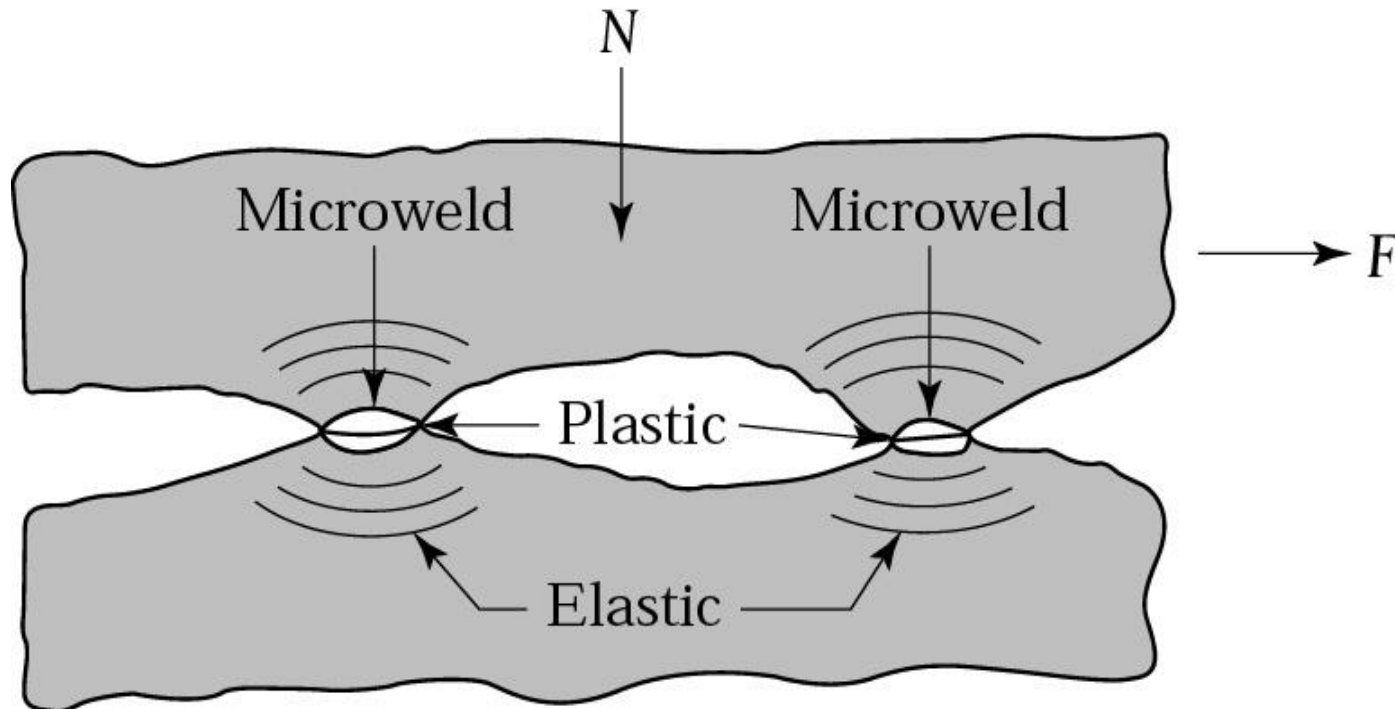


Chapter 4

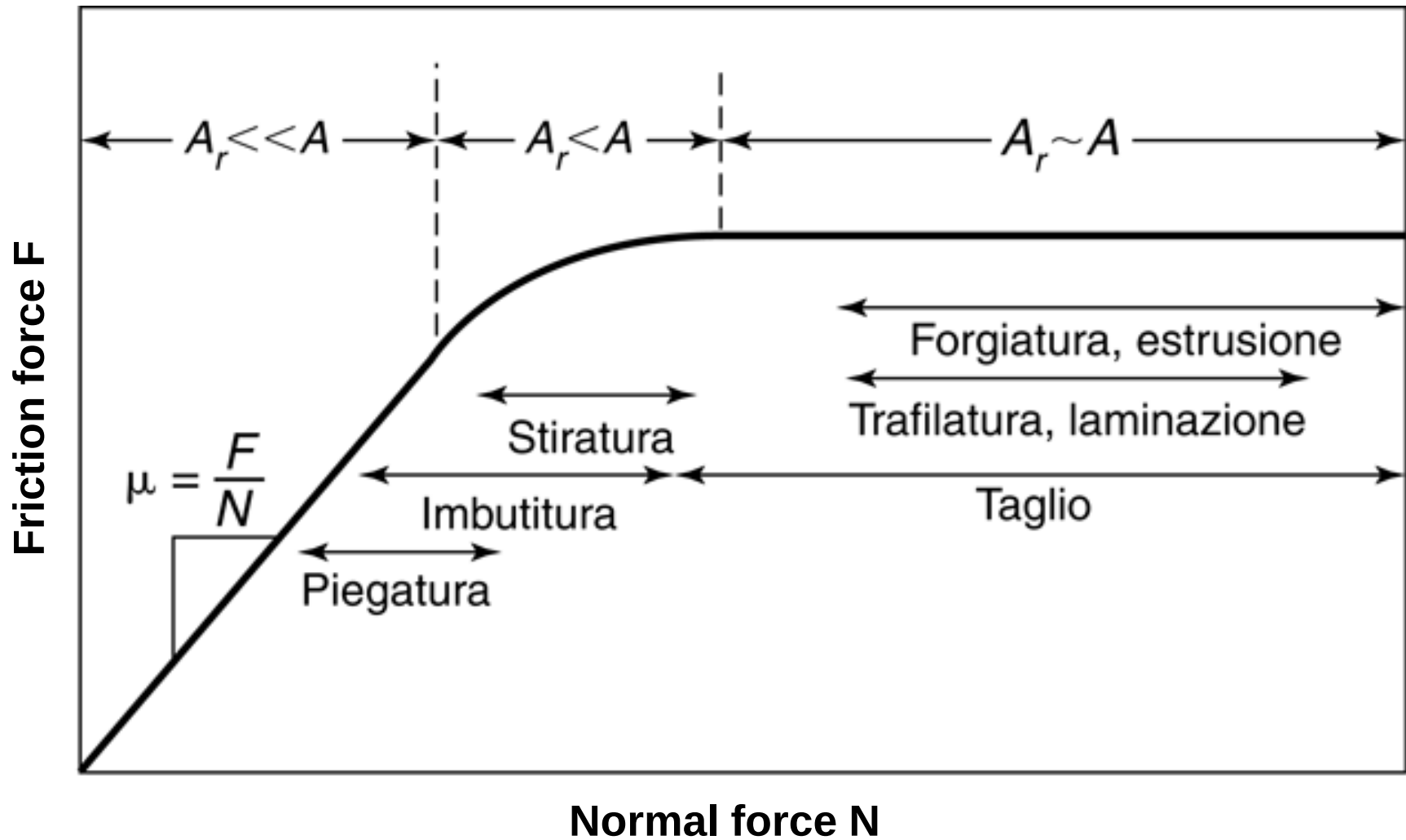
Tribology: Friction, Wear and Lubrication

Contact between two bodies



Schematic illustration of the interface of two bodies in contact, showing real areas of contact at the asperities. In engineering surfaces, the ratio of the apparent to real areas of contact can be as high as 4-5 orders of magnitude.

Real area of contact



Analytical modelling

$$\tau = \mu \sigma_N$$

μ : friction coefficient
(*Coulomb*)

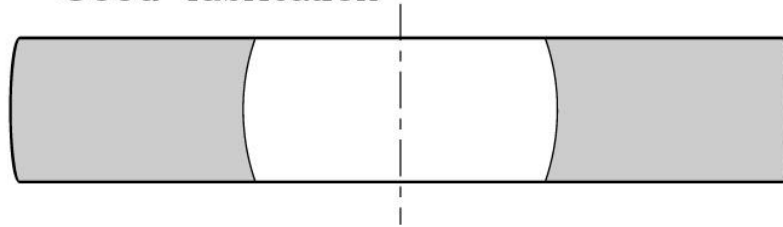
$$\tau = \bar{m} \cdot k$$

$\bar{m}$: friction factor
(*Tresca*)

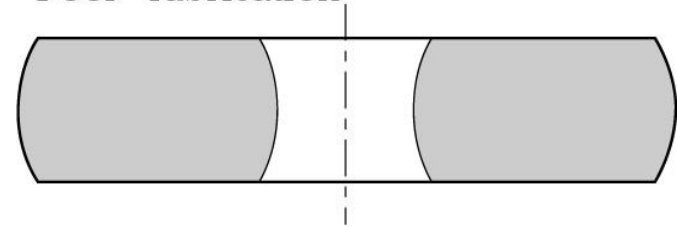
Process	Coefficient of friction (μ)	
	Cold	Hot
Rolling	0.05–0.1	0.2–0.7
Forging	0.05–0.1	0.1–0.2
Drawing	0.03–0.1	—
Sheet-metal forming	0.05–0.1	0.1–0.2
Machining	0.5–2	—

Ring compression test

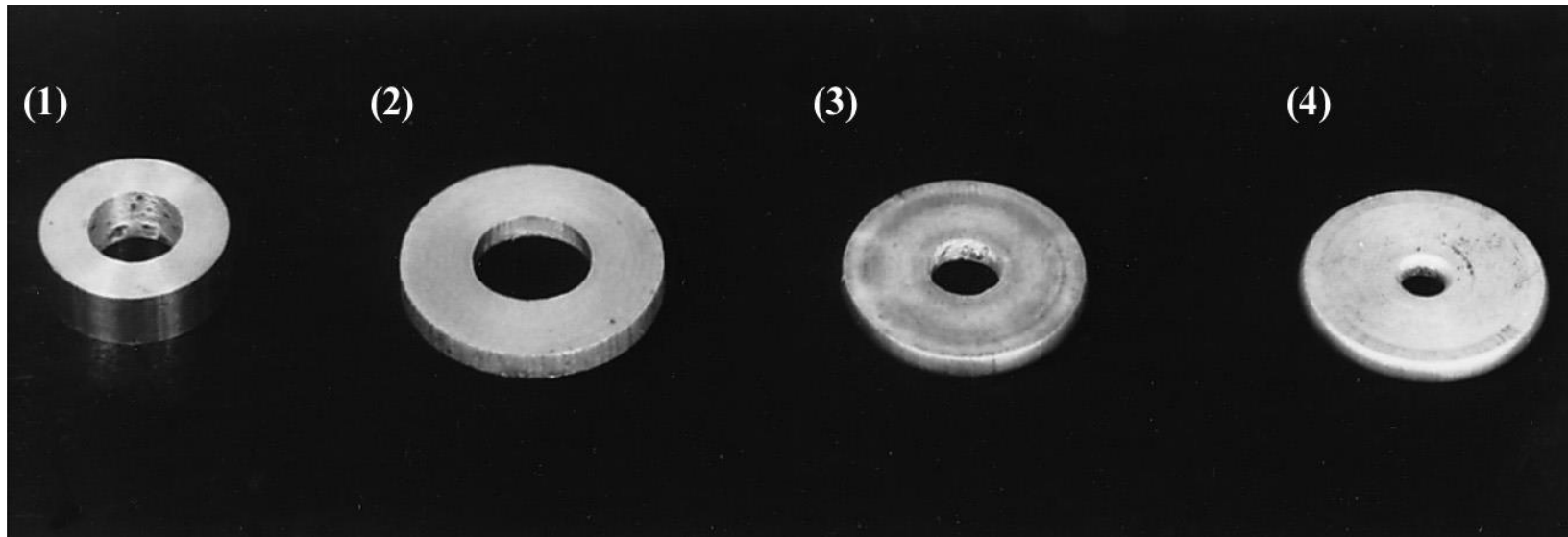
(a) Good lubrication



Poor lubrication

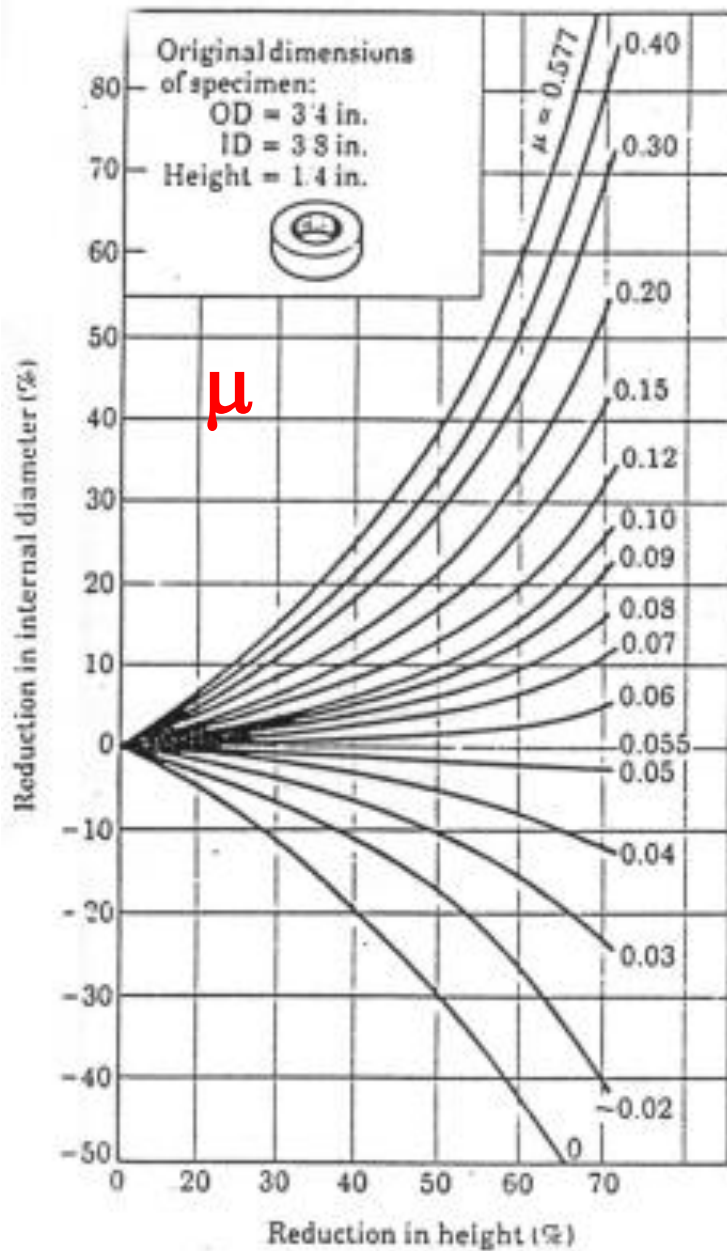
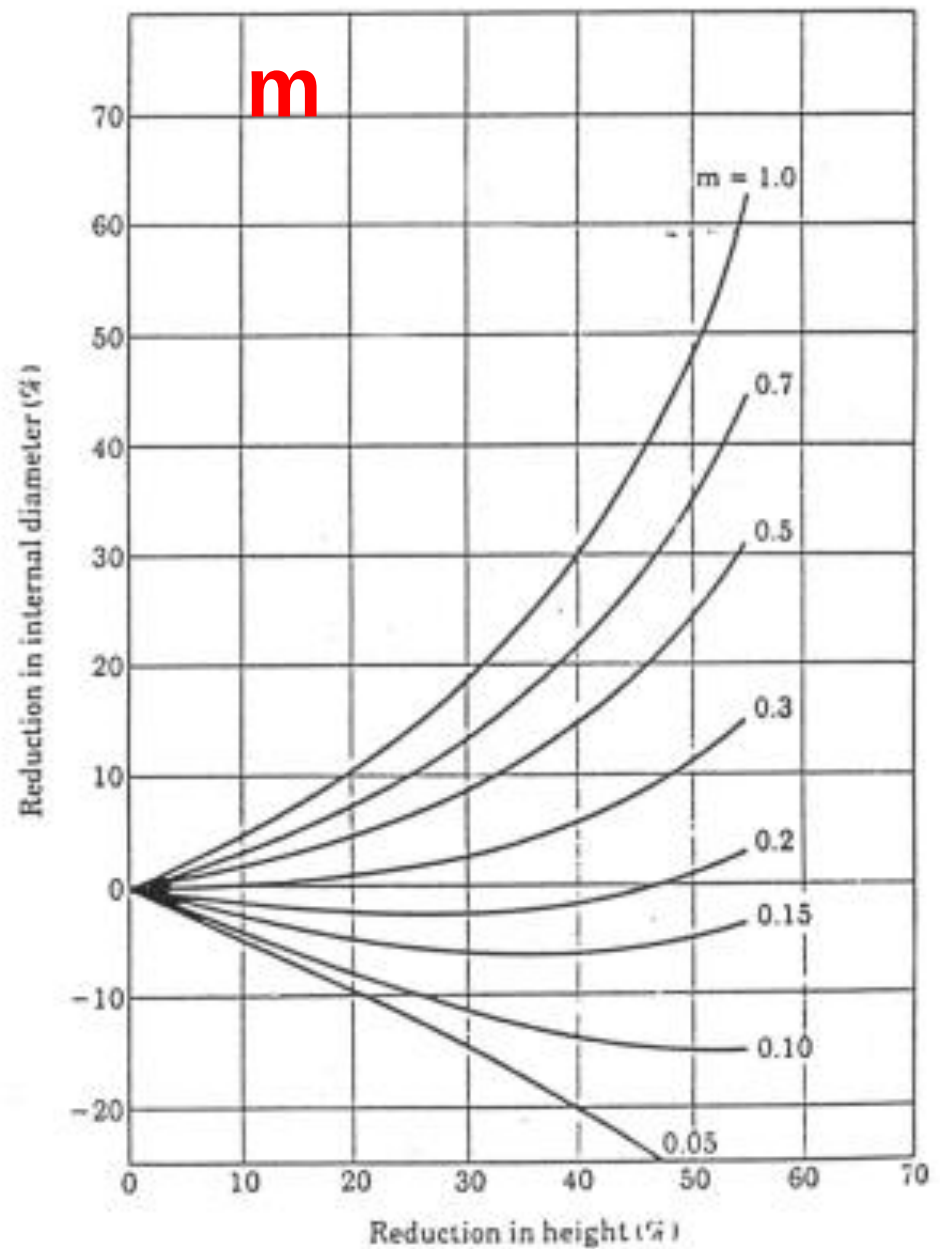


(b)

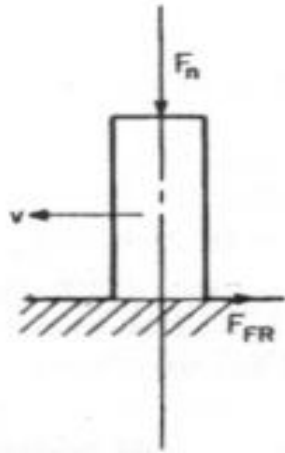


Ring compression test between flat dies. (a) Effect of lubrication on type of ring specimen barreling. (b) Test results: (1) original specimen and (2)-(4) increasing friction.

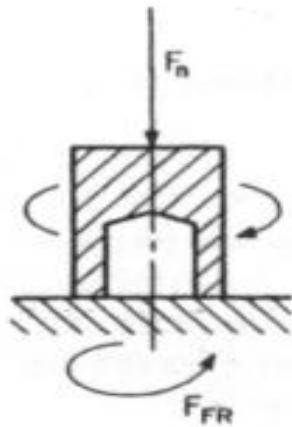
Ring compression test



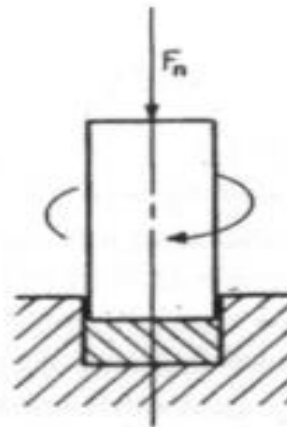
Friction tests



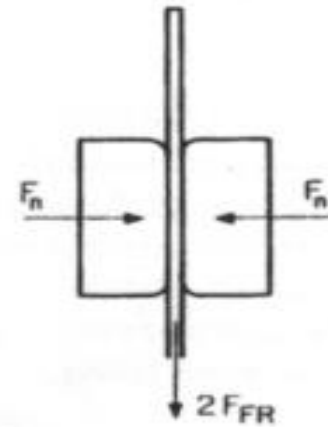
Pin on flat



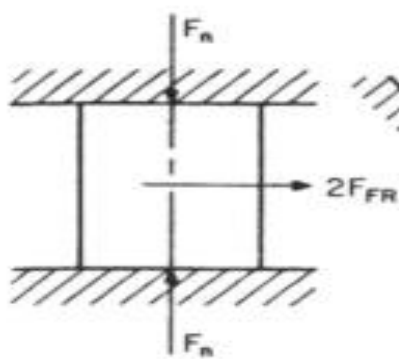
Twist compression



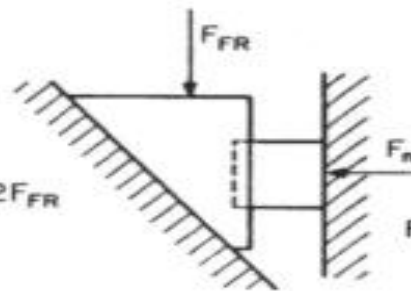
**Twist compression with
confined workpiece**



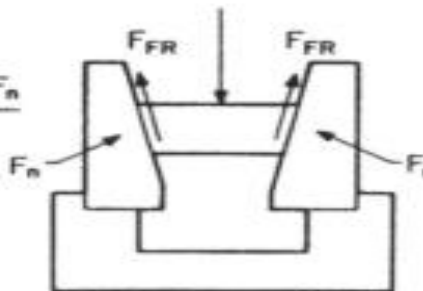
Strip drawing



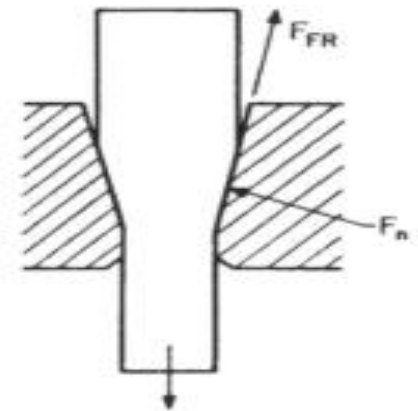
Bulk deformation



**Bulk deformation
with sliding**

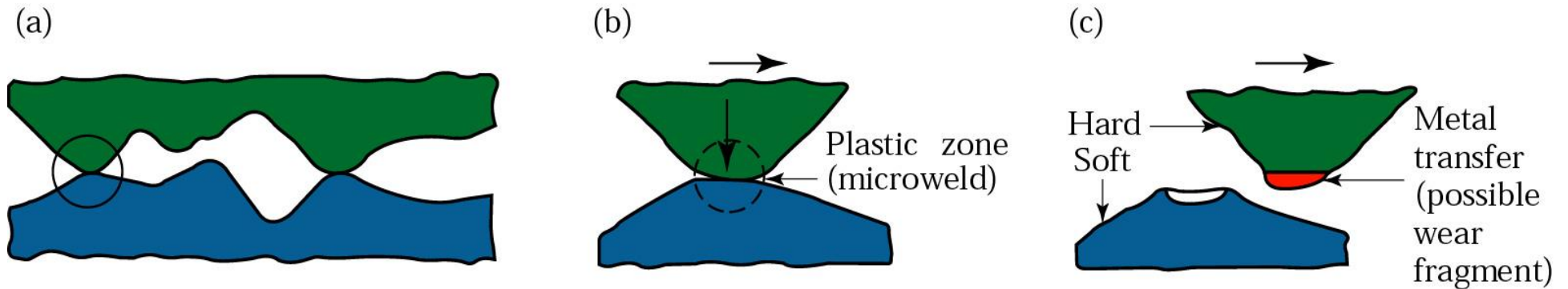


Pushing through



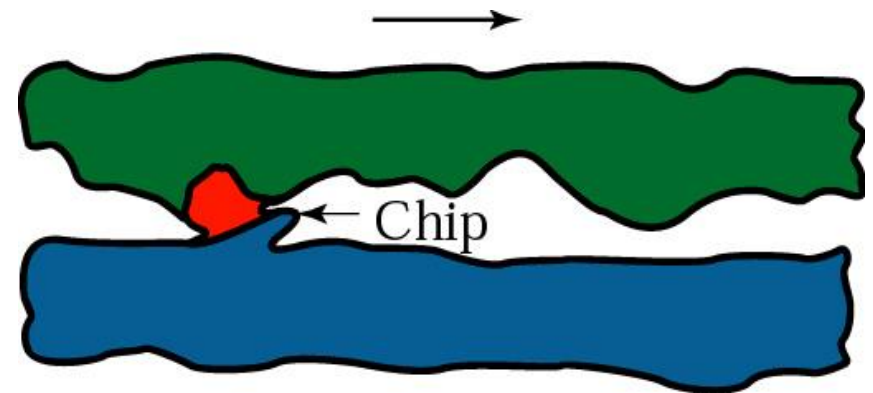
Flat bar drawing

Adhesive and abrasive wear



Schematic illustration of (a) two contacting asperities, (b) **ADHESION** between two asperities, and (c) the formation of a wear particle.

Schematic illustration of **ABRASIVE** wear in sliding. Longitudinal scratches on a surface usually indicate abrasive wear.



Wear law

Archard's wear law

$$V = k \cdot \frac{L \cdot W}{3p}$$

V = volume of material removed by wear from the surface

k = wear coefficient

L = length of travel

W = normal load

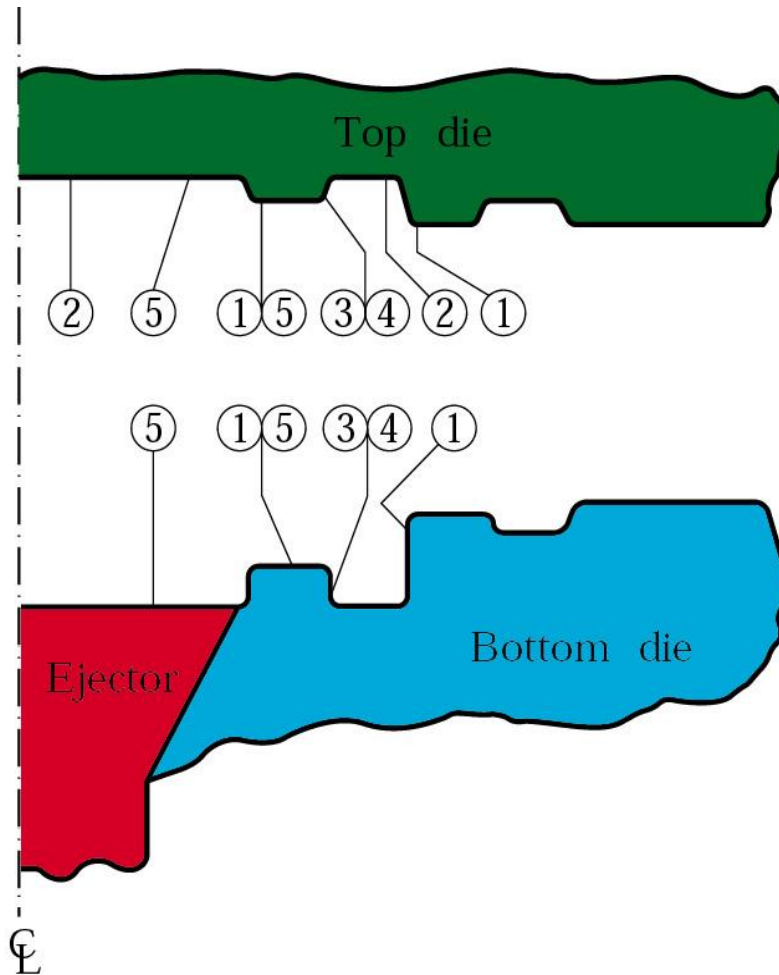
p = indentation hardness of the softer body

UNLUBRICATED	<i>k</i>	LUBRICATED	<i>k</i>
Mild steel on mild steel	10^{-2} to 10^{-3}	52100 steel on 52100 steel	10^{-7} to 10^{-10}
60-40 brass on hardened tool steel	10^{-3}	Aluminum bronze on hardened steel	10^{-8}
Hardened tool steel on hardened tool steel	10^{-4}	Hardened steel on hardened steel	10^{-9}
Polytetrafluoroethylene (PTFE) on tool steel	10^{-5}		
Tungsten carbide on mild steel	10^{-6}		

Wear in a hot forging die

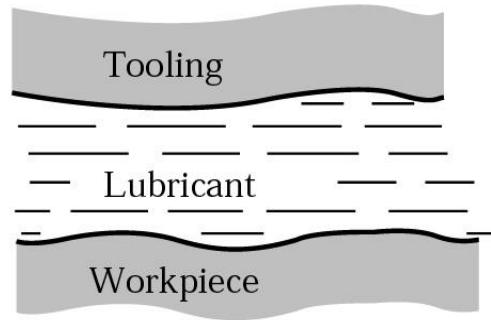
Types of wear observed in a single die used for hot forging

1. Erosion
2. Pitting (lubricated dies only)
3. Thermal fatigue
4. Mechanical fatigue
5. Plastic deformation

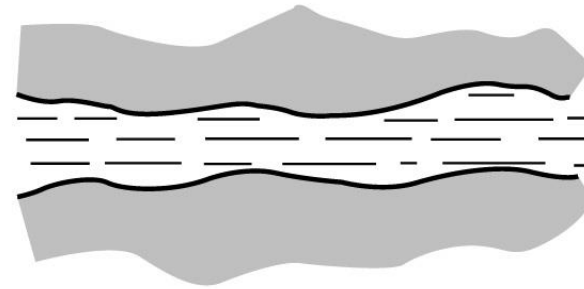


Lubrication modes in metalworking operations

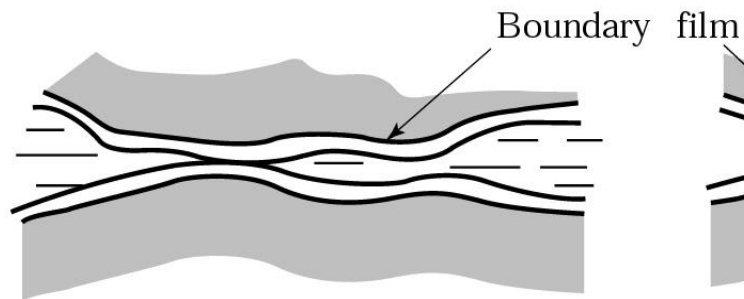
(a) Thick film



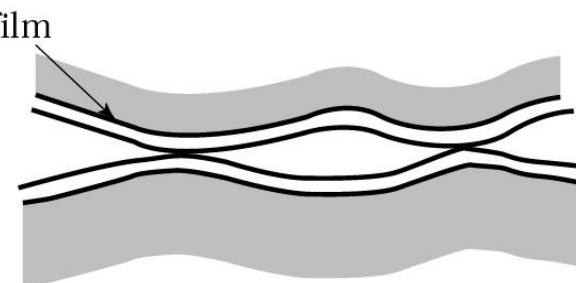
(b) Thin film



(c) Mixed



(d) Boundary



Lubricants

⊕ Functions:

- ⊕ To reduce friction
- ⊕ To reduce tool wear
- ⊕ To act as thermal barrier
- ⊕ ...

⊕ Characteristics:

- ⊕ Easiness to apply
- ⊕ Non-toxic, non-inflammable
- ⊕ Odourless
- ⊕ Non-reactive
- ⊕ Adaptable to different process conditions, temperature, sliding speed, pressure, ...

⊕ Selection:

- ⊕ Process type
- ⊕ Compatible with workpiece and tools
- ⊕ Preparation of the surfaces
- ⊕ Methods to apply and remove
- ⊕ Treatment of exhausted lubricants
- ⊕ Storage and conservation
- ⊕ Environmental and biological hazards

Lubricants

⊕ *Mineral oils:*

- ⊕ Hydrocarbon derivatives

⊕ *Natural oils:*

- ⊕ Vegetal, animal and marine derivatives
- ⊕ Waxes, soaps,...

⊕ *Synthetic fluids:*

- ⊕ Silicone and ester compounds
- ⊕ Stable at elevated temperatures

⊕ *Compound lubricants:*

- ⊕ Mineral and synthetic oils, additives

⊕ *Aqueous lubricants:*

- ⊕ Water as base for other lubricants (emulsions, suspensions)
- ⊕ Water high cooling capacity

⊕ *Coatings:*

- ⊕ Metallic (zinc, lead)
- ⊕ Polymeric (teflon)
- ⊕ Glasses