ME 355

NOTES ON FRICTION & WEAR

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FRICTION - WEAR - LUBRICATION

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TRIBOLOGY

- FRICTION 10 b
- WEAR 100 b
- ELECTRICAL CONTACTS 2 b
- ADHESION (W/O ADHESIVES) ·03

LOSS OF USEFULNESS OF MATERIAL OBJECTS

- OBSOLESCENCE 15 %
- BREAKAGE 15 %
- 70 % SURFACE DETERIORATION
  - WEAR 55 %
    - Adhesive 25 %
    - Abrasive 20 %
    - Corrosive Wear 2 %
    - Surface fatigue 8 %
  - Corrosion 15 %

SOME COUNTER-INTUITIVE EXAMPLES

1. FILE VS FILE WITH LUBRICANT

LESS NOISE; LESS WORK DONE

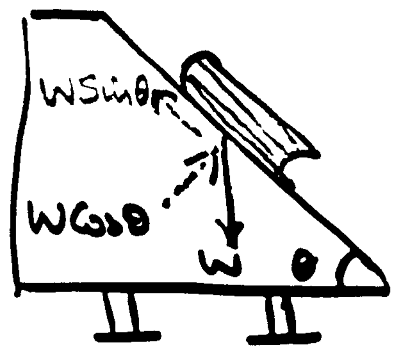
BUT MORE MATERIAL REMOVED!

2. GENERALLY BELIEVED:

HIGHER ROUGHNESS ⇒ HIGHER FRICTION

BUT A VERY SMOOTH SURFACE MAY HAVE HIGHER FRICTION

TRIBOLOGICAL PROPERTIES



- SURFACE INTERACTIONS

THREE MECHANICAL PHENOMENA:

FRICTION : TANGENTIAL FORCE TRANSMITTED

WEAR : MATERIAL REMOVED

ADHESION: EXTENT OF INTER-ATOMIC BONDING

MATERIAL PROPERTIES THAT INFLUENCE SURFACE INTERACTIONS

1. VOLUME PROPERTIES:

YIELD STRENGTH
HARDNESS

YOUNG'S MODULUS
SHEAR MODULUS
STORED ELASTIC ENERGY

BRITTLENESS (i.e., PLASTIC DEFORMATION BEFORE FRACTURE)

THERMAL PROPERTIES (IMPORTANT IN HIGH SPEED SLIDING)

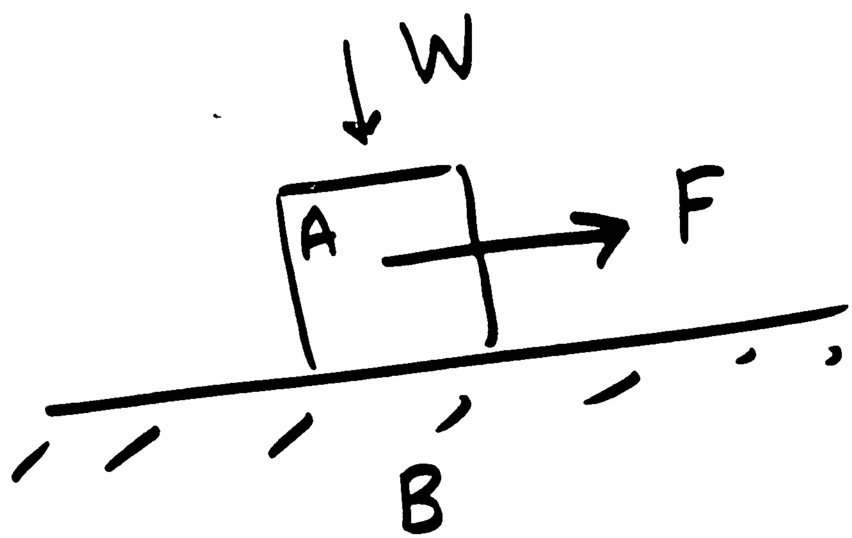
MATERIAL PROPERTIES, CONT'D.

2. SURFACE PROPERTIES

- CHEMICAL REACTIVITY
  - Tendency of a surface to acquire a film of different chemical composition (e.g. an oxide film)
- CHEMICAL ABSORBTIVITY
  - tendency to absorb molecules from the environment
- SURFACE ENERGY
  - determines work needed to create fresh surface area
- INTERFACIAL ENERGY
  - determines the compatibility of two contacting surfaces.

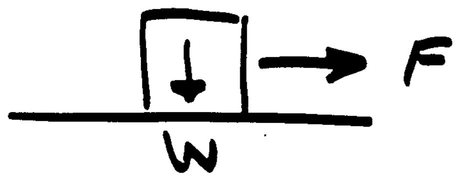
KNOWLEDGE OF INTERFACIAL PHENOMENA IS STILL IMPERFECT!

FRICTION



$$\mu = \frac{F}{W}$$

"LAWS" OF FRICTION



$\mu = F/W$

F = FORCE REQ'D TO INITIATE MOVEMENT

1. μ INDEPENDENT OF LOAD (AMONTON, 1699)

2. μ INDEPENDENT OF AREA OF CONTACT (AMONTON, 1699)

3. μ INDEPENDENT OF SLIDING VELOCITY (COULOMB, 1783) COUNTER INTUITIVE

4. μ INDEPENDENT OF SURFACE ROUGHNESS (MODERN)

- THE COEFFICIENT OF FRICTION DEPENDS ON MATERIALS IN CONTACT
  AND
  CONTAMINANTS AND LUBRICANTS

THEORIES OF FRICTION

COULOMB:

FRICTION DUE EITHER TO

ADHESION (IN WHICH CASE IT SHOULD DEPEND ON THE AREA OF CONTACT)

AND/OR

ROUGHNESS (INTERLOCKING OF ASPERITIES)

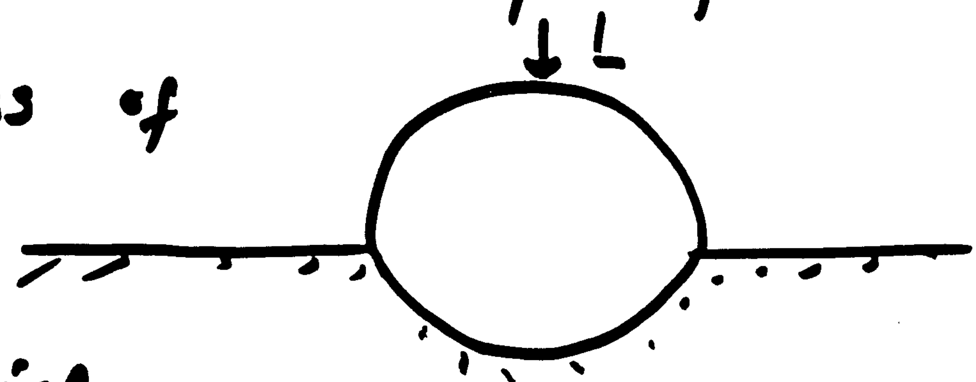
(IN WHICH CASE A SMOOTH SURFACE SHOLD HAVE A LOW μ)

(AND μ SHOULD DEPEND ON THE TOTAL CONTACT AREA)

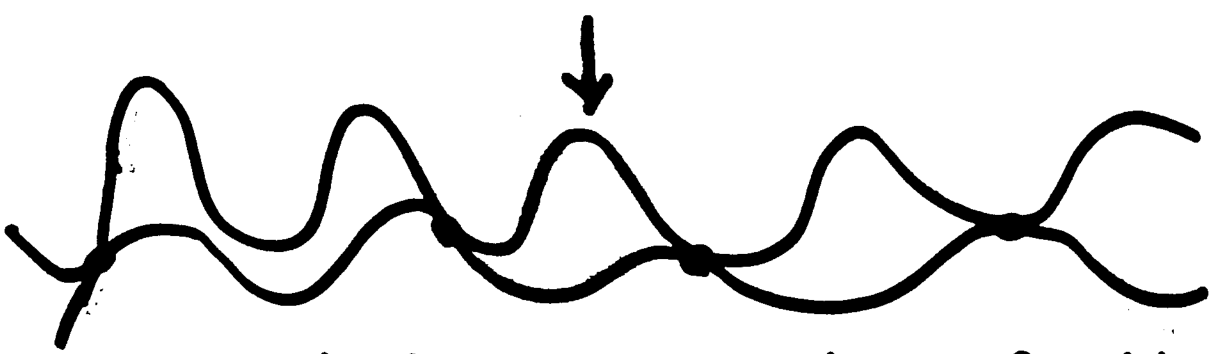
MODERN THEORY OF FRICTION:

Modified Adhesion theory

draws on the Concept of hardness of a material.



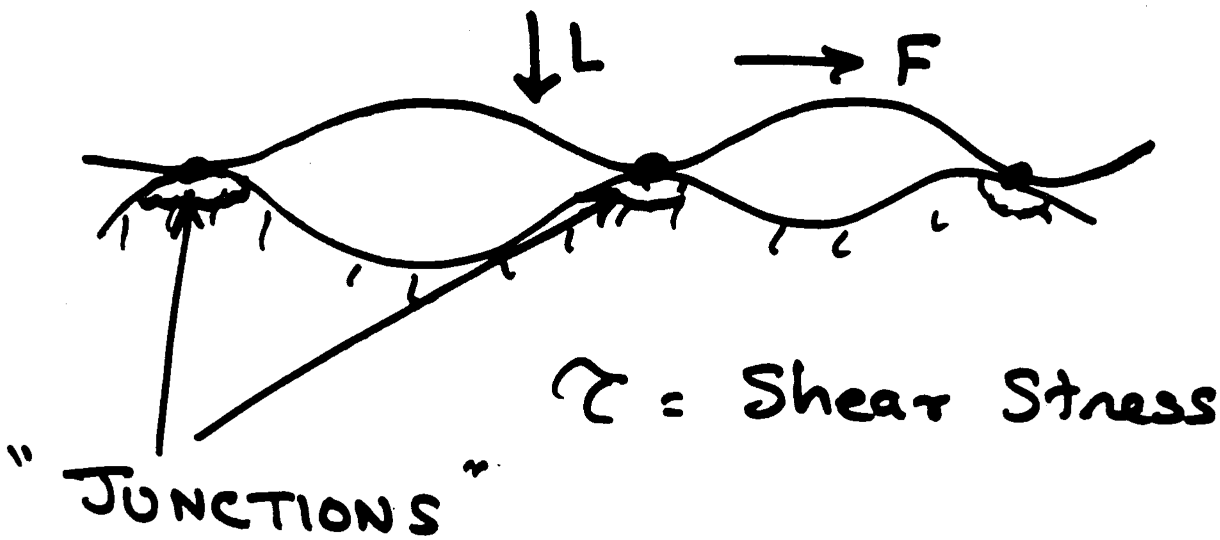
hardness $p = \dfrac{\text{Load}}{\text{Area of Contact}}$



Contact occurs at a finite number of "junctions". The load ΔL carried by a junction is $\Delta L = p \cdot \Delta A_r$

$L = \sum \Delta L$; $A_r = \sum \Delta A_r$

MODIFIED
ADHESION THEORY OF FRICTION



- CONTACT OCCURS AT JUNCTIONS

REAL AREA (A_r) IS SAME

$$L = A_r \cdot p$$

L = Normal Load

p = hardness of the Softer material

Sliding → Shearing of junctions

- $$F = A_r \cdot \tau$$

↑ Shear Stress

- Then:

$$\mu = \frac{F}{L} = \frac{\tau A_r}{p A_r} = \frac{\tau}{p}$$

Note: μ is independent of A_r!

Consider identical materials in contact (e.g. Cu on Cu)

- τ = Shear Strength $\sim \frac{\sigma_y}{2}$

  $p \sim$ indentation hardness

  $\sim 3\sigma_y$

  $\Rightarrow \quad \mu = \frac{1}{6} = 0.17$

  In practice μ is higher than 1/6.

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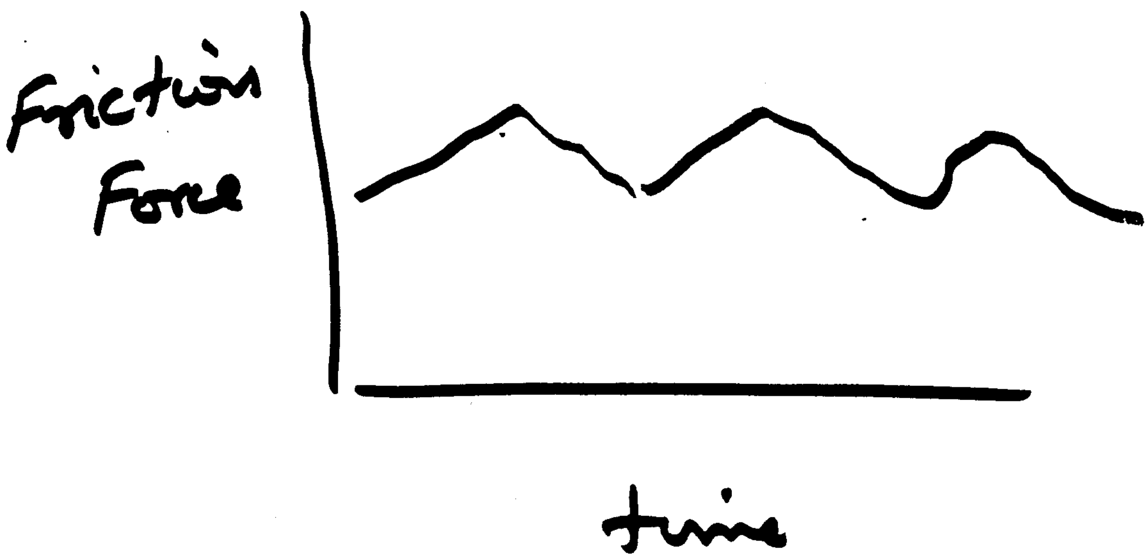
OTHER FRICTION RELATED PHENOMENA

- STICK-SLIP (e.g. Chatter)



- TEMP. RISE DUE TO FRICTION

$$\theta = f(\mu, \underset{\text{Load}}{L}, \underset{\text{Vel.}}{V}, \lambda, \underbrace{k_1, k_2}_{\text{thermal conductivities}})$$

rad. of contact → λ

SOME μ VALUES

CONDITION	EXAMPLES	μ
Clean unlubricated	Steel on Ag Leather/Wood Nylon/steel	·3 - ·5
	Cu on Cu Brass on Brass	·8 - 1·5
	Rubber on others	·6 - ·9
	Teflon on others	·04 - 0·1
	Graphite on others	·08 - ·16

BOUNDARY LUBRICATED

(covered by liquid lubricant)

ineffective lubricant	water gasoline	μ Same as for Clean surfaces
effective lubricant	Mineral oils fatty oils	
	Steel/steel Nylon/steel	.05 - .1

SOLID LUBRICANT

HARD METAL COVERED BY THIN LAYER OF Soft Metal or by graphite or Molybdenum disulphide

$\mu \sim .06 - .12$

Hydrodynamic lubrication

A fluid film produced by Sliding action separates the Surfaces (Speeds >> 10 ft/min.)

μ .01 - 0.001

Hydrostatic lubrication

fluid film produced by external pressurization separates the surfaces

μ 0.001 to 0.000,001

depending on design parameters

ROLLING CONTACT

pure rolling contact	Cylinder over a plane	.001-.0001
Normal rolling contact (some shear)	Commercial ballbearings	.01-.001

CLEAN METALS in good vaccum (10^{-6} mm of Hg or better)

μ 3.0 and higher

non-metals under good vaccum

μ 0.4 to 1.0

In Vaccum adhesion is higher (real area of Contact increases)

MECHANISMS OF WEAR

– "Progressive loss of material from the surface" as a result of sliding against another surface.

- <u>WEAR</u> IS

NOT ALWAYS "NEGATIVE":

EG: SAND BLASTING

PENCILS (WRITING!)

POLISHING

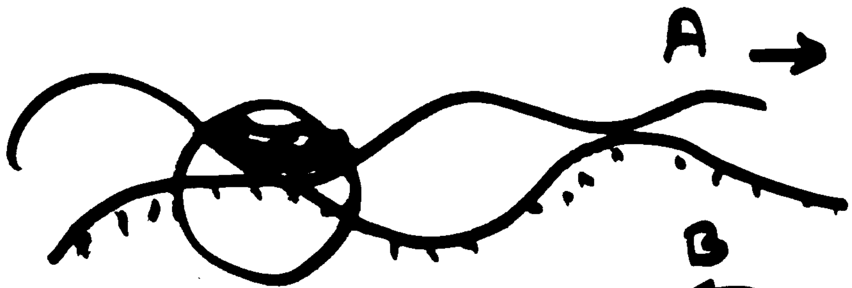
- wear can give a signal for other problems – eg. tires, shoes

Quantity of material usually very small: Radioactive techniques used extensively.

- Today precision weighing possible (up to 1 μg)

FORMS OF WEAR

1. ADHESIVE WEAR



junction : plastic deformati

particle could shear →
"wear particle"

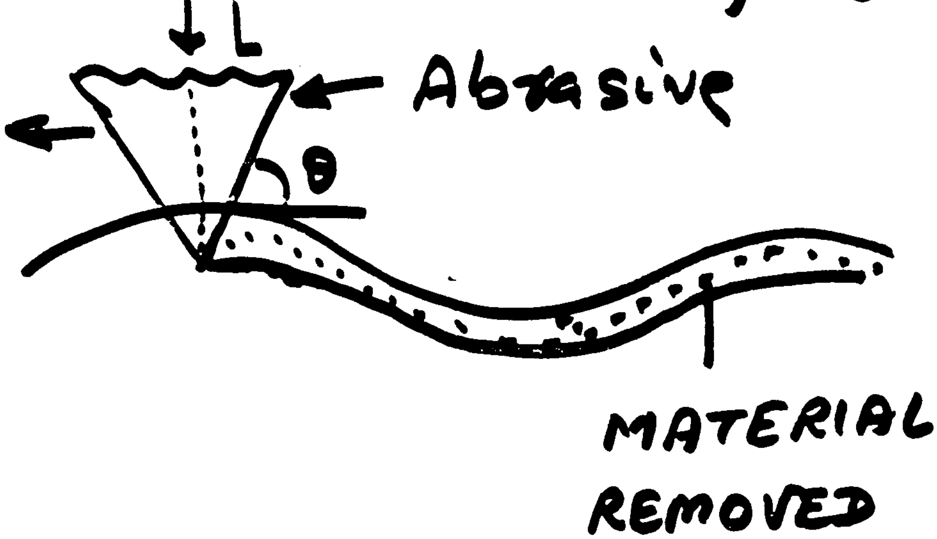
k = experimental constant

$$V = k \frac{LW}{3p}$$

V = VOL. OF material removed
L = Length of travel
W = Normal load
p = Hardness of softer body

2. ABRASIVE WEAR

Hard, Sharpe Surface
Slides on a Soft Surface



(very reproducible wear data)

Vol. of Wear $V = \dfrac{L \tan\theta \, x}{\pi \, p}$

L = Total normal load

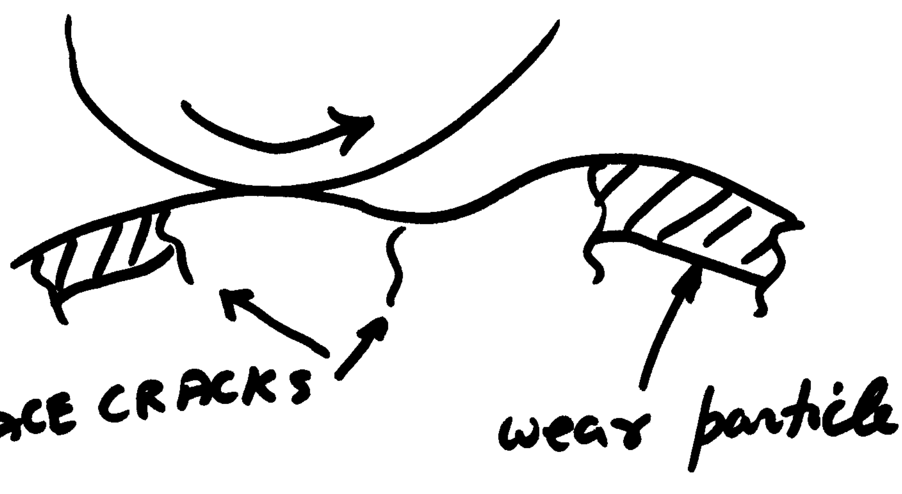
x = distance slid

p = Hardness of softer material

3. CORROSIVE WEAR

chemical attack on surfaces in toxic environments

4. Surface fatigue and fracture wear



e.g. ball bearings, gears, railroad wheels, etc.

wear is mainly due to surface fatigue. Rolling contact produces little adhesive wear