Tips and Tricks from Joe Flow - Stribeck curves: A powerful screening tool for tribology in a nutshell

Tribological measurements determine the friction and wear behavior between materials that rub together. A powerful measuring tool is now available for understanding and screening lubricated tribological systems: Stribeck curves.
Tribology is everywhere!

Tribology enables us to live our life as it is. The name is derived from the words “tribos”, which means “to rub”, and “logy”, which means “science”; hence, tribology is the science of things rubbing against each other.

Without friction, we would not be able to sit on a chair, we could not hold a glass of juice in our hands, or listen to the sound of a violin playing. On the other hand, with too much friction, we could not slide a drawer open to get fresh socks in the morning; we could not even open a window to get air into a meeting room, let alone get into the meeting room through the door.

Friction forces \( F \) are those forces that counteract the motion of one body on another when forces \( F \), like gravity, are applied; the two bodies are then pressed together by a normal force \( F_N \); e.g., the own body weight. Fig. 1 shows a basic tribological application; i.e., a spatula distributing putty on a wall. In this case, the aim is to form a defined film over the hole. Speed and pressure are carefully balanced to achieve a suitable film height to cover the hole. But the intact wall doesn’t need the putty. Thus, once the hole is covered, the pressure on the spatula is increased, and the speed reduced in order to stop further film formation.

Figure 1: A tribological application – applying putty to a wall with the help of a spatula

Are rheology and tribology connected?

Many tribological systems also include a lubricant; in the example above, the spatula “floats” on the putty film. The putty determines the forces needed to form a suitable film. Film formation is one crucial aspect of tribology in which rheology plays a significant role.

The formation of the putty film as a tribological system is shown in Fig. 2. The spatula is pressed down with a defined normal force. To form the film, the spatula must tilt and gain speed. The upward forces from the putty counteract the spatula and lift it up. If the putty is applied with too much downward (normal) force, or too quickly, the film fails. If the normal force is greater than the upward force, the film breaks. If the speed is too high, the friction between putty and spatula gets too high and a smooth film cannot form.

Figure 2: Principles of applying putty with a spatula from a tribologist’s point of view

In tribology, speed-dependent film formation and changes in the frictional properties are portrayed through “Stribeck curves”. Richard Stribeck was a German scientist and engineer, living from 1861 to 1950, who investigated the film-forming properties of lubricants in journal bearings. He found a distinct correlation between frictional properties and films of lubricant formed between two surfaces.

Figure 3: Schematic diagram and principles of Stribeck curves

Stribeck observed that, at low speeds, it is mainly the two surfaces that interact and determine the friction (boundary friction). The friction is represented by the coefficient of friction, \( \mu \), which is the ratio between the frictional force \( F_F \) and normal force \( F_N \). With increasing speed, the lubricant is transported into the space between the surfaces and, just like the putty between the spatula and the wall, the upward forces of the lubricant push the surfaces apart (mixed friction). The further the surfaces are pushed apart, the lower the friction. The minimum friction is reached when the surfaces are just no longer touching. This is the elasto-hydrodynamic friction regime. If films are formed, they prevent or reduce wear. When the sliding speed is further increased, the film gets thicker. Just like in a flow curve, the internal friction of the lubricant then increases, and thus the friction of the entire tribosystem increases again (hydrodynamic friction).
Stißeck curves change characteristically with changing viscosity, as shown in Fig. 4.

![Figure 4: Schematic diagram and principles of Stißeck curves](image)

Two main effects can be observed: If the viscosity increases, the speed necessary to float decreases, and the surfaces are pushed apart earlier. Further, the slope in the hydrodynamic friction increases with viscosity, as you would expect in a flow curve. How would things change for our wall-repair attempt with changing viscosity? If too much water were used in the putty, the viscosity would be too low to form a suitable film, and the hole would not be properly filled. If not enough water were used, the viscosity would be too high, and the resulting film would probably be too thick because so much applied and normal force would be needed to apply the putty.

**What do I see in a Stißeck curve?**

The test settings for Stißeck curve measurements can be selected flexibly from the available template, and adapted to suit your application. We can help you create a suitable measurement profile for your sample.

A typical test consists of two intervals:

1. Relaxation time: The system is moved into measuring position until a critical normal force is reached. The tribological system needs time to relax into the forces induced while moving into the measuring position.
2. The measuring system is rotated at logarithmically increasing speeds following a speed ramp while the normal force is also controlled.

Other procedures can expand the measuring profile; e. g.,

1. This measurement procedure can be repeated as often as required within a test. Repetitions reveal running-in processes, and show where the main impact of running-in takes place.
2. Speed ramps with decreasing speeds. Increasing and decreasing speed ramps are often not congruent.

The following shows some examples of measuring curves. Typically, the coefficient of friction is plotted as a function of sliding speed. The coefficient of friction as a function of sliding distance can also be useful, especially if you are also interested in the static friction of the tribological system. This can be determined if the starting speed is slow enough.

The various regimes are analyzed, including boundary friction (including static friction), mixed friction, and (elasto-)hydrodynamic friction. If samples of different compositions or manufacturing processes are compared, then the critical parameters can be identified. If they differ significantly in the regimes where boundary lubrication and, thus, surface interactions are dominant, then low speed and additive performance are critical. On the other hand, if they differ more in the mixed and hydrodynamic regime, then the flow properties of the lubricant and its film-forming abilities are critical. In this way, the most suitable composition or manufacturing process of lubricants, materials, or surfaces can be identified. Note that the goal is to define the tribological properties that suit the application, not necessarily to determine high or low friction or wear, as such.

The model tribological measurements reveal which regimes are most affected by the changes in the tested products. A comparison between application and model tribological measurements can show how changes in a lubricant, for instance, would affect the performance in the application, and which phenomena could be responsible for it. This enables an effective optimization.

**Greases to grip or greases to slide?**

Looking at these examples of lubricant greases, both static and kinetic friction are of importance. In the static case, a lubricant grease may be required to hold components in place, e. g. in worm gears. In motion, on the other hand, rapid film formation is required to ensure low resistance against motion. In a further case, a low static friction may be needed, for example, in a height adjuster in a seat, where the customer does not want to exert high forces to make an adjustment.

In the boundary and static friction regimes, the main criterion is the maximum value of the coefficient of friction and how fast it transfers into mixed friction. In an application requiring low break-away torques, the maximum coefficient of friction needs to be low, preferably at the level of the kinetic friction. An application that requires high break-away torques but good lubricity in motion, needs high static friction for self-holding properties, but fast reduction of these values with increasing speeds.

![Figure 5: Evaluation of greases by means of Stißeck curves](image)

Grease 1 features a comparatively low static friction, and the coefficient of friction is low (around 0.1) at low speeds (~10^4 rpm). Values below 10^4 rpm are within static friction,
so there is no relative motion between the samples. The coefficient of friction is rather constant over the whole speed range. This grease would be ideal for an application requiring low static friction, but would fail in applications requiring high static friction.

Grease 2 features a comparatively high static friction; 0.2, which is twice that of Grease 1. If the speed is increased, the coefficient of friction drops almost to the level of Grease 1; i.e., in the range of ~ 0.1, which is good for technical applications. This grease would be ideal for an application where self-holding properties are necessary.

Effective reduction in static friction can have various causes, like tribo-film formation; additives and other molecules may react on the surface, forming a protective layer, as shown in Figure 6; or a grease film may be keeping the surfaces apart.

![Tribo-film (black) formed on a specimen surface](image)

Thus, a lot of information can be extracted from the straightforward measurements needed to generate Stribeck curves. The frictional properties of both low- and high-speed regimes (static and dynamic friction, respectively) can be determined. The performance of additives, the film-formation properties of lubricants, and wear mechanisms can all be identified with one measurement.