Frictional Contact

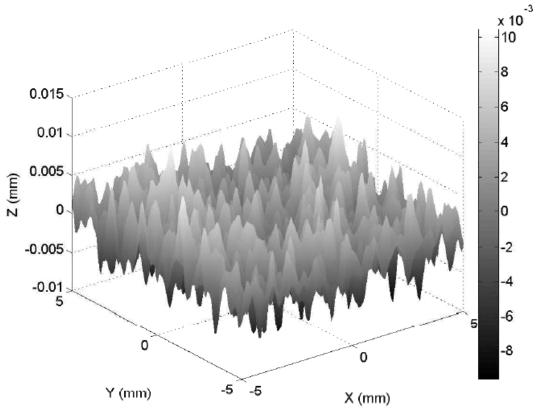
Contact Mechanics – Lesson 2

Ansys

Origin of Friction

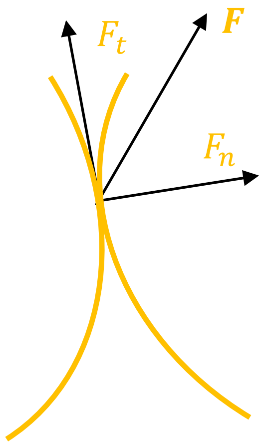
- All engineering surfaces have irregularities at various scales.
- When two surfaces slide over each other, these irregularities interact and result in forces that resist the motion, which is nothing but friction.
- These irregularities are called asperities and they result in the surface roughness.
- Several factors affect the frictional behavior between the surfaces. A few examples include:

1. Surface finish
2. Material properties of surfaces
3. Chemical properties of the surfaces
4. Loads and boundary conditions



Origin of Friction (cont.)

- In terms of contact forces, the force component F_t in the tangential direction is nothing but the frictional force.
- So, the normal force F_n tries to prevent penetration of bodies into each other and F_t tries to prevent the sliding of bodies over each other.

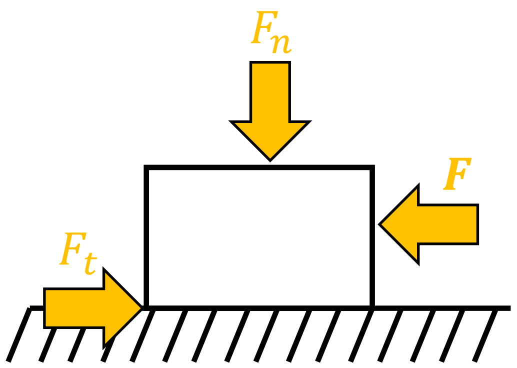


Coulomb's Law of Friction

- Friction is a very complex phenomenon and capturing a fully detailed response is often challenging.
- But, holistically, it can be described using a simple model called the Coulomb friction model.
- This law states that the body starts sliding only when the applied force is more than or equal to the product of normal force times the coefficient of friction.

$$F \geq F_t = \mu F_n$$

- When F<Ft, then the body remains in a static state and this is called a sticking state.
- When F>Ft, the body starts sliding and this state is called a slipping state.



Coefficient of Friction

- The coefficient of friction (COF) is a single property that encapsulates the frictional behavior between two surfaces.
- This quantity is specific to a pair of surfaces; it depends on surface roughness, material properties, adhesion, etc., between the pair of surfaces.
- In the simplest form, a constant value of COF is used to model the frictional behavior.
- If a body transitions from a stick to slip state, then its COF may change as a function of the sliding velocity (V). This is defined by Coulomb's law as

$$\mu(V) = \mu_d + (\mu_s - \mu_d)e^{-c|V|}$$

- Where μ_d is the COF in slipping state, μ_s is the COF in sticking state and c is a decay constant.

Coefficient of Friction (cont.)

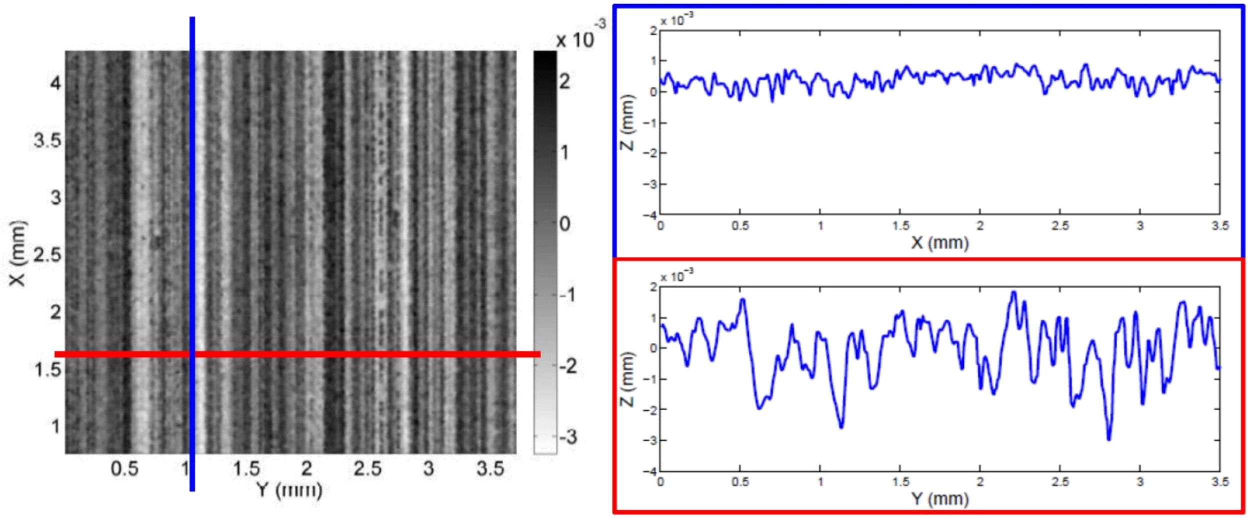
- In some systems the difference between the static and dynamic COFs may be too little, in which case one may use a constant value for COF.
- Here are the values for a few common, unlubricated systems:

System	μ_s	μ_d
Wood on wood	0.5	0.3
Metal on wood	0.5	0.3
Steel on steel	0.6	0.3
Teflon on steel	0.04	0.04

- Note that these values are just estimates and may vary depending on applications and loading conditions of the systems.

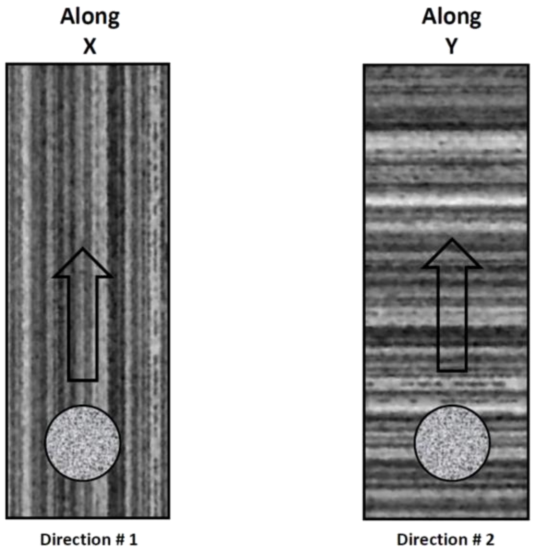
Directional Friction

- Since friction depends on the texture of the surfaces, it can be dependent on the direction of sliding if the surface has an oriented texture.
- In this example, the aluminum sample has a texture in the direction in which it was extruded.



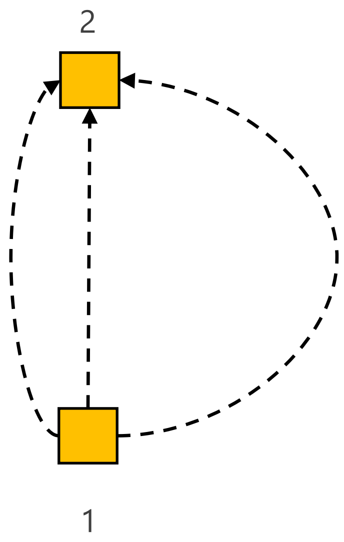
Directional Friction (cont.)

- As a result, a body sliding in the X direction experiences different frictional forces compared to the Y direction.
- This is called anisotropic friction.
- In this case, the Coulomb friction model can be modified to have different COFs in two directions.



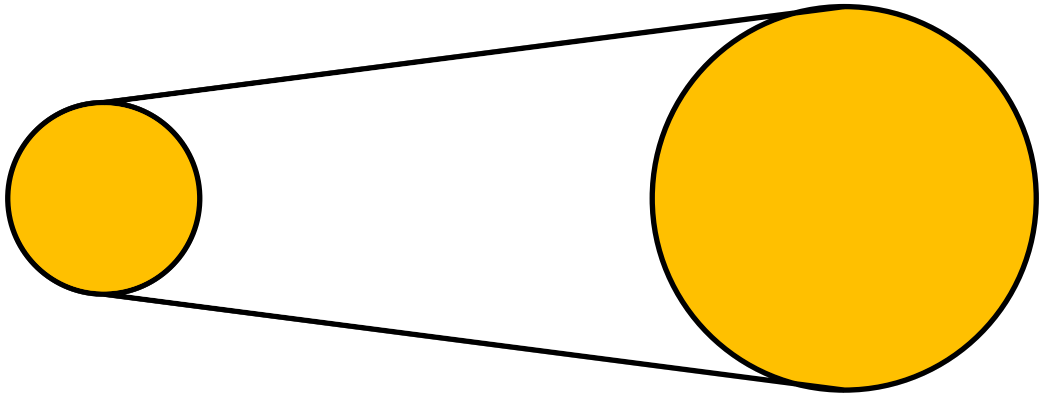
Energy Loss

- Friction is a retarding force which dissipates the kinetic energy of the system as heat energy.
- So, the path taken by the sliding body can affect the amount of energy dissipated by the system, which makes friction a path-dependent force.
- For instance, in this case, a body slides from position 1 to 2 and it takes three different paths.
- If the surface is frictionless, then there's no loss of energy and this is a path-independent system.
- If the surface has finite friction, then the energy lost in each path is different and this makes it a path-dependent system.



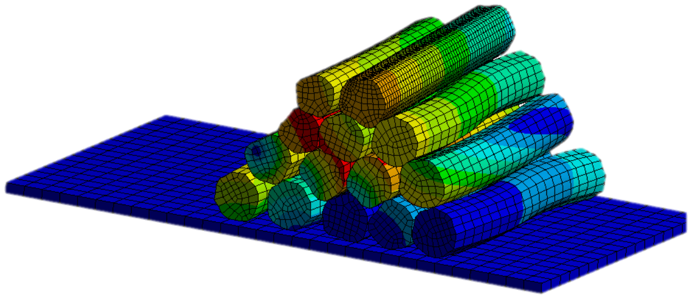
Importance of Friction

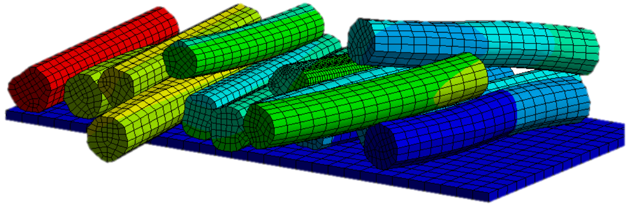
- Friction is a key physical behavior in many applications and not including it may change the behavior of a system drastically.
- For instance, in a belt drive system, the transmission of power takes place from the driver to the driven due to the friction between the belt and the shafts.
- In the absence of friction, the belt slips on the driver shaft and does not transfer the power to the driven shaft.



Importance of Friction (cont.)

- Similarly, when a bunch of wood logs are piled on top of each other, they stay in place because the frictional force between them is able to balance the gravitational pull and maintain a static state.
- If the friction force is not accounted for, then there are no forces to balance the gravity and the wood logs would simply slide away and turn into a transient case.





Limiting Frictional Force

- When the applied force is less than the frictional force, the bodies do not slide over each other.
- Sometimes, when the applied force is very high and yet smaller than the frictional force, the surface tears at the microscopic level and results in gross sliding.
- This is commonly seen in applications such as surface grinding or when surfaces wear during operation.
- This is because when the friction force is limiting any sliding, the shear stresses at the surface increase and when it exceeds the material failure limits it fails and allows for gross sliding.
- This limiting friction force is dependent on the properties of the softer material between the two mating surfaces.

Limiting Frictional Force (cont.)

- In case of metals, this limiting shear stress is defined as a function of the yield strength.

$$\tau_f^{max} = \frac{\sigma_Y}{\sqrt{3}}$$

- If there are two different metals in contact (e.g., steel-aluminum), then the limiting shear stress is calculated based on the yield strength of the softer material (aluminum).
- In case of other materials such as elastomers, this limiting force is calculated based on the failure properties of those materials.
- A reasonable estimate of this value should be calculated from physical experiments.

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