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Wide Spectrum Wear Test

11/15/2011

Material: Saint-Gobain Rulon® LR

Introduction

This report provides high P-V wear and friction test results for Rulon® LR conducted on a Tribis Engineering Inc. model TS-01D disc style Tribo-Spectrometer™. A high P-V test matrix (up to 570,000 psi/ft/ min) was utilized to demonstrate the heat generation profiling potential enabled by wide spectrum P-V testing. One Hundred discrete friction and wear rate tests were completed for a spectrum of test pressures (P) from 1MPa to 10MPa and velocities from 200 mm/s to 2000 mm/sec (V). Note, the maximum P and maximum V levels are in the range of those published for Rulon® LR, however, most of the tested P-Vs exceed the published max P-V of 10,000 psi/ft/min.

The report includes

- Background on select concepts related to Tribo-Spectrometry and the TS-01D Tester
    - Focus on Heat Generation concept
- Discussion of the Test Procedure
- HI P-V Test Results
    - Wear Rate Design Map Summary
    - Friction Profile Design Map Summary
    - Heat Generation Profile Design Map Summary

Background

Tribis' TS-01D Tribo-Spectrometer™ was developed to generate a wide spectrum of P-V wear and friction tests in an accelerated timeframe (as compared to common tribometers). Up to 100 P-V permutations have consistently been completed in as little as 24 elapsed hours. The Tribo-Spectrometer™'s unique design characteristics also provide some valuable benefits beyond testing efficiency. One of these is the ability to calculate heat generation across the tested P-V spectrum. For example:

> In the following test of Rulon® LR, the Tribis TS-01D test method resulted in very acceptable wear rate and friction characteristics for P-Vs that are orders of magnitude (more than 50x) above the manufacturer's stated P-V limit. Tribis attributes this performance to the heat management capacity of the TS-01D. The counterface of the TS-01D is considerably larger and is a more effective heatsink than the counterface configuration of common tribometers. For a given pressure and surface speed, the TS-01D dissipates far more heat during a test run than other tribometers. Since a smaller counterface mass is also a less effective heatsink, it is possible that the common tribometer test experiences material failure limits from retained heat rather than exceeding the physical pressure and/or velocity limits of the tested material.
>
> With years of application engineering experience in our background, Tribis believes that heat generation is an overlooked, but extremely critical design input for bearing application engineering efforts. Frequently, application failure (excessive/catastrophic wear) is the result of exceeding thermal limits at the contact surface. Excessive retained heat can explain the occasional application design failure even when operating below the material manufacturer's

stated P-V limit. In such applications, the configuration may not allow sufficient heat dissipation, resulting in a "heat soak" effect at the bearing surface. With this perspective, heat toleration and management are the most important factors in selecting a bearing material for an application. Not only are exceptionally high P-V's possible. Low P-V's can result in thermal failure for systems that retain heat.

Test Procedure

The tests were conducted using Tribis' P-V test protocol. This entails programming the TS-01D for the desired range of P-V permutations, pre-test cleaning of the sample and counterface, a brief break-in period, followed by sequential performance of all pre-programmed P-V permutations. Individual test sufficiency is determined via proprietary algorithms that continuously assess speed, pressure and temperature stability plus wear and friction measurements. Once the algorithms determine that acceptable test results are achieved, the next P-V permutation is initiated. This protocol allows the completion of a wide spectrum of test results in a reasonable timeframe with minimal technician involvement (as compared to common tribometers).

Test Setup

Date & Duration:		Nov. 2, 2011, Appx 24 hrs.
Material:		Saint-Gobain Rulon® LR (filled PTFE) 10mm x 10mm x 1.5mm thick bonded to aluminum substrate
Counterface Material:		4140 Steel disk, through hardened for a surface hardness HRc 45
Contact Radius		Sample contacted the counterface disk at a radius of: 159.2mm for a sliding distance of 1m/rev.
Pressure	Min	1MPa
	Max	10 MPa
	Increments	10, evenly spaced every 1MPa
Velocity	Min	2000mm/s
	Max	2000mm/s
	Increments	10, evenly spaced every 200mm/s
Break-in		30 minutes @ 5MPa & 100m/s
Test By		RCA

Contact Pressure: Contact pressures are pneumatically controlled with PID loop feedback to achieve high programmable accuracy and stability.

Sequence: Test sequenced 100 permutations for 10 increasing sliding speeds at 10 increasing pressures. All speeds are tested at each pressure before incrementing to the next highest pressure.

Break in: This system does not require breaking before testing. Break-in is detected through thermal stability and wear rate linearity (steady state conditions). A brief break in period is used to establish a transfer film layer and burnish the material surface. This reduces the time required for detection of steady state conditions.

Data Recorded: For each P-V permutation, at each revolution of the counterface disk, differential laser measurements were made of the counterface surface and the back of the sample holder. This was recorded at a resolution of 10 nm (0.4 micro-inch). Simultaneously, the average contact pressure, average friction, and average sample holder temperature for each revolution were recorded.

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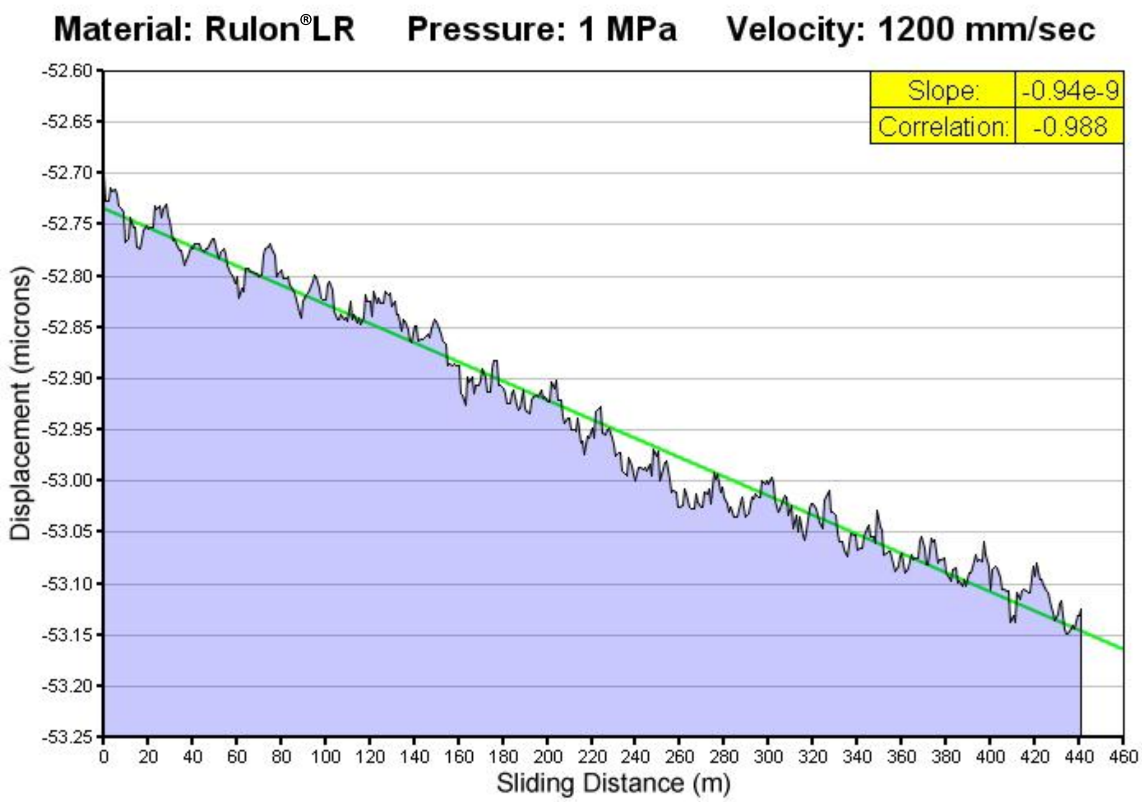
Along with the raw wear data, the system records:

- Calculated wear rate
- Coefficient or correlation for wear data
- Coefficient of Friction
- The attempted contact pressure
- The actual contact pressure
- Load cell force
- Friction force
- Sample fixture temperature
- Counterface disk temperature
- Ambient temperature
- Ambient relative humidity

Test Results

Raw Data

For each test permutation, the raw displacement wear data was recorded. A graph of the wear data for each was automatically generated. An example is shown below. The raw data graphs are used to verify the systems selection of acceptable data. The specific wear rate (slope) and coefficient of correlation are recorded on each graph. The vertical axis is a reference of laser displacement measurement in microns. The resolution of the axis is 0.01 microns (10nm). The horizontal axis is shown in meters, the resolution of the axis is one disk revolution, i.e., each revolution is 1m. In this case, total wear is about 0.42 microns over 440 meters of sliding distance. The resultant wear rate for this permutation is less than 1nm/m.

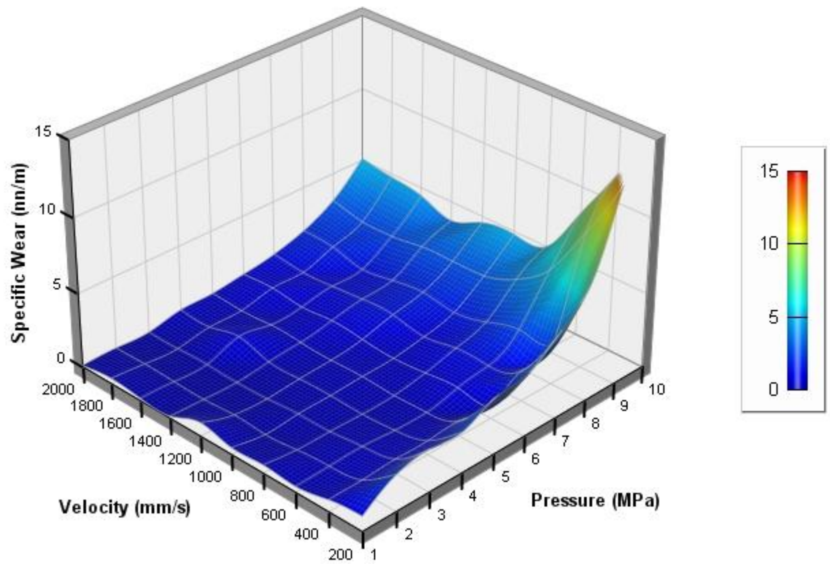


Specific Wear Rate

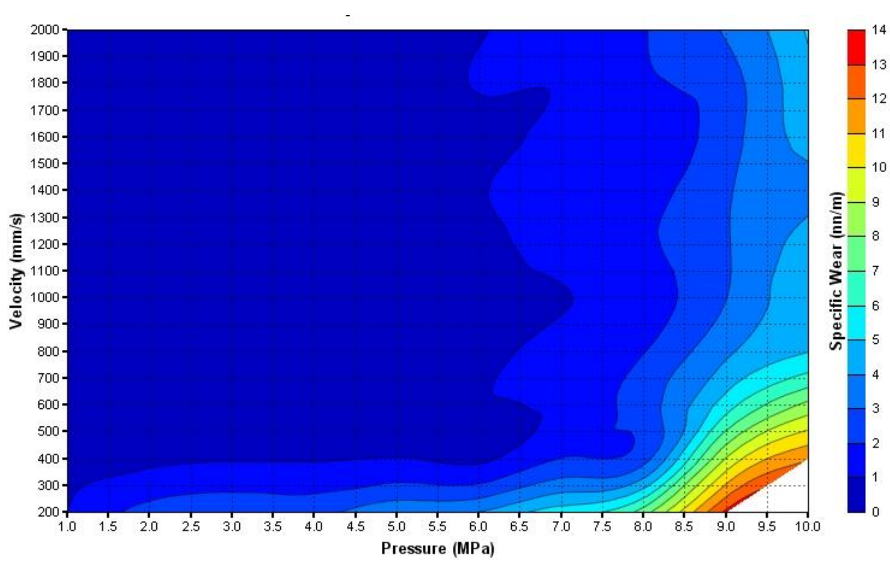
Specific wear rate is unitless and is recorded on the order of magnitude of 10^{-9} (m/m, mm/mm, or in/in). For convenience, it is displayed here at an equivalent nanometers/meter (nm/m).

Data with low correlation coefficients have been excluded from the graphs (See Appendix).

This material shows excellent wear properties at all speeds at all but the lowest loads and speeds tested. Wear behavior is increased at very low speeds



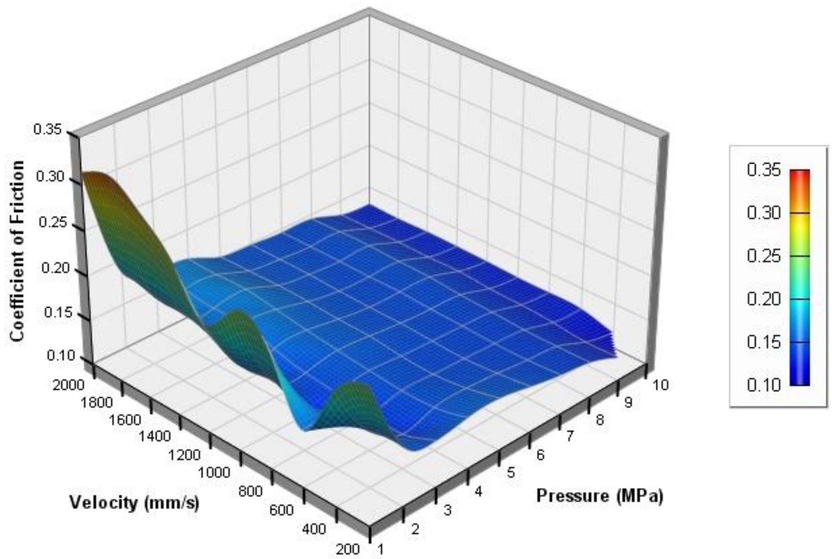
Wear can be considered acceptable for some P-V combinations up to 20 W/mm^2 (570,000 psi*ft/min) provided sufficient heat dissipation is available (See Heat Generation).

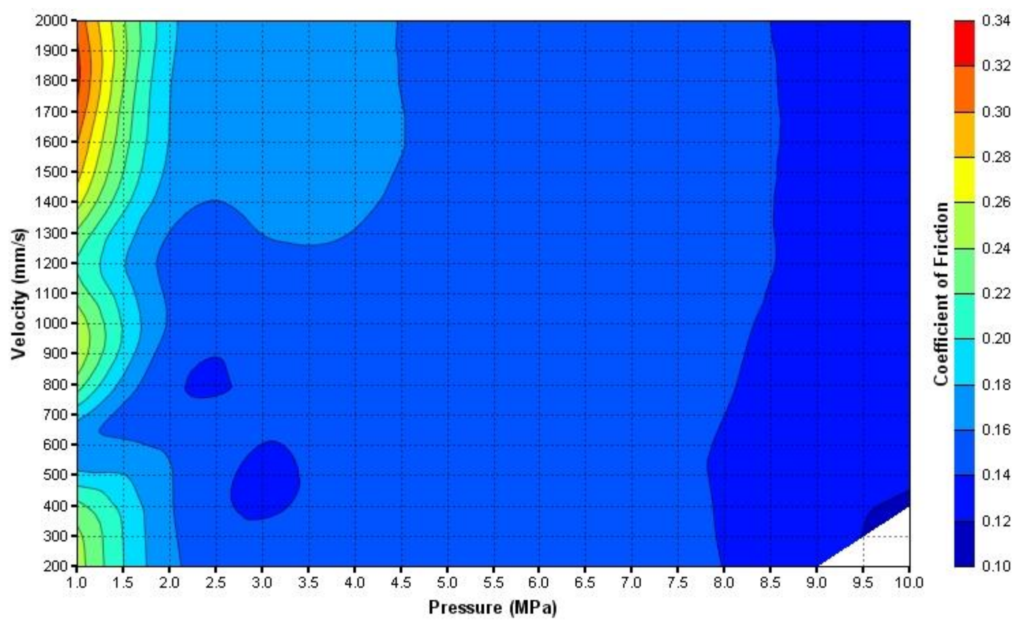


Coefficient of Friction

This material has a nearly linear friction relation to contact pressure. As is common in many materials, there is a significant increase in friction at the lowest pressures. It is important to note that this test reflects lineare sliding wear.

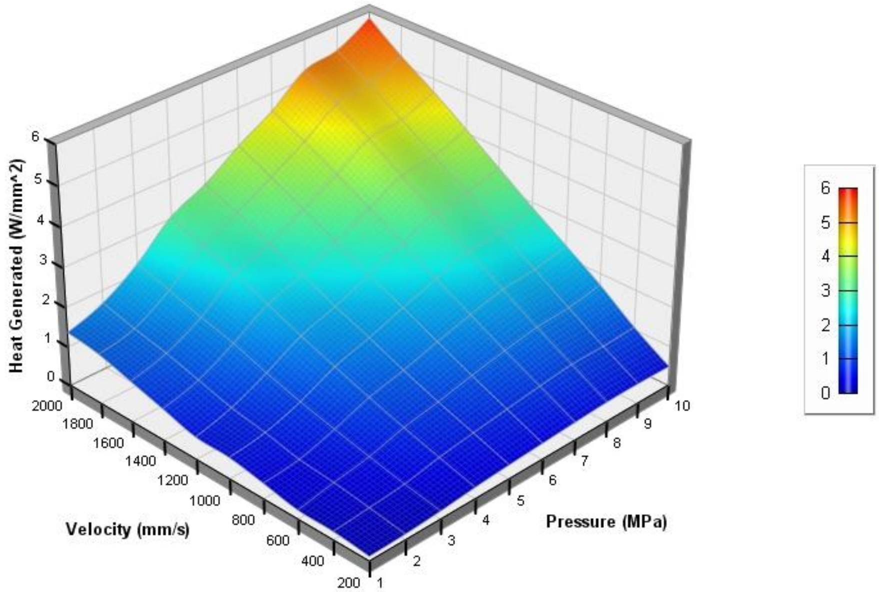
Coefficients may differ significantly with other tribological regimes. In linear sliding, weare debris tends to be pushed ahead of and out of the wear path. Some other regimes (cylindrical or thrust washer) trap the wear debris between the wear surfaces and act as a lubricant to further reduce friction.





Heat Generation

Heat generation is the product of Pressure, Velocity, and the coefficient of friction. When operating at high P-V combinations, this a valuable tool for determining application feasibility.



The published P-V limit for this material is 10,000 psi*ft/min. This corresponds to heat generation less than 0.1W/mm^2 at the frictions measured.