DEFORMING

Outline

Deformation processes

- Deformation process characteristics
- Deformation physics
- Common deformation processes
- DFM

Process characteristics

Material/continuum changes during processing

- Machining = Local, concentrated
- Deformation = Over large volume

Force

- Machining: ~10s - 100s of lbs
- Stamping: ~10s - 100s of tons

Materials - Virtually all ductile materials

Shapes - Limited by strain/flow

Size - Limited by force/equipment

Important physics

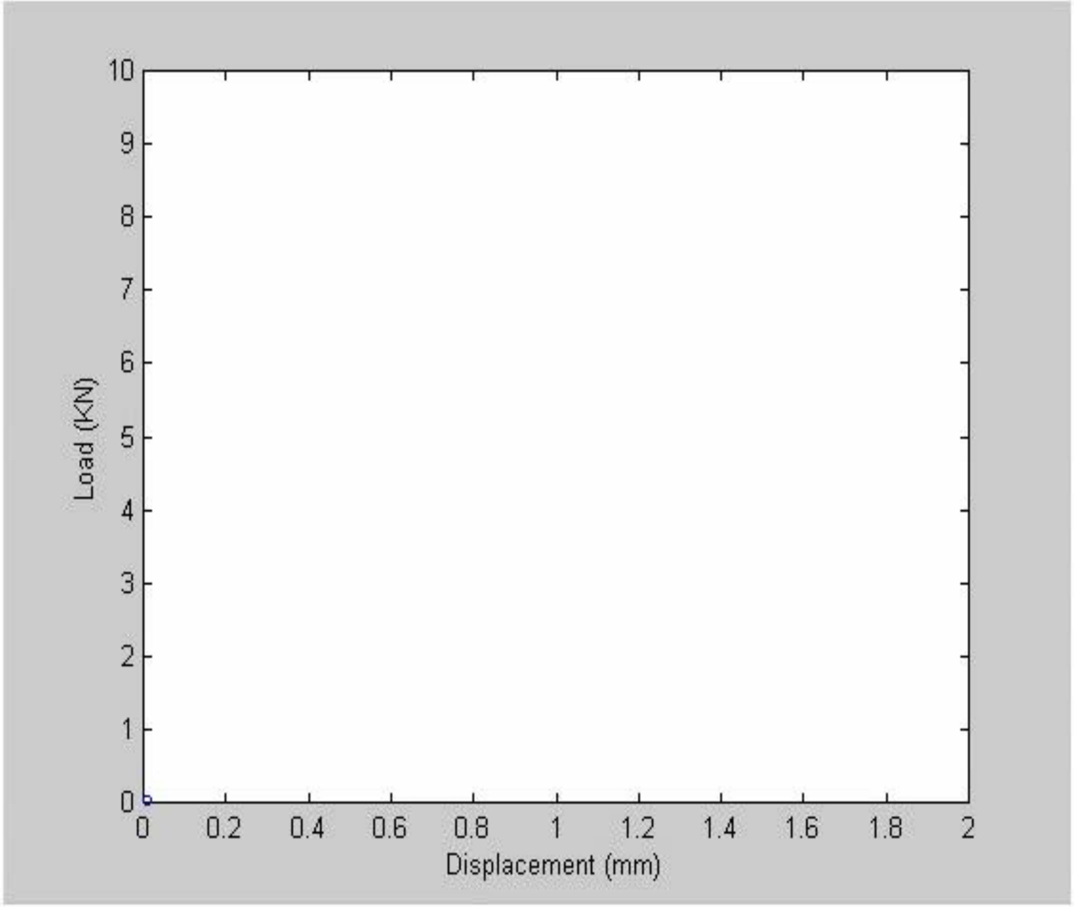
Stress/strain

- Affect rate, cost, quality and flexibility
- Affect deformation force -> equipment & energy requirements

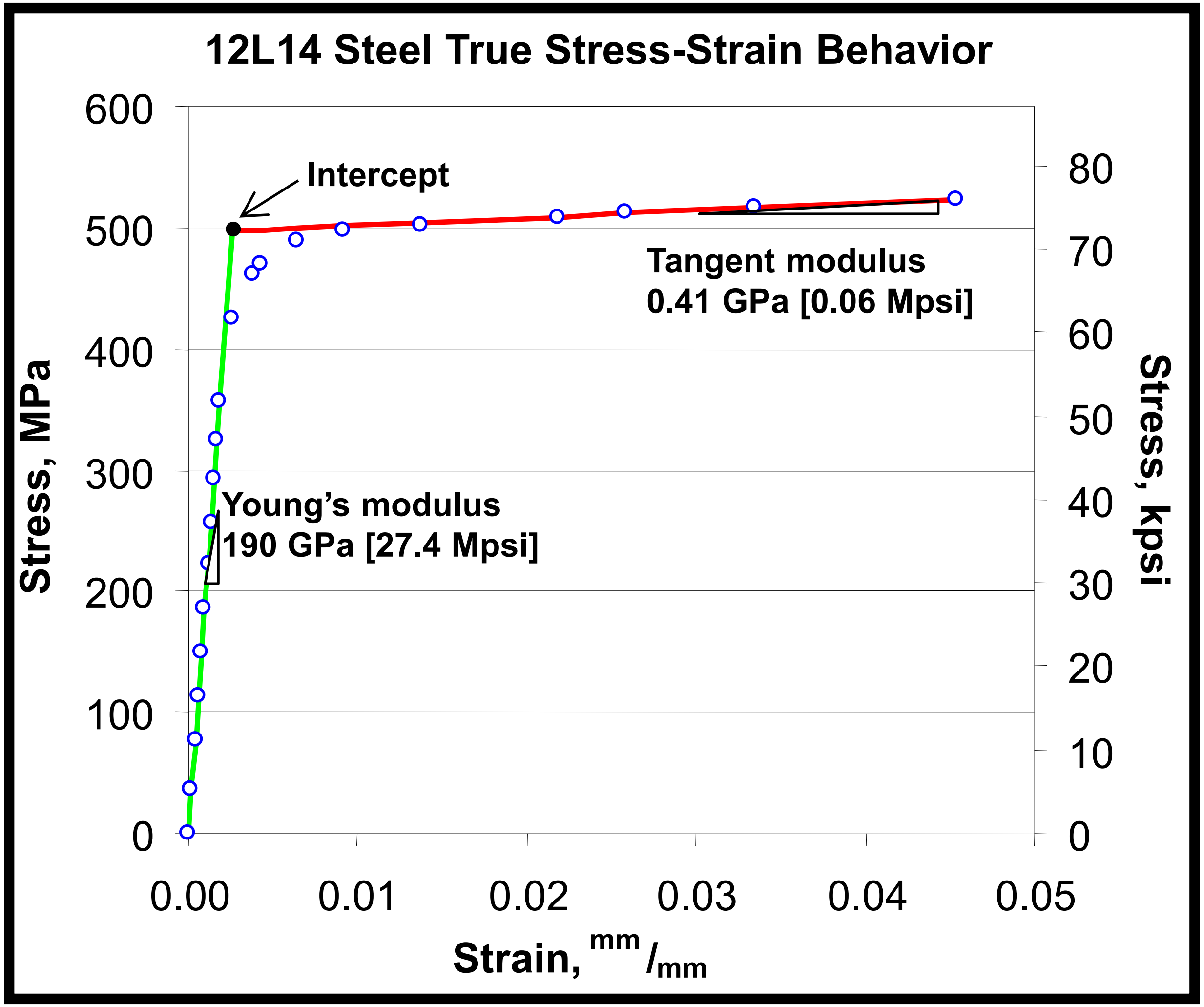
Friction

- Affect on deformation force -> equipment & energy requirements
- Why lubrication is needed and can help
- Friction is not repeatable… quality….

Tensile test: Al6061

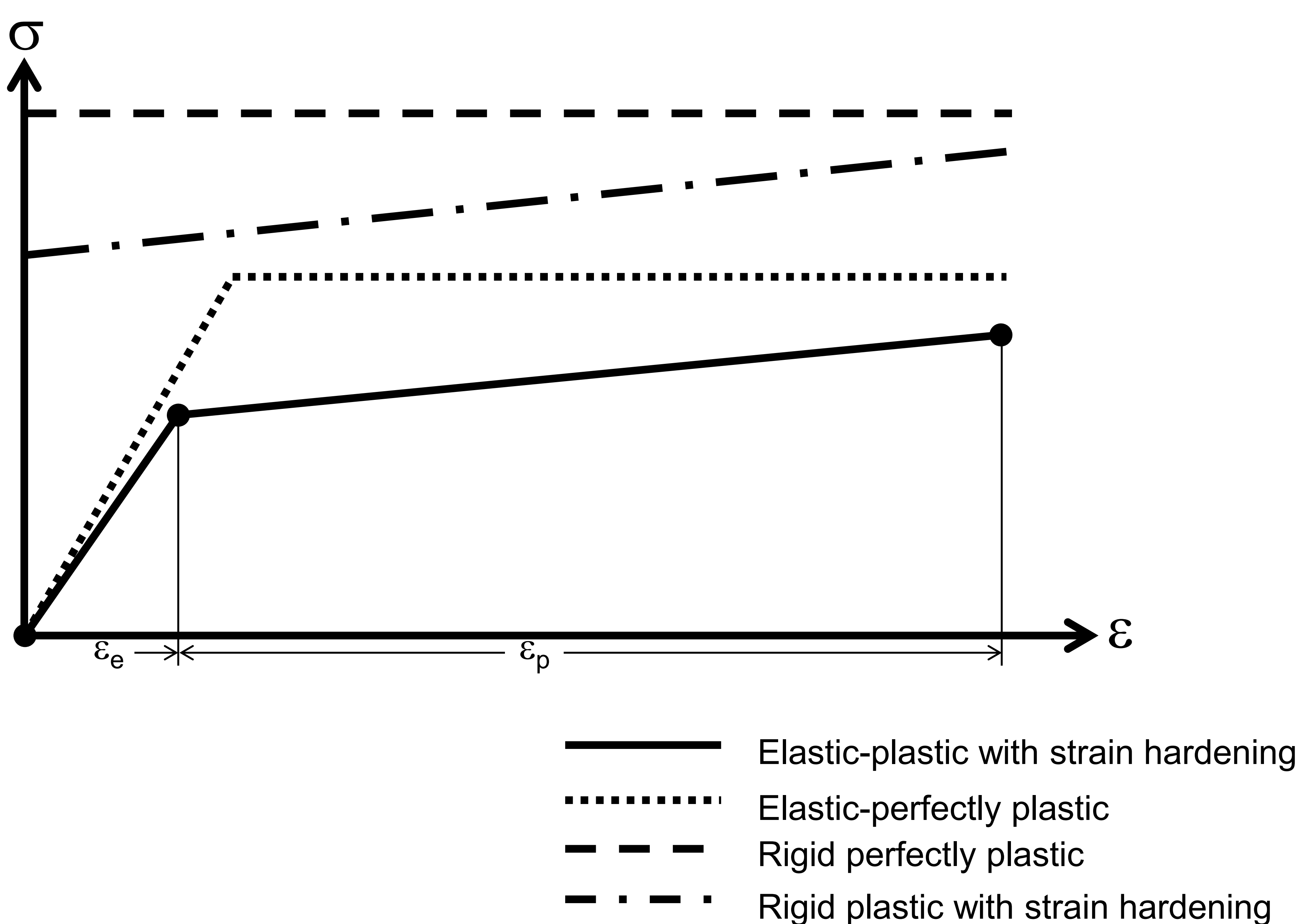


12L14 Steel

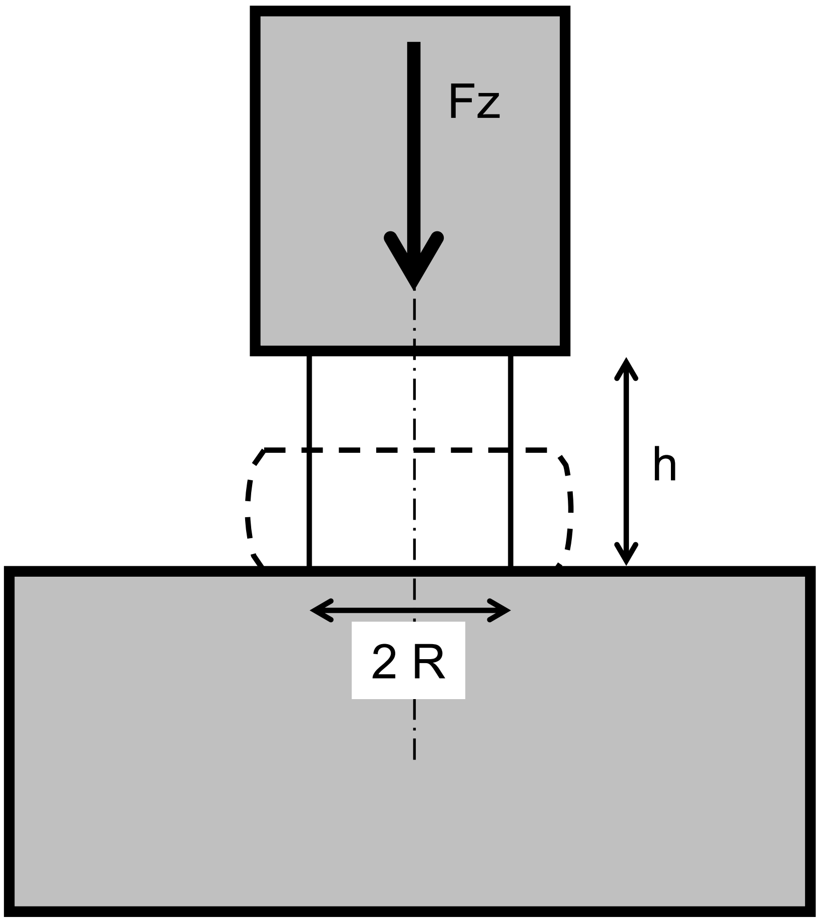


12L14 Steel True Stress-Strain Behavior
Intercept
Tangent modulus
0.41 GPa [0.06 Mpsi]
Young's modulus
190 GPa [27.4 Mpsi]
Stress, MPa
Stress, kpsi
Strain, mm/mm
0
100
200
300
400
500
600
0
10
20
30
40
50
60
70
80
0.00
0.01
0.02
0.03
0.04
0.05

Stress strain behavior of ductile materials



Forging force and friction



Axi-symmetric upsetting

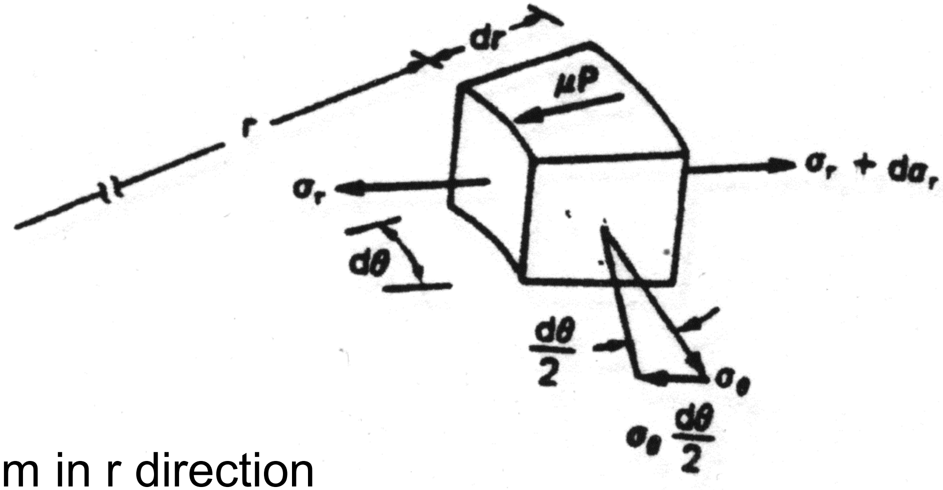
Purpose

- Find $F_z(\mu)$
- Sensitivity

Assumptions:

- Tresca flow
- Constant friction coefficient
- Plastic deformation

Forging force and friction



Eq. A – Equilibrium in r direction

$$\Sigma dF_r = 0 = \underbrace{-\sigma_r \cdot h \cdot r \cdot d\theta}_{dF_{\text{inner arc}}} \underbrace{- 2 \cdot \mu \cdot p \cdot r \cdot d\theta \cdot dr}_{dF_{\text{friction top \& bottom}}} \underbrace{- 2 \cdot \sigma_\theta \cdot h \cdot dr \cdot \frac{d\theta}{2}}_{dF_{\text{hoop}}} + \underbrace{(\sigma_r + d\sigma_r) \cdot (r + dr) \cdot h \cdot d\theta}_{dF_{\text{outer arc}}}$$

$$\frac{d\sigma_r}{dr} = \frac{2 \cdot \mu \cdot p}{h} = -\frac{2 \cdot \mu \cdot \sigma_z}{h}$$

Eq. B - Tresca Yield Criterion

$$\sigma_r - \sigma_z = Y$$

$$\sigma_z = -Y \cdot \exp\left[\frac{2\mu}{h}(R - r)\right]$$

Forging force and friction cont.

$$F_z = \int_0^R \sigma_z \cdot 2 \cdot \pi \cdot r \cdot dr = \left(\pi \cdot R^2\right) \cdot \frac{1}{2} \cdot \left(\frac{h}{\mu \cdot R}\right)^2 \cdot Y \cdot \left[\exp\left(\frac{2 \cdot \mu \cdot R}{h}\right) - \left(\frac{2 \cdot \mu \cdot R}{h}\right) - 1\right]$$

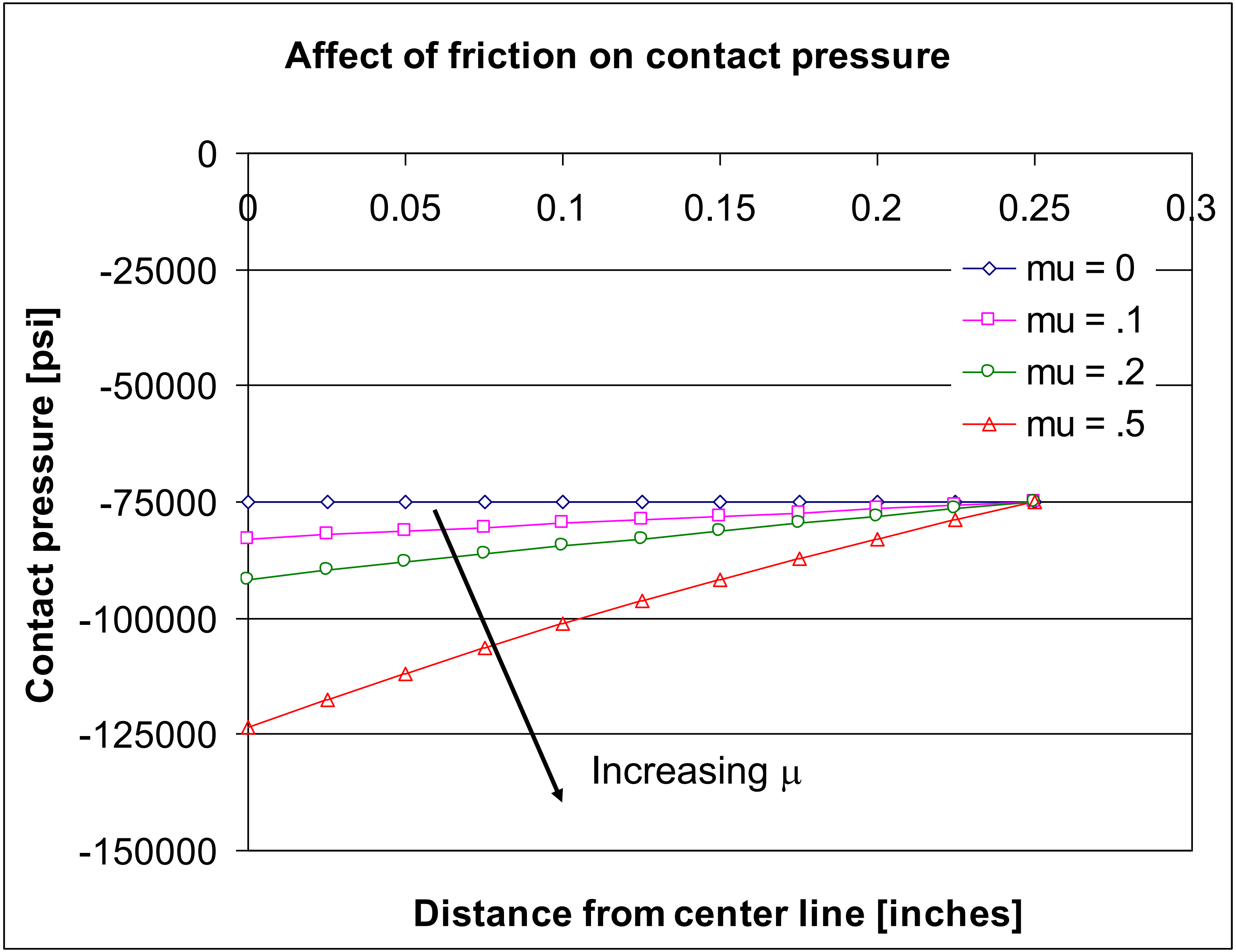
Now use Taylor's series expansion (3 terms) to approximate the exponential function

Expand about 0, makes this approximation valid for small values of $2\mu R/h$

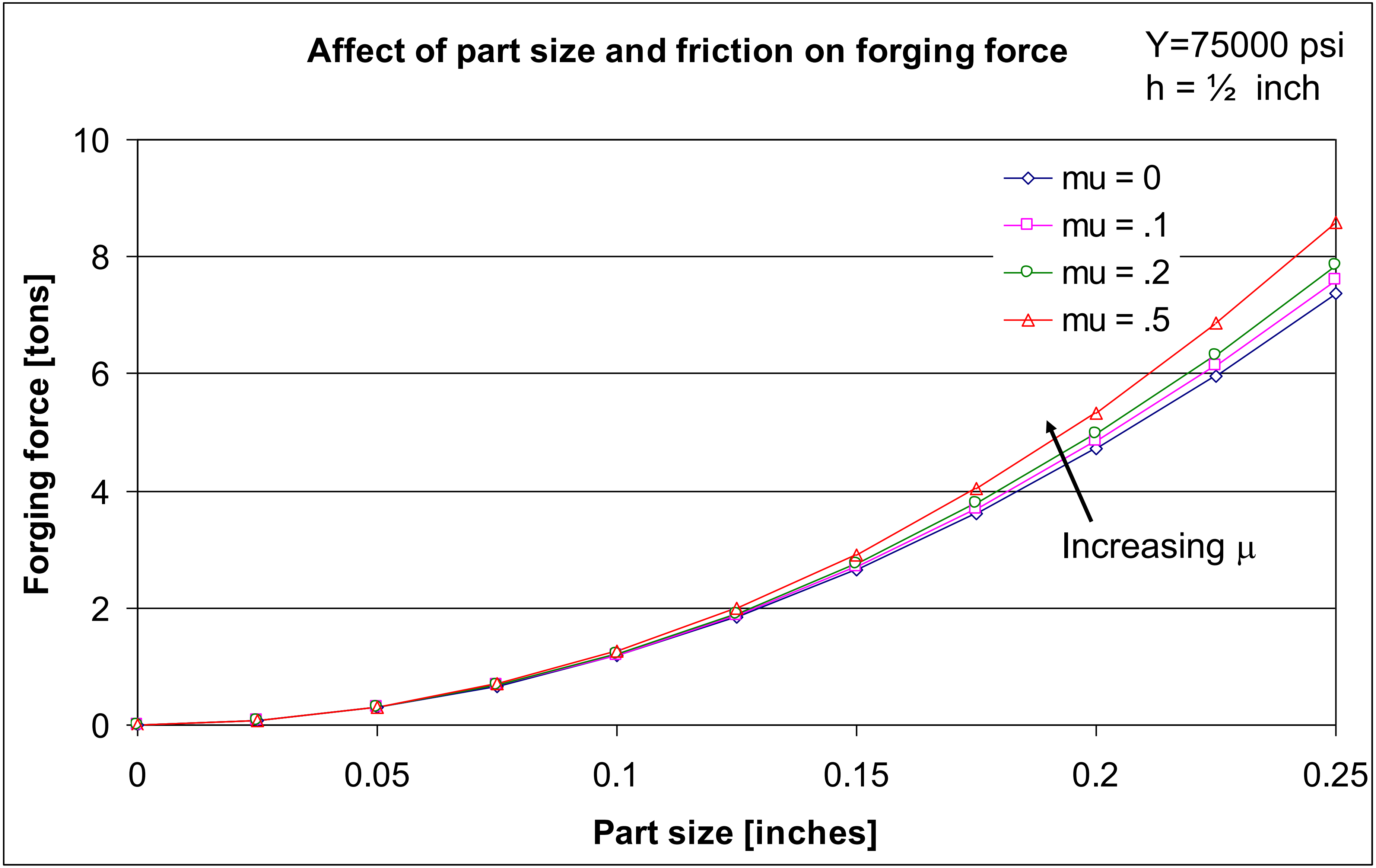
$$\left|F_z\right| = \left(\pi \cdot R^2\right) \cdot Y \cdot \left[1 + \left(\frac{2}{3} \cdot \frac{\mu \cdot R}{h}\right)\right]$$

Forging force and friction

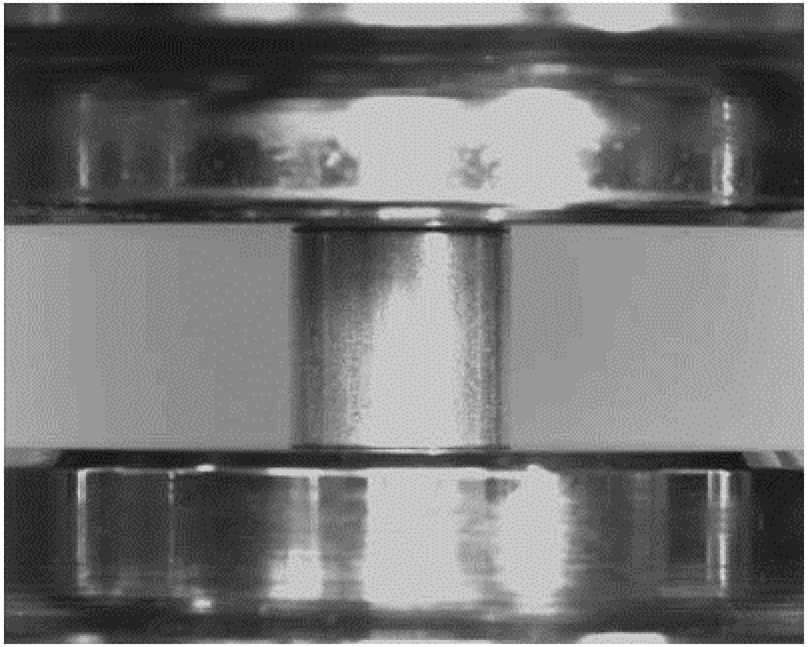
Y=75000 psi
h = ½ inch

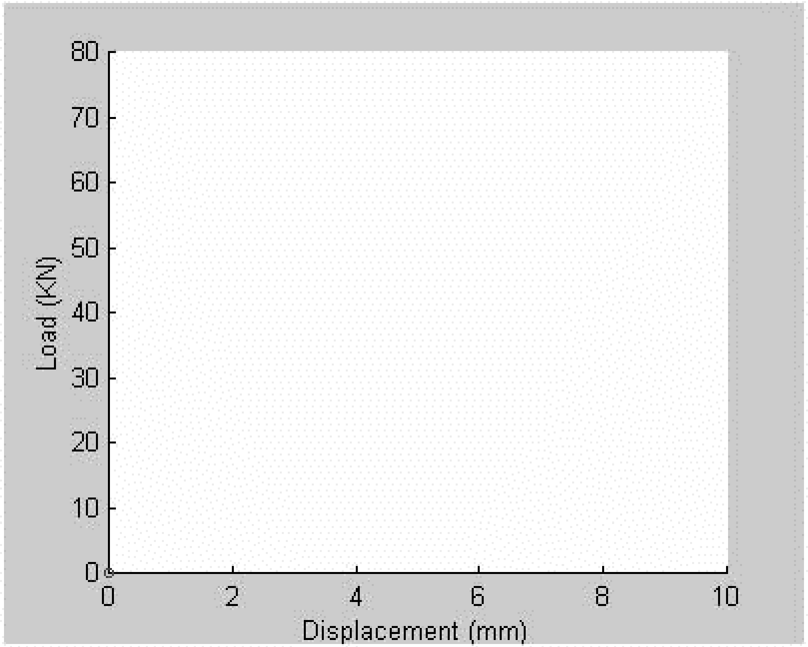


Forging force and friction

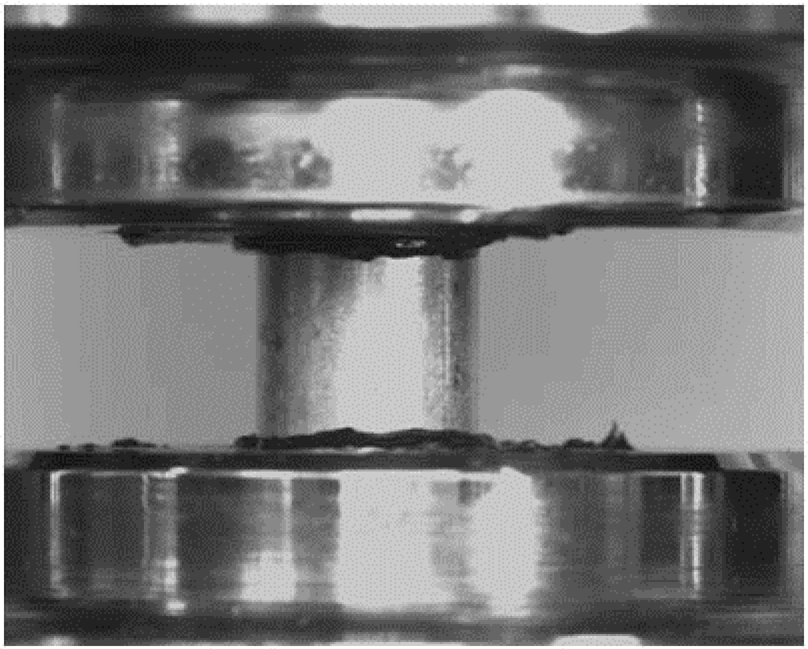


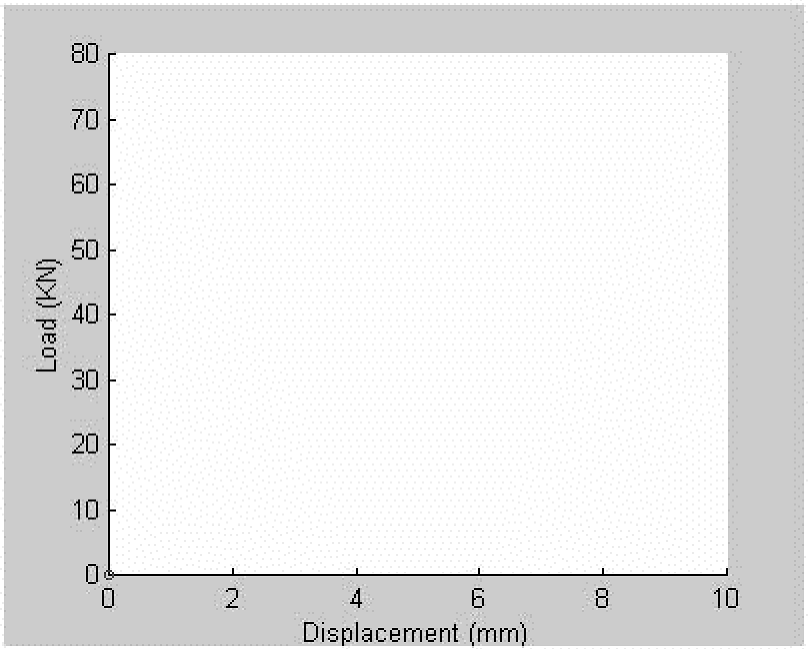
Upsetting with friction





Upsetting without friction





Common processes

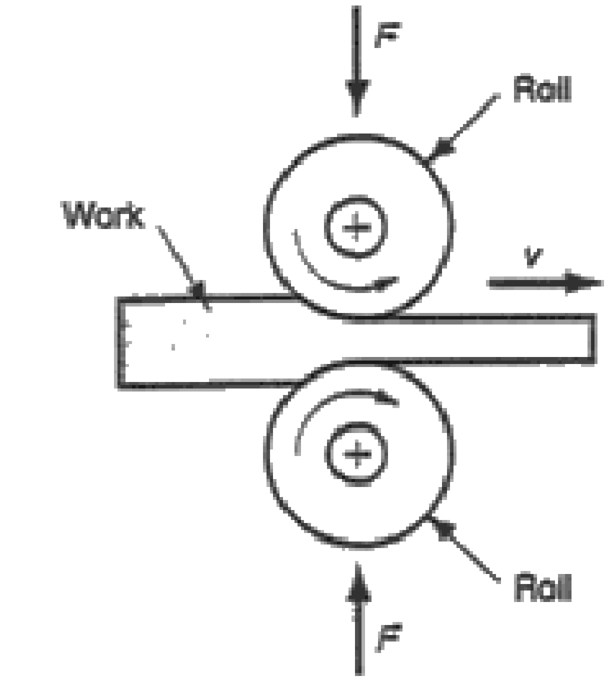
Rolling

Forging

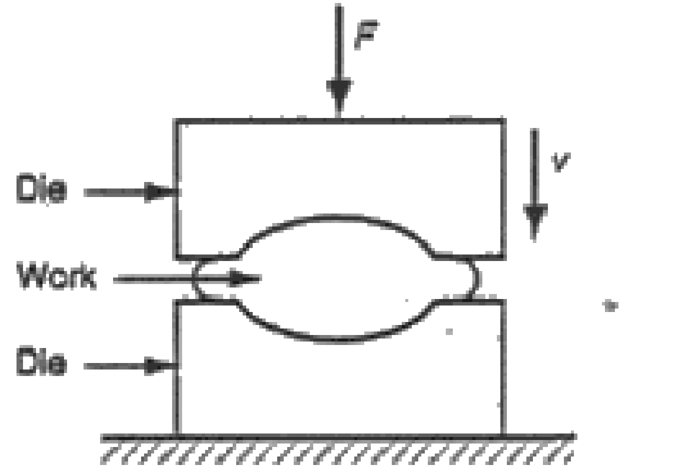
Extrusion/Drawing

Sheet metal

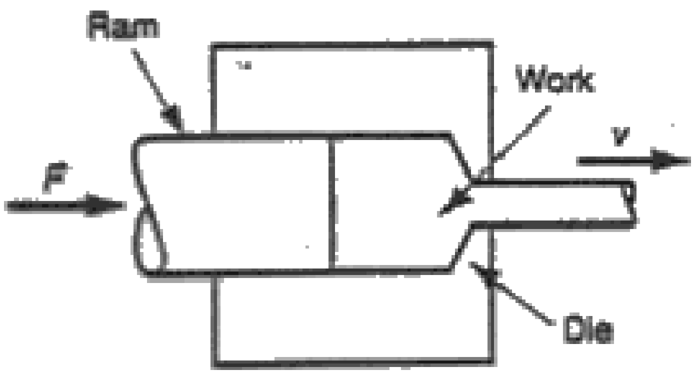
Rolling, forging, extrusion and drawing



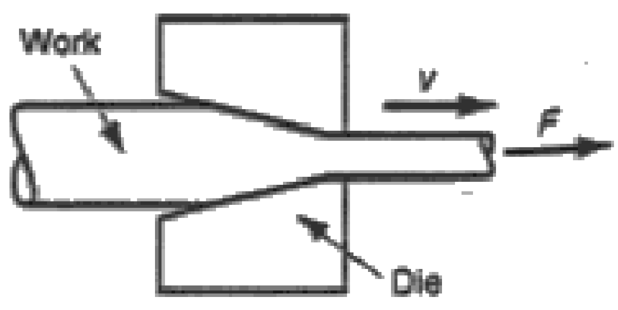
(a)



(b)

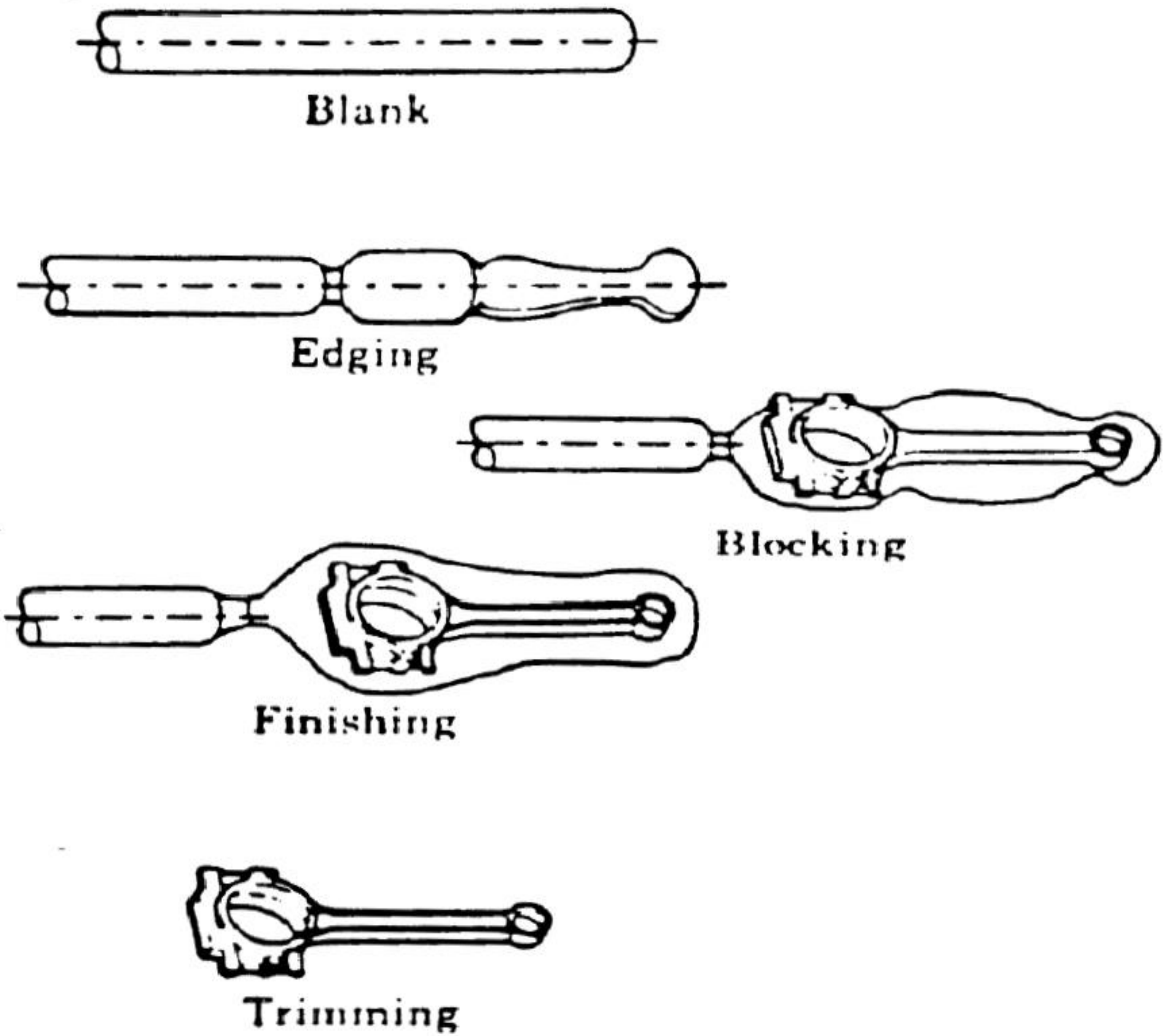


(c)



(d)

Forging



Effect of grain size

Properties affected by grain size

- **Strength**
- **Hardness**
- **Ductility**
- **For example (Ferrite)**

$$\sigma_y = \sigma_o + \frac{k_y}{\sqrt{d_{grain}}}$$

We desire smaller grains for better properties

DFM for forging processes

Parting line and flash

Draft angle

Radii

Lubrication

Considerations for Rate, Quality, Cost, Flexibility

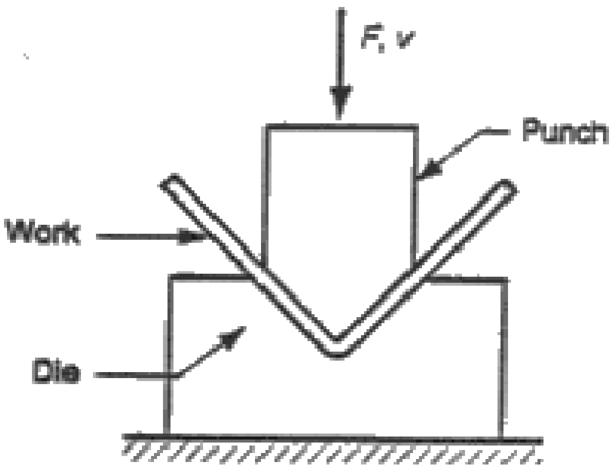
Advantages

- Parallel process: rapid bulk formation
- Overall material properties improved

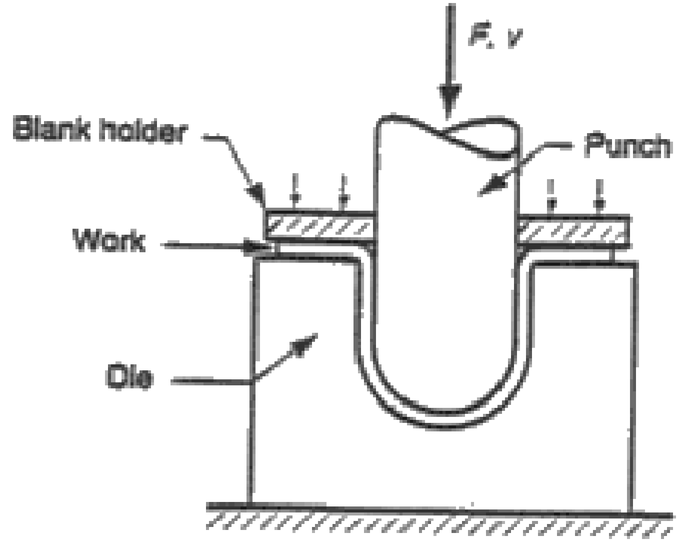
Disadvantages

- Cost of equipment and dies
- Limited flexibility in shapes and sizes (i.e. compared to machining)
- Accuracy
- Repeatability

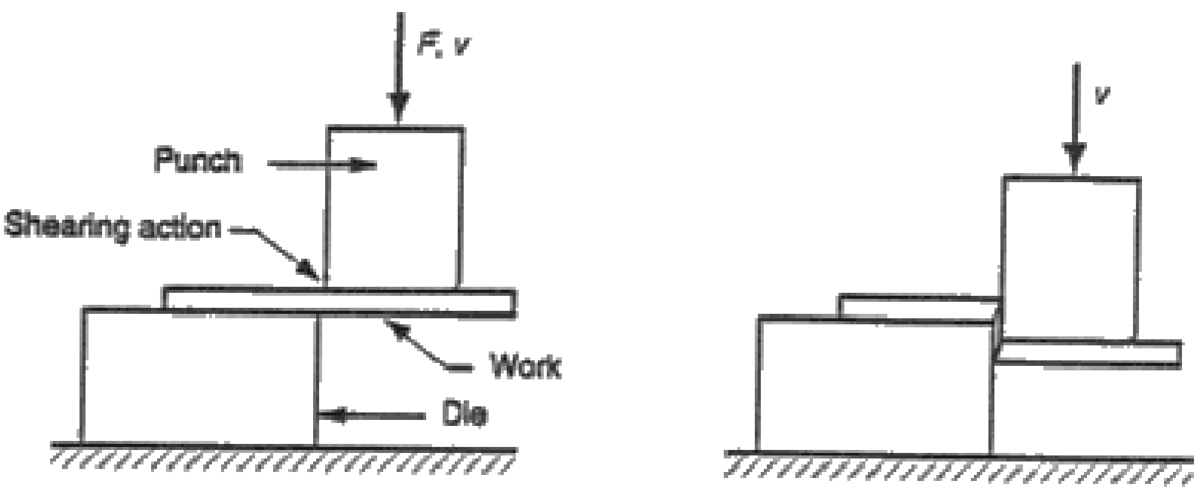
Bending, stretching and drawing



(a)



(b)

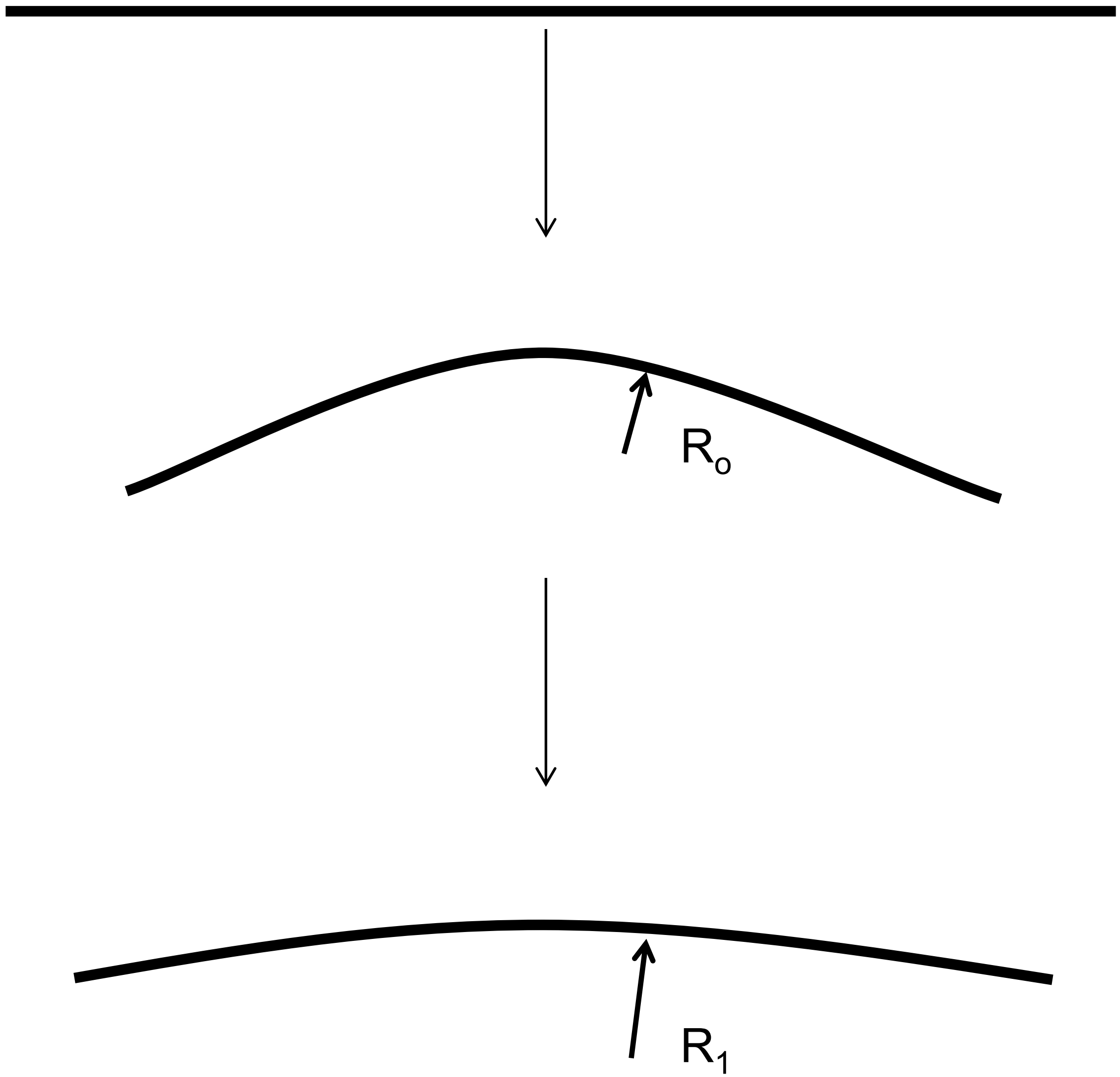


(1) (2)

(c)

Spring back

Example: Bending wire

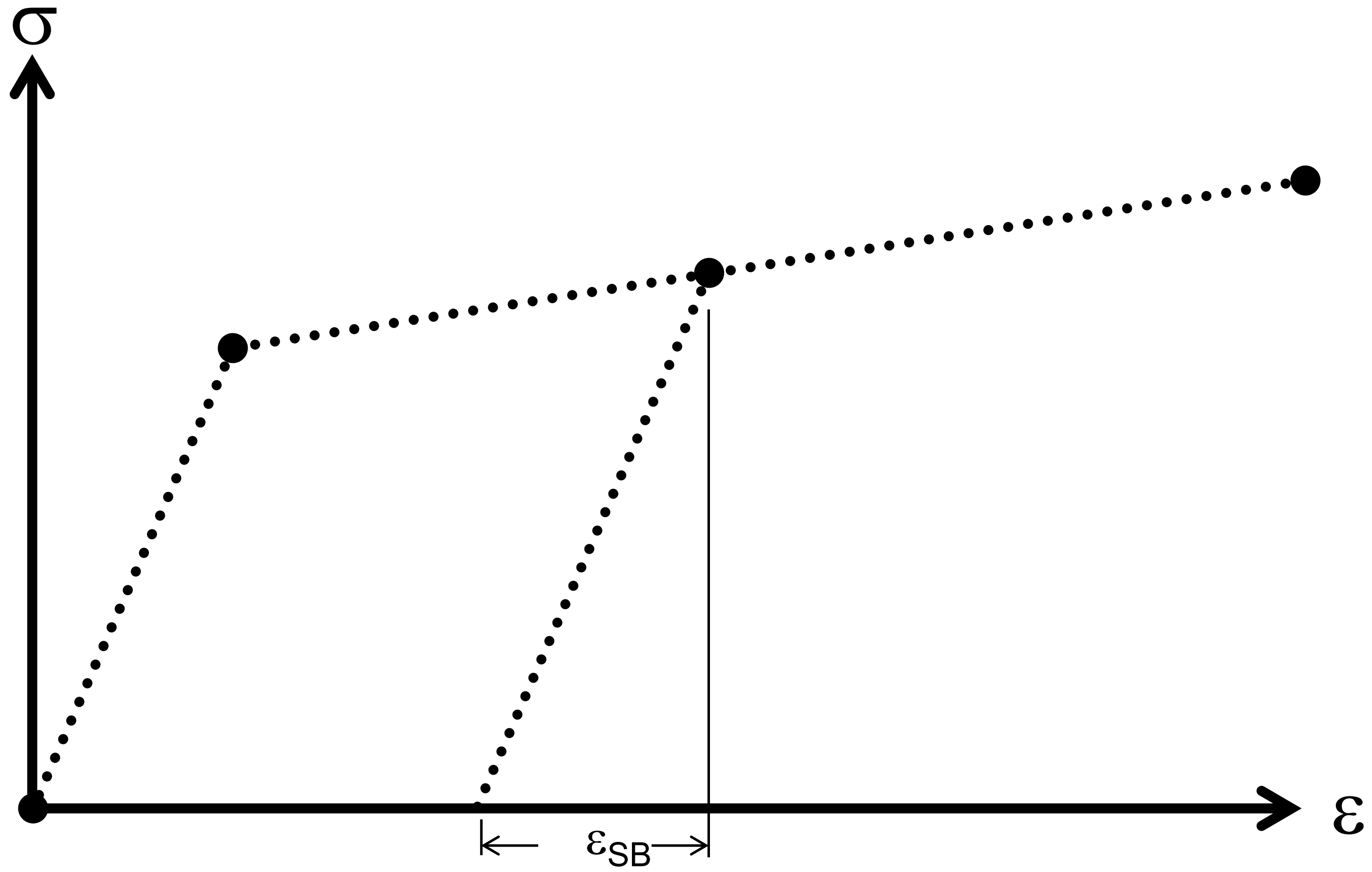


$$R_o < R_1 \Rightarrow \frac{1}{R_o} > \frac{1}{R_1}$$

Mechanics of spring back

Q: Why do we see spring back?

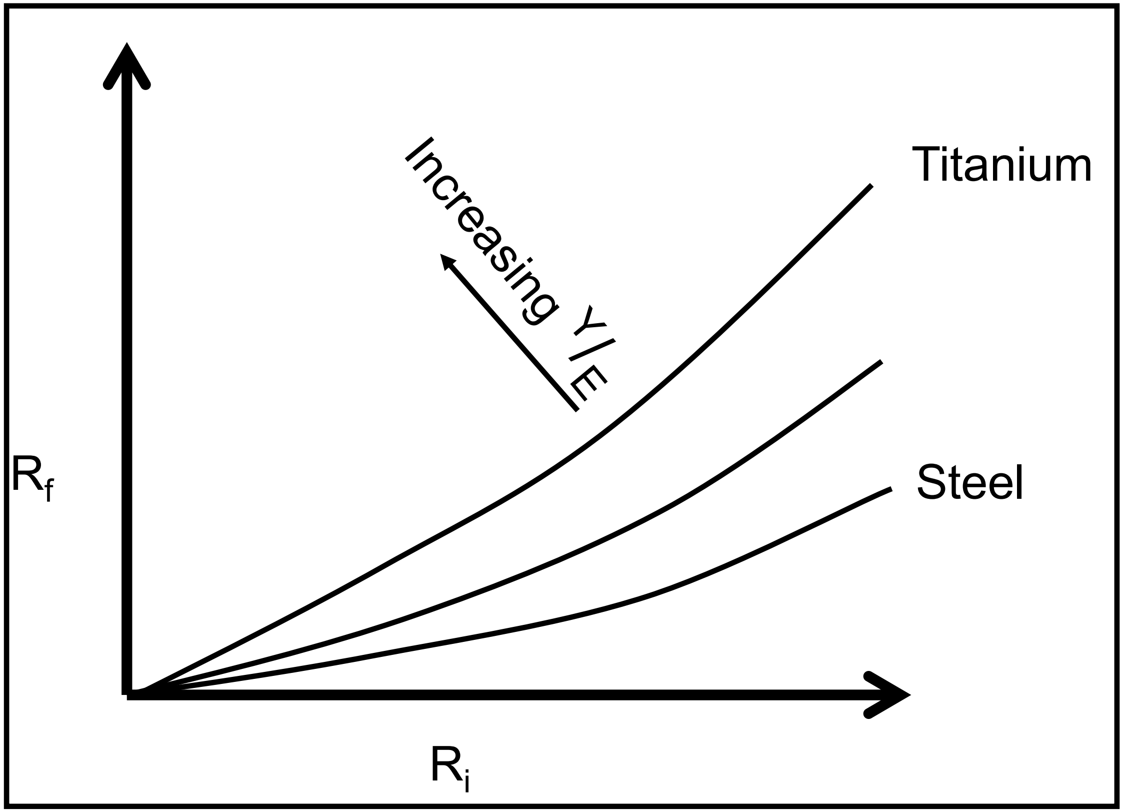
A: Elastic recovery of material



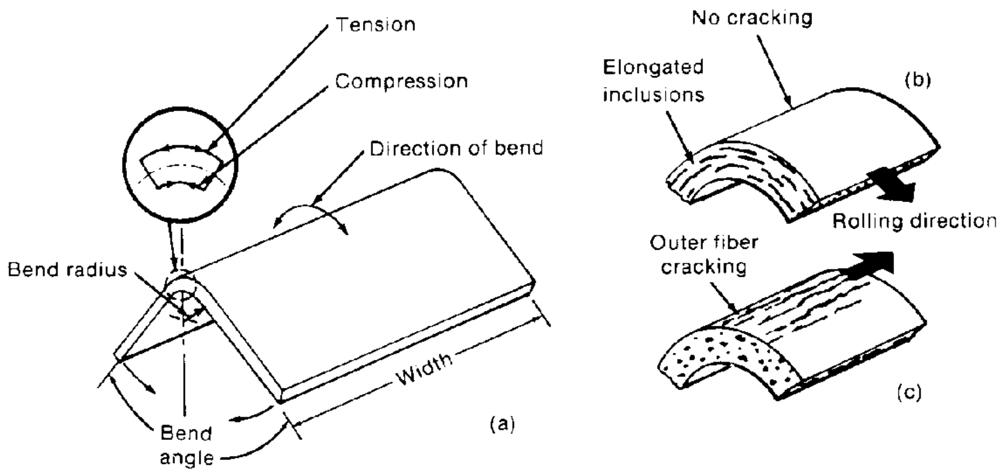
Quantifying elastic spring back

Elastic recovery of material leads to spring back

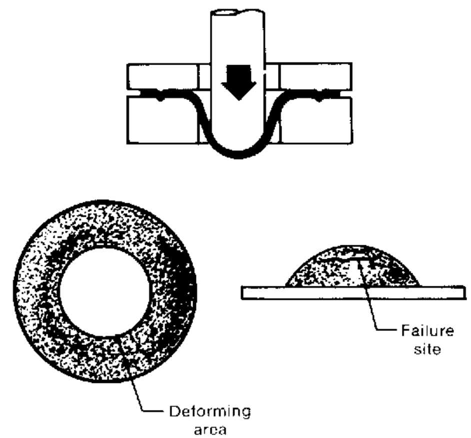
- Y = Yield stress E = Young's Modulus t = thickness
- $$\frac{R_i}{R_f} = 4\cdot\left(\frac{R_i}{t}\cdot\frac{Y}{E}\right)^3 - 3\cdot\left(\frac{R_i}{t}\cdot\frac{Y}{E}\right) + 1 \longrightarrow \frac{1}{R_i} - \frac{1}{R_f} = \frac{3}{t}\cdot\left(\frac{Y}{E}\right) - \frac{4R_i^2}{t^3}\cdot\left(\frac{Y}{E}\right)^3$$
- With increase in R_i / t or Y OR decrease in E spring back increases



Bending is by far the most common of all sheet forming operations. Performed with or without superimposed in-plane tension, some form of bending is observed in most sheet forming operations. When bending is performed with one or both ends free, the situation resembles pure bending.

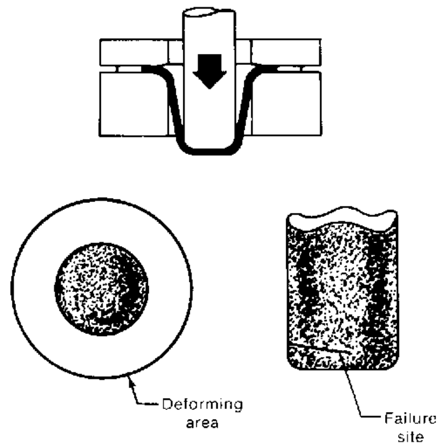


Stretching is best described as the deformation of a sheet by a punch (or by fluid pressure) while its edges are clamped in a die, and the flange material is restricted from being pulled into the cavity.



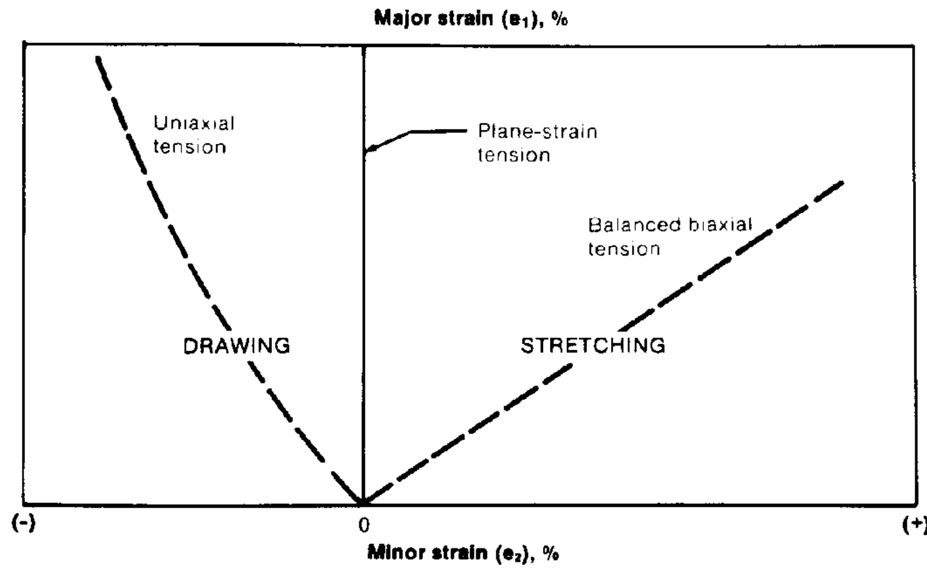
In the case of punch stretching, the local in-plane strain state in the plastically deforming region is tensile in any two orthogonal directions.

Drawing may be described as the deformation of a sheet by a punch while its edges are not held, and the flange material is pulled into the die cavity.



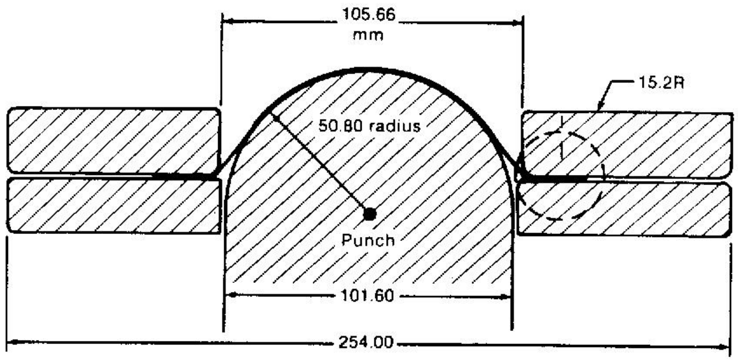
In the case of cup drawing, most of the plastic deformation occurs in the flange, where the strain state is tensile in the radial direction, and compressive in the circumferential direction.

Late e_1 and e_2 denote the local **major** and **minor** in-plane strains in a sheet.

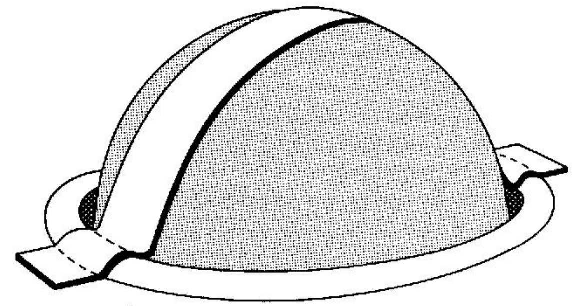


Strain paths for stretching and drawing.

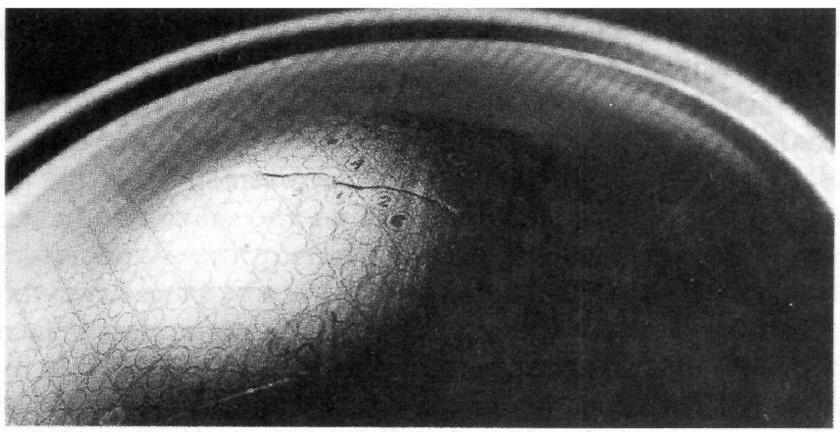
In **stretching**, the strains in all directions in the sheet are tensile. In **drawing**, the major strain is tensile, whereas the minor strain is compressive.



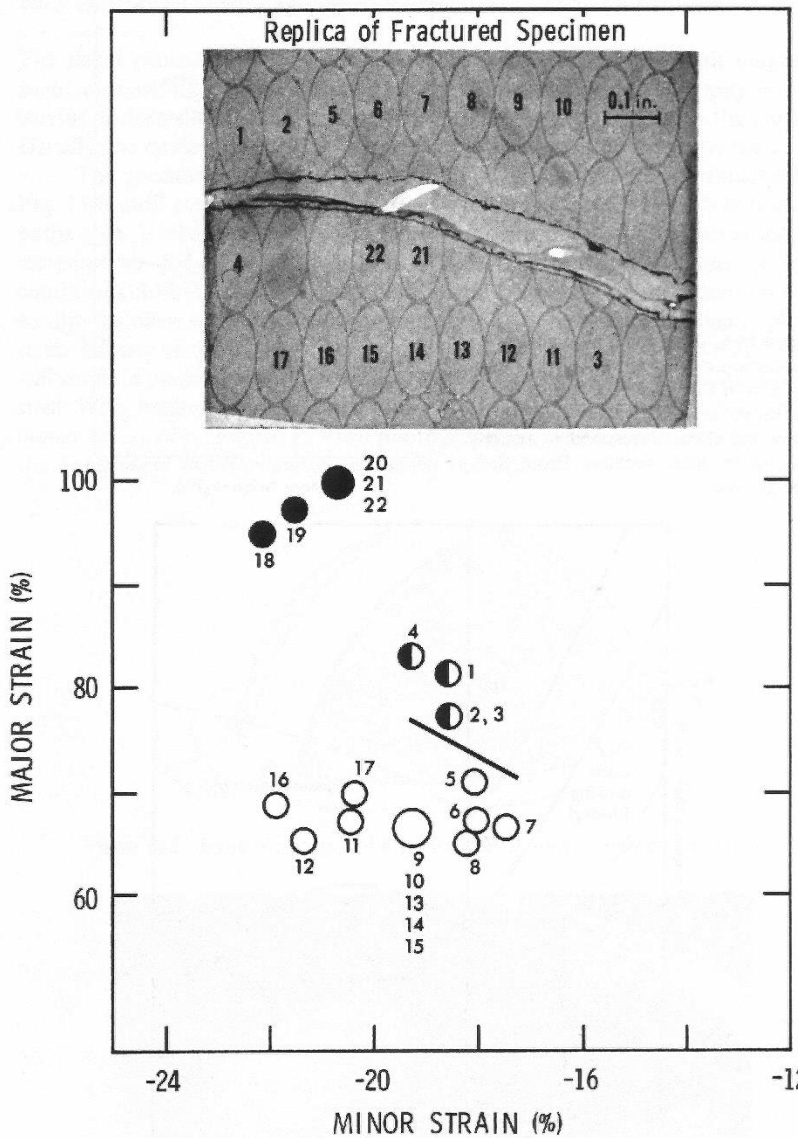
Schematic illustration of punch-stretch test apparatus for FLC (or FLD) measurements.



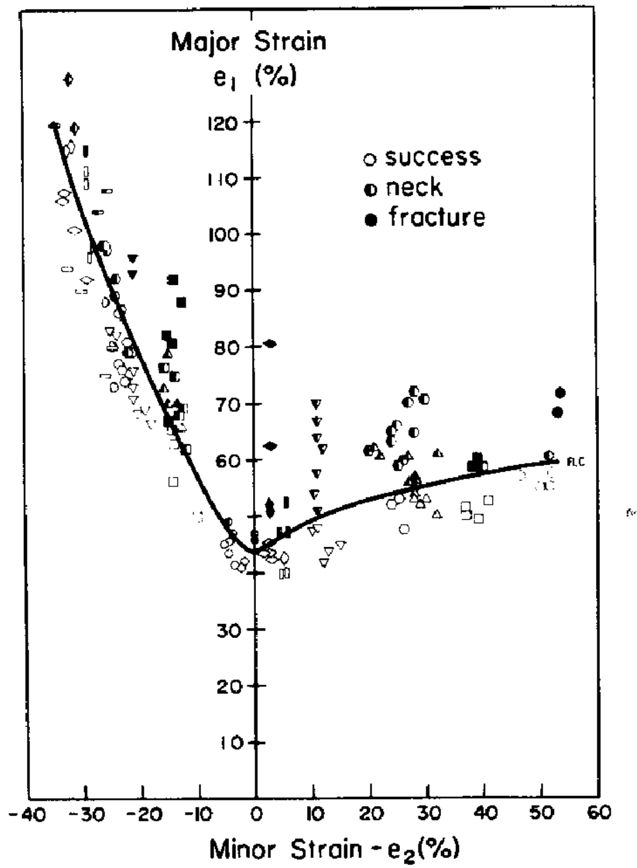
Strips of varying width are stretched to obtain different e_2/e_1 ratios.



Failure under biaxial tension ($e_2 = e_1$) near the top of the dome in a full-width, well-lubricated specimen.



Distortion of printed circles near a localized neck and a plot of the strains in the circles. Solid points are for grid circles through which failure occurred, open points are for grid circles removed from failure, and partially filled points are for grid circles very near failure. From S. S. Hecker, *Sheet Metal Ind.*, 52 (1975), pp. 671–75.



Forming limit diagram for an aluminum-killed low carbon steel.

Recrystallization

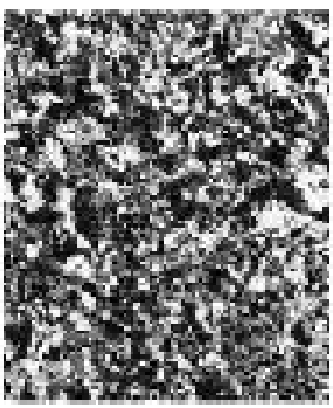
Recrystallization and Grain Growth in Brass

Figure 7.21 Callister

Cold-worked (33% CW)

3s at 580 C: initial recrystallization

4s at 580 C: partial replacement



8s at 580 C: complete recrystallization

15 min at 580 C: grain growth

10 min at 700 C: grain growth

http://www.mmat.ubc.ca/other/courses/apsc278/lecture11.pdf

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