Proceedings of Malaysian International Tribology Conference 2015, pp. 230-231, November 2015

Development of a versatile mechanical property testing platform

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Keywords: Lubricant; 4-ball test; Stribeck curve

ABSTRACT – Eco-friendly and bio-degradable lubricants and additives have gained tremendous attention in recent years due to sustainability awareness. Implementing green solutions for oil and lubricants has become mandatory due to high regulatory controls. To meet these requirements, extensive tribology tests are needed. Tribology tests usually need to mimic real situations in terms of load, speed and lubrication. However, current tribology tools are designed for a specific experiment only such as four-ball testing for lubricant; making it difficult for Tribologists to assess different aspects of an object under scrutiny without multiple testing tools. Other drawbacks include low usage of each tool, waste of lab space, tests cannot be done on the same location or same material, making it difficult to correlate different properties which is critical in understanding the mechanism behind. In this article, we report the development of a versatile testing platform which covers most standard tests ranging from lubricant, coating reliability, friction and wear on mechanical parts to tribology test under controlled environment such as temperature, gas and electrochemical environment.

1. INTRODUCTION

Reducing friction and wear, reducing use of lubricants or implementation of bio-based or biodegradable lubricants, environmentally friendly coatings and re-designing of engineering parts to minimize consumption and improve energy efficiency are all part of green tribology. In recent years, eco-friendly and bio-degradable lubricants and additives have become hot research topics. In these researches, extensive tribology tests are required. In general, tribology test needs to mimic the real situation, in terms of load, speed and lubrication, demanding the test instruments to be versatile and user configurable. The existing testing tools are usually designed for a specific experiment. To assess different properties of a test object, multiple testing tools are usually required, resulting in low usage of each test tool and challenging to achieve different tests on the same sample and same location. Different properties from the same sample are usually required in understanding the mechanism behind. This casts some shadow on traditional tribology testers.

In this article, we report the development of a versatile testing platform, which can cover most of the standard tests, ranging from lubricant, coating reliability, friction and wear on mechanical parts, tribology test under controlled environment, such as temperature, gas environment, electrochemical environment. In addition to the platform, new force sensing technique is also developed. With the new force sensor, the noise level is significantly reduced and the sensitivity is enhanced greatly. With the new force sensor, the platform's capability is extended beyond the traditional tribology test, such as sophisticated scratch test to measure thin film adhesion energy, indentation for micro/nano hardness test. In addition that multiple tests can be implemented on one platform, materials or lubricants required for the tests are greatly reduced, making the test itself environment friendly. On top of those, the platform allows user to program with high level language, this is important for sophisticated test or user tailored tests. In the meantime, multiple step tests can be implemented automatically, and work efficiency is improvement obviously compared with traditional tribology testers.

A series of experiments have been carried on the new versatile platform. In this article, we will report several application case studies, including Stribeck curve analysis on green lubricants, adhesion energy analysis of different coatings, micro/hardness on device surface, tribology test on bearing.

2. EXPERIMENTS AND RESULTS

2.1 *Force Sensor Performance Test*

To evaluate the noise level of new force sensor, we compared it with the traditional force sensor commonly used in tribology testers. Both sensors were installed into a Bruker Universal Mechanical Tester (UMT) and the outputs from the sensors were recorded by the UMT software. To make a direct comparison, the two sets of data were plotted with the same scale. The data were intentionally offset to avoid overlay. The noise level of the new force sensor is improved by 20 times.

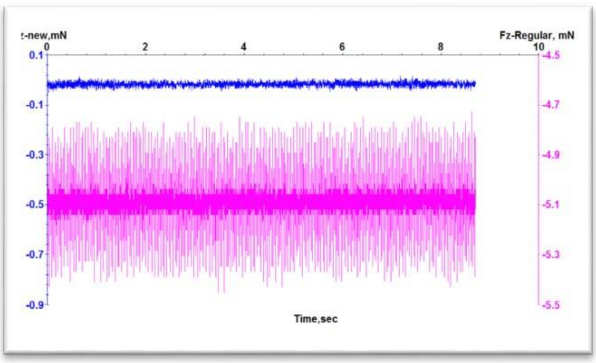

Figure 1 Comparison between the new force sensor and the traditional force sensor. The noise level is improved by 20 times.

2.2 *Tribotest on Soya Bean Oil (SBO) Based Lubricants*

In this experiment, 4 types of oil were measured, i.e. soya bean oil (SBO), modified soya bean oil A (MSBO-A), modified soya bean oil B (MSBO-B), and mineral oil. Two basic types of tribotests were conducted using a Bruker UMT. In the Four-Ball wear tests, three balls are fixed in a lubricant-filled cup and the forth ball is pressed against these, forming a tetrahedron. After one-hour relative rotation at 1200 rpm between the single ball and the three fixed balls, the wear scar diameters on each of the three balls are measured and averaged. The scar diameters provide a measure of wear resistance. The smaller the wear scar, the better the wear resistance. Tests were conducted at both 15 kg load and 40 kg load, as allowed by ASTM D-4172. The results are shown in Figure 2 for the 15 and 40 kg tests, respectively.

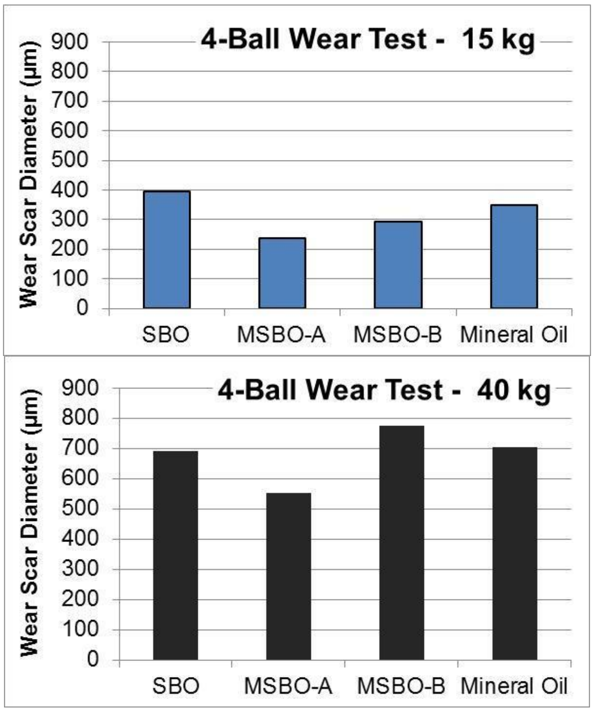

Figure 2 Wear scar diameter obtained from four-ball tests at two different loads.

The second type of Tribological characterization was the development of Stribeck Curves. In a Stribeck Curve experiment, a converging geometry is required which allows the lubricant to be pulled into the gap between the two surfaces, and the coefficient of friction (COF) is measured over the range of boundary, mixed film and fully hydrodynamic friction regimes. When the COF is plotted against the Hersey number (velocity x viscosity / load), the level of the boundary friction, the position of the "knee" in the curve showing the transition to full hydrodynamic lubrication and the level of the COF at higher Hersey numbers provides a measure of the shear-rate properties of the fluid. While any of or all three the variables can be changed to develop a Stribeck curve, in this work, the load was maintained constant and only the velocity was varied. A 10 mm diameter steel cylinder, 12 mm long was held on its side at an average radius of 20 mm and loaded in line contact against a rotating polished steel disk. The velocity was held for 20 seconds at each of 13 discreet levels from 15 rpm (0.03 m/s) up to 2,000 rpm (4.2 m/s). A constant load of 2 N was used for all tests. It was assumed that significant heating did not take place over the course of the test, and therefore the viscosity was assumed constant for these initial screening tests. As such the plot could be simplified to COF versus velocity. Figure 3 shows the average of five repeat runs for each of the four oils investigated in this work. While the knee in the curve is slightly higher (150 rpm vs. 90 rpm) it can be seen that the boundary friction level and hydrodynamic for MSBO-A and Mineral Oil are equivalent.

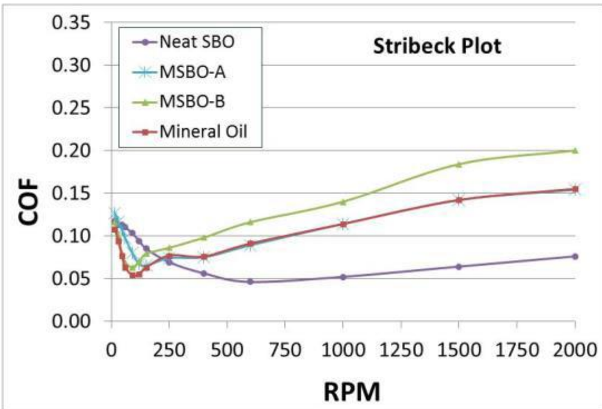

Figure 3 Stribeck curve for bio-based oils and mineral oil USP.

3. CONCLUSION

In this case study, the modified soya bean oil demonstrate good wear resistance with equivalent boundary and hydrodynamic friction as Mineral Oil. Modified SBO-A showed better properties for the use as a base stock oil as compared with both unmodified soya bean oil as well as unformulated Mineral Oil. Based on the results, it is expected that moderate formulation can be performed on modified soya bean oil to provide a viable, bio-based industrial lubricant for a variety of oil and grease applications.

This case study also demonstrate that Bruker UMT is a versatile platform capable in different tribology tests.