. In order to ensure the reliability of the test, each test is repeated three times, and the average value is taken as the final result. After the test, the morphologies and elements of the worn surfaces are characterized and analyzed by SEM and Energy Dispersive X-Ray Spectroscopy (EDS).

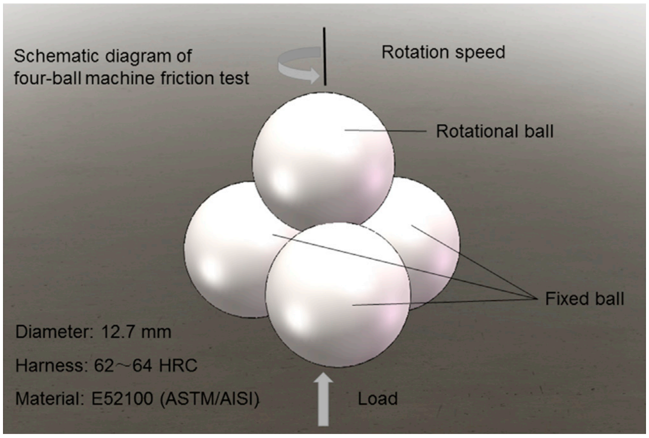

Fig. 1. Schematic diagram of four-ball machine friction test.

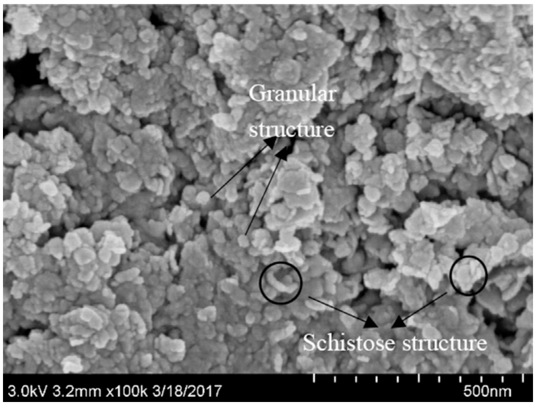

Fig. 2. SEM image of MSH nanoparticles.

3. Results

3.1. MSH characterization

The morphology of MSH nanoparticles is shown in Fig. 2. It can be seen that the synthesized nanoparticles exhibit different morphologies, mainly in the form of granular structure, and the size is between 50 nm and 100 nm. In addition, there is a small amount of schistose structure whose thickness is about 25 nm. The diffraction pattern in Fig. 3 matches the PDF card 25–0645, which belongs to the chrysotile (a type of serpentine) [17]. From the XRD results, it can be found that all the peaks at 12.01°, 19.45°, 24.30°, 34.41°, 36.63° and 60.41° correspond to (002), (110), (004), (131), (202) and (029) planes which belongs to chrysotile crystal.

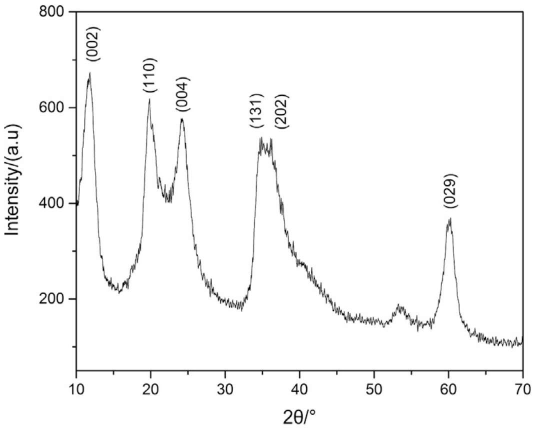

Fig. 3. XRD patterns of synthetic MSH.