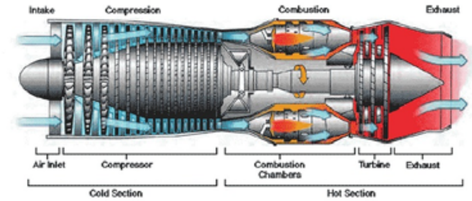
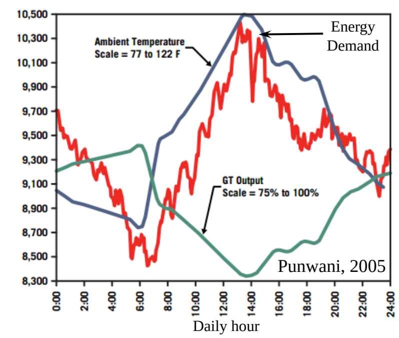
Outline

- Introduction
- Friction
- Example
- Lubrication

Water Droplet Impingement Erosion (WDIE)

Incoming air temperature ↑
Mass flow rate ↓
Output power ↓





Temperature 1°F ↑ → Turbine efficiency 0.3-0.5% ↓

Turbine inlet cooling system

Applying a MeeFog system

The cost per kilowatt of a plant can be reduced by as much as 15%
MEE industries inc. 2013

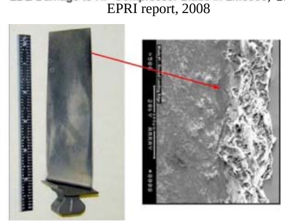
Water Droplet Impingement Erosion (WDIE)

WDIE on blades and their degradation

- Reduction in aerodynamic performance
- Reduction in life time
- Unscheduled outage and maintenance
- Engine instability
- Engine shut-off/power loss
- High Cost

Understanding WDIE and failure mechanism is crucial for gas and steam turbine alloys, e.g. Stainless Steel and Titanium alloys

LDE Damage to HP Compressor Blade in LM6000, GE
EPRI report, 2008



Alstom Steam Turbine, airfoil
A. Uihlein, EPRI 2012

Solid Particle Erosion

BA 9 from London to Auckland – Jakarta incident

Flying through sand storm

Flying through volcanic ash

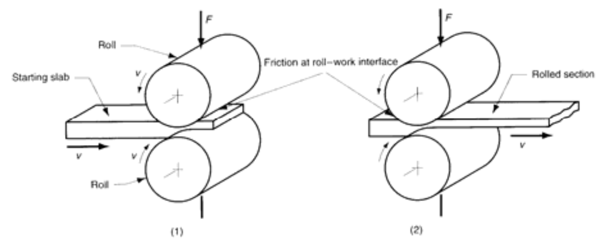
Introduction

- Tribology – the study of friction, wear and lubrication of interacting surfaces in relative motion.

Friction:

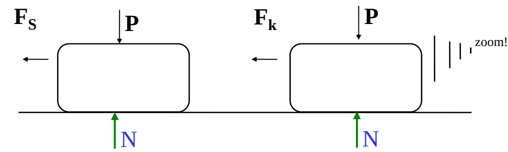
- Barreling in compression test
- In forging, rolling, sheet metal forming and machining
- Friction – the resistance to relative motion between two bodies in contact.
- Force to overcome friction
- Static (μ_s) and Kinetic (μ) frictions

- Cutting Processes
- Material Handling
  - *- Conveyors*
- Forming
  - *– Forging*
  - *– Rolling*



Wear and Friction

- BEARINGS - Minimal friction & Minimal wear
- BRAKES - Maximum friction & Minimal wear
- MACHINING - Maximum wear & Minimal friction



$F_S = \mu_S N$ $F_k = \mu_k N$

Frictional force is lower once object is moving. $\mu_{kinetic} < \mu_{static}$
Note: Not dependent on area!
only on P

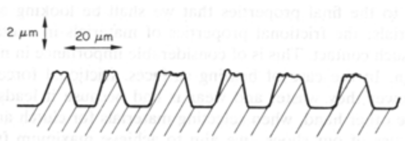
The nature and strength of the interface is the most significant factor

$$\mu = \frac{F}{N} = \frac{\tau \times A}{\sigma \times A} = \frac{\tau}{\sigma}$$

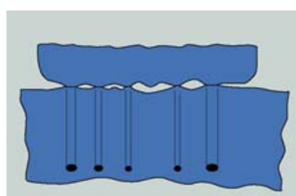
Surface property (τ), *Bulk property* (σ)

- Friction coefficient can be reduced by decreasing τ and/or increasing σ.
- This observation suggests that placing thin films of low shear strength over a substrate with high hardness is the ideal method for reducing abrasive friction.
- In fact this is exactly what is achieved by a lubricant layer.

Friction



Finely machined metal surface at high magnification (not linear)

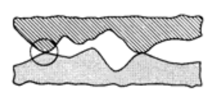


The ratio of the apparent and real areas can be as high as four to five orders of magnitude.

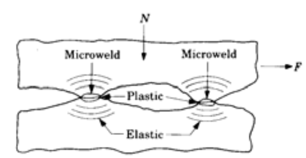
- So two surfaces touching have only very small real contact area.
- Initially, get elastic deformation at asperities for low loads.
- Then as loads increase, get plastic deformation forming junctions.

- Need relatively large force to break these.
- Once moving - less force.

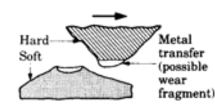
Friction



Asperities Contact

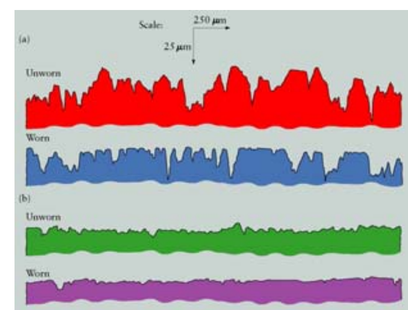


Adhesion Theory

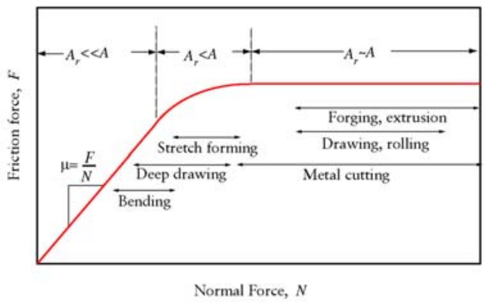


Effects of Microwelding

Changes in originally (a) wire-brushed and (b) ground-surface profiles after wear. (*From Kalpakjian Figure 4-9)*



Friction Force vs. Normal Force



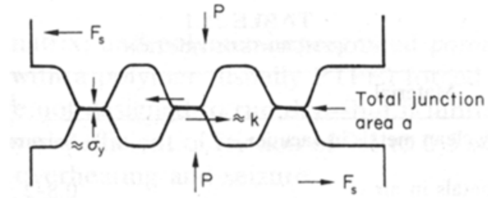
Schematic illustration of the relation between friction force F and normal force N.

- As the real area of contact approaches the apparent area, the friction force reaches a maximum and stabilizes.
- Most machine components operate in the first region.
- The second and third regions are encountered in metalworking operations, because of the high contact pressures involved between sliding surfaces, i.e., die and workpiece.

Friction

Load transmitted across surface:

$P \approx a\,\sigma_y$ ....(1) a is the real contact area, σ_y is the compressive yield stress.



So $a \approx P/\sigma_y$ and if P is doubled so is the real contact area.

Sliding is opposed by a shear stress, τ, in asperities and is greatest at contact region. Force resisting sliding is then given by:

$F = a\tau$ .... (2)

There is now atom-to-atom contact across junctions (high plastic deformation causes micro-welding) so that junction has shear strength as large as material (k).

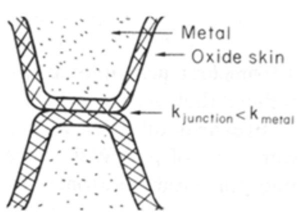
From eqn's 1 and 3

$F_s \approx P/2$ (and as $F_S = \mu_S P$, then μ_S should be ≈ 0.5 for machined metal surfaces - which is of the right order)

Sliding takes place when $F = F_s \approx ak \approx (a\sigma_y)/2$ .... (3)

Friction

Complete seizure of metals in vacuum (or reducing atmosphere which removes oxide layer).



Oxide film reduces shear stress required to break junction and reduces μ.

COEFFICIENTS OF FRICTION

Material	μ
Perfectly clean metals in vacuum	Seizure $\mu > 5$
Clean metals in air	0.8-2
Clean metals in wet air	0.5-1.5
Steel on dry bearing metals (e.g. lead, bronze)	0.1-0.5
Steel on ceramics (e.g. sapphire, diamond, ice)	0.1-0.5
Ceramics on ceramics (e.g. carbides on carbides)	0.05-0.5
Polymers on polymers	0.05-1.0
Metals and ceramics on polymers (PE, PTFE, PVC)	0.04-0.5
Boundary lubrication of metals	0.05-0.2
High-temperature lubricants (MoS_2, graphite)	0.05-0.2
Hydrodynamic lubrication	0.001-0.005

Friction

- When soft metals slide on soft metals (*e.g. lead on lead*)
  - *junctions are **weak** but area is large so μ is large (0.5 to 1.5).*
- When hard metals slide (*e.g. steel on steel*)
  - *junctions are small, but they are strong, and again friction is large.*

→ Bearings usually made of a thin film of a soft metal between two hard ones: weak junctions of small area.

E.g. ***White metal* bearings**: soft alloys of lead or tin in a matrix of stronger phases;

bearing bronzes consist of soft lead particles (which smear out to form the lubricating film) supported in a bronze matrix;

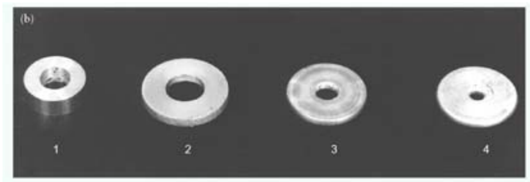
and polymer-impregnated ***porous bearings*** are made by partly sintering copper with a polymer (usually PTFE) forced into its pores.

These bearings are not designed to run dry -but if lubrication does break down, the soft component gives a coefficient of friction of 0.1 to 0.5 which may be low enough to prevent catastrophic overheating and seizure.

Measuring Friction

- One popular test is the ring compression test.
- In which the effects of lubrication on barreling can be monitored.

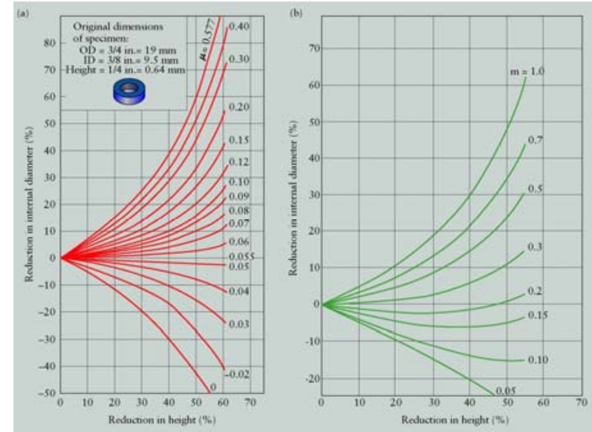
(a) With good lubrication, both the inner and outer diameters increase as the specimen is compressed; and with poor or no lubrication, friction is high, and the inner diameter decreases. The direction of barreling depends on the relative motion of the cylindrical surfaces with respect to the flat dies.



(b) Test results: (1) original specimen, and (2-4) the specimen under increasing friction.

Ring Compression Tests

Friction is determined from these charts from the percent reduction in height and by measuring the percent change in the internal diameter of the specimen after compression.



(a) coefficient of friction, μ (b) friction factor, *m*.

Friction factor:

$$m = \frac{\tau_i}{k}$$

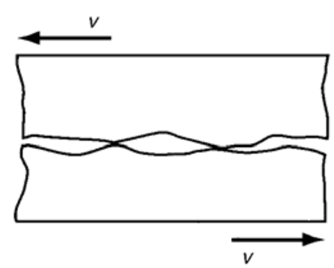
where τ_i is the shear strength of the interface and k is the shear yield stress of the softer material in a sliding pair.

Example

In a ring compression test, a specimen 10 mm high with outside and inside diameters (OD and ID) of 30 mm and 15mm, respectively, is reduced in thickness by 50%. Determine the coefficient of friction, μ, and the friction factor, m, if the OD after deformation is 39 mm.

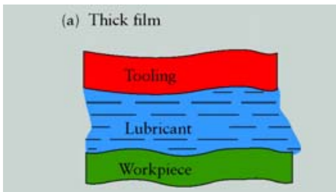
Friction

- Dry Friction
  - No Lubrication
  - Use the Right Materials
  - Very Smooth Surfaces
  - Low Speeds and Pressures



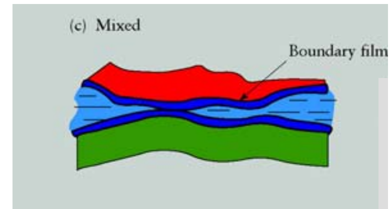
Lubrication

- Fluid Film Lubrication
  - Thick-film or hydrodynamic lubrication.
    - *Viscosity of a lubricant*
    - *Results erosion*
  - Thin-film lubrication
    - *Friction is higher than in thick-film*



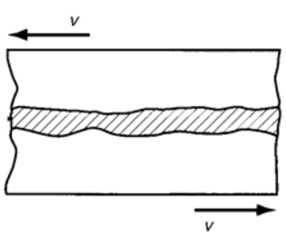
Lubrication

- Mixed-film lubrication
  - *Rough surface peaks occasionally in contact*
- Boundary Lubrication– presence of boundary layer that carry normal force
  - Extreme pressure lubrication for high T and P



Lubrication

- Solid lubrication
  - *Low coefficient of friction*
  - *High temperature resistance*



Lubricants in Manufacturing

- Functions of Metal Working Lubricants
  - Separate surfaces
  - Protect surfaces
  - Remain stable and durable
  - Cool the materials
  - Not Health-hazard
  - Inexpensive
- Mineral oil, Natural oil, synthetic fluids, Compounded lubrication, Aqueous lubrication, and coating and barrier.

Lubrication

• Friction absorbs a lot of work.

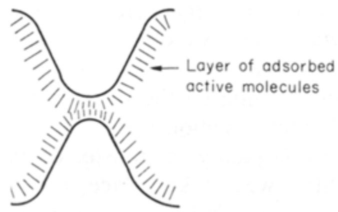
- In machinery: wastes power and generates *heat (*damage/melt bearing).

• To minimize frictional forces surfaces must easily slide over one another.

• Contaminate the asperity tips with something that:

(a) can stand the pressure at the bearing surface and prevent atom-to-atom contact between asperities;

(b) can itself shear easily.



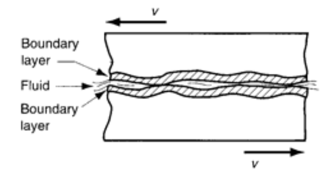
Usually, however, we would like a much larger reduction in μ than that given by soft films or polymers, and then we must use *lubricants*

Lubrication

Standard lubricants - oils, greases and fatty materials (soap, animal fats).
• "contaminate" surfaces, preventing adhesive contact;
• thin layer of oil or grease shears easily and lowers the coefficient of friction.

• Fluid oil must not get squeezed out by the enormous pressures generated, therefore active organic molecules are added (= 1%) to prevent this.
• One end of the molecule reacts with the metal oxide surface and sticks to it, whereas the other ends attract one another to form an oriented "forest" of molecules.
- can resist very large forces normal to the surface,
- separate the asperity tips very effectively;
- two layers of molecules can shear over themselves quite easily.

This type of lubrication is termed *boundary lubrication*, and is capable of reducing μ by a factor of 10.



Lubrication

• The best boundary lubricants cease to work above about 200°C.

• Soft metal bearings can cope with *local* hot spots: soft metal melts and provides a local lubricating film.

• When the entire bearing runs hot, special lubricants are needed:

- suspension of PTFE in oil (good to 320°C)

- graphite (good to 600°C)

- molybdenum disulphide (good to 800°C).

Next time:

Continue Wear