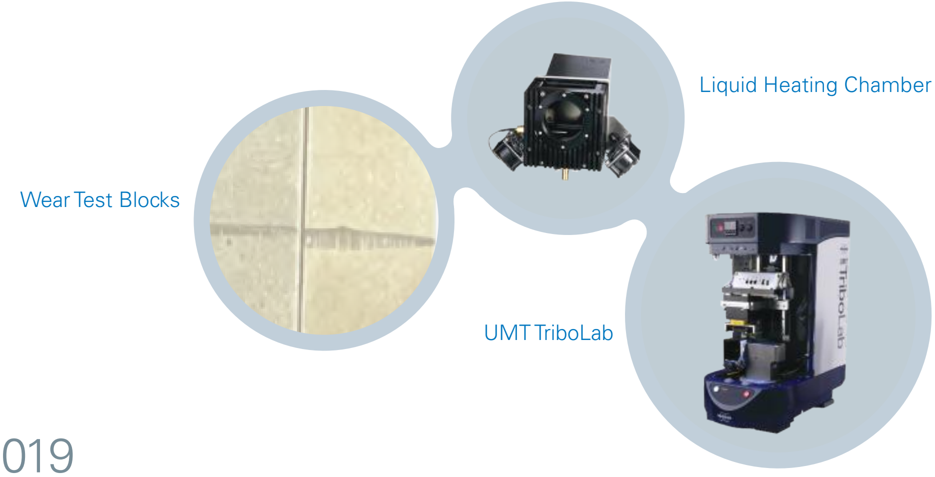

Application Note #1019

The Advantages of Precise Temperature Control for Block-on-Ring Lubricant Testing

A significant number of mechanical components function under lubricated conditions, where the primary role of the lubricant is the reduction of both friction and wear of sliding contacts. Variation of interfacial friction in a wide range of operating conditions affects the behavior and performance of the lubricant. Hence, it is critical that lubricant and machinery manufacturers understand the oil-surface interaction so that better selection of both lubricants and component materials can be made for different applications. This application note discusses the advantages that Bruker's liquid heating chamber provides for the block-on-ring tribosystem on the UMT TriboLab™. TriboLab's modularity offers the capability to simulate a wider range of field conditions to better evaluate the friction and wear characteristics of materials and lubricants in research and development, quality control, and application engineering.

Figure 1. UMT TriboLab Liquid Heating Chamber on Block-On-Ring Module.

Why a Liquid Heating Chamber

The addition of a liquid heating chamber to the tribosystem portfolio further enhances productivity in lubrication testing. Bruker's fully enclosed liquid heating chamber stores up to 170 mL, and is specially designed to prevent liquid spillage even during high-speed horizontal axis rotation (≤5000 rpm), on the TriboLab Block-On-Ring Module (see Figure 2a). As only a small amount of lubricant is needed to continuously supply sufficient lubrication for materials testing, chemical wastage can be reduced, thus promoting environmental sustainability. Elevated temperature testing is enabled with the chamber's direct-contact heat transfer between the heater and liquid via rapid and homogenous heating to the entire lubricant reservoir, from ambient to 150°C (see Figure 2b). The desired temperature set points, ramp rates, and test sequences can be easily programmed to simulate different real-world work conditions in material and lubrication testing. When used together with the TriboLab "Gold Series" linear-force sensors (1 mN to 2 kN load range), this block-on-ring system can be configured to enable an unprecedented breadth of wear testing. The rate of wear and/or total wear is easily calculated through

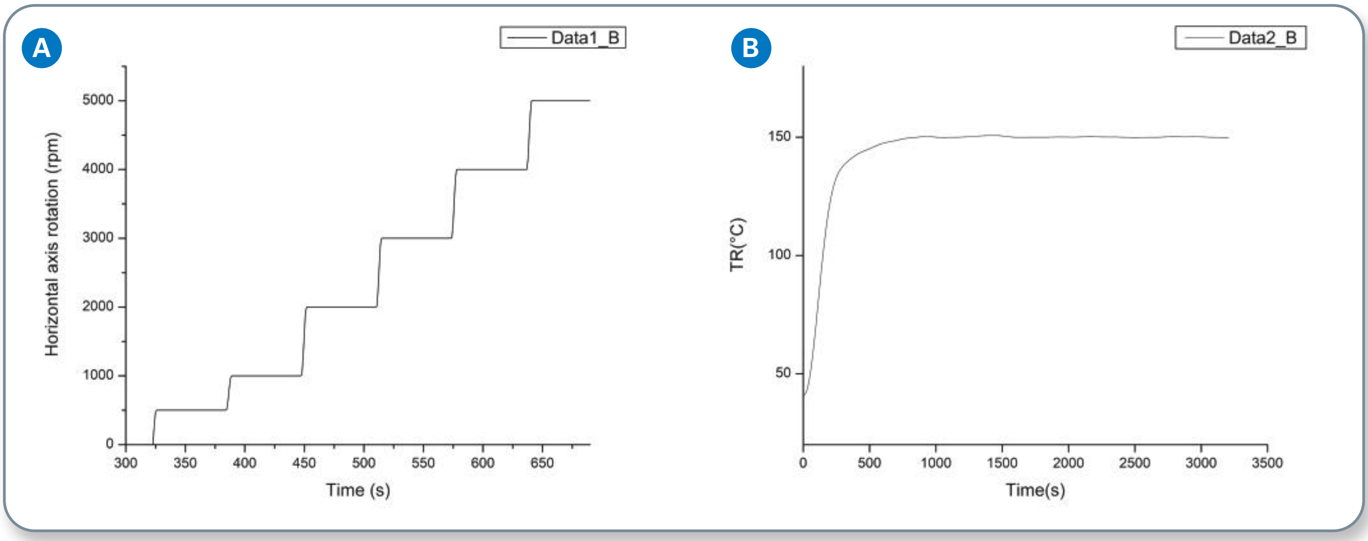

Figure 2. (a) High-speed horizontal axis rotation up to 5000 rpm; (b) Rapid and homogenous heating from ambient to 150°C.

real-time monitoring and data acquisition of the test specimen dimensional change.

Characterization of Lubricity by Stribeck Test

An overview spectrum of lubrication transition from boundary to hydrodynamic is typically investigated by establishing the relationship between friction against the Hersey number ($\eta V/Fz$), commonly referred to as the Stribeck curve. The Stribeck curve shows how friction in fluid-lubricated contacts behave non-linearly of lubricant viscosity, entrainment velocity, and contact load. Generating a Stribeck curve requires a fluid that can be drawn into a converging gap, thus creating pressure to support the load (see Figure 3). However, developing sufficient velocity to build up the pressure and film thickness required to achieve the hydrodynamic lubrication regime is challenging without a proper tribotester. Bruker's liquid heating chamber on a block-on-ring makes such tests much simpler and more convenient.

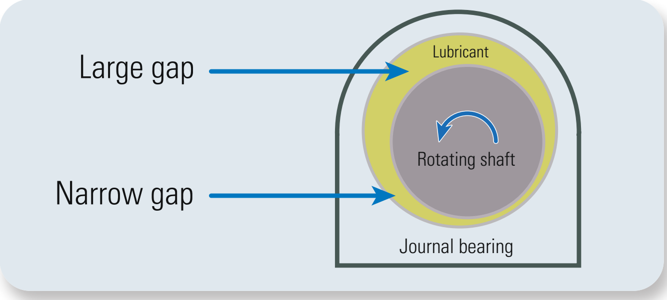

Figure 3. Converging gap of a journal bearing.

To demonstrate the Stribeck curve method in characterizing the lubricity of synthetic and bio-based lubricants at different temperatures, the liquid heating chamber on a TriboLab equipped with a block-on-ring drive was used. In the experiments, an SAE 52100 steel block was pressed against a 35 mm diameter chrome steel ring submerged in 130 mL of lubricant. Two commercially available lubricants, Bio-A (bio-based) and Synthetic-B (fully synthetic) were used in this study. The chrome steel ring was revolved at a horizontal axis up to a maximum rotating speed of 5000 rpm while a maximum normal load up to 20 N was applied on the ring. The friction behavior of the lubricants over a wide range of temperatures were studied by utilizing the precise temperature control from direct heating the lubricant at 25°C, 80°C, and 120°C, respectively.

Coefficient of Friction and Lubrication Regimes

Frictional characteristics of metal to metal during lubricated sliding contacts are influenced by the asperity height and lubricant film thickness. With a proper tribosystem setup, the contact interface going through the region of asperity contact (boundary), semi fluid-film separation (mixed), as well as full fluid-film separation (hydrodynamic), can be easily distinguished by plotting the coefficient of friction (COF) against the V/Fz ratio, as shown in Figure 4. High friction (COF >0.1) was observed at low V/Fz as the two metal surfaces come into direct contact and the load is mainly supported by surface asperities. The average COF value decreased (in the range of 0.05-0.1) as the lubricants transited from the boundary to the mixed lubrication regime, where the load is supported by both asperities and lubricant film. At higher V/Fz, where the friction coefficient is relatively lower, asperity contact was negligible, and the load is supported mainly by hydrodynamic pressure exerted by the lubricant. The coefficient of friction is minimal at this regime (COF<0.08). However, the increased coefficient of friction observed toward V/Fz >2000 suggests that the lubrication film may be broken, thus bringing the lubrication back to the mixed regime with asperity contacts.

In boundary-friction-dominated operating conditions, the relationship between the friction coefficient and temperature at the contact surface is important to determine the performance of lubricants, where viscosity of a lubricant changes with temperature. The friction coefficients of Bio-A and Synthetic-B lubricants were observed to increase as the contact temperature increased from 25°C to 120°C. Typically, the rise in friction coefficient is less rapid in the lower temperature range. At lower temperature, the lubrication film is thicker due to higher viscosity. Both lubricants were very close in performance, so enhancing the understanding of their small differences made it possible to identify the former as a greener substitute in the pursuit of green tribology and sustainability.

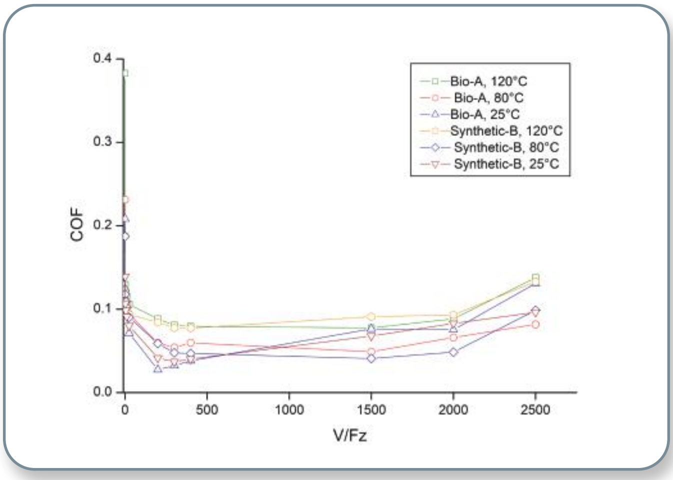

Figure 4. Stribeck curves generated under different temperatures.

Lubricated Sliding Wear Test

The block-on-ring wear test is a common method for assessing the wear behavior of materials in laboratories due to its feasibility in scientific investigation of wear mechanisms under various conditions. The ASTM G77-17 standard describes the reporting of scar width, scar depth, scar volume, and COF in the ranking resistance of materials to sliding wear using block-on-ring wear tests. Figure 5 shows the scar depth of test blocks at various temperatures. The UMT TriboLab provides real-time monitoring of in-situ scar depth measurements and COF that provides better understanding to the mechanisms of wear formation during sliding wear tests. Figure 6 depicts the block scar volume and the average friction coefficient of the Bio-A and Synthetic-B lubricants used in this study. The block scar volume was calculated based on the width of the scar. The lubricant performance can be easily assessed and compared by plotting these two parameters within the same graph. This study found the Bio-A and Synthetic-B

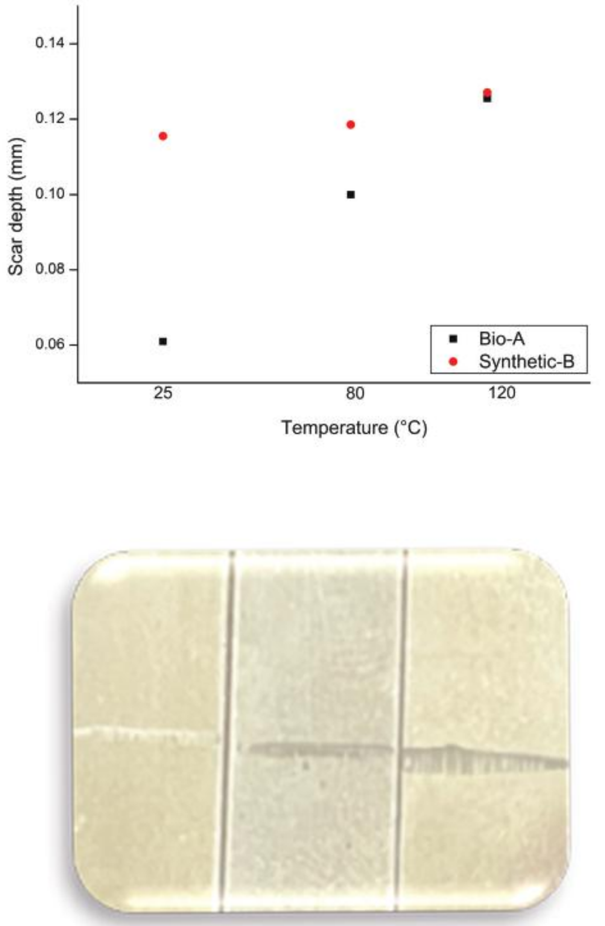

Figure 5. Measured scar depth of test blocks at 25°C, 80°C, and 120°C, respectively.

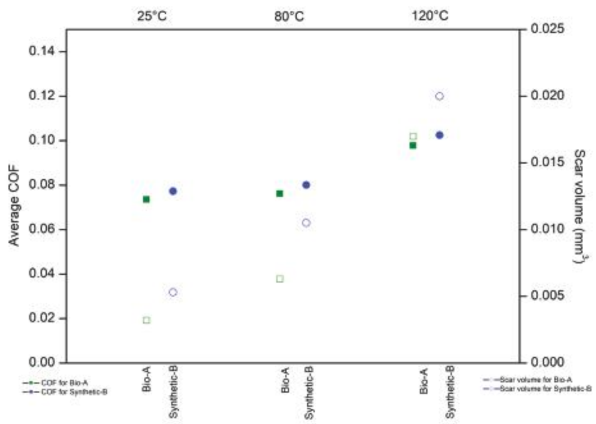

Figure 6. Average COF and calculate block scar volume at 25°C, 80°C and 120°C, respectively.

lubricants were very close in performance, across the tested temperatures. This finding agrees with the Stribeck curve described in the earlier section.

Conclusions

The Stribeck curve generation that is done using unidirectional testing has been demonstrated as a reliable method for lubricant evaluation due to its clearer discrimination of boundary, mixed, and hydrodynamic lubrication regimes. The benchtop UMT TriboLab equipped with a liquid heating chamber and block-on-ring module provides unprecedented flexibility that allows researchers to perform multiple measurements at different conditions, which is essential in understanding key performance differences of lubricants at different regimes. The modular design of TriboLab enables lubricants and materials testing at a horizontal axis rotation that is ideal for a wide range of test methods, including, ASTM G77, ASTM D2509, ASTM D2714, ASTM D2782, ASTM D3704, and other testing standards.

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