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Combined Use of ZDDP and Organic Friction Modifier Leads to Lower Coefficient of Friction; A Study Using Atomic Force Microscope

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Tribological properties of Zinc dialkyldithiophosphates (ZDDP) and amine-based Organic Friction Modifiers (OFMs) along with the combination of these two additives were tested with Atomic Force Microscope (AFM). The results suggest that the coefficient of friction (COF) of OFM increased as the contact pressure rose. The results also suggest that although COF of OFM was lower than COF of ZDDP in low contact pressure range, it exceeded COF of ZDDP as contact pressure rose. Moreover, the combination of ZDDP and OFM shows a synergistic effect.

Keywords: combination use, ZDDP, oiliness additives, AFM, tribology

1. Introduction

ZDDP has been widely used in engine oil as an anti-wear, extreme-pressure additive. Recent years, the growing demand on fuel efficiency requires new engine oil formulations that are able to reduce friction loss while maintaining the anti-wear characteristics of ZDDP. Several studies suggested that the combination of ZDDP and proper organic friction modifiers (OFMs) are able to improve the friction behavior. [1][2] However, the interaction between ZDDP and OFMs during lubricating film formation and the nanotribological properties of the lubricating film formed is still unknown. Thus, in this study, we use AFM to observe the formation status of lubricating films during scratching while to measure the friction force of lubricating film.

2. Methods

2.1. Materials

Secondary ZDDP (R=C_4H_9, 700 ppm of phosphorus) in PAO, amine-based OFM (0.3 mass%) in PAO and the combination of ZDDP and OFM in PAO were tested in this study. Substrates used in this study were Fe film sputtered on silicon wafer.

2.2. Experimental procedure

Step1: [Material preparation] Drop lubricants on substrates 12 hours before test.

Step2: [Hertz pressure calculation] Measure the adhesion force in area A (as shown in Figure 1) with SiO_x colloidal probe AFM to determine hertz pressure during scratching and friction test. The approaching and releasing speeds were 200 nm·s^{-1}.

Step3: [Surface profiling] Surface profiling in Area C.

Step4: [Scratching] Scratch the substrate with colloidal probe AFM for 1 hour under 325 MPa in Area A. The sliding speed was 4 μm·s^{-1}.

Step5: [COF measurement] Measure the COF with colloidal probe AFM at 150MPa to 300 MPa every 25 MPa in Area B (containing Area A). The sliding speed was 10 μm·s^{-1}.

Step6: Repeat Step3 to Step5 for three times.

2.3. Results

The results are shown in Figure 2 where ZDDP-1 means the COF of ZDDP after 1-hour scratching. Combination of ZDDP and OFM showed the lowest COF among all lubricants. COF of OFM was lower than COF of ZDDP below 200 MPa, however, COF of OFM exceeded the COF of ZDDP above 225 MPa.

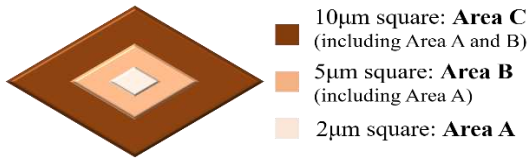

Figure 1: Test areas on substrates

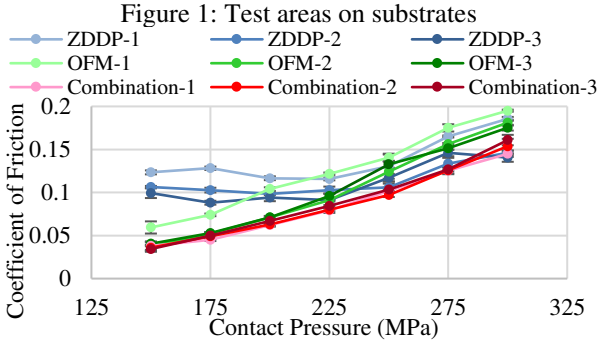

Figure 2: COF of ZDDP, OFM and Combination.

3. Discussion

The results show that OFM-1 was higher than OFM-2 and OFM-3 significantly, which indicates that one-hour scratching was not enough to form sufficient lubricating film for OFM. There is also a significant reduction in COF when OFM was combined with ZDDP compared with ZDDP only. The COF of ZDDP-OFM combination remained as low as COF of OFM in low contact pressure area, and lower than COF of ZDDP even when contact pressure rose, which indicates the synergistic effect of ZDDP-OFM combination. However, further study is necessary to investigate the adsorption state, tribo-chemical reaction during scratching and the mechanism of friction reduction of this combination.

4. References

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