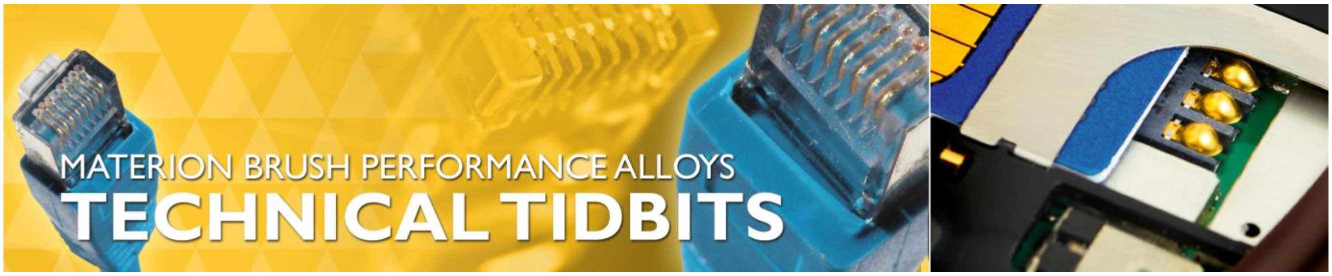


Issue No. 73 – January 2015 **New Publication**

Don't let friction burn you – An introduction to the science of friction and implications in design

- **Physical Property**
- **Mechanical Property**
- **System Property**
- **Coefficient of Static Friction (μ_s)**
- **Coefficient of Kinetic Friction (μ_k)**
- **Asperities (A-spots)**
- **Cold Weld**
- **Adhesive Wear**
- **Abrasive Wear**

The next issue of Technical Tidbits will initiate a discussion how to determine appropriate friction values to use in calculations.

Introduction to Friction

Friction is a concept that engineers and non-engineers alike are intimately familiar with. So, why would we need to read an article on an introduction to the concept? As in all engineering, there is far more to the subject than what was taught in engineering school.

Most engineering textbooks, when presenting homework problems, will tell you to assume a given friction coefficient, instead of telling you what it actually is. The reason is that there is no means of calculating a friction coefficient, since it is a system property, not a physical property or mechanical property.

A **physical property** is one that is inherent in a material and does not change (too much) when the material is processed from its initial state into final form. A **mechanical property** is a property that will change according to how the material is processed. Yield strength would be an example of a mechanical property of a metal, as it will change depending on cold work (temper). Half hard is stronger than annealed, full hard is stronger than half hard, extra spring hard is stronger than full hard, etc. Meanwhile, elastic modulus, density, and electrical conductivity would show very little variation among tempers, and would thus be physical properties.

System properties are those that are dependent on entire system (materials, loading condition, environment, etc.) and not only on the properties of the materials involved. Examples would be the contact resistance of an electrical interface, and the coefficient of friction between two parts in contact. In fact, the coefficient of friction is really an instantaneous property, as slight changes in the interface system can greatly change the relationship between friction and normal force.

The coefficient of friction between two surfaces is influenced by:

- Normal force
- Relative velocity
- Type of relative motion (sliding, rotating, rolling, etc.)
- Surface roughness
- Shape of contacting bodies (both on the macroscopic & microscopic scales)
- Surface hardness
- Inherent lubricity of each surface
- Type of applied lubricant (grease, oil, water, air, etc.)
- Lubrication condition (hydrostatic, hydrodynamic, boundary)
- Wear (abrasive or adhesive)
- Time (the coefficient will change over time)
- Temperature and thermal expansion
- Environment (humidity, oxidation, corrosion, dust, particulate, other contamination)
- Microstructure of materials in contact
- Plating or other surface coating (composition, thickness, hardness, etc.)
- The phase of the moon (OK, probably not, but you will be hard pressed to prove otherwise, given all the confounding factors above, and a reasonable understanding of chaos theory.)

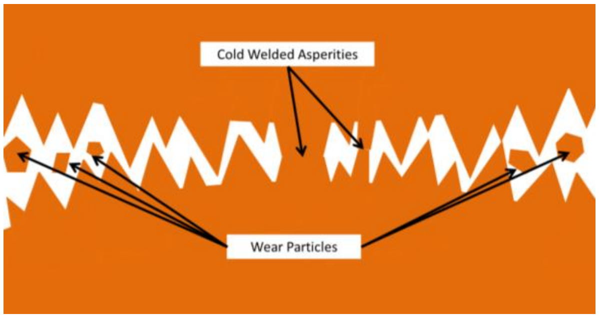
Recall the formula for calculating frictional force: $F=\mu\cdot N$. This implies that the frictional force resisting motion between two bodies in contact is a linear function of the normal force. However, even this is a dramatic oversimplification, as this is probably only true for infinitely small variations in normal force, where the dynamics of the contact interface do not change much. In reality, as the normal force increases, the surfaces will deform, generating additional areas of contact between two surfaces, which means that the frictional force is nonlinear with respect to the normal force, and that the coefficient of friction is not a constant but is also a function of normal force (as well as the rest of the factors listed above.

Introduction to Friction (continued)

You will probably remember that the textbooks describe two coefficients of friction, static and kinetic. The **coefficient of static friction (μ_s)** describes the force that is required to start relative motion between two bodies in contact. It is always higher than the **coefficient of kinetic friction (μ_k)**, which describes the force opposing the motion once it has already started. So why should it be different? This implies that there is something different about the contact interface before and after the onset of motion.

To understand what is going on, we need to look at the interface on a microscopic level. No surface is perfectly smooth – they all have local peaks and valleys. The high spots are known as **asperities**. When the surfaces are in contact with no motion, the asperities tend to interlock (Figure 1), and may even **cold weld** to the other surface, if there is no lubricant, oxide, or contaminant to get in the way.

Figure 1. Microscopic Scale View of Two Surfaces in Contact. In order for these 2 surfaces to begin moving relative to each other, enough force must be applied to shear through the cold welded asperities, and to plastically deform or shear through any other asperities that come into contact with each other.



In order for the two surfaces to move, the asperities must deform and move out of the way of each other, or the tips that interfere with the motion of the other surface must be sheared off. If the two surfaces had cold welded together, usually the softer material will shear off, leaving their asperities attached to the harder surface. Over time, this results in what is known as **adhesive wear**, when the surface of the (usually) softer material transfers onto the surface of the (usually) harder material. If the asperities shear off and remain free between the surfaces, they can cause further shearing and wear of the two surfaces. This is known as **abrasive wear**.

Once the asperities have been sufficiently deformed or sheared off, then the two surfaces can move relative to each other. The force to keep the bodies in relative motion is now less than that required to begin the motion, since there are likely to be far fewer asperities to get in each other's way, and less force will be required to overcome them. Once the motion stops, the asperities will once again lock up as the surfaces more or less settle into each other, and additional force will be required to get the surfaces moving again. This phenomenon also explains why surfaces that run against each other for a long time tend to become smoother.

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TECHNICAL TIDBITS

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