Testing and Analysis

Measuring Rubber and Plastic Friction for Analysis

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Introduction

Friction is the resistance to sliding between two surfaces in contact when pressed together. Friction is often described with a single coefficient which is the sliding resistance force divided by the normal pressure pushing the 2 surfaces together. This coefficient of friction (COF) is often considered a material property that is applicable across a broad range of pressures, velocities and temperatures. However, this is not often the case with plastic, rubber and various hard surfaces.

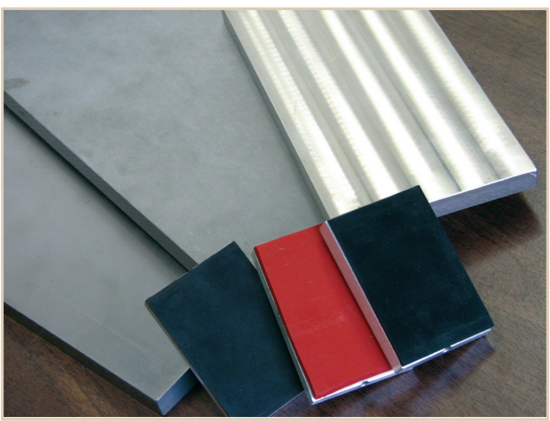

Figure 1, Various Polymer and Metal Surfaces

For example, changing the normal pressure from values typical of lightweight sled tests to normal pressures typical in sealing applications can double the measured coefficient of friction in some cases and reduce measured coefficient of friction in other cases! In general, rubber and plastic materials are more strain rate sensitive, more temperature sensitive and exhibit more dramatic creep and stress relaxation effects than other engineering materials. It is only natural that these same sensitivities would appear in the frictional forces during sliding. While it may seem natural that these sensitivities exist, the actual effects on frictional forces are sometimes counterintuitive.

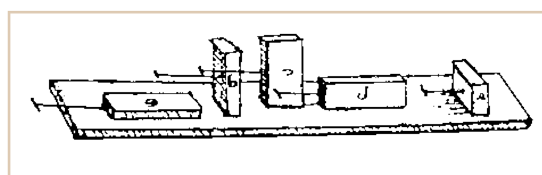

Figure 2, Sketch of Leonardo da Vinci's Test Apparatus

Based on logic and experience in the lab, the following are few of the considerations when measuring friction values for use in engineering analysis.

The Right Material

This may seem obvious but based on experience it is important to mention. The specimens used in the laboratory need to be of same material as the application. A soft silicone (say, 50 durometer) is different than a stiff silicone (say, 75 durometer) and the resulting friction values will be very different. Stainless steel is different than Bronze. Ideally, the two materials used in the experiment will be the same materials as in the application, processed in the same way.

Surface Finish

This can be tricky but the surface finish is very important. Hard surfaces like steel need to be machined to a similar roughness and if possible, in the same direction as the application. Plastics and rubbers need to have a similar mold surface as the actual parts. Glass needs to be cleaned to match the application. Soft elastomers may exhibit higher friction against a smooth hard surface than against a rough hard surface.

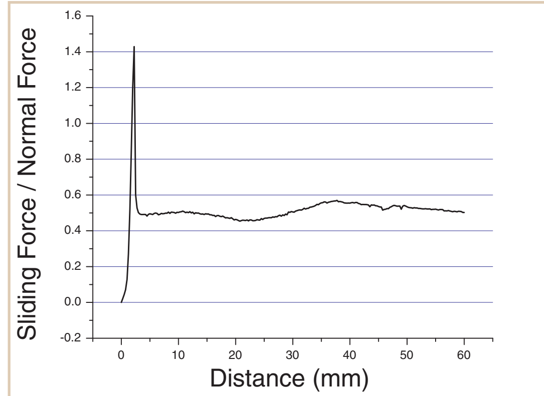

Figure 3, Typical Rubber to Metal Friction

Frictional Normal Pressure

Changing the normal pressure between the two surfaces by 10% or 50% may not have much effect. However, changing the normal force by two orders of magnitude could have a dramatic effect. Often friction data is developed using a lightweight sled that generates a relatively small normal pressure between subject materials. For many applications, this will generate meaningful values but for compressed elastomer seals, the normal pressure of interest will be orders of magnitude higher. In other cases, coatings intended to reduce friction will physically break down under high surface pressure and can generate friction forces higher than would have been present without the coating.

Plastic parts that remain in contact for a long time prior to relative movement may creep such that the soft material flows into the surface of the other. This can result in very high static friction values. The static friction is the friction measured at the first instance if movement and can sometimes be much higher than the steady state or dynamic friction. This can be approximated in the laboratory by holding the subject materials in contact under pressure for a period of time prior to testing.

Application Temperature

Plastics and rubbers will soften at elevated temperatures and stiffen at cold temperatures. Naturally, the friction measurements will change as well. In addition, special attention needs to be applied in cases where the material moves through a glass transition temperature because material properties change so dramatically.

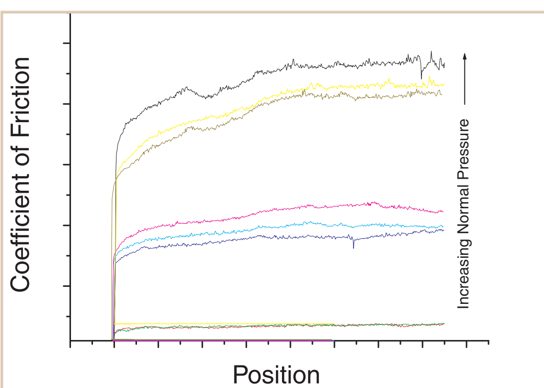

Figure 4, Friction Data at Several Normal Pressures

Rate of Relative Movement

Because the stiffness of some materials can increase with rate due to the rate sensitive properties of one or both, the relative rate of movement is important. For most materials, changing the rate by 50% will have little effect. However, if the relative velocity in the application is orders of magnitude higher or lower than the experiment, there will likely be a significant error.

When the static friction is much greater than the dynamic friction, there is a greater likelihood of slick-slip behavior resulting in squeak and itch noises. This behavior is complex and beyond the scope of this note.

Application Sensitivity of the Value of Friction

If getting the exactly right value for friction is critical to the analysis, then all of the above factors need to be carefully examined. If small changes in friction parameters cause a design to fail then the design may not be sufficiently robust. In real world applications, surfaces wear, materials deteriorate and unintended material may contaminate surfaces. Small changes in the basics can cause big frictional force changes. Understand how friction data that is used was measured. If possible, define experiments to be done under your specific application conditions. Specify the materials, the surface finish, the normal pressure, the temperature and the rate of movement.

Experiments

There are many experiments designed to generate friction data. Most are designed to generate friction data for specific applications. ASTM Document G 115, Standard Guide for Measuring and Reporting Friction Coefficients is a very good general resource which describes and lists friction experiments, associated standards and applications. Most friction experiments are designed for a particular application.

A couple of the experiments used at Axel Products to measure friction under a wide range of conditions are described herein.

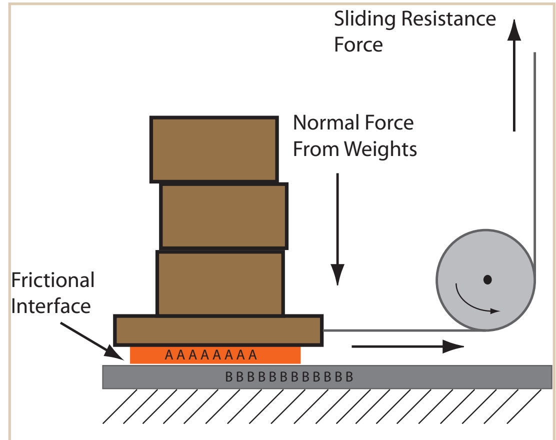

Figure 5, Schematic Diagram of the Friction Sled Experiment

Friction Sled Experiment

In the friction sled experiment, a sheet of material is attached to a sled and dragged against a fixed surface of a second material. The normal force between the surfaces is created by the weight of the sled plus additional weights that may rest on the sled. The sliding resistance is measured using the load cell of a tensile tester that pulls the sled via a simple pulley arrangement. This is a popular friction experiment.

The main advantages of the sled experiment are that the test is easy to set up and the test is easy to understand. The friction values are generally comparable to published values.

There are several disadvantages to the sled experiment. The normal pressure is limited to the pressure created by the sled plus additional weights. This pressure may be much less than the normal pressure in the application of interest. The experiment is generally limited to the measurement of coefficient of friction values below 1.0 because at values above this, the sliding force exceeds the normal force and the sled will begin to skip and leap rather than slide across the surface. In addition, the front edge of the sliding surface may indent the fixed surface and cause an "edge effect" which is difficult to understand.

Figure 6, Friction Sled Experiment

Axial Torsion Friction Experiment

In the axial torsion friction experiment, the end surface of a cylinder is forced against a fixed surface of a second material using a servo hydraulic actuator. The same actuator also rotates the cylinder to create sliding between the surfaces. A load cell capable of measuring axial forces and torsion forces is used to measure the normal force and the frictional forces between the surfaces.

The main advantages of the axial torsion experiment are that a broad range of normal pressures and a broad range of velocities may be achieved. In addition, there is no "front edge" pushing into the fixed surface that in some cases can cause measurement difficulties.

One disadvantages of the axial torsion experiment is that the test method is a not standardized method and the measurements may not be comparable to published values. In addition, one of the subject materials must be able to be bonded to a cylinder or machined into a cylindrical shape and must be able to transmit an axial force and a torsional displacement.

Temperature

Both the friction sled experiment and the axial torsion experiment may be fitted with environmental chambers so that the experiments may be performed under non-ambient conditions.

Data Reduction

The sliding force measured during a friction experiment is not a simple constant value. There is typically considerable oscillation in the data. Sometimes the initial force is larger than subsequent forces and is determined to be the static friction followed by a lower average force that may be labeled as the dynamic friction. Sometimes there isn't a clear larger static force.

It may be valuable to look at the actual sliding resistance force over time to develop an intuitive sense for the oscillations and variability in the data.

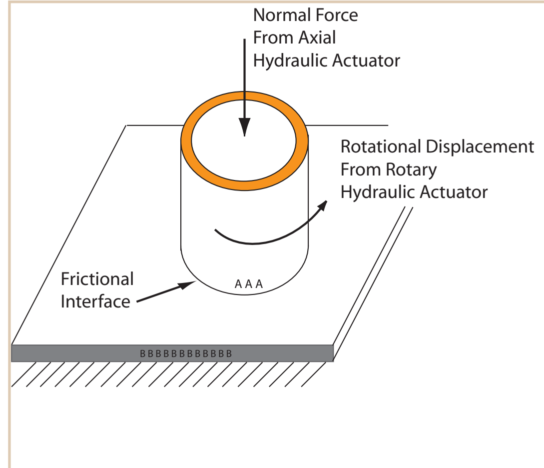

Figure 7, Schematic Diagram of the Axial Torsion Friction Experiment

Figure 8, Axial Torsion Friction Experiment

Figure 9, Axial Torsion Friction Experiment Material Specimens Aluminum and Rubber

Summary

The frictional forces generated between plastic, rubber and various hard surfaces are often represented with a simple coefficient of friction (COF) value yet in reality can be a function of material, surface finish, temperature, rate of relative movement, time and normal pressure. Using frictional measurements where these parameters are matched to the application conditions will help to create a more realistic analysis.

For more information, visit www.axelproducts.com.

Axel Products provides physical testing services for engineers and analysts. The focus is on the characterization of nonlinear materials such as elastomers and plastics.

Data from the Axel laboratory is often used to develop material models in finite element analysis codes such as ABAQUS, MSC.Marc, ANSYS, Endurica and LS-Dyna.

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