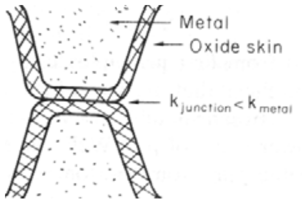
Outline

- Review: *Friction*
- Wear of Materials
    - \- *Adhesive wear*
    - \- *Abrasive wear*
    - \- *Surface Fatigue*
    - \- *Corrosion wear*
- Wear Prevention
- Design of Journal Bearing
- Materials for Skis and Sledges

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

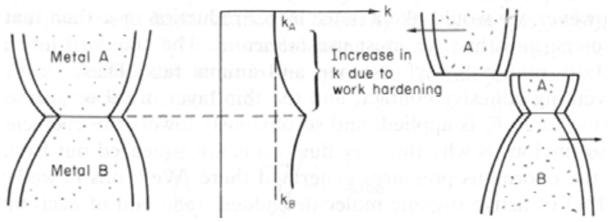
Wear of Materials

Even when solid surfaces are protected by oxide films and boundary lubricants, some solid-to-solid contact occurs at regions where the oxide film breaks down under mechanical loading, and adsorption of active boundary lubricants is poor. This intimate contact will generally lead to *wear*.

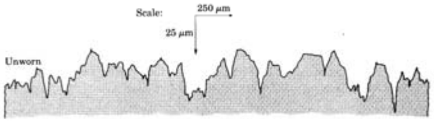
Wear is normally divided into two main types:

- \- *adhesive wear*
- \- *abrasive wear*

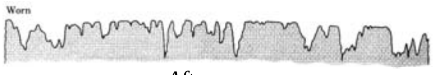
Adhesive Wear



If the adhesion between A atoms and B atoms is good enough, wear fragments will be removed from the ………. metal A. If materials A and B are the same, wear takes place from ….….. surfaces.



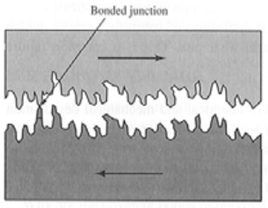
Before



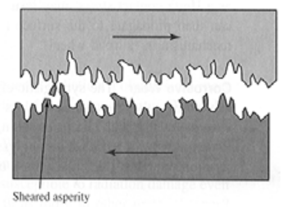
After

Adhesive Wear

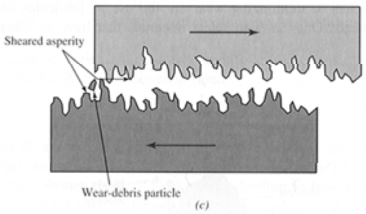
The sequence of steps occurring during adhesive wear:



(a) High local stresses plastically deform the material in the vicinity of the contact points, resulting in the formation of atomic bonds across the interface.



(b) As the force causing the relative sliding motion is increased, the shear stress in the joined region increases until it exceeds the shear strength of one of the solids.



(c) Subsequently, material is lost into the region between the two solids.

Adhesive Wear

- **The size** of the piece of metal removed from a particular asperity depends on how far away from the junction the shearing takes place.
- If the **work-hardened region extends** well into the asperity, the tendency will be to produce large pieces;
- This tendency will be reduced if the **cross-section** of the asperity increases away from the contact region.
- In order to minimise *rate of wear*, we need to minimise the size of metal pieces removed.

1) Minimise the area of contact, *a*.

Since $a = P/\sigma_y$, reducing the loading on the surfaces will reduce the wear, e.g. chalk on the blackboard

- high load → plenty of transfer of chalk to the board- severe wear .
- low load → little wear takes place.

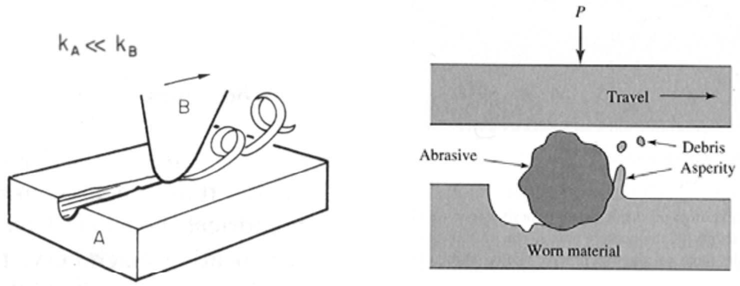
2) Increase σ_y, i.e. the *hardness*. - hard pencils write less clearly than soft pencils.

Adhesive Wear

- Metals, with their intermediate values of strength and hardness, are generally …….. resistant to adhesive wear than either:
  - *the low-strength, high-ductility polymers or*
  - *the high-hardness, low-ductility ceramics.*
- The normally **incompatible requirements** of high hardness and low shear strength make …………… materials ideal candidates for this application. Hence bearing materials are based on this idea:
  - 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.

Abrasive Wear

The loss of surface material is caused by an interaction with a separate particle "trapped" between the two sliding surfaces.



Schematic illustrations of the abrasive wear mechanism.

Abrasive Wear

- It is not unusual for the **abrading particles** to be wear debris from an adhesive mechanism, can also be caused by dirt particles (e.g. sand) making their way into the system, or - in an engine - by combustion products: that is why it is important to filter the oil.

- The rate of material loss is related to the relative hardness of the abrading particles and the sliding surfaces. *If the surface is harder than the particle, the wear rate is minimal.*

- Materials with high hardness, high toughness, and reasonable temperature stability are good candidates for applications requiring high abrasive wear resistance.

- Common selections for this application include tempered martensite, surface-hardened steels, cobalt alloys, and many ceramics.

- Abrasive wear is usually bad - as in machinery - but we would find it difficult to sharpen lathe tools, or polish brass ornaments, or drill rock, without it.

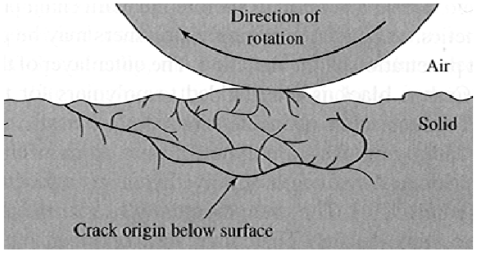
Surface Fatigue

- The previous two wear mechanisms are common during sliding motion.

- If, however, one component is rolling over another, the wear mechanism is often surface fatigue.

- The state of stress developed during rolling contact shows that a …………. shear stress (*Hertz contact stress*) is developed slightly below the surface, and may result in the nucleation of subsurface cracks, which can then propagate to the surface and form wear pits.

- This is a common failure mechanism in railroad wheels.



Wear fatigue mechanism showing the location of the subsurface crack origin

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Corrosive Wear

- The synergistic effects of …………. and …………… degradation can increase the rate of material loss from a solid surface.

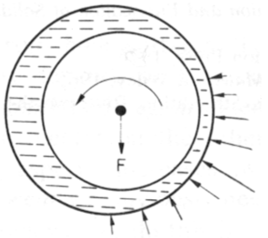
- For example, mechanical wear associated with sliding or rolling can break down a protective film and expose the underlying material to an aggressive environment. Alternatively, the corrosion reaction products, particularly hard oxide particles, can serve as abrasive particles.

Corrosive wear

Wear Prevention

- Common approaches to minimizing wear are:
  - Lubricants
  - Surface-hardening treatments.
  - Wear resistance materials.
- Surface-hardening treatments for reducing wear include:
  - *case carburising commonly used in engine crankshafts,*
  - *ion implantation used in surgical instruments*
  - *hard-faced ceramic coatings used in turbine blades and fibre guides in the textile industry .*

Design of Journal Bearings



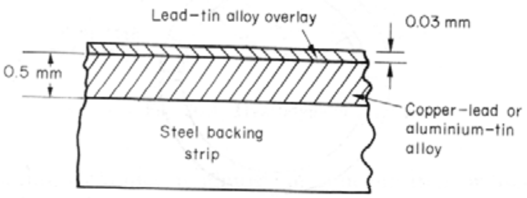
- In the proper functioning of a well-Lubricated journal bearing, the frictional and wear properties of the materials are, surprisingly, irrelevant.
- The mating surfaces are kept apart by a thin pressurized film of oil formed under conditions of *hydrodynamic lubrication.*
  - Working clearance is concentrated on one side.
  - Oil is viscous, and is dragged around by shaft.
- The convergence of the oil stream causes an increase in pressure of the oil film, and this pressure literally holds up the shaft against the applied force.
- Pressures of 10 to 100 atmospheres are common under such conditions.
- Journal bearings only operate under hydrodynamic lubrication when the rotational speed of the journal is high enough. When starting an engine up, or running slowly under high load, **hydrodynamic lubrication is …………….**, and ……………………… occurs.

Design of Journal Bearings

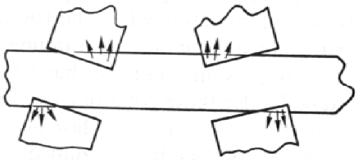
- Provided the oil is sufficiently viscous, the film is thick enough to cause complete separation of the mating surfaces:
  - *there should be no asperity contact, and*
  - *no wear, under ideal hydrodynamic conditions.*
- Sliding of the mating surfaces takes place by shear in the liquid oil itself.
- Coefficients of friction (hydrodynamic lubrication) are reduced to 0.001 to 0.005.
- Real bearings contain dirt- (silica), (*new automobile engines contain hard cast-iron dust from machining operations*).
- If particles are thicker than the oil film at its thinnest - **abrasive wear will take place**.
- Make the mating surfaces harder than the dirt particles. *("case-hardened" to increase the hardness of the surface of the journals/shafts*)
- Make the bearing metal soft enough, so dirt particles will be pushed into the surface and out of harm's way. This property of bearing material is called **………………….**
- Principle of *plastic constraint* is used in bearing design by depositing a very thin layer (about 0.03 mm thick) of soft alloy on to the bearing shell. This is thick enough to embed most dirt particles, but thin enough to support the journal forces.

Design of Journal Bearings

- If oil supply fails, frictional heating will rapidly increase the bearing temperature, normally lead to metal-to-metal contact and eventual seizure.
- Soft bearing material (low melting point) will be able to shear and may also melt locally. **Protects** the journal from severe surface damage, and helps to avoid component breakages (*sudden locking of mating surfaces*)

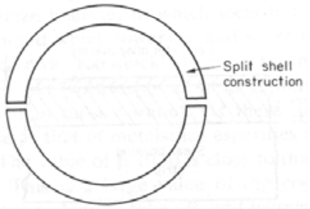


- Soft bearing material has *conformability*. Slight misalignments of bearings can be self-correcting if plastic flow occurs easily in the bearing metal.
- Clearly there is a compromise between load-bearing ability and conformability.

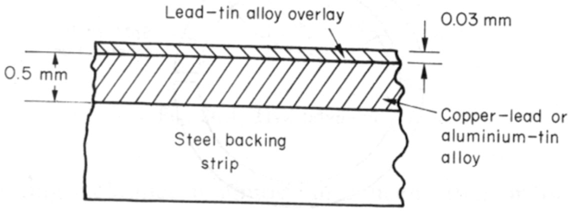


Design of Journal Bearings

- Thin overlay of lead-tin can get worn away under severe operating conditions **before** the end of the normal life of the bearing,



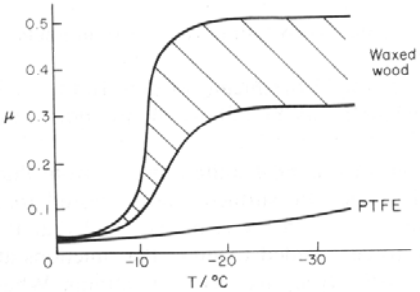
- Customary to put a second thicker, and harder, layer between the overlay and the steel backing strip. The alloys normally used are copper-lead, or aluminium-tin.
- In the event of the wearing through of the overlay they are still soft enough to act as bearing materials without immediate damage to the journal.



Materials for Skis and Sledge Runners

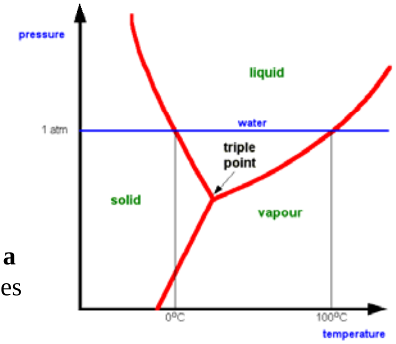
- Skis, (for people and aircraft), used to be made of waxed wood.
- Down to about ~ -10°C, the friction of waxed wood on snow is very low (is about 0.02).
- Below -10°C, bad things start to happen μ rises sharply to about 0.4.
- Polar explorers have observed this - Wright, (*1911-13 Scott expedition*), writes:

"*Below 0°F (-18°C) the friction (on the sledge runners) seemed to increase progressively as the temperature fell*".



Materials for Skis and Sledge Runners

- For ice, its melting point drops if you compress it.
- Many believe that pressure from the skis causes the snow beneath to melt.
- Nonsense: large man lowers the melting point by only 0.1°C at asperities: (*10^{-3} of nominal area*),
- Work is done against the frictional forces; heat is generated at the sliding surface, sufficient to melt a layer of ice, **producing a thin film of water**, at points where asperities touch the ski.
- The skier hydroplanes along on a layer of water generated by his/her own friction.



Materials for Skis and Sledge Runners

Why skis with exposed metal (aluminium or steel edges) are slower at low temperatures than those without?

- Below -10°C, heat is conducted away too quickly to allow melting
- The mechanism of friction is the same as that of metals: where ice asperities adhere to the ski and must be sheared when it slides.
- Coefficient of friction is large (0.4) - (*ski-planes, skis, sledges etc have problems*)
- When ceramics (ice is a ceramic) slide on polymers, μ can be as low as 0.04.
- PTFE ("Teflon ") and polyethylene have very low μ values.
- By coating the ski or sledge runners with these materials, the coefficient of friction stays low, *even* when the temperature is so low that frictional heating is unable to produce a boundary layer of water.

- Aircraft and sports skis now have polyethylene or Teflon under surfaces.

Next time:

Materials Selection