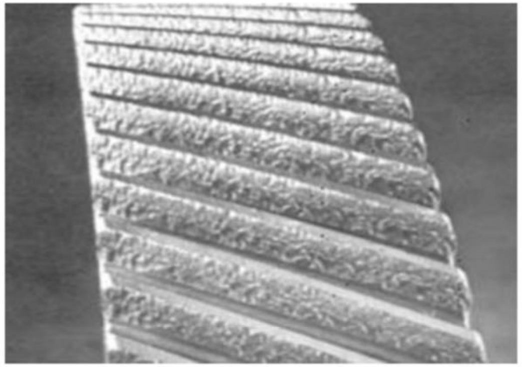
Definition of Abrasive Wear

Abrasion is the most common form (55-60%) of wear in industry.

- Abrasive wear occurs between surfaces of different relative hardness.
- Abrasive wear is caused by hard particles on the surface or within the work material such as inclusions.
- These particles act as micro cutting tools on a microscopic scale.

Abrasive Wear

- Abrasive wear, sometimes called cutting wear, occurs when hard particles slide and roll under pressure, across the tooth surface.
- Hard particle sources are: dirt in the housing, sand or scale from castings, metal wear particles, and particles introduced into housing when filling with lube oil.
- Scratching is a form of abrasive wear, characterized by short scratch-like lines in the direction of sliding. This type of damage is usually light and can be stopped by removing the contaminants that caused it. Fig. shows abrasive wear of a hardened gear.



Machines/ components affected by abrasive wear:

1-Cutting tools
2-Machine component

- Piston/cylinders
- Journal bearings
- Gears
- Cams

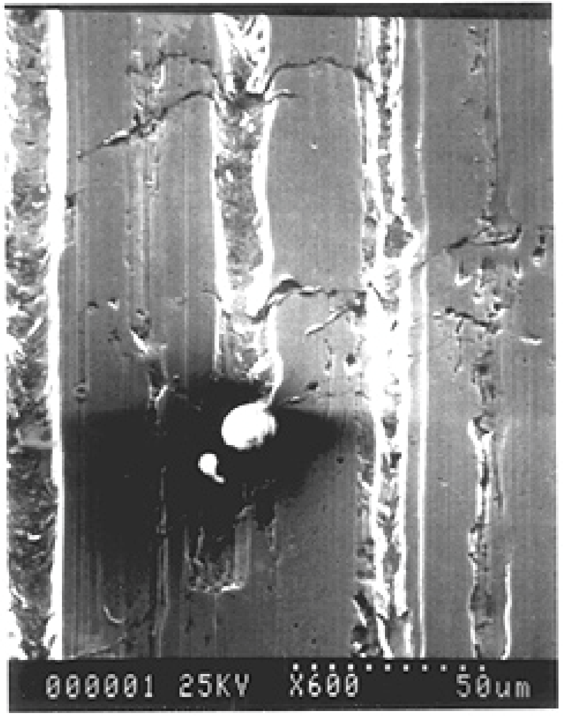
3-Agricultural implements
- Swash plates
- Slurry pumps

4-Digging tools
- Augers
- Scraper blades

High magnification of a punch edge shows a characteristic pattern caused by abrasive wear.

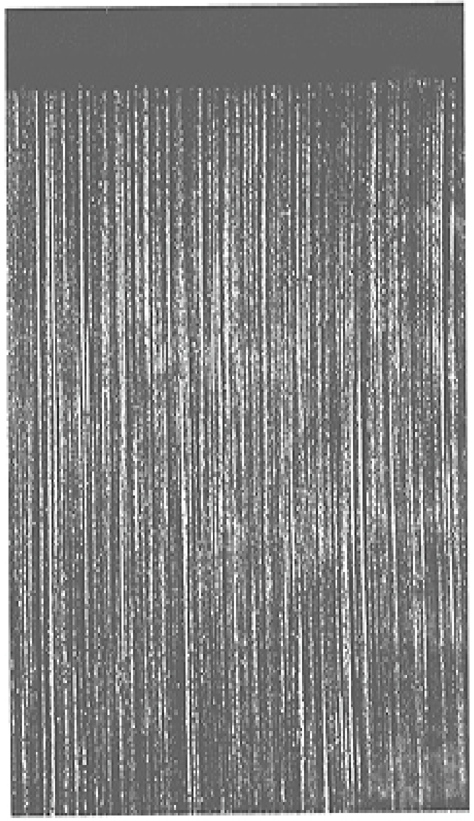
Marine Diesel Engine Piston Ring

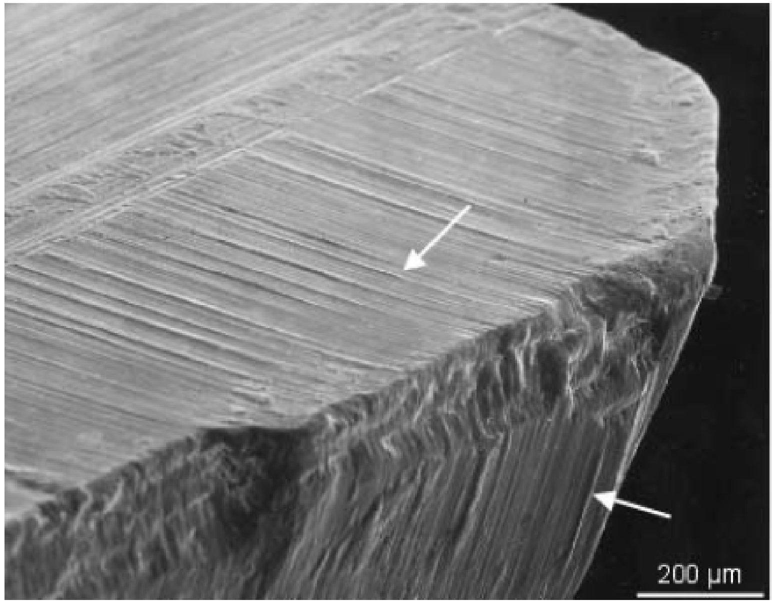
Magnification 400x



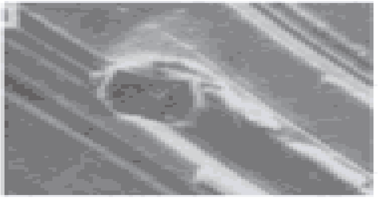
Magnification 600x

ABRASIVE WEAR
Gear Tooth

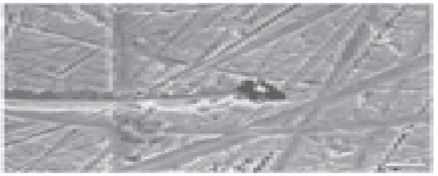




Imbedded Particle



Scratch Marks

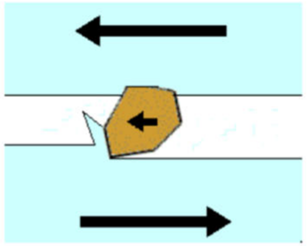


Abrasive wear in punch

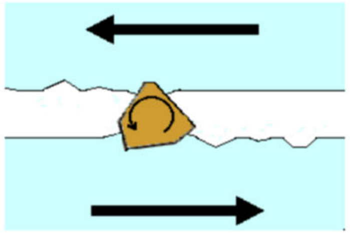
- Because of the motion between the punch and work material, small microchips are cut out of the tool, which leads to a gradual loss of tooling material.
- On a macroscopic level, this type of tool wear causes a rounding of the punch edge, yet the punch still appears relatively smooth
- A closer inspection shows characteristic parallel scratch marks on the edge and along the sides of a punch where particles cut into the tool surface during the stamping.

Types of Abrasive wear

- Abrasive wear is commonly classified according to the type of contact and the contact environment
- The two modes of abrasive wear are known as two-body and three-body abrasive wear
- Two-body wear occurs when the grits or hard particles remove material from the opposite surface.
- Three-body wear occurs when the particles are not constrained, and are free to roll and slide down a surface.



Two-body wear

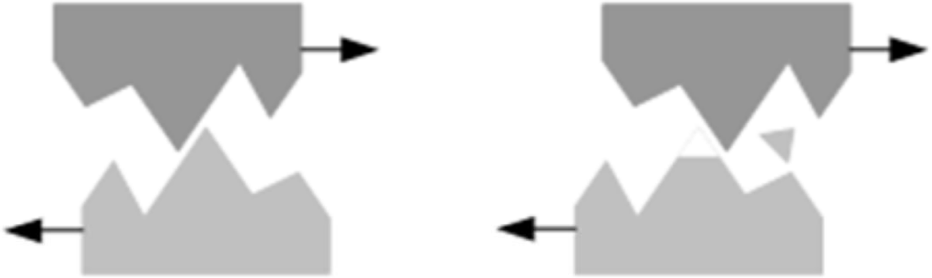


Three-body wear

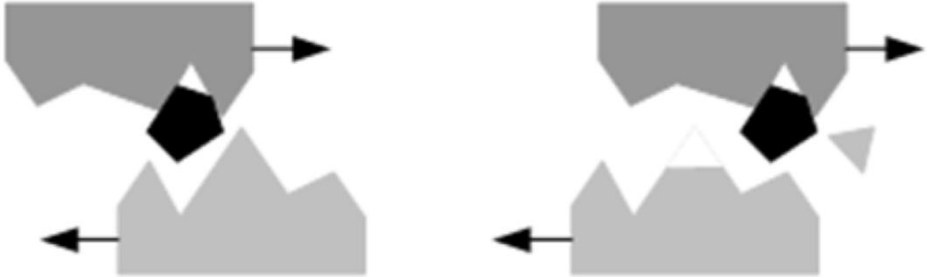
Abrasive wear

Abrasive wear occurs when a harder material is rubbing against a softer material

Two body wear



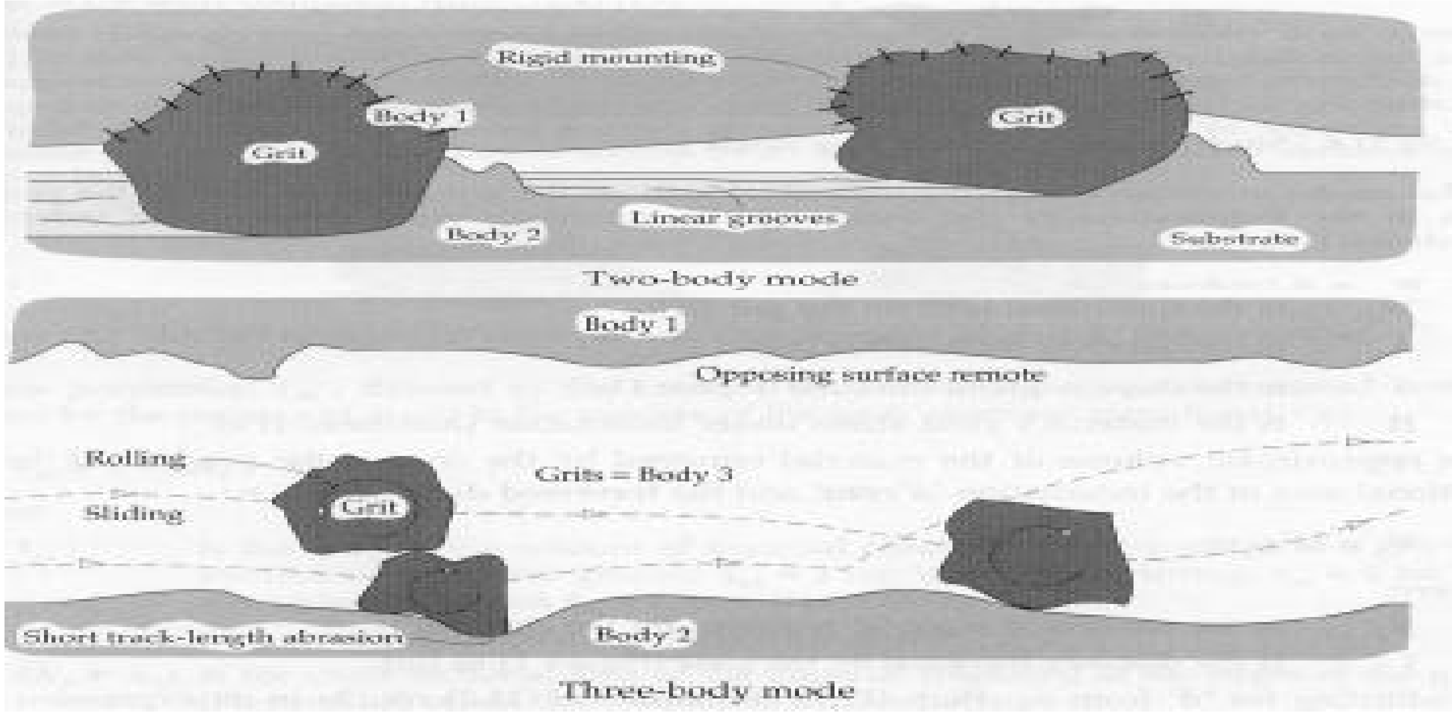
Three body wear



Types of Abrasion (environment mode)

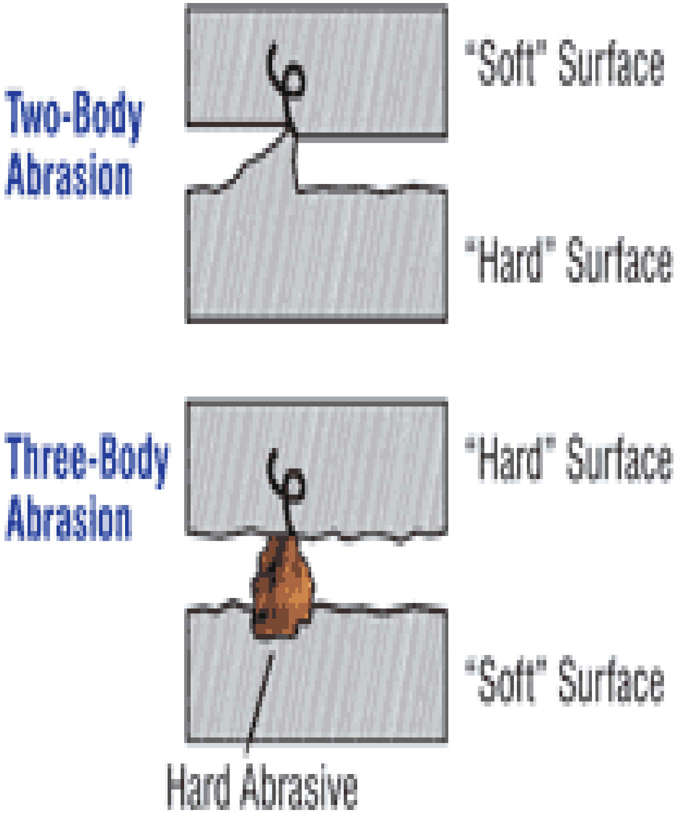
Closed mode of wear is ten times faster than open body mode

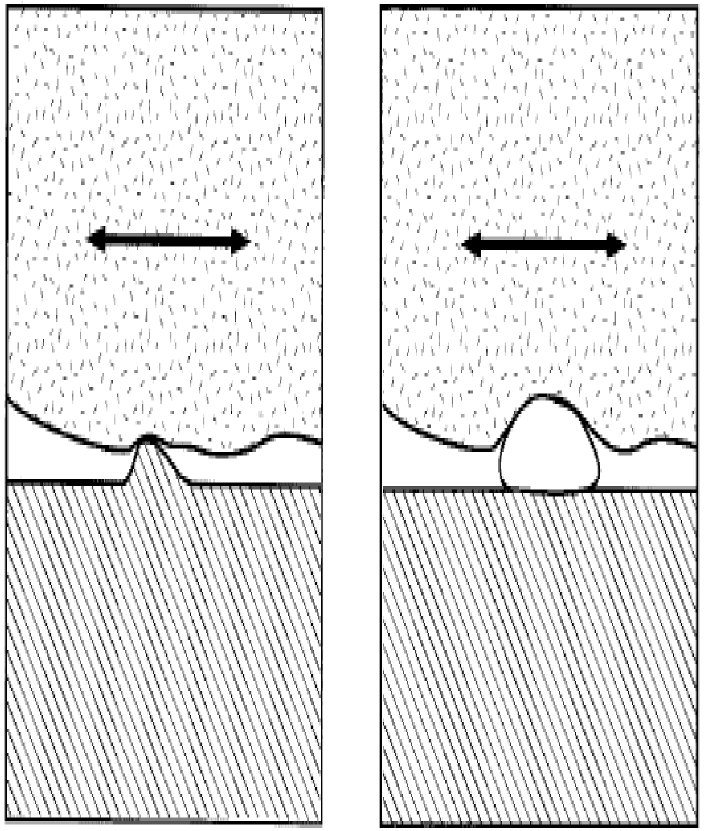
Two-body wear occurs when the grits, or hard particles, are rigidly mounted or adhere to a surface



Three-body wear occurs when the particles are not constrained and are free to roll and slide down a surface

Abrasive Wear type

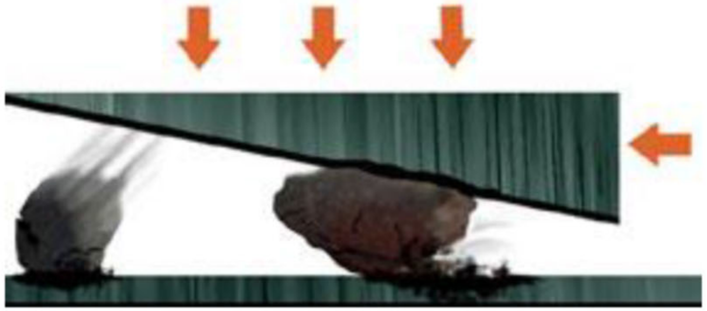




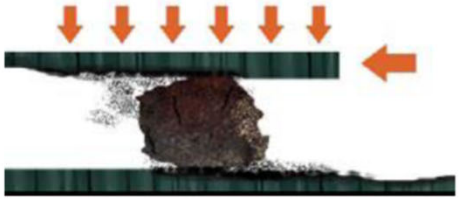
Types of Abrasion (Stress mode)

- Gouging (impact Stress)
- Grinding (High-Stress)
- Scratching (Low-Stress)

Types of abrasive wear



Gouging abrasion
- Large particles
- High compression loads



High stress or grinding abrasion
- Smaller particles
- High compression load

Low stress or scratching abrasion
- No compression load
- Scratching abrasion while material is sliding

Polishing abrasion

Gouging (impact Stress)

The resulting wear can be extreme when high-stress or low stress abrasions are accompanied by some degree of impact and weight.

The metal surface receives prominent gouges and grooves when massive objects (often rock) are forced with pressure against them.

Grinding (High-Stress)

This is more intense than simple scratching or less than gouging.
It happens when small, hard, abrasive particles are forced against a metal surface with enough force to crush the particle in a grinding mode. Most often the compressive force is supplied by two metal components with the abrasive sandwiched between them.

Even with low nominal loads on the metal portion of this sandwich the unit stresses in the abrasive, and consequently on its metallic contact areas, may be very high.

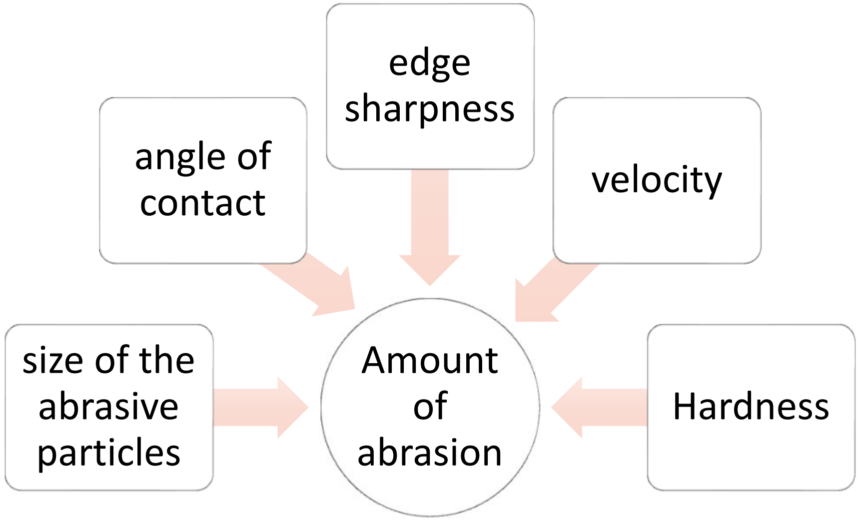
These stresses crack or crush the abrasive grains.

The broken edges are sharp and can
- score effectively
- local plastic flow
- surface micro-cracking

Scratching (Low-Stress)

This is normally the least severe type of abrasion. Metal parts are worn away through the repeated scouring action of hard, sharp particles moving across a metal surface at varying velocities.

The abrasive may be present within the product, either as a filler or a pigment. (glass fibers in plastics) such products suffer what is called:
”Low Stress Abrasive Wear”



edge sharpness

angle of contact

velocity

size of the abrasive particles

Amount of abrasion

Hardness

Mechanisms of abrasive wear

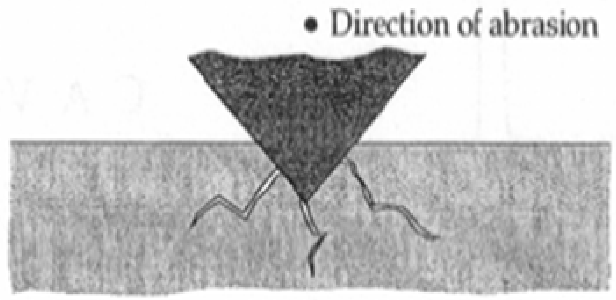
- Plowing
- Cutting
- Fracture

Plowing occurs when a material is displaced to the side, away from the wear particles, resulting in the formation of grooves that do not involve direct material removal. The displaced material forms ridges adjacent to grooves, which may be removed by subsequent passage of abrasive particles

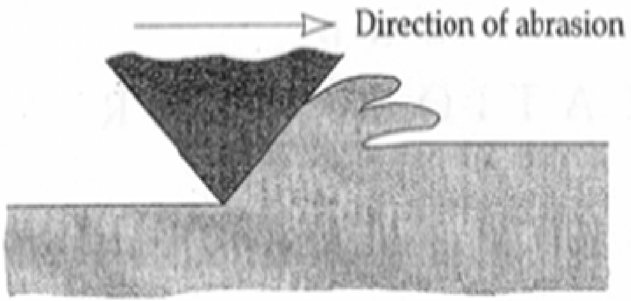
Mechanisms of abrasive wear

Cutting occurs when material is separated from the surface in the form of primary debris, or microchips, with little or no material displaced to the sides of the grooves. This mechanism closely resembles conventional machining.

Fragmentation causes localized fracture of the wear material



b) Fracture



a) Cutting

In the micro-level, abrasive action results in one of the following wear modes:

- **Ploughing**. The material is shifted to the sides of the wear groove. The material is not removed from the surface.
- **Cutting**. A chip forms in front of the cutting asperity/grit. The material is removed (lost) from the surface in the volume equal to the volume of the wear track (groove).
- **Cracking (brittle fracture)**. The material cracks in the subsurface regions surrounding the wear groove. The volume of the lost material is higher than the volume of the wear track.

Mechanism of Abrasive Wear

a) Cutting

b) Fracture

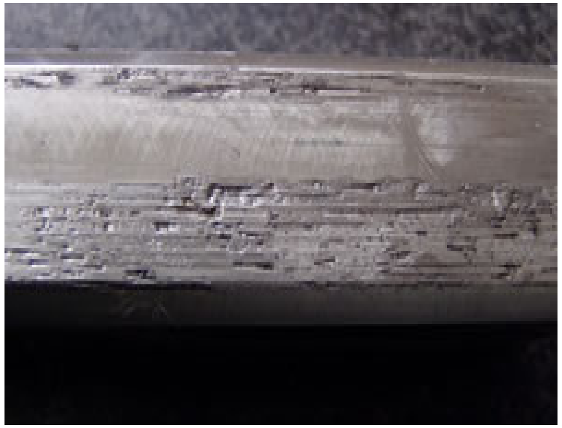
c) Fatigue by repeated ploughing

d) Grain pull-out

Fig. *Mechanisms of abrasive wear: microcutting, fracture, fatigue and grain pull-out*

The consequences of abrasive wear are:

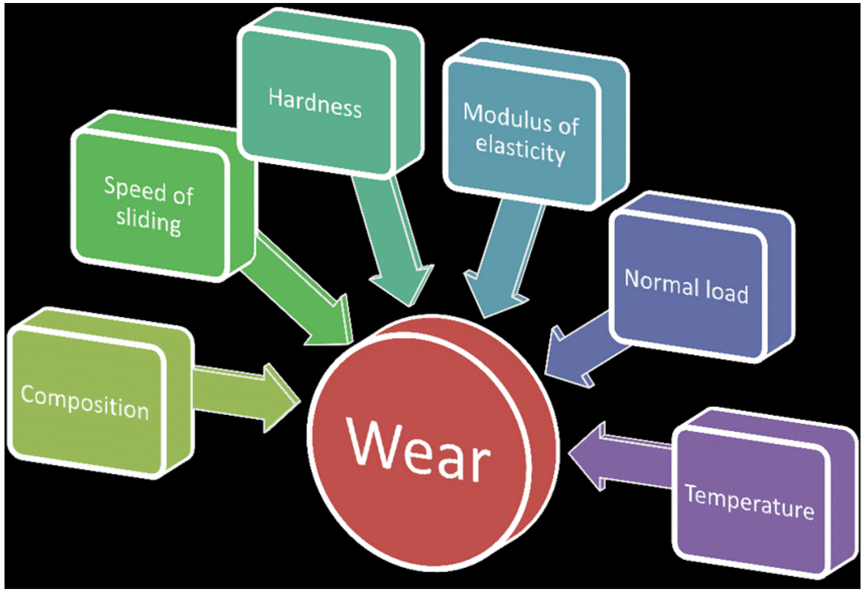
- Grooves
- Scratches marking
- Micro-chips
- Furrows
- Leakage
- Lower efficiency
- Dimensional changes
- Shiny spots on textured tool surfaces



Wear Dependence

For Dry/unlubricated surfaces sliding

- Normal Load
- Relative sliding speed
- The initial temperature
- Thermal, Mechanical , chemical properties of the material in contact
- No simpler Model to explain wear



Occurrence of Wear depends on

- ★ Geometry of the surface
- Applied load
- The rolling and sliding velocities
- Environmental conditions
- Mechanical, Thermal, Chemical and Metallurgical properties
- ★ Physical, Thermal and Chemical properties of the lubricant

Conditions Promoting Wear

- Hard particles contaminating oil
- Insufficient metal hardness
- Hard metal with rough surface against soft metal
- Temperature
- corrosion

Influencing factors:

- Surface hardness
- Particle size/ hardness
- Particle concentration
- Alignment
- Film thickness
- Load
- Viscosity
- speed

Load effect

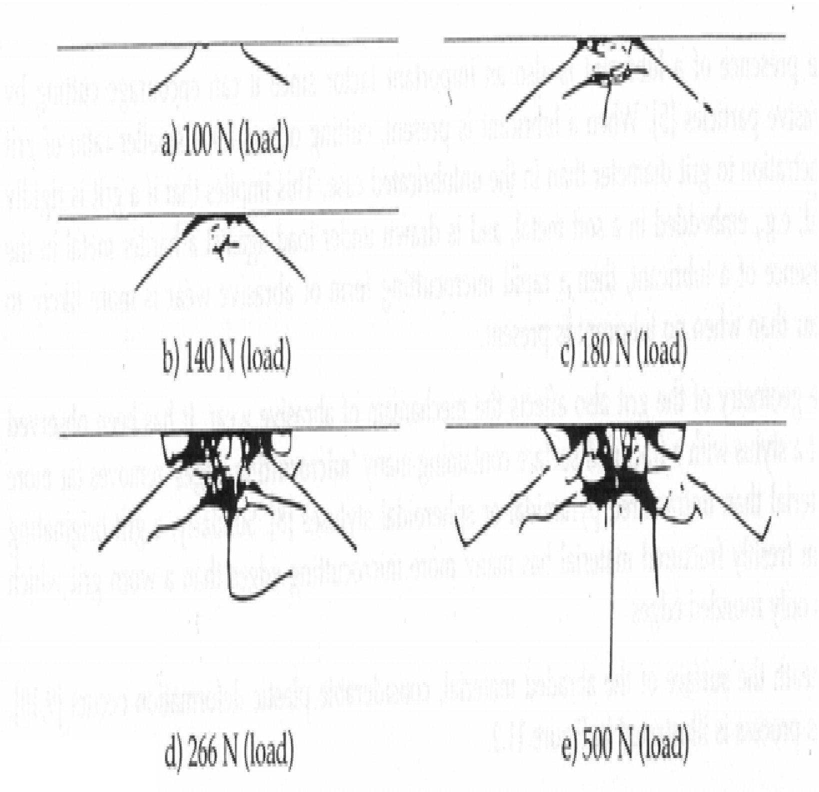
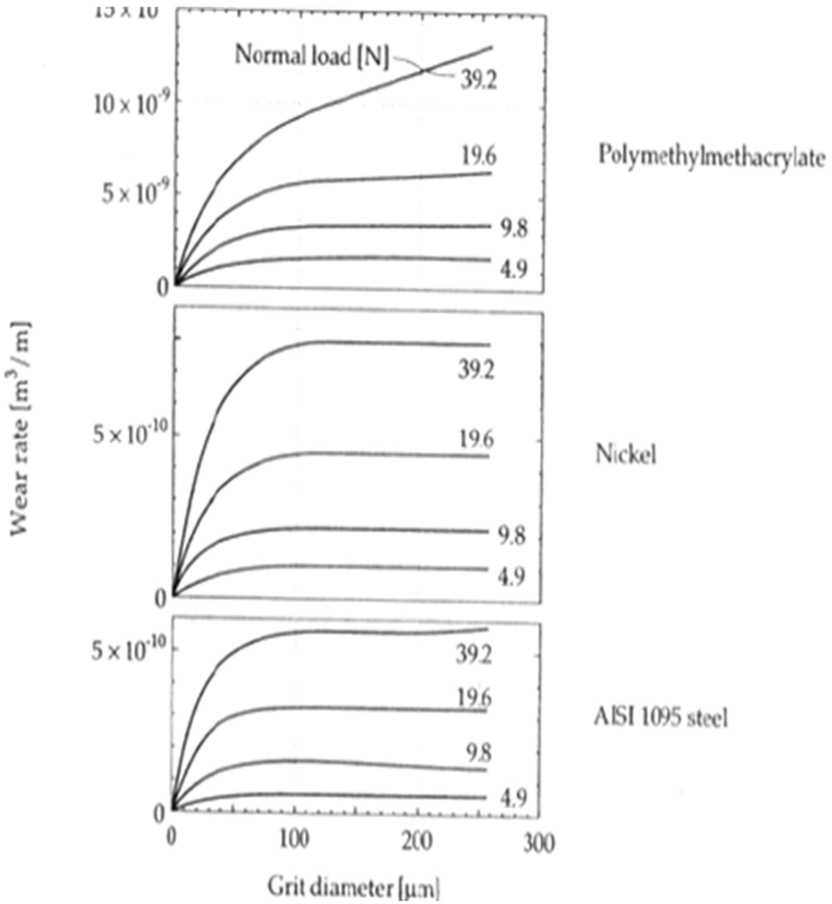
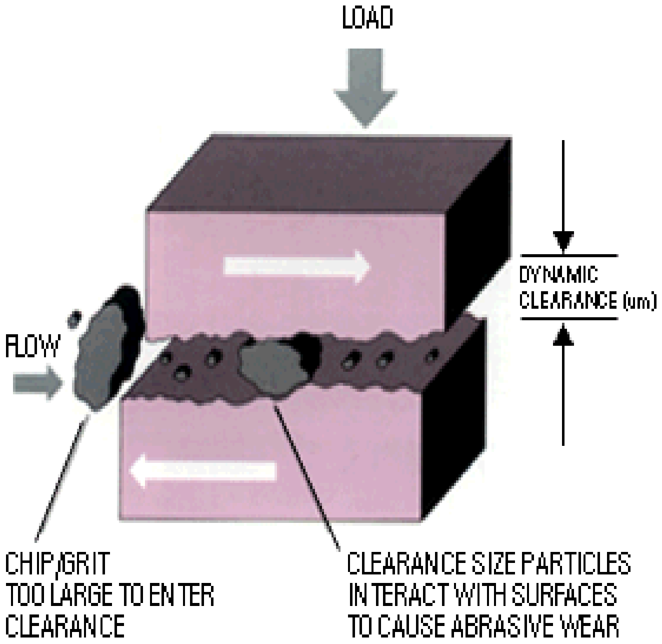


FIGURE 11.3 Generation of cracks under an indenter in brittle solids (adapted from [12]).



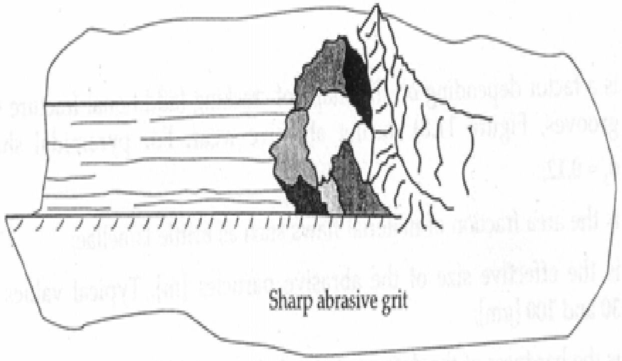
Wear debris is from joining of cracks in Ceramic

Debris size effect

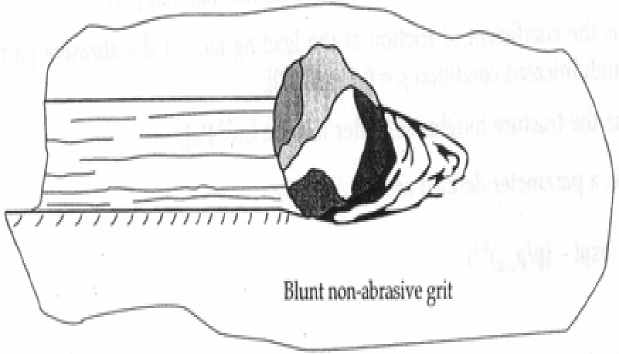


The particle sizes causing the most damage are those equal to and slightly larger than the clearance space.

Bluntness effect

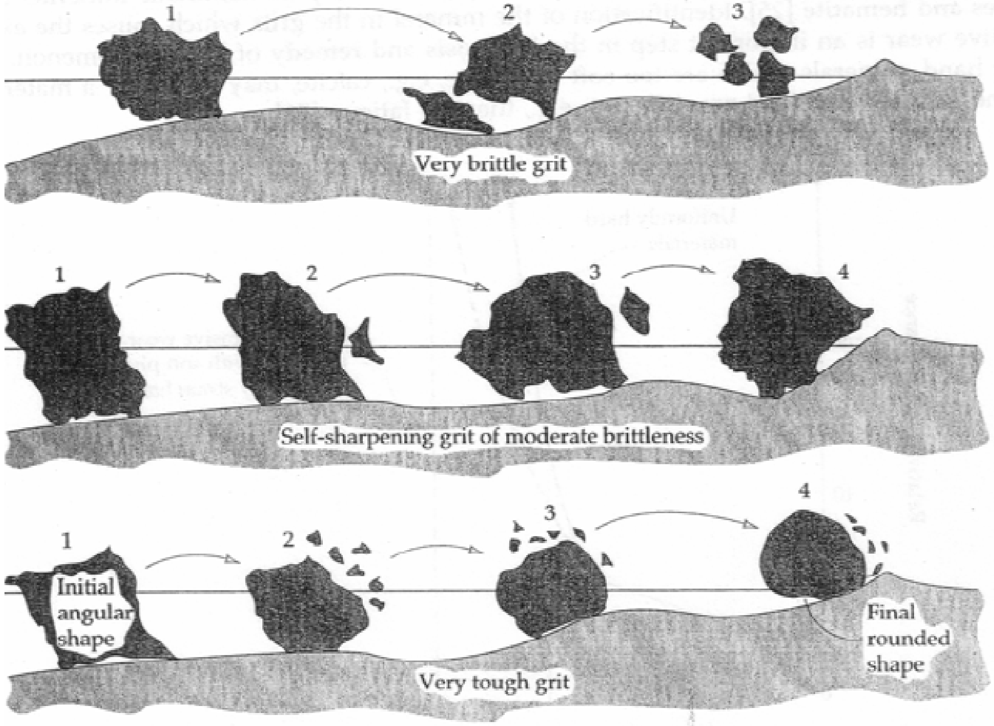


Sharp abrasive grit



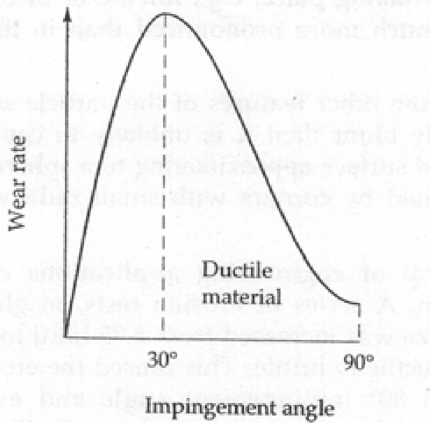
Blunt non-abrasive grit

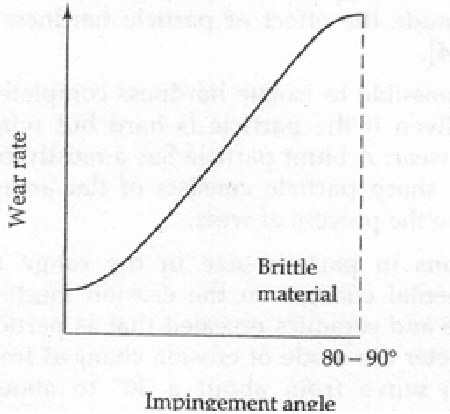
Hardness and contact angle effect



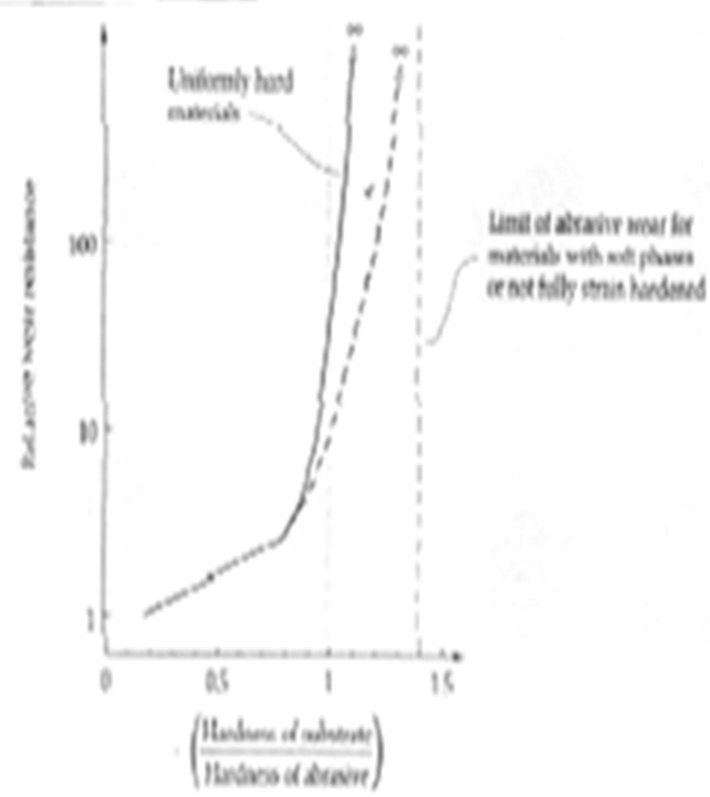
11.12 Effect of grit brittleness and toughness on its efficiency to abrade.

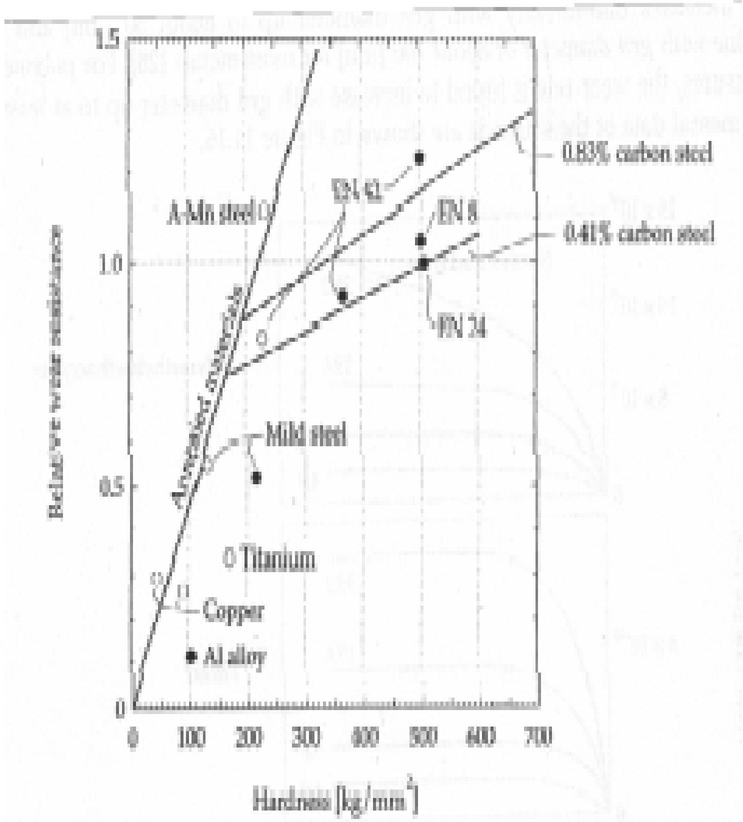
If the surface is harder than the particle, the wear rate is minimal.





Hardness effect

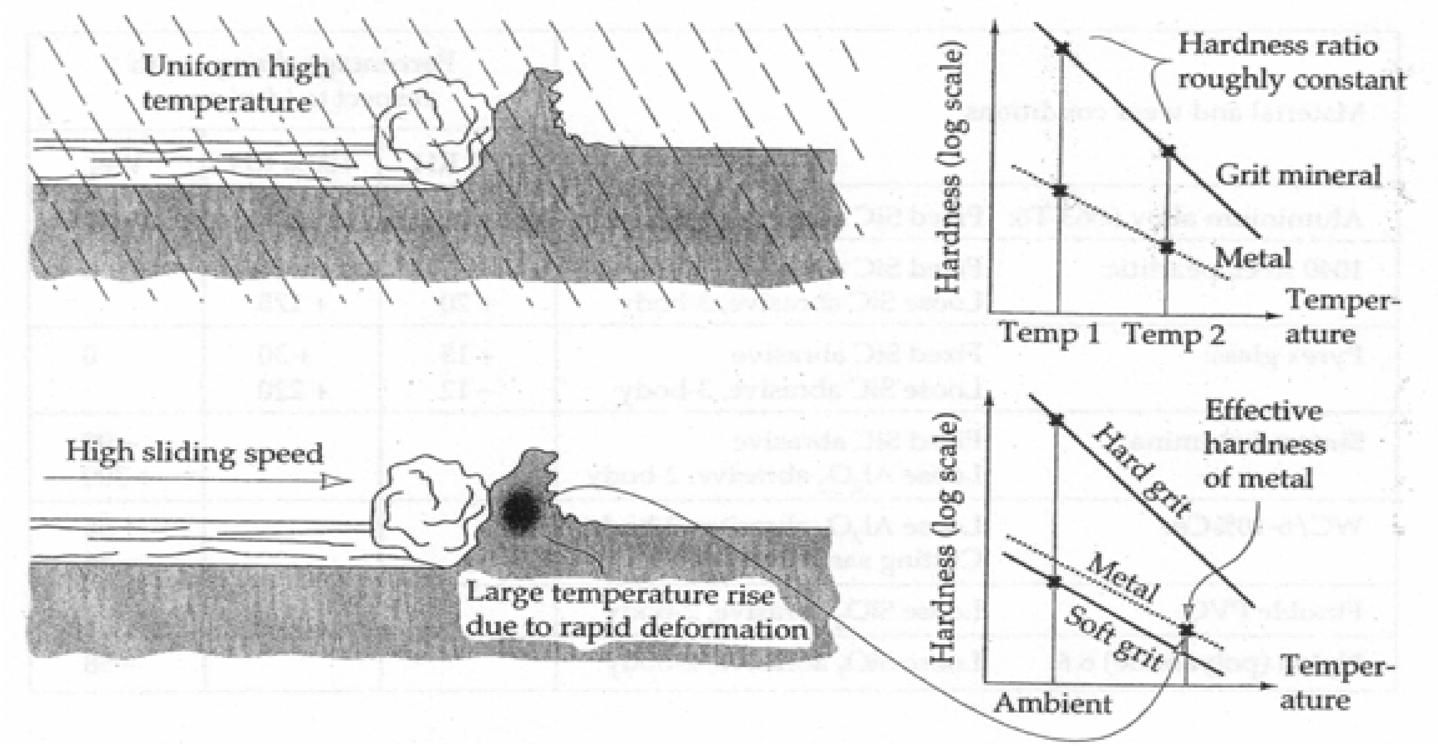




Severe abrasive wear when substrate hardness is less than 0.8 abrasive particle hardness

Effect of temperature

The hardness of materials decreases rapidly after $0.8xT_{melt}$
The flash temperature at micro contacts.
Localized heating of softening of ploughed material



Effect of moisture:

- chemical reaction between moisture and substrate
- chemical reaction between moisture and lubricant
- corrosive property of the moisture

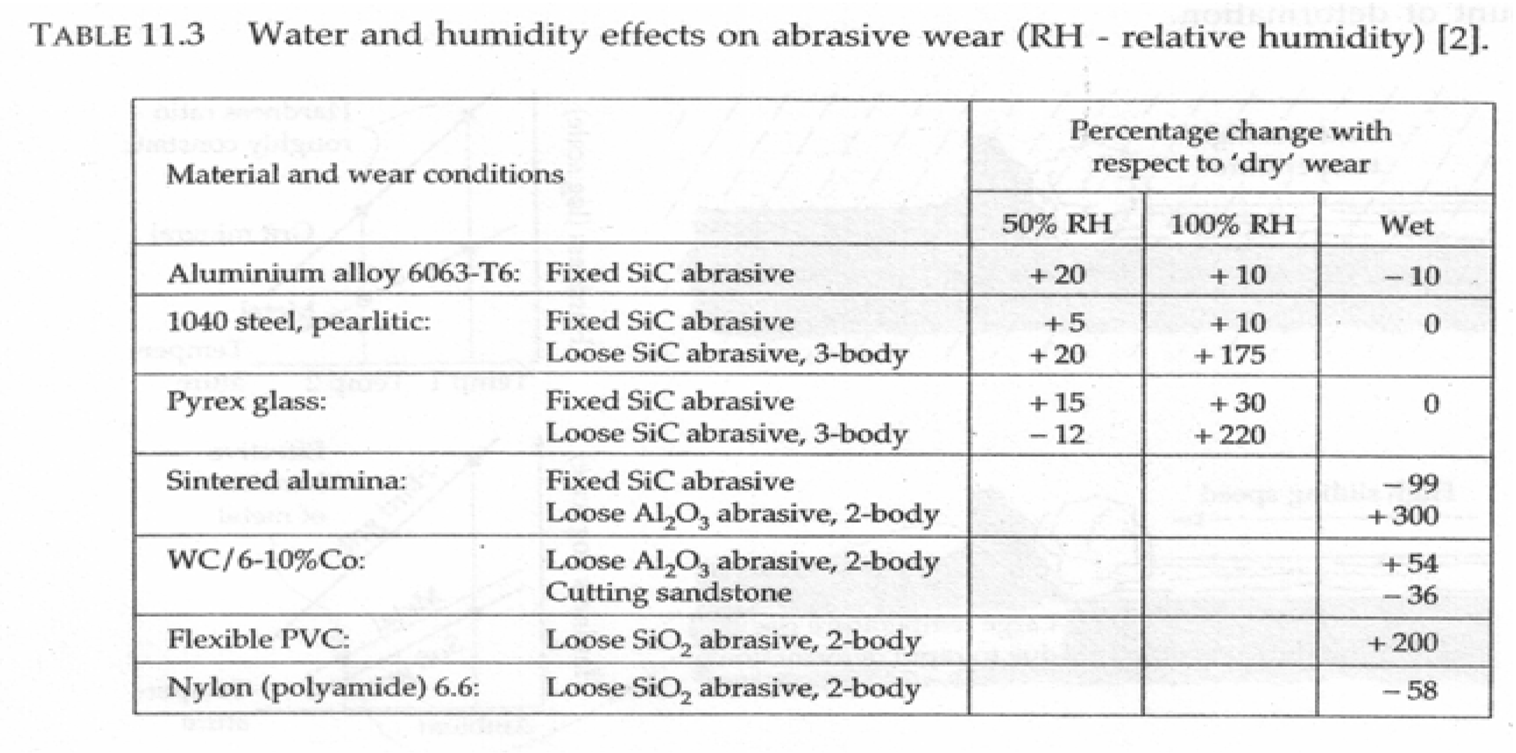
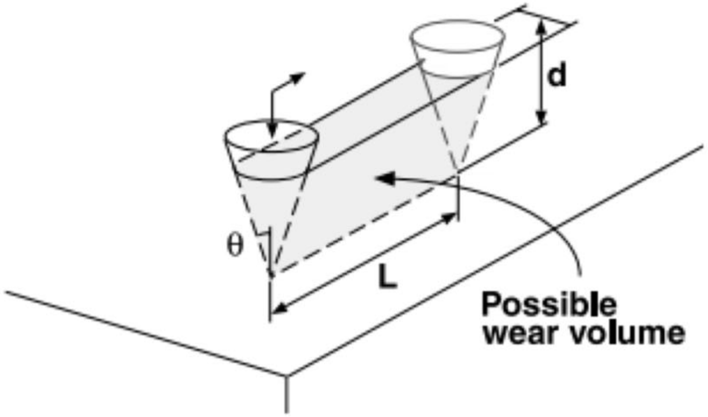


TABLE 11.3 Water and humidity effects on abrasive wear (RH - relative humidity) [2].

Material and wear conditions		Percentage change with respect to 'dry' wear		
		50% RH	100% RH	Wet
Aluminium alloy 6063-T6:	Fixed SiC abrasive	+ 20	+ 10	− 10
1040 steel, pearlitic:	Fixed SiC abrasive Loose SiC abrasive, 3-body	+ 5 + 20	+ 10 + 175	0
Pyrex glass:	Fixed SiC abrasive Loose SiC abrasive, 3-body	+ 15 − 12	+ 30 + 220	0
Sintered alumina:	Fixed SiC abrasive Loose Al_2O_3 abrasive, 2-body			− 99 + 300
WC/6-10%Co:	Loose Al_2O_3 abrasive, 2-body Cutting sandstone			+ 54 − 36
Flexible PVC:	Loose SiO_2 abrasive, 2-body			+ 200
Nylon (polyamide) 6.6:	Loose SiO_2 abrasive, 2-body			− 58

Estimation of Abrasive wear Volume



$$V = \frac{2}{\pi \cdot \tan\theta} \cdot \frac{WL}{H_v}$$

Typical model of abrasive wear by a conical indentor.

Based on Sliding Velocity

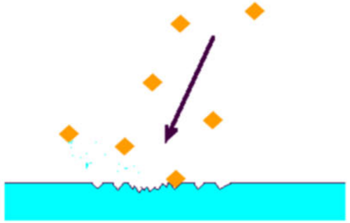
V = K (WVs/3 σs)

Where
V = wear volume, Vs = sliding velocity
W = applied load, σs = surface strength
K = wear coefficient

Erosive Wear

- **Erosive Wear**

  Erosive wear can be described as an extremely short sliding motion and is executed within a short time interval. Erosive wear is caused by the impact of particles of solid or liquid against the surface of an object.



Types of erosion

Solid particle erosion

Surface wear by impingement of solid particles carried by a gas or fluid.

e.g. Wear of helicopter blade leading edges in dusty environments.

- **Liquid drop erosion**

  Surface wear by impingement of liquid drops.

e.g. Wear of centrifugal gas compressor blades by condensate droplets.

- **Cavitation erosion**

  Surface wear in a flowing liquid by the generation and implosive collapse of gas bubbles.

e.g. Fluid-handling machines as marine propellers, dam slipways, gates, and all other hydraulic turbines.

EROSIVE WEAR

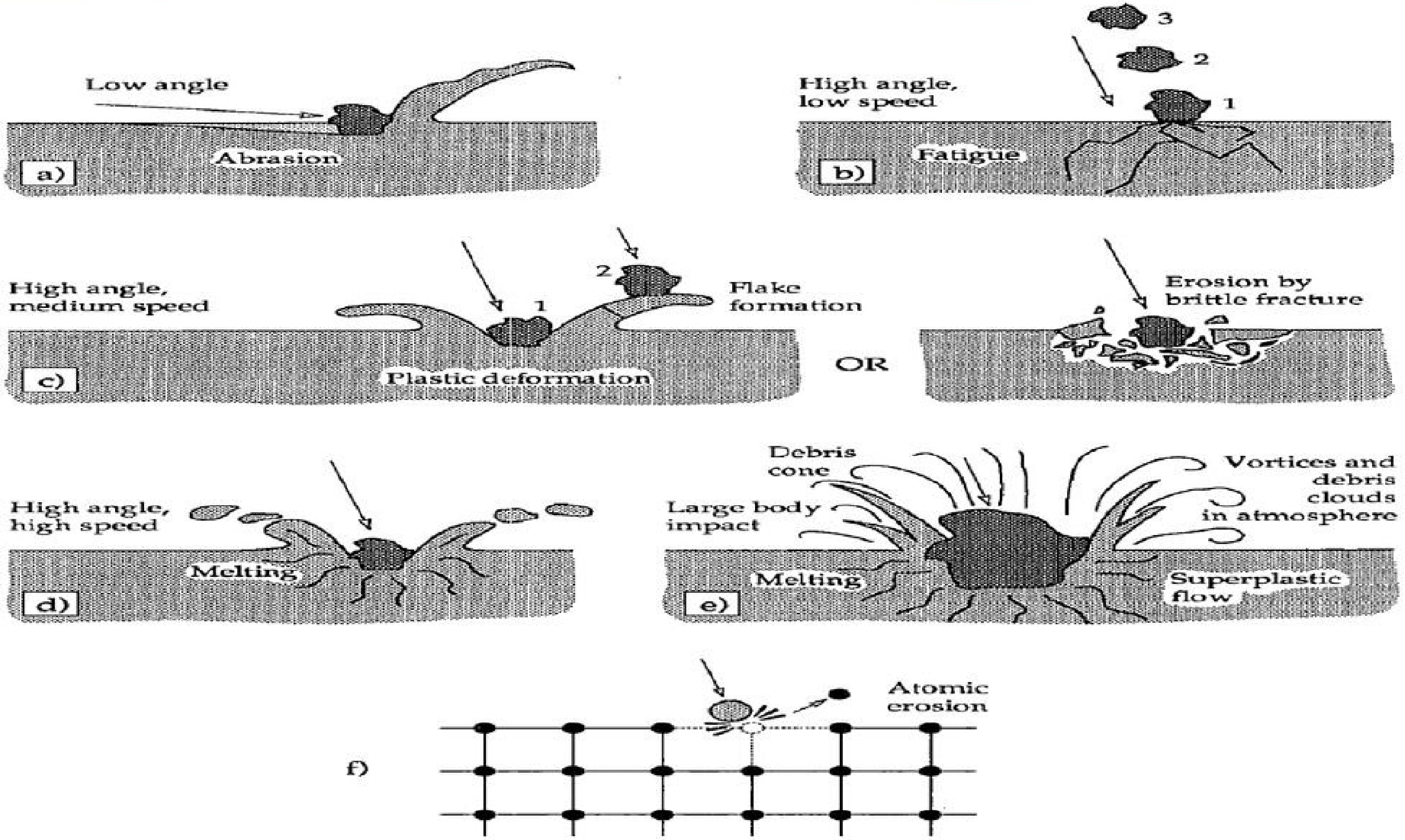


FIGURE Possible mechanisms of erosion; a) abrasion at low impact angles, b) surface fatigue during low speed, high impingement angle impact, c) brittle fracture or multiple plastic deformation during medium speed, large impingement angle impact, d) surface melting at high impact speeds, e) macroscopic erosion with secondary effects, f) crystal lattice degradation from impact by atoms.

CAVITATION WEAR

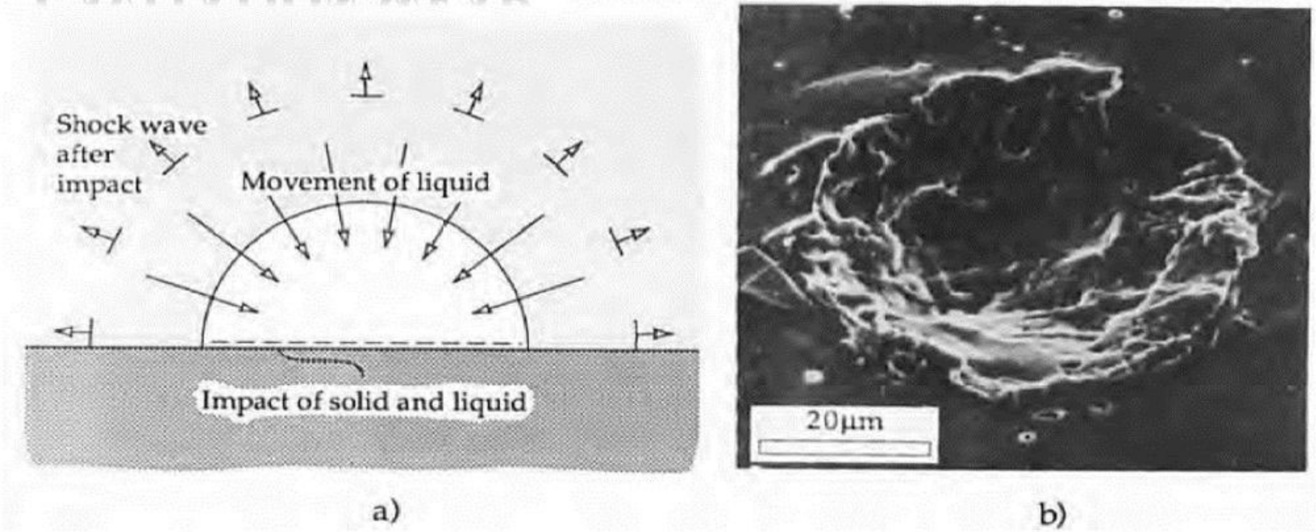
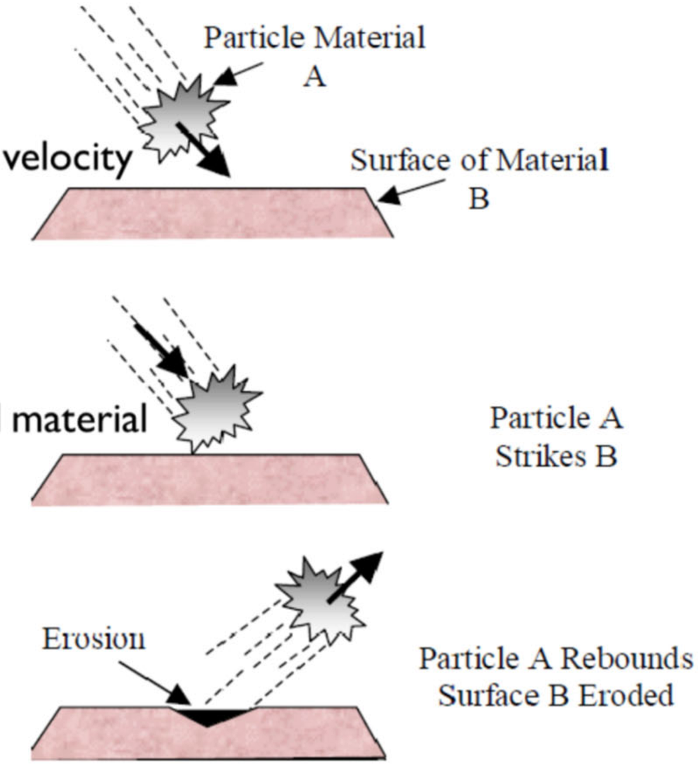


FIGURE Mechanism of cavitation wear; a) mechanism of bubble collapse, b) experimental evidence of damage by cavitation to a metallic (indium) surface

Cyclic formation and collapse of bubbles on a solid surface.
Bubble formation is caused by the release of dissolved gas from the liquid, which has negative pressure.

Erosive wear

The impingement of solid particles, or small drops of liquid or gas on the solid surface cause wear what is known as erosion of materials and components.



Pressure generated due to change in velocity

$$P = \Delta V \sqrt{E \rho}$$

P = Impact pressure
E = Modulus of elasticity of impacted material
ρ = Density of the fluid
V = Velocity

Advantages

- Cutting, drilling and polishing of brittle material

Erosive wear rate(V_e) is function of :

1. Particles velocity (K.E.)
2. Impact angle and
3. Size of abrasive.

$V_e = K.A(\alpha).(\text{particle\_vel})^n.(\text{particle\_size})^3$.