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Talc as friction reducing additive to lubricating oil

Pavlo Rudenko, Amit Bandyopadhyay*

School of Mechanical and Materials Engineering, Washington State University, Pullman, WA 99164, United States

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ABSTRACT

Reduction of friction and wear by colloidal suspensions of ceramic powders in lubricating oils is an approach that can allow to formulate environment friendly energy saving lubricants. Commercial talc powder was evaluated as an extreme pressure additive to a lubricating oil under different temperatures and concentrations. The best lubricity was achieved at the temperature of 100 °C and the concentration of 0.15 wt% when dynamic and static friction coefficients were reduced by over 30% in comparison to reference lubricating oil alone. At high temperature, talc forms transfer film on metal surface, which reduce both friction and wear behavior in mating surfaces. However, at room temperature, film formation was not observed. Results are explained using pressure and temperature induced lamellar dehydration mechanism when products of dehydration form oxide transfer films on the friction surface.

1. Introduction

One third of the energy produced via different techniques is lost due to friction [1]. Methods that minimize friction losses are of significant importance. Mineral or synthetic oil-based lubricants are the most popular solution to friction and wear related losses for many steady regime applications. Under optimal conditions, oils can significantly lower friction losses as well as minimize wear. To minimize losses, rubbing partners must be separated by a thin lubrication film and the speed of the mating parts must match the properties of the lubricating film. Under such condition, surface asperities become elastic, which is also called Elasto-Hydrodynamic Lubrication or EHL. Among many factors, the main parameter to achieve EHL is the viscosity of the lubricant. However, since many mechanisms work during dynamic operation of moving parts at a variable speed, the optimal regime may not always be achieved using lubricating oils alone. If elasto-hydrodynamic regime is not reached, then the surfaces will be in direct contact with each other during operation, which is commonly referred as the boundary lubrication (BL) regime. Under boundary lubrication regime, the reduction of wear can be accomplished via surface-interacting, extreme pressure (EP) additives. Chemisorption of EP additives to various surfaces followed by formation of molecular boundary layer is the most common process, which can then reduce wear behavior in materials [2].

For more than 50 years, the family of Zinc dialkyldithiophosphates commonly referred as ZDDP, were the most frequently used EP additives to reduce friction and wear behavior because they form a phosphate-based, glassy, protective film on the interacting surfaces. However, ZDDP have been phased out due to their poisoning effect to catalytic convertors in automotive applications as well as general environmental toxicity. The future of better wear-reducing additives has been suggested to follow two main routes: (i) a traditional route focusing on molecular liquid additives which interacts with surfaces chemically to form protective films, or (ii) a non-traditional route involving solid, nanoparticle-based additives that are present in the asperities regions to carry load and reduce friction and wear behaviors [3]. Concurrent with the recent shift to more environment-friendly technologies, interest in the application of nanopowders, including ceramics, in lubricating oils has grown. However such particles are still not widely employed due to a general lack of understanding about their behavior under frictional pressure.

The molybdenum disulfide (MoS_2) based composite grease which is used in constant velocity (CV) joints in front wheel drive cars probably is the most common ceramic additive used today [4]. However, when MoS_2 is oxidized, it forms a hard abrasive molybdenum oxide MoO_3 that is undesirable. Among other materials, graphite is also used frequently [5], which displays low adhesion to surfaces and easily gets removed from the interfaces. Moreover, lubricity of graphite also depends on adsorbed gases [6], which results in performance variation depending on application environment. With the reduction of powder size to a smaller scale, there are many new materials that display improved lubricating properties, although not being lubricants at the bulk scale or even in micron-scale. Such examples include nanodiamonds [7], carbon materials [8] or some nano-metals [9]. Several ceramic nano-powders have recently been tested as anti-wear and EP additives such as oxides

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* Corresponding author. Tel.: +1 509 335 4862.
E-mail address: amitband@wsu.edu (A. Bandyopadhyay).

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Table 1
O'Reilly 5w30 oil product specification (provided by manufacturer).

Parameter	Value
Specific Gravity (60 °F)	0.865
Viscosity, @ 40 °C, cSt	52.0–71
Viscosity, @ 100 °C	9.3–12
Viscosity index, min	150
Flash point, °C (°F), min	177 (350)
Pour point, °C (°F)	−29 (20)
Color	2.0–4.5

Table 2
Vantalc 6H-II chemical analysis data (provided by manufacturer).

Chemical analysis (calculated as oxides):	% by weight
Magnesium oxide (MgO)	31.5
Silicon dioxide (SiO_2) – by difference	61.4
Calcium oxide (CaO)	0.2
Aluminum oxide (Al_2O_3)	0.6
Ferric oxide (Fe_2O_3)	1.1
Sodium oxide (Na_2O)	<0.1
Loss on ignition (1000 °C)	5.2

[10], sulfides [3,11,12], and nitrides [13]. A general characteristic that has been observed is that an optimal concentrations exist where below which those nano-powders improve wear behavior however higher doses have the reverse effect [1,13].

In many cases, the cost of nanoparticle manufacturing is a limiting factor to their wider usage [14]. However, among the economically viable nanopowder additives, talc powder is commercially available as a filler for plastics. Talc ($Mg_3Si_4O_{10}(OH)_2$) is a 2:1 layered magnesium hydrosillicate that is composed of an octahedral magnesium hydroxide layer sandwiched between two tetrahedral layers of silica. Those layers are weakly bonded together, giving talc its remarkable softness under sheer deformation. Talc is the softest known mineral with a hardness of 1 on the Mohs' scale. It is already widely used in medicine [15] and plastics [16] and extensive testing has been done on its safety [17]. Moreover, specific properties of talc such as hydrophobicity, and inertness are also well established and beneficial in wet environment where corrosion can be a problem [18]. Talc has been known for centuries as a solid lubricant and was studied in that role extensively, but rarely as a part of an oil-based lubricating composition [19,20]. Due to its low environmental toxicity, talc can be used as a part of lubricating formulations with applications in total-lubrication-loss systems such as two-stroke engines and environmentally conscience systems such as farming as well as hydropower.

Conflicting results have been published about the ability of talc to form a transfer film during friction. Early publications did not observe talc adhering to the surface as a lubricant and the friction coefficient of a bulk dry solid powder increases rapidly due to an increase in temperature [21]. However, recent studies report excellent lubricity both at room temperature as well as at 150 °C [22]. In light of this disparity, we hypothesize that the interaction of talc with a surface is different under room temperature versus elevated temperature and that the main mechanism of this change is powder dehydration. An understanding of any temperature dependence will allow the formulation of additives for specific applications. The main objective of this study is to evaluate the tribological properties of talc powder as an environmentally friendly ceramic extreme pressure additive to lubricating oils.

2. Experimental procedure

2.1. Materials

A commercial mineral energy-conserving fully formulated engine oil (API SM grade 5W-30, O'Reilly, USA) was used as a base oil without further processing. The typical parameters of the oil provided by the manufacturer are listed in Table 1. To avoid batch to batch variations, oil for every test came from the same container.

To guarantee filter penetration in lubricating systems where the typical cutoff size is between 5 and 20 μm, we have to employ powder of the finest grind. One of the finest grinds of talc that is commercially available is Vantalc 6H-II (Vanderbilt, USA). Powder particle size distribution as determined by the manufacturer is as follows: LD20 200 nm LD50 1.0 μm LD90 2.5 μm. Manufacturer provided chemical composition is represented in Table 2 and technical parameters in Table 3.

A Siemens D500 Kristalloflex X-ray diffractometer using copper K_α radiation at 30 kV and 30 mA at the room temperature was used to determine phases in the powder with a Ni-filter over the 2Θ angle range between 5 ° and 40 °. A step size of 0.002° and a count time of 0.5 s were used for powder characterization. The powder was fixed on the observation glass with acetone and dried at the room temperature.

The surface area was measured using Brunauer, Emmett, and Teller (BET) surface area analysis (Tristar 3000, Micromeritics, Norcross, GA, USA). Before measuring the surface area, samples were dried in the sample holder at 200 °C for 2 h, in presence of flowing N_2. The particle size distribution was measured using a dynamic light scattering (DLS) particle size analyzer NICOMP 380 DLS (Particle Sizing Systems, FL, USA) using an ultrasonicated solution of particles in deionized water. Samples of powder and wear tracks were observed under a field-emission scanning electron microscope (FESEM), equipped with an secondary electron Everhart-Thornley Detector (ETD), in high vacuum at 30 kV acceleration voltage with no applied coating (FEI Inc., Hillsboro, OR, USA).

2.2. Wear and friction test

A reciprocating ball-on-plate wear-testing was performed on the tribopair using a tribometer (NANOVEA, Microphotonics Inc., CA, USA) with 3 mm diameter hardened chrome steel ball (100Cr6, 58Ð63 HRC) rubbing against the stainless steel test samples. 20 mm^2 wear test bottom samples were used. Before each test, all samples were cleaned with 99% isopropyl alcohol followed by 100% acetone to assure a clean surface as recommended by the ASTM133 (2010) Section 3. For other parameters, we have used ASTM 133 as guideline for performing tests except the parameters below. Wear tests were performed under a normal load of 5 N and at a sliding speed of 40 mm/s. This load gives mean Hetzian contact pressure of 0.75 GPa. Lubricating oil was applied in a temperature regulated bath. The oil level was chosen to cover samples completely but prevent splashing. Each experiment was run for a distance of 2000 m. Friction coefficient was measured with sampling rate of a 100 ms.

Table 3
Vantalc 6H-II typical technical properties (provided by manufacturer).

Parameter	Value
Density at 25 °C, mg/m^3	2.8
pH (ASTM D 1208)	9.4
G.E. brightness, (TAPPI T 646)	>91
325 mesh, %	Trace
Oil absorption (ASTM D 281)	55
Hegman fineness (3 lbs/gallon)	6
Einlehner abrasion loss, g/m^2	8
Moisture, %	<0.5
Median particle size Ð SediGraph 5100, μm	1.0
Bulk density, kg/m^3 (lbs/ft^3)	240 (15)