# FRICTION – SOME NOTES

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## INTRODUCTION AND PURPOSE

This report is part of the graduate course CONTACT MECHANICS AND WEAR. This is a “literature course” during summer of -97. The contents of the course should be equivalent to 6 weeks of full time work.

Note that the comments reflect my thoughts on the paper. I may well have misunderstood some of the contents etc. Also, I have included my own associations and comments in the notes below (not always explicitly stated). So, read the following with a “suspicious mind”.

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This paper mainly consists of notes from [1]

## 1. SURFACE TOPOGRAPHY AND TRIBOLOGY

When two surfaces are brought together, they touch only at the tips of a few asperities. Here, plastic deformation can take place on a very local scale. Also, cold welding can form bonded junctions between the two materials.

When sliding begins, the bonds between the two materials have to be broken, also the asperities may plow across the surface of the other body in contact, which will lead to plastic and elastic deformation. Since the static friction may be higher than the kinematic friction, friction oscillations (i.e. “stick-slip”) may occur when the surfaces stick together until the elastic energy of the system has built up to the point where a sudden forward slip takes place. This may cause vibration, noise etc.

The roughness of a surface can be divided into four categories:

- Macrodeviations , typically due to lack of accuracy in manufacturing
- Waviness , typically due to oscillations of the machine-tool-workpiece system during machining
- Roughness , typically due to geometry of cutting tool, structure of workpiece, vibrations, etc.
- Microroughness , typically due to internal imperfections in the material, nonuniform deformation, oxidation etc.

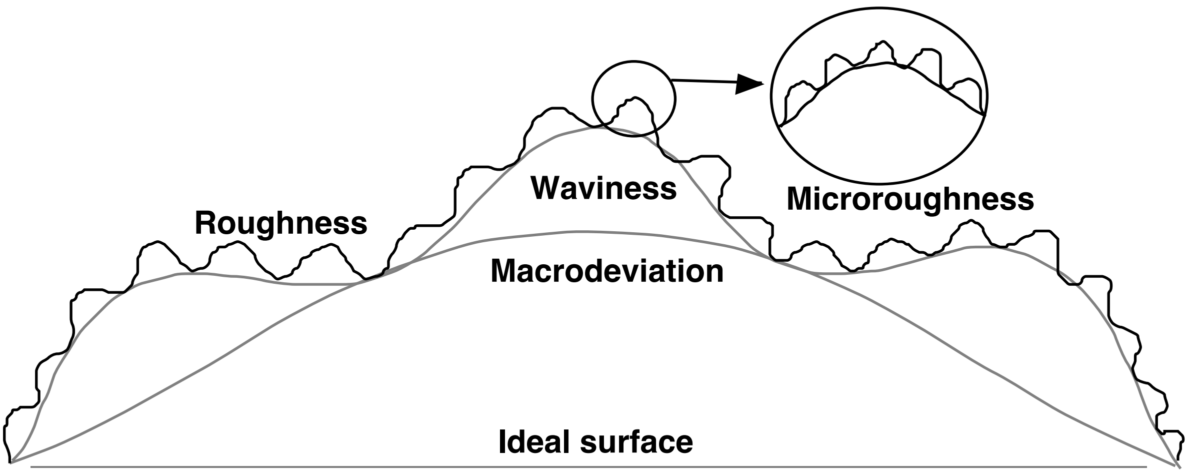


Fig. 1 Schematic sketch of macrodeviation, Waviness, roughness and microroughness.

The roughness can be measured by the use of a profilometer, which measures the peaks and throughs along a line. As a measure of the roughness, the roughness average (i.e. the mean vertical deviation from the center line) or the root mean square value (RMS) of the deviation is normally used. For two surfaces in contact, the composite roughness is defined by

$$\sigma = \sqrt{\sigma_1^2 + \sigma_2^2} \tag{1}$$

where $\sigma_1$ and $\sigma_2$ are the RMS-roughness of the two surfaces.

Often, only the highest 10% of the asperities are involved in contact. Their height distribution can often be represented by the tail end of a Gaußian distribution.

## 2. ELASTIC AND PLASTIC DEFORMATION DURING CONTACT

During wear, the surface layers of metals tend to be heavily deformed. Often plastic deformation occur even in brittle material (due to compressive loading). The depth of the deformation is typically some 40 μm, and the shear strains can be as high as 1100%.

In order to model the transition from elastic to plastic contact, Greenwood and Williamson introduced a plasticity index, defined as

$$\psi = \frac{E'}{H}\sqrt{\frac{\sigma}{\beta}} \tag{2}$$

where $\psi$ is the plasticity index, $\sigma$ is the standard deviation of the asperity height distribution and $\beta$ is the radius of the asperity tips. Also, E' is the effective elastic modulus given as

$$E' = 1 \Big/ \left( \frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2} \right) \tag{3}$$

where index 1 and 2 denotes the two bodies in contact, E is Young's modulus and $\upsilon$ is Poisson's ratio.

Typically,

- ❑ $\psi > 1 \Rightarrow$ significant plastic flow
- ❑ $0.6 < \psi < 1 \Rightarrow$ mixed elastic/plastic conditions
- ❑ $\psi < 0.6 \Rightarrow$ plastic flow is unlikely

According to this model, surface geometry and topography are determining the amount of plastic deformation. This is obvious since load does not enter the expressions above. Also, an initial plastic deformation may smoothen the surfaces and the contact will then be elastic.

## 3. FRICTION COEFFICIENT

Friction is usually represented by the friction coefficient, which is defined as

$$F = \mu N \tag{4}$$

where F is the friction force, N is the normal force and $\mu$ is the friction coefficient. The static friction coefficient, $\mu_s$ (which is the friction which has to be overcome to initiate motion) is normally higher than the kinematic friction coefficient, $\mu_k$ (which is the friction that has to be overcome to maintain a motion). $\mu_s$ can be measured by tilting a plane and measure the angle where a body placed on the plane starts to slip. One obtains

$$\mu_s = \frac{F}{N} = \frac{W\cos\theta}{W\sin\theta} = \tan\theta \qquad (5)$$

where W is the weight of the body.

The friction coefficient typically ranges from 0.03 for a well lubricated bearing, up to 0.7 for dry sliding (could be ≥5 for dry sliding in vacuum).

It has been found that the friction coefficient is not a unique materials property, instead it is considered a systems property that depends on the nature of the two surfaces, the materials, the environment, etc. However, for a certain pair of materials, there are ranges of the friction coefficient that are valid for most practical circumstance.

The occurrence of friction has been accounted to two different mechanisms, the plowing of asperities (peaks) and adhesion (i.e. atomic bounding between the two surfaces). For materials in vacuum, the latter term is of great importance, together with the flow stress properties of the near-surface material (since the majority of the sliding deformation takes place here).

For materials under "normal" conditions, the adhesion term is hard to distinguish. This is possibly due to two factors

- ❑ A large part of the surface is covered with oxides, absorbates etc. Only a few high asperities penetrate these coatings and form a metal to metal bond which gives adhesion.
- ❑ There are locally large elastic deformations below the asperities. When the body slides, these stresses are released and will rupture the adhesive bonds (this should be as valid in vacuum conditions).

It is therefore generally thought that adhesion is not a clearly separate part of the friction under "normal" conditions, but rather a part of the plastic deformation of asperities.

By equating the plastic work in surface deformation with the work done by the friction force, the friction coefficient can be expressed as

$$\mu = \frac{\tau_0\gamma_0}{H(1+n)} \qquad (6)$$

where H is the hardness and n is the work-hardening exponent in the shear stress/strain flow equation $\tau = \tau_0\gamma^n$. This model does not take adhesion into account.

To make a more general expression, the friction coefficient can be expressed as

$$\mu = \mu_a + \mu_p + \mu_e + \mu_{part} \quad (7)$$

where $\mu_a$ is due to adhesion, $\mu_p$ is due to plastic deformation and plowing, $\mu_e$ is contribution from elastic deformation below the plastically deformed zones and $\mu_{part}$ is due to the influence of third-bodies (mainly trapped wear particles). The relative contribution from the different parts depends on surface geometry, load level etc.

Also, the microscopic mechanisms are a bit more complicated than the description above, and additional mechanisms, such as mechanical interaction of surface asperities, deformation/fraction of surface layers and interference and local plastic deformation caused by third bodies (such as wear particles) are involved.

Normally, the friction coefficient, $\mu$, is lower in air than in vacuum due to the absorption of molecules from the ambient air.

# 4. Rolling Friction

The friction coefficient in rolling can be as low as 0.001 for hard materials. Lubricants have little effect on rolling friction.

Free rolling (with no adhesive forces) are made up from three components, which will be described below. Rolling friction is usually very low and mainly due to inelastic deformation.

### Microslip and Friction in the Interface

Microslip occurs when the two bodies have different elastic properties or different curvature. However, the effects are insignificant unless there is a large area of contact (e.g. a ball in a deep groove) in which cases $\mu_r$ may approach 0.3 or when the rolling is tractive, in which case the friction will approach sliding.

### Inelastic Properties of the Materials

Dominate rolling friction in free rolling. For ideally elastic materials, there would be no energy loss during rolling, but in reality, there is some inelastic hysteresis and the pertinent energy loss is dissipated at a depth corresponding to maximum shear. If the thermal conductivity is low and the dissipated energy is large, this can lead to thermal fatigue or even thermal failure.

### Surface Roughness

For a ligthly loaded rough hard surface, the energy expended in lifting the rolling body over irregularities gives a small contribution to the rolling friction. This contribution increases with the rolling speed. Also, at local asperities in rough surfaces, the contact pressure may be concentrated to the point where permanent deformation occurs. Both of these effects are usually small.

# REFERENCES

1. ASM International, ASM Handbook, vol XXX, xxx pp., Materials Park, Ohio, U.S., 19XX