Nanofluid Applications in Tribology

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Summary

The friction and wear characteristics of nano fluids with Molydisulfide (MoS$_2$) nano particles was compared with fluids with different particle sizes (grades) of MoS$_2$. For further investigation of nano fluids, A. C. fine dust was included. Nano fluids were made by the suspension of nano MoS$_2$ in mineral oil, polyalphaolefin (PAO) and commercial engine oil at 1% concentration by weight.

Tribological performance of nano fluids and others was conducted with the modified Four-Ball Friction and Wear tester at 100 °C, 1200 RPM, 40 kg load for a duration of four hours for test. The higher than standard temperature is used to amplify the effect of the solid additives and the longer than standard test time is used to give us a better picture of the period after run-in or just how long the run-in period lasts. The friction will be monitored for the whole test period.

1. Introduction

Nanoparticles, copper (Cu), Iron (Fe), Molydisulfide (MoS$_2$), Tungsten disulfide (W$_2$S) and others are applied in several tribological fields with their superior performance as the lubricant additives. The environmental, health and safety (EHS) effects of nanoparticles are under study by the Environmental Protection Agency (EPA) and other organizations, such as suppliers and nanotechnology research centers worldwide. At the present time there are no adversarial reports on EHS of these nanoparticles on the applications in tribology.

MoS$_2$ is not only safe in EHS but also it’s HCP (Hexagonal closed pack) lamellar structure and excellent boundary lubricant characteristics lead to bountiful tribological applications.

Shen et al (1) and Para Kalita (2) applied nano MoS$_2$ for Minimum Quantity Lubrication (MQL) in grinding operation and made improvement of G ratio. Demydov et al (3) investigated the tribological performance of the hybrid of nano MoS$_2$ with borate and phosphate. It reduced friction and wear at the asperities contact zone and enabled strong tendency to adsorb on the surface of the Four-Ball tester. Tenne et al (4) studied tribological properties of Fullerene-like (IF) MoS$_2$ suspension in Polyalphaolefin (PAO) and tested using reciprocal ball on flat device for the tribological performance with great improvement of wear and friction.
2. **Objective**

This study pursued the tribological characteristics of nano fluids with MoS$_2$ nano particles by suspension in mineral oil, polyalphaolefin (PAO), and commercial engine oil by measuring the friction coefficients and wear scars with the modified Four-Ball, friction and wear tester (5).

Three different particle sizes of MoS$_2$, (technical grade, technical fine grade, superfine grade) and A. C. fine dust were included for further investigation of mechanism of tribological characteristics of nano fluids in the Four-Ball tester, elastohydradynamic lubrication, boundary lubrication or mixed lubrication of both.

Formations of tribofilms of Zindialkyl-dithiophosphate (ZDDP) and MoS$_2$ nano fluids on the surface of the bearing of the Four-Ball friction and wear tester were investigated along with different grades of MoS$_2$ fluids and A. C. fine dust fluids.

3. **Materials**

MoS$_2$ technical grade, technical fine, and superfine grades, MoS$_2$ nanoparticles, and A C fine dust were used for experiments. Their particle sizes are 25 micron for MoS$_2$ technical grade, 4.5 micron for MoS$_2$ technical fine grade, 1.2 micron for MoS$_2$ superfine, 50 nm for nano MoS$_2$ and 80 micron for A C fine dust. Mineral oil, PAO and engine oil were from commercial products.

For the preparation of nano fluids, 1.0 wt. % nano MoS$_2$ particles was suspended into mineral oil, PAO and commercial engine oil, respectively, by ultrasonic device.

The same preparation method was applied to the fluids of three other grades of MoS$_2$ (technical grade, technical fine and superfine grade) and A C fine dust.

ZDDP was added into mineral oil, PAO and commercial engine oil for pursuing the tribological performance of ZDDP itself and combinations of other fluids.

4. **Experimental procedure**

Tribological tests were conducted with the modified Four-Ball tester, Fig. (1, 2, 3) from the Ann Arbor Testing & Development, Inc. From this modified Four-Ball tester can be obtained not only the results of friction and wear but also oxidation stability, film strength of lubricant, residue condition and the presence of unstable and reactive components in the test fluids. The balls of 12.7 mm diameter were made of RHZ4 bearing steel 52,100. The testing procedure was adapted from ASTM D 2266 but modified as discussed below.

25 ml test sample was poured into the sample compartment, fully submerging the stationary balls under the applied load 40 kg (392 N), rotation speed of 1200 rpm, the machine was run for four hours at 100 °C.

The average friction coefficients were measured by using the load cell and the wear scars were measured by the optical microscope.

5. **Result and Discussion**

The results of the average wear scars and friction coefficients of nano MoS$_2$ fluid are listed in Table 1 and Fig 6.
It appears that nano MoS$_2$ does not improve much wear scar and/or friction coefficient in mineral oil, PAO and motor oil (Fig. 7).

5.1 Paraffinic Oil

Wear scar of mineral oil itself and MoS$_2$ nano fluid were 1.41 mm and 1.25 mm respectively. By adding 0.5 wt. % of ZDDP into mineral oil and MoS$_2$ nano fluid, wear scars were further reduced to 0.63 mm and 0.54 mm respectively.

The effects of other MoS$_2$ additives, such as technical, fine technical and superfine and nano grades are overshadowed by that of ZDDP. The wear scars of those fluids were not significantly different as shown in Fig. 8 and Table 1.

The fluid with A C find dust showed the highest wear scars even with the addition of ZDDP.

The friction coefficient of mineral oil itself and with nano MoS$_2$ were 0.122 and 0.125 respectively. The friction coefficients remained about the same by addition of ZDDP to mineral oil, but addition of other MoS$_2$ grades significantly reduced the coefficient except A C fine dust (Fig. 9).

Although the wear scar and friction coefficient of nano MoS$_2$ fluid were expected to be smaller than other MoS$_2$ grades, they were in the same range. Those of the A C fine dust showed much higher since it has larger particle size of 80 micron.

5.2 PAO

The wear scars of PAO itself and with MoS$_2$ nano fluid are not much different, 1.34 mm and 1.36 mm respectively. Addition of ZDDP into PAO significantly reduced the wear scar, and additional MoS$_2$ grades had minor effect on the wear scar (Table 1, Fig. 10).

A. C. fine dust had an antagonistic effect with ZDDP on the wear scars.

The friction coefficients of MoS$_2$ nano fluid were slightly lowered to 0.126 from 0.130 of PAO itself.

The friction coefficient of PAO is not significantly reduced by any grade of MoS$_2$ (Fig. 11).

5.3 GTX Motor Oil

The commercial motor oil itself already showed low wear scar and friction coefficient and additional additives of MoS$_2$ grades do not lower the scars and coefficients. A C fine dust rather increased the scars and coefficients (Fig. 12, 13 and Table 3).

It appears the commercial motor oil already contains sufficient anti-wear and anti-friction agents.

6. Conclusion

* Nano particles of MoS$_2$ are suspended in base oils longer in the fluid than technical grades MoS$_2$ as we expected.

* A C fine dust has higher wear scar and friction coefficient than MoS$_2$ fluids.

* MoS$_2$ nano fluid alone does not reduce
the wear scar and friction coefficient significantly.

* Addition of ZDDP in MoS$_2$ nano fluid in mineral oil reduced wear scars and average friction coefficient. Most of the cases ZDDP showed the synergetic effects of tribological performance of MoS$_2$.

* Commercial engine oils are not affected by the addition of ZDDP even with nano particles of MoS$_2$.

* There is no one to one correlation between wear scars and average friction coefficient.

* The modified Four-Ball tester is a good tool for screening the tribological performance of nano fluid, as well as macro one.

7. Future Work

* Pursue the mechanism of tribological phenomena of MoS$_2$ nano fluid with different particle sizes.

* Nano fluids applications such as MQL for reaming operations of aluminum parts.
<table>
<thead>
<tr>
<th>Base Oil</th>
<th>Add I</th>
<th>Solid</th>
<th>Wear Scar (mm)</th>
<th>Coefficient (Avg.)</th>
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<tbody>
<tr>
<td>CP150</td>
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<td>1.41</td>
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<td>CP150</td>
<td>E-102</td>
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<td>AC Fine Dust</td>
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Table 2. Durasy 170 (PAO)

<table>
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<tr>
<td>170</td>
<td>E102</td>
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<td>E102</td>
<td>n-MoS2</td>
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<td>170</td>
<td>E102</td>
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<td>170</td>
<td>E102</td>
<td>TFMoS2</td>
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<td>170</td>
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<td>170</td>
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<td>AC Fine Dust</td>
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<td>0.125</td>
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Table 3. 20W50 Castrol GTX Motor Oil

<table>
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<tr>
<th>Base Oil</th>
<th>Add I</th>
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<th>Wear Scar (mm)</th>
<th>Coefficient (Avg.)</th>
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<td>T-MoS2</td>
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<td>20W50</td>
<td>0</td>
<td>TFMoS2</td>
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<td>0.098</td>
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<tr>
<td>20W50</td>
<td>0</td>
<td>SF-MoS2</td>
<td>0.55</td>
<td>0.099</td>
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<tr>
<td>20W50</td>
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<td>AC Fine Dust</td>
<td>0.71</td>
<td>0.108</td>
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<tr>
<td>20W50</td>
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<td>ACF/TF MoS2</td>
<td>0.69</td>
<td>0.108</td>
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</table>

- E-102 – ZDDP from Elco Corp.
- n-MoS2 – Nanoparticle
- T-MoS2 – Technical grade
- TFMoS2 – Technical fine grade
- SFMoS2 – Super fine grade
- AC Fine Dust
References:


Figure 1. Four-Ball Test Arrangement

Figure 2. Four-Ball Tester

Standard  New AATD
Figure 3. AATD Four-Ball Tester

Figure 4. Four-Ball Test Result

Sample: T6V2
Test No.: 2293
Date: 5/29/99
Product Number: P6
R. Temp.: 70
F. Temp.: 5
R. Humidity: 50%

Sample Description: T6V2, 150x130x35 mm, Zeller 5500a, 5000 g, 1200 g.

Wear Track Diameter: 0.65 mm, Avg. Friction Coef.: 0.101, Std. Dev.: 0.001, Rel. Std. Dev.: 0.051

Wear Test Details:
- App. Volume: 85.7 x 0.0001
- App. Test Loading: 41.865 g
- Test Speed: 60 rpm
- Test Time: 30 minutes
- Test Temperature: 70°F
- Test Humidity: 50%

Wear Track:
- Wear Track of Rotating Ball
- After wiping with paper towel
- Wear Track right after testing
Figure 5. Four-Ball Test Result

Figure 6. Wear Scars
Figure 7 Friction Coefficient

Figure 8. 150 Paraffinic Oil
Figure 13. GTX Motor Oil

Friction Coefficient

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<tr>
<th>Condition</th>
<th>Friction Coefficient</th>
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<tr>
<td>acfineDust</td>
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<td>acf+HfMoS2</td>
<td>0.12</td>
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