WEAR

- Damage to a surface from relative motion
  Loss of material from surface during sliding
  Movement of material (plastic deformation)
  Cracking of surfaces

- Applications:
  reduce: brakes, clutches
  increase: chalk on blackboard, cutting, grinding

- Wear & Friction related. Changing one alters the other.
CONTROLLING FRICTION & WEAR

• Lubrication:

Lubricant: liquid, solid, gas  
Pressures/forces separate surfaces  
Reduced surface contact reduces friction & wear  
Lubricant sacrificed  
Mechanically compliant  
Moderate friction: $\mu \approx 10^{-2}$ to $10^{-1}$

• Surface Coatings:

Coating protects substrate  
Hard or soft  
Example: tungsten carbide coating on saw blade

• Surface vibrations:

Vibrations alter geometric clearance & alignments  
Interfacial events disrupted  
Interfacial physics changed
WEAR

Loss of material from surface during sliding

Complicated: many mechanisms operating at same time
• Adhesive: mild
• Abrasive: moderate to severe
• Corrosive
• Delamination/peeling
• Pitting
• Thermal effects
• Thermomechanical effects: severe

Measuring wear
• weight loss
• volume reduction
• surface recession: constant cross sectional area
• radioactive implants
• collect/sample wear debris
Surface Damage

- Surfaces of machine parts damaged

- Part malfunctions
  - slowdown
  - machine inaccuracies
  - further damage
  - part/ machine replacement
  - shutdown

- Types (cost in 1978)
  - corrosion (70 billion)
  - wear (20 billion)
  - surface fatigue
  - thermal fatigue
  - arcing (~ 5 billion)

- ~ $100 billion ≈ 5% GNP 
  COSTLY!
WEAR

Relationships to other variables
- Geometry
- Force Sliding speed
- Distance slid
- Power dissipated
- Material combinations
- Environment

Sensitive to environment
- temperature
- humidity
- vibrations
- chemistry: atmosphere, contaminants, surface deposits

Same test, but different location and/or time
Variations of 2 to 10 common
WEAR MECHANISMS

• Total wear sum over competing mechanisms

\[ W = \sum_{i} W_i \approx W_k \]

all mechanisms proper conditions (Dominates)
ADHESIVE WEAR

- fundamental (always present), but dominant @ low speed

- mechanism
  sliding ⇒ asperities approach each other
  asperities interfere: bond/weld
  further sliding breaks ⇒ 10 to 100 µm wear particle

- Example:
  http://www.tribology-abc.com/calculators/data_00.htm
ARCHARD/HOLM WEAR LAW

• asperities contact, maximum area of contact

\[ \delta A = \frac{\delta P}{H} \]

• wear particle detaches, volume

\[ \delta V \propto (\delta A)^{3/2} \]

• sliding distance between interactions

\[ \delta L \propto (\delta A)^{1/2} \]
• assemble:
  \[
  \frac{\delta V}{\delta L} = K \delta A = K \frac{\delta P}{H}
  \]

• sum over all asperities between sliders: \( \delta P \rightarrow P \)
  sum over sliding path: \( \delta L \rightarrow L \)

\[
V = \frac{K}{H} P L
\]

V: total volume of material lost from slider [m\(^3\)]
P: total normal force [N]
H: material hardness [N/m\(^2\)]
L: total distance slid [m]
K: wear coefficient
VALUES OF WEAR COEFFICIENT

<table>
<thead>
<tr>
<th>Slider</th>
<th>H $10^8$ N/m²</th>
<th>K $10^{-3}$</th>
<th>Counter surface</th>
<th>Friction Coeff</th>
</tr>
</thead>
<tbody>
<tr>
<td>mild steel</td>
<td>18</td>
<td>7 x $10^{-3}$</td>
<td>mild steel</td>
<td>0.6</td>
</tr>
<tr>
<td>60/40 leaded brass</td>
<td>9.5</td>
<td>6 x $10^{-4}$</td>
<td>tool steel</td>
<td>0.24</td>
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<tr>
<td>stainless steel</td>
<td>25</td>
<td>1.7 x $10^{-5}$</td>
<td>tool steel</td>
<td>0.53</td>
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<tr>
<td>tungsten carbide</td>
<td>130</td>
<td>1 x $10^{-6}$</td>
<td>tungsten carbide</td>
<td>0.35</td>
</tr>
<tr>
<td>polyethylene</td>
<td>1.7</td>
<td>1.3 x $10^{-7}$</td>
<td>tool steel</td>
<td>0.53</td>
</tr>
<tr>
<td>electrographite</td>
<td>1 to 2</td>
<td>8 x $10^{-8}$</td>
<td>copper</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Environmental conditions: dry/air
**Example**

Aluminum impregnated graphite block
(area $A_o = 1 \text{ cm}^2$, length $l = 10 \text{ cm}$, hardness $H = 100 \text{ MPa}$)

slides against steel ($H \approx 3000 \text{ MPa}$).

Surface speed $U = 1 \text{ m/s}$, normal force $F = 100 \text{ N}$.

Estimate total wear over 1 hour.

**Solution**

$H_{\text{graphite}} < H_{\text{steel}} \Rightarrow \text{graphite wears}$

Total wear volume

$$V = W_V t = \frac{K_{G/St} F U t}{H_g A_o}$$

$$= (0.26 \times 10^{-10} \text{ Pa}^{-1}) \frac{100 \text{N}}{10^{-4} \text{m}^2} (1 \text{ m/s}) (3600 \text{s})$$

$$= 0.0936 \text{ m} = 9.36 \text{ cm}$$

**Block almost gone!**
WEAR LAW / OTHER FORMS

- Volumetric

\[ V = K_v P L \]

\[ K_v = \frac{K}{H} \]

- Surface recession

\[ \delta = \frac{V}{A} = K_\delta P L \]

\[ K_\delta = \frac{K_v}{A} \]

A: cross sectional area of slider \([\text{m}^2]\)

- Volumetric wear rate

\[ \dot{V} = K_v P \nu \]

\( \nu \): relative surface sliding speed \([\text{m} / \text{s}]\)

- Mass wear rate

\[ WR = K_m P \nu \]

\[ K_m = \rho K_v \]

\( \rho \): mass density of slider \([\text{g} / \text{m}^3]\)
ABRASIVE WEAR

• Hard abrasive particles
  from environment
  generated by wear processes
  become entrapped within sliding interface

• Sliding
  particles become plows
  surfaces gouged/scratched
  ⇒ large wear particles

• High wear coefficient
  \( K_{\text{abrasive}} \approx 10 \text{ to } 100 \ K_{\text{adhesive}} \)
OTHER WEAR MECHANISMS

• Corrosive wear
  Adhesive or abrasive wear, but with corrosion affecting wear surface. K can be higher or lower.

• Delamination/peeling
  Stress from repeated application of load causes subsurface cracking parallel to the contact surface. Strips delaminate and peel off.

• Pitting
  Stress from repeated application of load causes subsurface cracking at angle (∼20°) to contact surface. Cracks eventually meet surface, resulting in wear particle and "pit".
THERMAL EFFECTS ON WEAR

• Heat generated by friction

\[ Q = \mu P v \quad [W] \]

\( \mu \): friction coefficient
\( P \): total normal force [N]
\( v \): relative surface sliding speed [m/s]

• Material properties altered

metals softened: yield strength & hardness reduced

carbon mixtures hardened

thermal & electrical properties altered
thermal, electrical conductivities reduced
heat capacity

• Concentrated contact (hot spots, thermal mounds)
\( \Rightarrow \) much higher wear
CONCENTRATED CONTACT

- contact between rough surfaces
  ⇒ discrete spots (islands) of contact between surfaces

- sliding commences, @ higher sliding speeds
  friction heats @ contact spots
  spots expand & grow
  some spots separate
  loads transferred to still-connected spots
- loads transferred to still-connected spots
- more intense conditions
- process continues until slider runs on few spots
References


