



FROM FRICTION TO TRACTION: A PRACTICAL INDUSTRY GUIDE TO LUBRICANT TESTING

Lubricants in Rolling-Sliding Applications

In many industrial applications, such as gears, rolling bearings, cam-follower systems, metal rolling, traction drives, and even electric vehicle transmissions, performance, efficiency, durability, and noise are governed by the friction, viscosity and high-pressure rheological characteristics of the lubricant. In rolling-sliding EHD contacts, friction is more accurately described as **traction**: the resistive force generated within the lubricated contact when relative sliding (or slip) occurs between the surfaces of components that are undergoing rolling motion. The thin lubricant film (typically < 1 micron) is subject to high contact pressures (several GPa) and high shear stresses in such non-conformal contacts. The rheological characteristics of confined fluids is described using piezo-viscous effect and the **oil behaves like 'a solid'** under such conditions, supporting shear stresses without being squeezed from the contact (Figure 1). This piezo-viscous property of the fluid leads to an exponential increase in fluid viscosity, by 6 orders of magnitude, at a contact pressure of 1 GPa.

The shear stress vs strain behavior dictates the traction response under EHD conditions. Traction directly influences:

- ✓ Control and predictability of torque transmission
- ✓ Power losses and efficiency
- ✓ Heat generation and thermal stability
- ✓ Surface damage such as micro-pitting

As machine designs push toward higher loads, higher speeds, smaller contacts, and lower-viscosity lubricants, understanding lubricant friction and traction behavior is no longer optional—it is essential. This is where traction tribometers become indispensable tools for lubricant formulation, selection, and validation.

Stribeck Curve: Concept and Significance

Two fundamental curves are used to describe friction in lubricated contacts: the Stribeck curve and the traction curve. While they are sometimes confused or used interchangeably, they describe different aspects of lubricant behavior based on the lubrication regime. Stribeck applies more to surface interactions whereas traction better describes the molecular interactions within the EHD fluid. The Stribeck curve (Figure 2) describes how the coefficient of friction varies as a function of lubrication regime. It is typically plotted as friction coefficient versus the Hershey parameter combining speed, viscosity, and load (often $\eta \cdot N/P$). The curve illustrates three main regimes:

- Boundary lubrication: Direct asperity contact dominates; friction is relatively high and strongly influenced by the surface chemistry and interaction of extreme pressure additives. Scuffing, a catastrophic failure, is a key property of interest.
- Mixed lubrication: Partial separation of surfaces; friction decreases rapidly with increasing speed or viscosity and is influenced by anti-wear additives, friction modifiers and viscosity of oil.
- Elasto-hydrodynamic lubrication: Surfaces are fully separated by a lubricant film; friction is mainly governed by lubricant high-pressure rheology and influenced by oil group, viscosity and viscosity index improvers

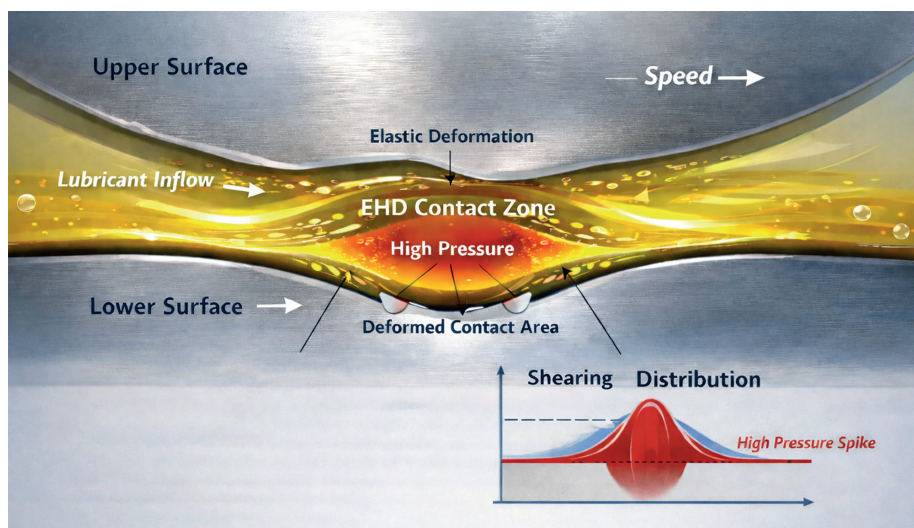


Figure 1: EHD contact showing the thin oil film (< 1 micron) separating the moving surfaces and severely stressed up to few GPa contact pressure and 10^7 per sec shear strain rate.

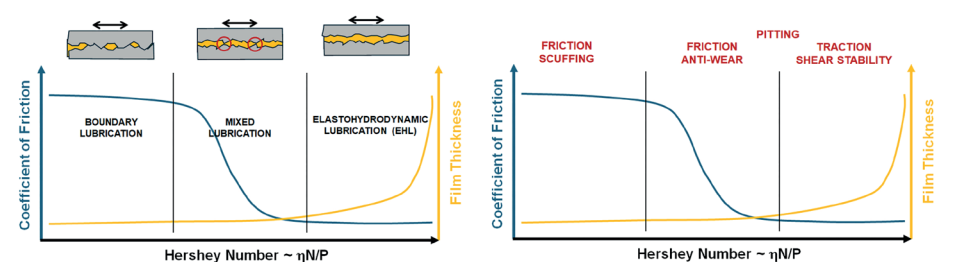


Figure 2: Illustration of Stribeck friction curve, lubricant film thickness and relevant lubricant properties

Traction Curve: Concept and Significance

Traction curve plots traction coefficient vs. slide-roll-ratio (SRR) at constant load, speed, and temperature and can be differentiated into three regimes –

- a linear portion representing Newtonian behavior at low % slip
- a non-linear portion associated with shear thinning at moderate % slip
- the thermal region associated with temperature dominated viscosity interaction at high % slip

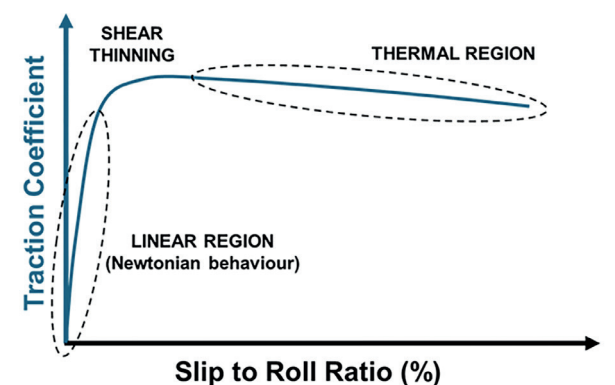


Figure 3: Characteristic traction curve showing different regimes

The traction curve can be interpreted as the high-pressure shear stress vs. shear strain behavior of the EHD oil film with shear strain analogous to SRR and shear stress being the resistive force exerted by the film. An important parameter that can be determined from traction plot data is the **limiting shear stress (LSS)**, which is the maximum resistive force that a lubricant can sustain in a high-pressure contact with increasing SRR.

The LSS can be calculated from traction measurements – as the product between the traction coefficient at the plateau and the mean contact pressure, approximated using the maximum Hertzian pressure, as follows:

$$\tau_{lim} = \mu_{plateau} \cdot p_m \text{ OR } \tau_{lim} \approx \mu_{plateau} \cdot p_0$$

where $p_m = N/A$ (N is the applied normal load and A is the contact area from EHL contact theory) is the mean contact pressure and p_0 is the maximum hertzian contact pressure (from Hertz contact theory).

From an engineering perspective, limiting shear stress directly influences the maximum torque or force that can be transmitted through lubricated contacts, making it especially critical in traction drives and continuously variable transmissions. It also plays a role in controlling frictional heating and wear, since it caps the shear forces generated within the lubricant film.

3D Plot of Friction and Traction

Traction and friction can be represented in a 3D plot (Figure 4) as a function of entrainment speed and slide roll ratio (SRR). The different regimes of lubrication relevant for friction and the different regimes of traction are approximated with dotted lines.

Based on the fundamental understanding, the key differences between traction and friction is summarised in Table 1.

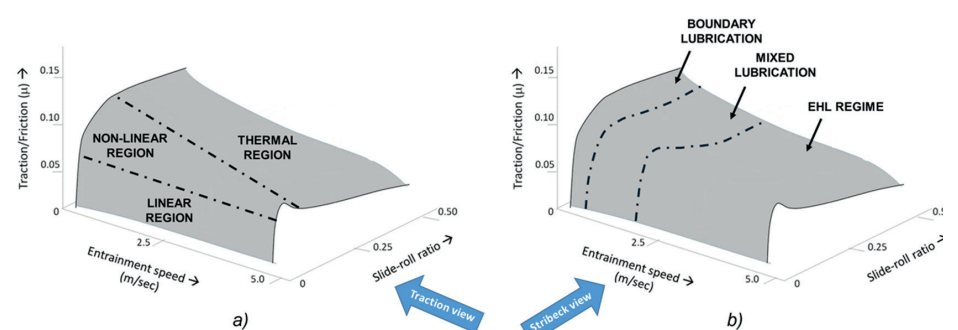


Figure 4: 3D illustrative plot of traction and friction of lubricants, highlighting a) the different traction behaviors and b) the different lubrication regimes.

Traction	Friction
EHD lubrication regime	ML, BL lubrication regime
Within film interactions, resistive force to shearing	Surface interactions, resistive force to sliding
Plotted vs. slide roll ratio	Plotted vs. entrainment velocity
Depends on base oil, viscosity modifiers	Depends on base oil, friction modifiers, anti-wear and extreme-pressure additives

Table 1

Laboratory Generation of Stribeck and Traction Curves

Rolling-sliding motion can be generated and lubricant friction and traction behavior evaluated using two standard configurations:

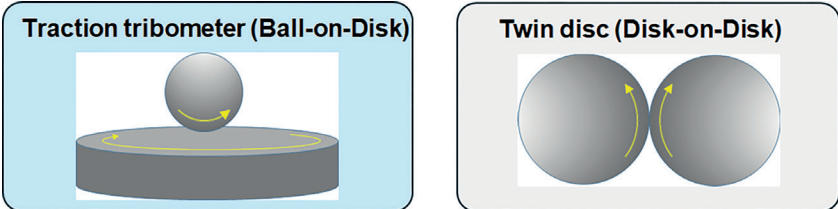


Figure 5: Rolling-sliding test configurations - ball on disc vs. disc on disc

- Traction tribometer (ball on disc)
- Twin disc machine (disc on disc)

Both setups use independent drives (Figure 5) to control speeds of ball and disc to achieve variable SRR, variable entrainment speed to map friction across lubrication regimes with each test configuration having its own strengths and limitations (Table 2). Ball on disc traction tribometer offers a simple and easy to use configuration for traction evaluation of lubricants in the lab.

Ball on disc	Twin disc
Self-aligning point contact (easy to setup)	Alignment required for line contact (elaborate setup)
Benchtop, small footprint	Floor mounted, larger footprint
50 ml oil sample per test	Atleast 500 ml oil sample per test
Loads of 10's of N (1 GPa stress)	Loads of 1000's N (1 GPa stress) > significantly larger heat dissipation
Primarily 52100 steel contacts	Flexibility to adapt actual gear materials, surface treatment and finish
Good for lubrication evaluation	Better at simulating actual component response, scuffing

Table 2

Terminology

To introduce the most important parameters, let's consider a ball (1) on disk (2) configuration that are rotating at two different rpm resulting in two different sliding speeds (U1 and U2, respectively) at the contact. (Figure 6) The following parameters can be defined:

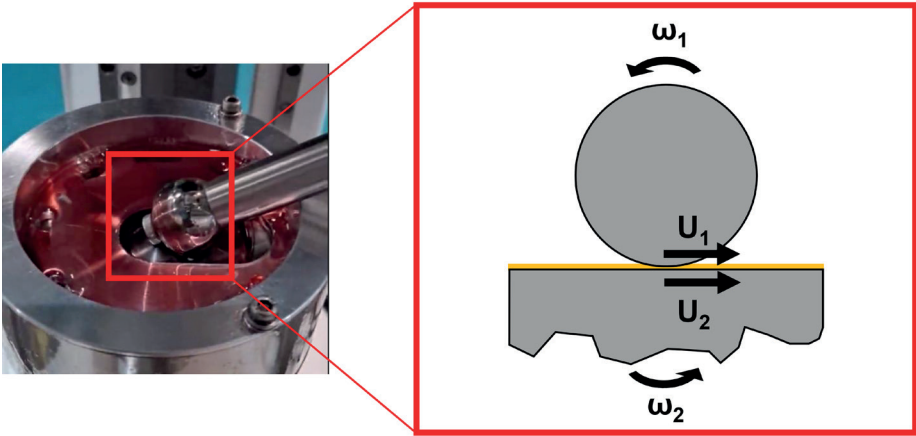


Figure 6: Modular Traction Tribometer: Ball-on-Disk configuration.

Sliding velocity (at the contact point): $|U_1 - U_2|$

Entrainment velocity (average surface velocity of the two rollers): $\frac{(U_1+U_2)}{2}$

Slide to Roll Ratio, SRR: $\frac{\text{Sliding velocity}}{\text{Entrainment velocity}} = 2 \cdot \frac{|U_1-U_2|}{U_1+U_2}$

Slide to Roll Ratio%, SRR%: $200 \cdot \frac{|U_1-U_2|}{U_1+U_2}$

If U1 = 0, the two rollers are in pure sliding motion (SRR = 2); if U2 = U1, the two rollers are in pure rolling motion (SRR = 0).

Modular Traction Tribometer: Traction Test Method and Case Study

Test standards to evaluate traction of lubricants are not available and are currently under discussion within the standards committee. Within the lubricants community, the method(s) used rely on varying SRR at fixed entrainment speed (for traction). The case study presented used the speed ramp profile to generate traction curves in 5 minutes in the **modular traction tribometers (MTT)** (Figure 7).



Figure 7: Modular Traction Tribometer: Ball-on-Disk configuration from Paltro.

Materials and Method:

The materials and testing conditons for traction are summarised in Table 3. The range for SRR was selected from -0.5 to +0.5 covering both -ve and +ve values. This was chosen to capture the transition from -ve to +ve friction force readings and establish the zero-reference point for SRR. Each test condition was repeated thrice on the same track without changing the ball and disc.

Test parameters	Value	Comments
Ball	20 mm dia. E52100 steel ball	lapped finish, Ra <0.05 μm
Disc	EN 31 steel disc, 58-62 HRc	lapped finish, Ra <0.05 μm
Lubricant	20W50 oil	
Load	50 N	contact pressure of 1 GPa
Temperature	40 deg C	
Test duration	5 mins	selected to minimize large temperature increase during high speed test
Entrainment speed	1 m/sec	constant during the test
SRR range	-0.5 to +0.5	selected range covers both -ve and +ve values to help determine zero reference point for traction
SRR profile	-0.5 to +0.5 +0.5 to -0.5	linear ramp profile both increasing and decreasing
Measurands	friction force, ECR	electrical contact resistance gives a qualitative measure of the oil film thickness and stability

Table 3

Precision:

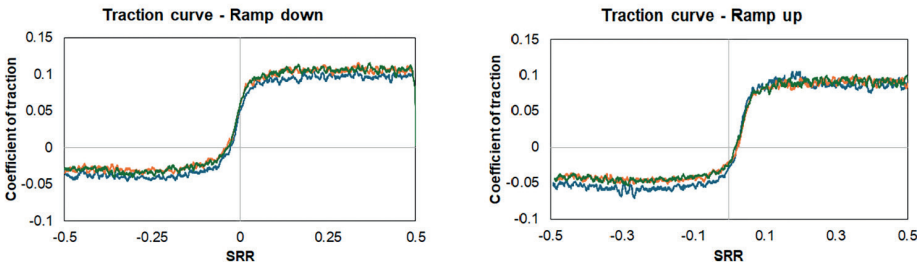


Figure 8: Traction curves for linearly decreasing and increasing SRR show good repeatability

Fairly repeatable and consistent traction curves were obtained for both linearly increasing and decreasing SRR ramp protocols (Figure 8).

A better representation of the traction behavior can be obtained by taking the average of data obtained from both increasing and decreasing SRR profiles (Figure 9)

The average traction data for consecutive tests with SRR increasing and SRR decreasing is shown in Figure 8 with the traction data being more consistent and nearly zero close to the zero SRR reference point.

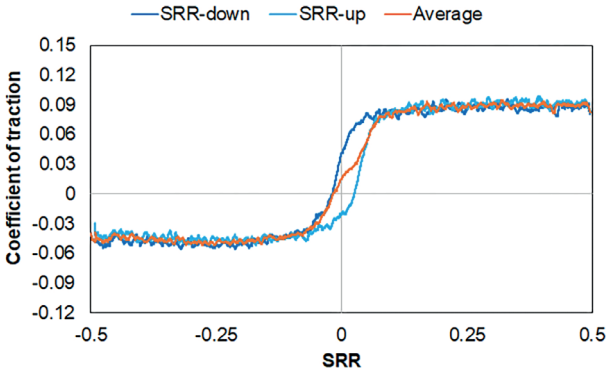


Figure 9: Average traction curve considering consecutive increasing and decreasing SRR data

Furthermore, a difference is observed in the maximum traction coefficient for both -SRR values and +SRR values.

The limiting shear stress value calculated using a maximum traction coefficient of 0.085 obtained at 40 deg C and contact pressure of 1.0 GPa is 85 MPa.

Summary

As machine designs push toward higher loads, higher speeds, smaller contacts and low-viscosity lubricants, understanding lubricant friction and traction behavior is no longer optional—it is essential. The modular traction tribometer (MTT) is a versatile tool designed to support both conventional mechanical systems and emerging technologies such as electric vehicles. By measuring friction and traction under realistic rolling–sliding conditions, it provides engineers with the insights they need to optimise efficiency and performance, bridging the gap between laboratory testing and real-world operation.

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