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Influence of Morphologies of Synthetic Magnesium Silicate Hydroxide on Their Tribological Properties

TRACK OF CATEGORY

Tribochemistry

AUTHORS AND INSTITUTIONS

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INTRODUCTION

Magnesium silicate hydroxide (MSH) with an ideal formula of $Mg_3Si_2O_5(OH)_4$ is the main composition of serpentine-group minerals. Serpentine particles as additives to oil can form a self-healing tribofilm on the sliding surfaces and significantly reduce the friction and wear [1]. In recent years, with the extensive applications of nanomaterials in different fields, there have been many investigations on the tribological properties of lubricants with nanoparticles added [2]. However, nano-sized serpentine powders are scarcely prepared by high-energy mechanical ball-milling which is not suitable to the applications as lubricant additives and clarification of its tribological mechanisms. Synthesized MSH nanoparticles can solve this problem to a certain extent. However, in the existing literatures, only Chang et al [3] used synthetically-prepared lamellate MSH nanoparticles as the polyalphaolefin base oil (PAO) additives and found an amorphous DLC self-healing film containing SiO_x formed on the sliding surfaces.

The main goal of this work is to explore the tribological behaviors of synthetized MSH nanoparticles with different morphologies in a pure PAO oil.

MAIN BODY

1. Experimental and materials

Using MgO and SiO_2 as precursors, we synthesized MSH particles with different morphologies hydrothermally. The molar ration of the MgO/SiO_2 was 1.5. After the reaction finished, the products were washed with distilled water to PH=7-8 and dried at 80℃. Table 1 shows the hydrothermal conditions for MSH particles with different morphologies. Oil samples were prepared by adding 1wt% synthetic MSH particles and 2wt% oleic acid as a dispersant in PAO base oil with a viscosity of 32.4cSt at 40℃ (termed as oil+MSH1, oil+MSH2 and oil+MSH3). The concentration was optimized in previous studies.

Table 1 Hydrothermal conditions for MSH nanoparticles with different morphologies

Samples	Temperature/℃	Reaction time/h
MSH1	200	18
MSH2	200	42
MSH3	300	42

A four-ball friction and wear test machine (MRS-10A) was utilized to test the tribological properties of PAO suspended synthetic MSH particles. The ball samples of 12Cr with 57HRC hardness were used. The experimental conditions were: normal load 600N, rotational speed 600rpm, duration 2h at room temperature. Once the test was finished, the wear scar diameter of ball was measured using an optical microscope (accuracy is 0.01mm) and all sets of the experiment repeated three times.

2. Results and discussion

The X-Ray fluorescence spectrometer (XRF) results (Mg 26.868% and Si 25.126%) shows the chemical formula of synthetic MSH particles can be expressed as $Mg_{2.775}Si_{2.225}O_5(OH)_4$.

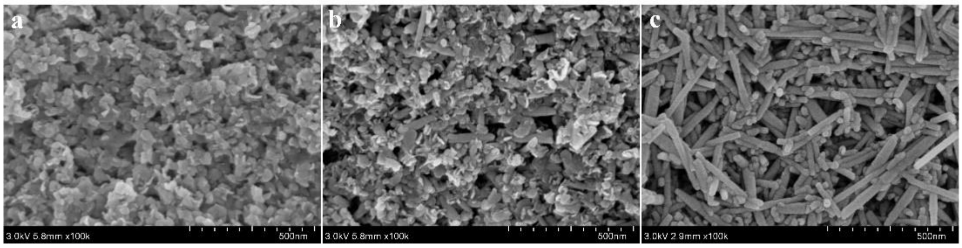

Fig.1 SEM images of the synthesized MSH particles (a) MSH1 (b) MSH2 (c) MSH3

The scanning electron microscopy (SEM) analysis were employed to investigate the morphologies of synthetic MSH particles. Fig. 1 (a) shows that MSH1 particles are lamellate and slightly curled with average lateral dimensions of approximately 50nm×10nm. With the increase of the reaction time to 42h, the MSH2 appears a great many of tubular particles with maximum length of 200nm and diameter of 50nm. Meanwhile there are also many flaky-like nanoparticles which are more evident curling than MSH2 particles. By controlling the hydrothermal-reaction temperature to 300℃, as can be seen form Fig. 2 (c), the MSH3 mainly consists of tubes/sticks with lengths of up to several hundred nanometers. Most of the tubes are straight and uniform throughout their diameter of approximately 30nm.

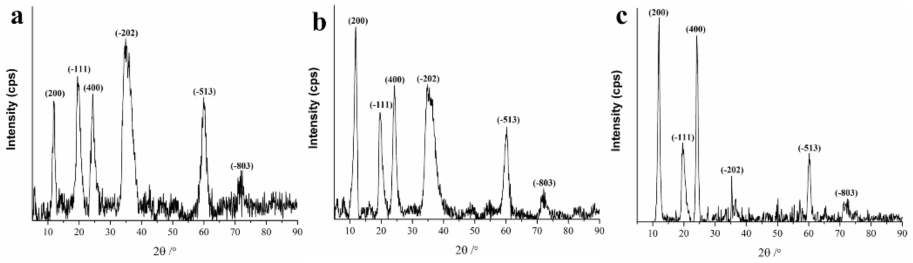

Fig.2 XRD spectra of the synthesized MSH particles with different morphologies (a) MSH1 (b) MSH2 (c) MSH3

Fig.2 shows the X-ray diffraction (XRD) spectra of the synthetic MSH1, MSH2 and MSH3 particles. The positons of the reflections in the XRD spectra of both synthetic three types of particles match well with serpentine minerals (PDF 02-0094). By increasing the hydrothermal reaction time to 42h and temperature to 300℃, some of the XRD reflections become sharper.

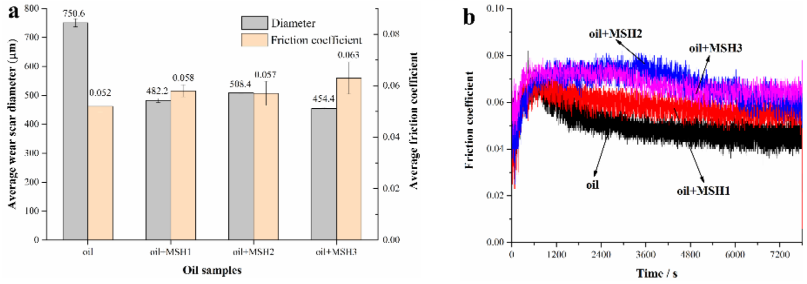

Fig. 3 Average wear scar diameter and coefficient of friction (COF) (a) and the evolution of COF (b) under different lubricating oil samples

Fig. 3 (a) shows the column charts of average wear scar diameter and coefficient of friction (COF) and Fig. 3 (b) shows the evolution of COF subjected to friction testing in four oil samples. Dispersing synthetic MSH1, MSH2 and MSH3 particles in oil all can significantly improve the anti-wear property of base oil and MSH3 particles as additives in PAO shows the smallest wear scar diameter. However, with the increase of tubular structure in particles, the value and stability of COF become worse.

Typical SEM morphologies of the worn surfaces lubricated with four different oil samples are shown in Fig. 4. The worn surfaces for pure oil have obvious scratches and furrows along the sliding direction indicating severe wear occurred on the contact surface at 600N for 2h. The furrows become shallow and less when adding synthetic MSH particles to oil. Meanwhile, a discontinuous black tribofilm forms on the iron substrate surface with the lubrication of oil+MSH2 and oil+MSH3. In addition, most areas of the worn surface in Fig. 4d are covered by dark tribofilm. This result is in accordance with the best anti-wear behaviors of oil containing MSH3 particles.

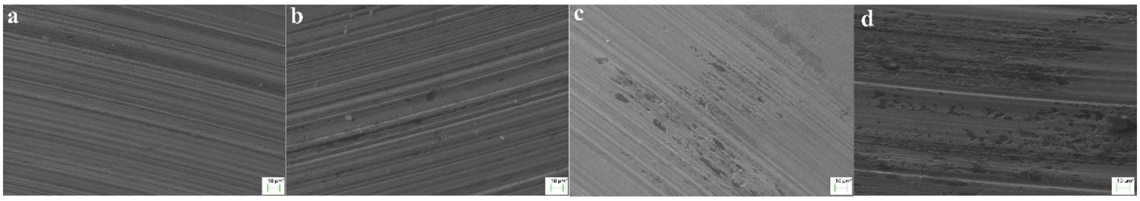

Fig. 4 SEM morphologies of the worn surfaces lubricated with (a) oil and (b) oil+MSH1 (c) oil+MSH2 (d) oil+MSH3

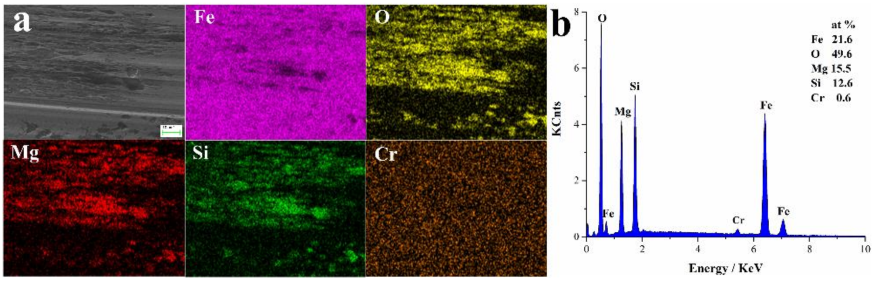

Fig. 5 EDS analysis of the worn surface shown in Fig. 4 (d) (lubricated with oil+MSH3 at a load of 600N for 2h) (a) enlarged SEM morphology and elemental distribution (b) EDS spectra from the dark region

Energy-dispersive X-ray spectroscopy (EDS) analyses have displayed that most areas of the worn surface are covered by a tribofilm containing O, Mg and Si. The synthetic MSH additive is a source for Mg and Si. The EDS spectra of the tribofilm (Fig. 5b) reveal that the molar rate between Mg and Si is 1.23 which is similar with that of synthetic MSH particles. These particles deposited and spread across the sliding surface under the combination of mechanical and thermal energy during the tribological test.

In conclusion, we tested the tribological properties of synthetic MSH nanoparticles with different morphologies as additives in PAO base oil. Results show that using synthetic MSH as additives can form a tribofilm on the sliding surface and significantly improve the tribological properties of oil. Synthetic MSH nanotubes have the best anti-wear properties due to they are more likely to deposit, adsorb and spread on the friction surface, and thus form a denser tribofilm.

ACKNOWLEDGMENTS

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REFERENCES

[1] Yu H, Xu Y, Shi P, Wang H, Wei M, Zhao K, et al. Microstructure, mechanical properties and tribological behavior of tribofilm generated from natural serpentine mineral powders as lubricant additive. Wear 2013;297:802–810. doi:10.1016/j.wear.2012.10.013.

[2] Gulzar M, Masjuki HH, Kalam MA, Varman M, Zulkifli NWM, Mufti RA, et al. Tribological performance of nanoparticles as lubricating oil additives. J Nanoparticle Res 2016;18:1–25. doi:10.1007/s11051-016-3537-4.

[3] Chang Q, Rudenko P, Miller DJ, Wen J, Berman D. Operando formation of an ultra-low friction boundary film from synthetic magnesium silicon hydroxide additive. Tribiology Internation 2017;110:35–40. doi:10.1016/j.tribological internation.2017.02.003.

KEYWORDS

Additives:Antiwear Additives, Wear:Wear Mechanisms, Friction:Friction Mechanisms