فورج

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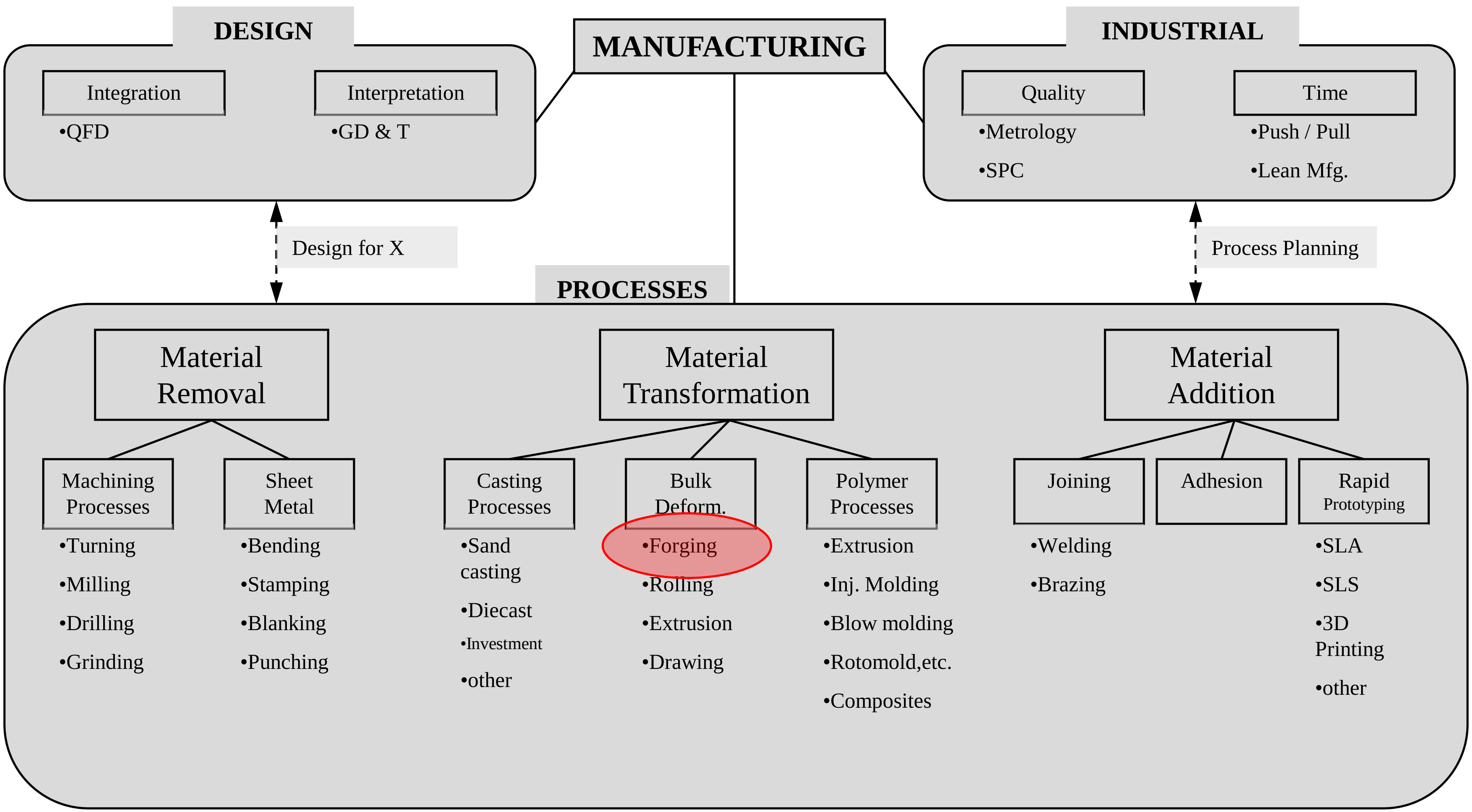
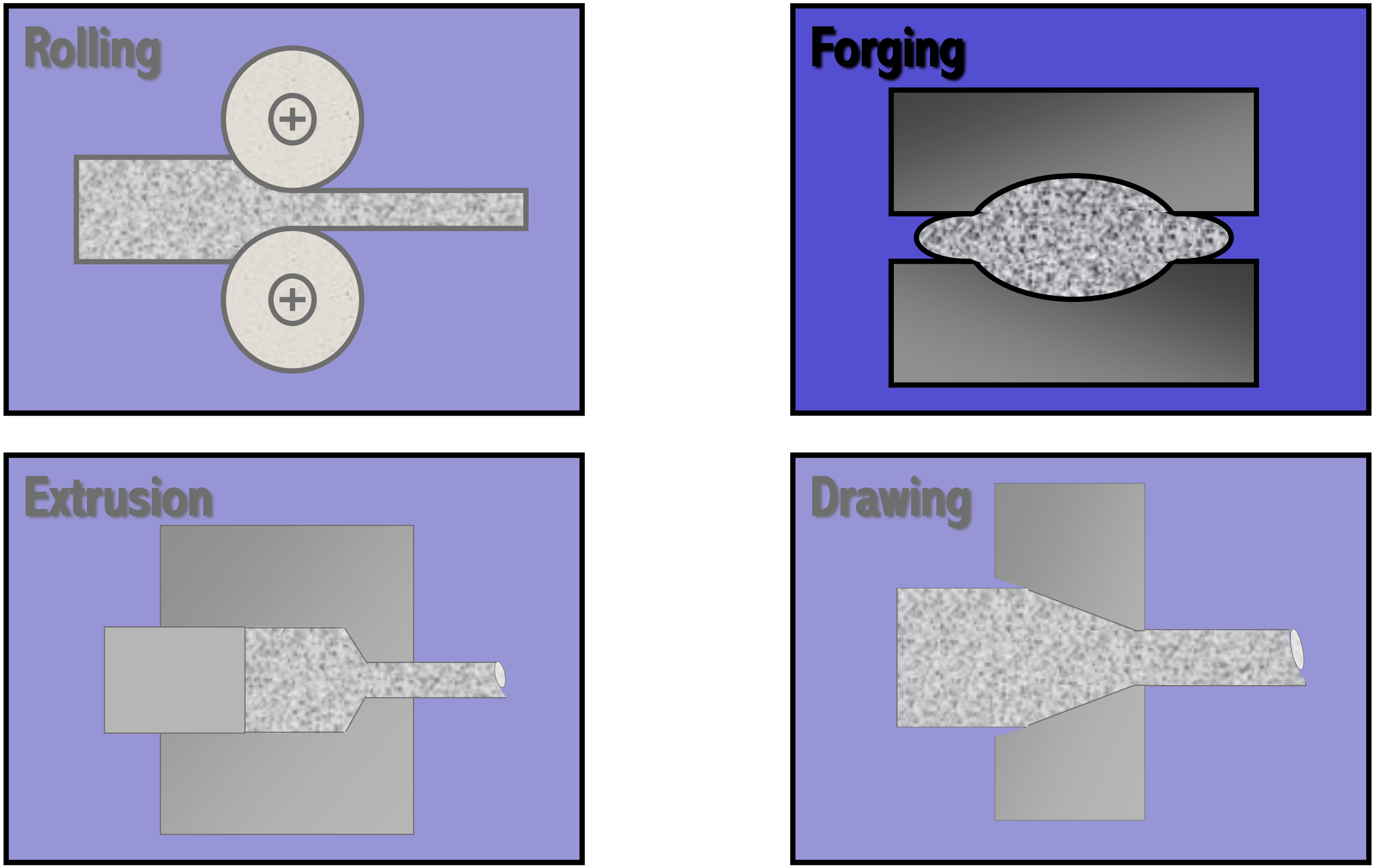
Mental Map



DESIGN
Integration
•QFD
Interpretation
•GD & T
MANUFACTURING
INDUSTRIAL
Quality
•Metrology
•SPC
Time
•Push / Pull
•Lean Mfg.
Design for X
Process Planning
PROCESSES
Material Removal
Machining Processes
•Turning
•Milling
•Drilling
•Grinding
Sheet Metal
•Bending
•Stamping
•Blanking
•Punching
Material Transformation
Casting Processes
•Sand casting
•Diecast
•Investment
•other
Bulk Deform.
•Forging
•Rolling
•Extrusion
•Drawing
Polymer Processes
•Extrusion
•Inj. Molding
•Blow molding
•Rotomold,etc.
•Composites
Material Addition
Joining
•Welding
•Brazing
Adhesion
Rapid Prototyping
•SLA
•SLS
•3D Printing
•other

Basic Bulk Deformation Processes



Introduction

Deformation of metal using impact (hammer) or gradual pressure (press) to form part of desired shape.

- Metal worked at ambient or elevated temperature
- Three types of die configurations
    - Open die (Upset)
    - Closed die (Impression Die)
    - Flashless

Benefits

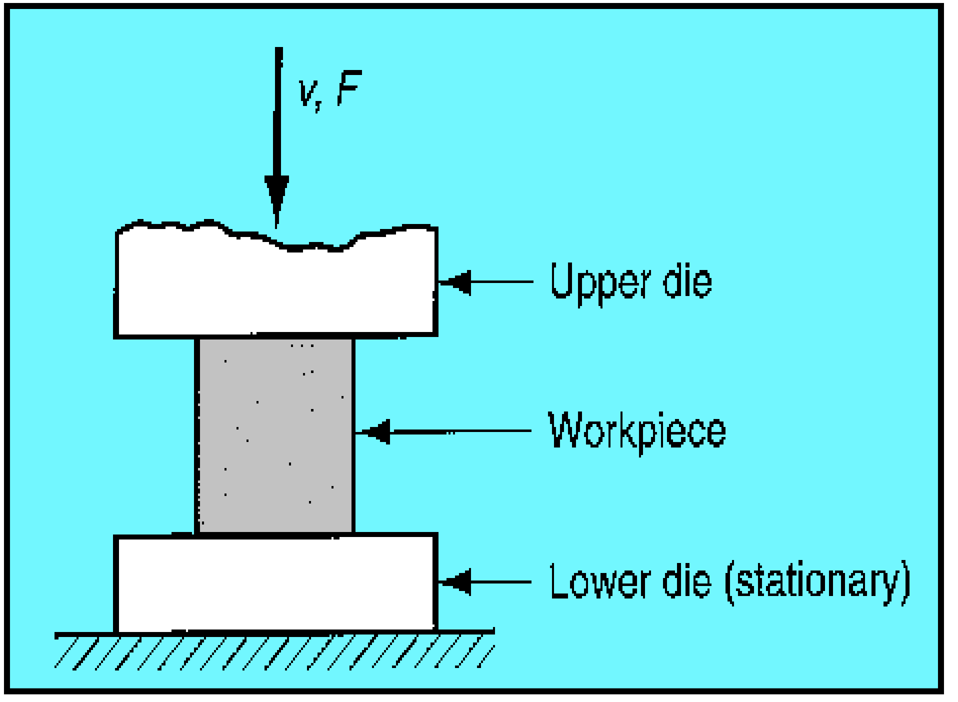
- Stronger Parts - can achieve preferred grain orientation
- “Near Net Shape” parts produced
- Parts can be produced at higher rate
- Little material wasted

Types of Products

- Crankshafts
- Gears
- Aircraft Structural Components
- Turbines

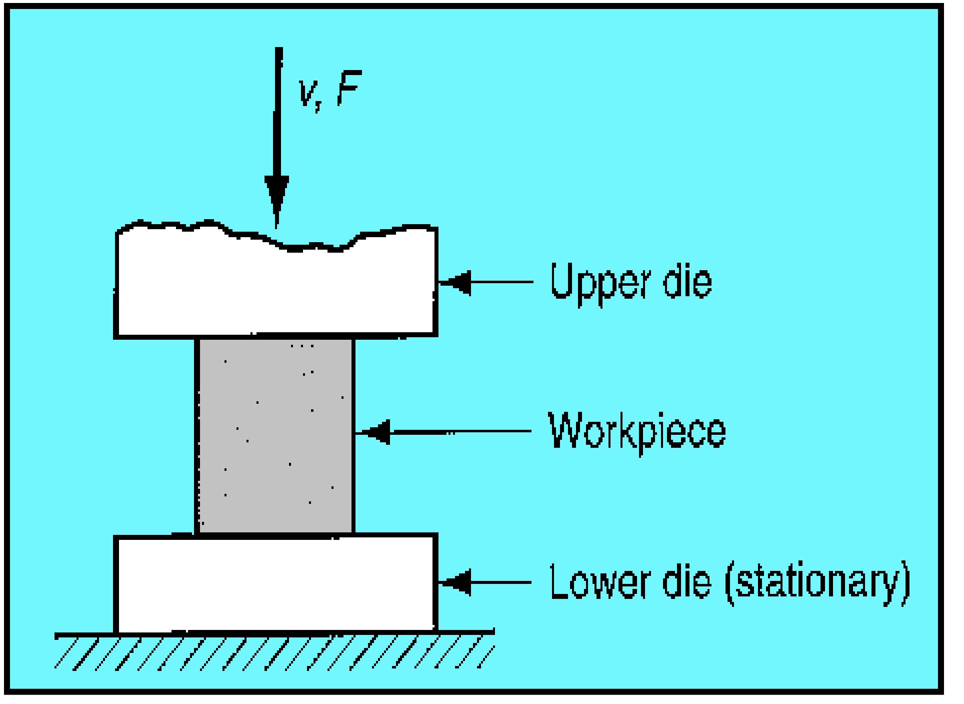
Upset (Open Die) Forging

- Metal flows without constraint between two dies
- Dies typically flat
- Friction plays an important role
- Forging may be done incrementally (in steps)



Upset (Open Die) Forging

- Produces simple shapes
- Often processed later by other methods



Forging Calculations

Cylindrical Workpiece

Reduction = $\frac{h_0 - h_1}{h_0} \times 100\%$

Engineering Strain…

$$e_1 = \frac{h_0 - h_1}{h_0}$$

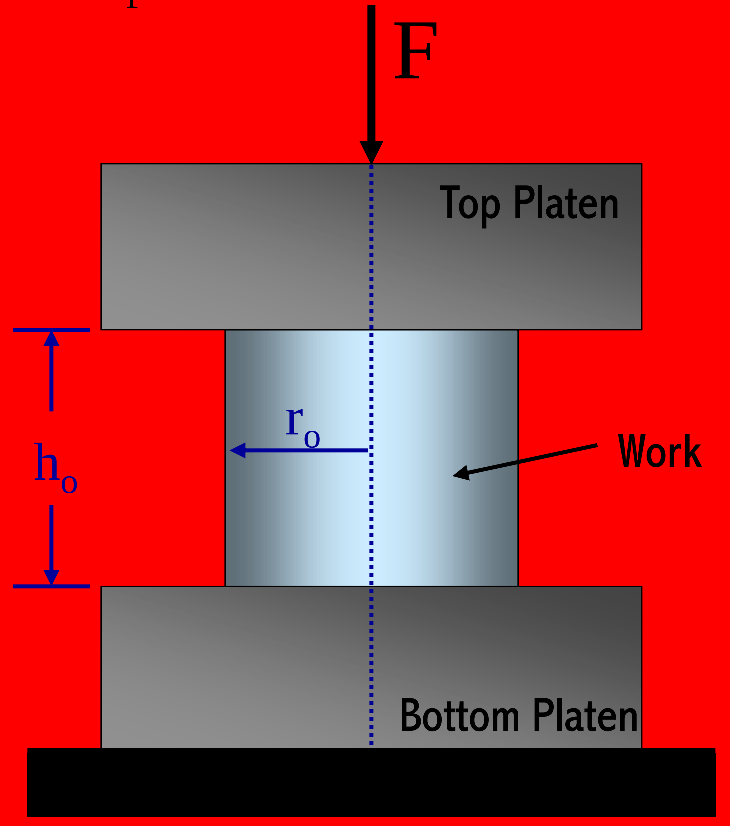
True Strain…

$$\varepsilon_1 = \ln\left(\frac{h_0}{h_1}\right)$$

Strain Rate…

$$\dot{\varepsilon}_1 = \frac{-v}{h_1}$$

Note: $Y_f = K\varepsilon^n$



Forging Calculations

Cylindrical Workpiece

Ideal (no friction, perfect plasticity)
0=initial state, 1=final state
Force in compression can be calculated:

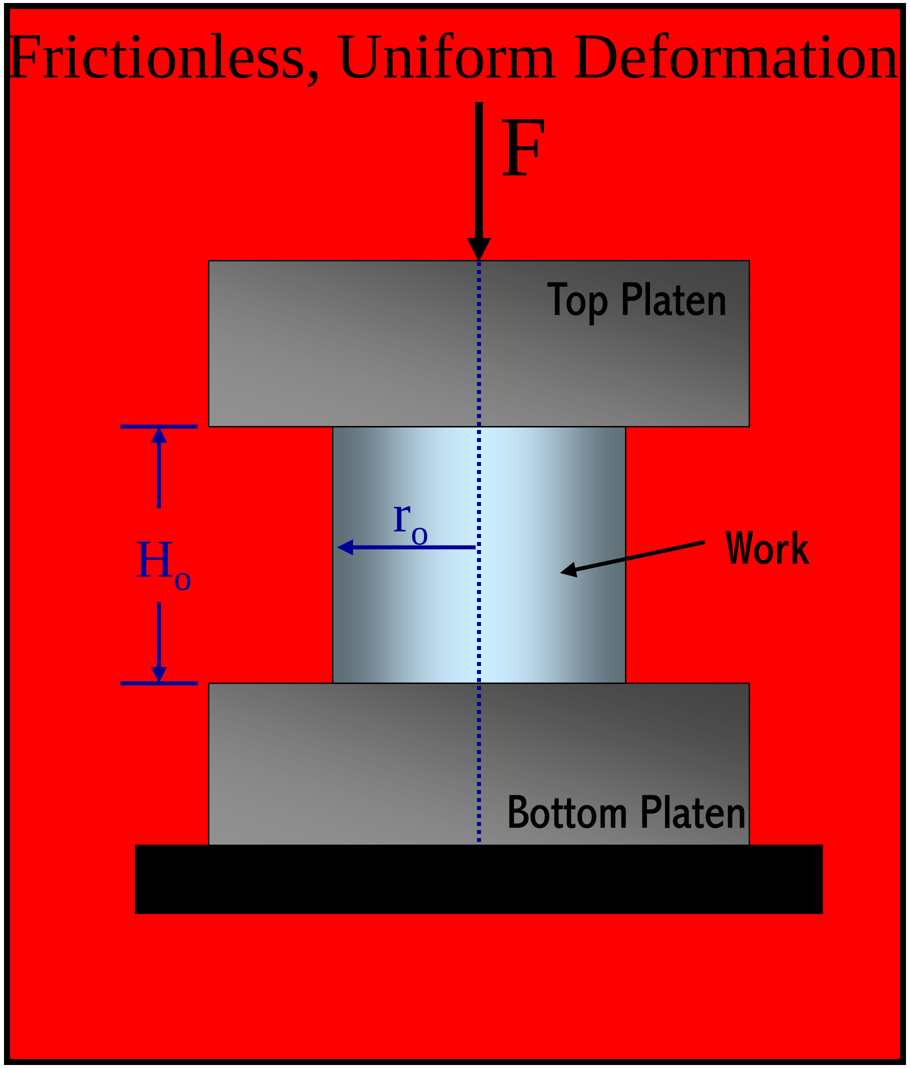
Compression Force:

$$F = Y_f A_1$$

Y= material yield stress

Volume is conserved…

$$V = A_0 h_0 = A_1 h_1$$



Forging Calculations

An Example

Given:

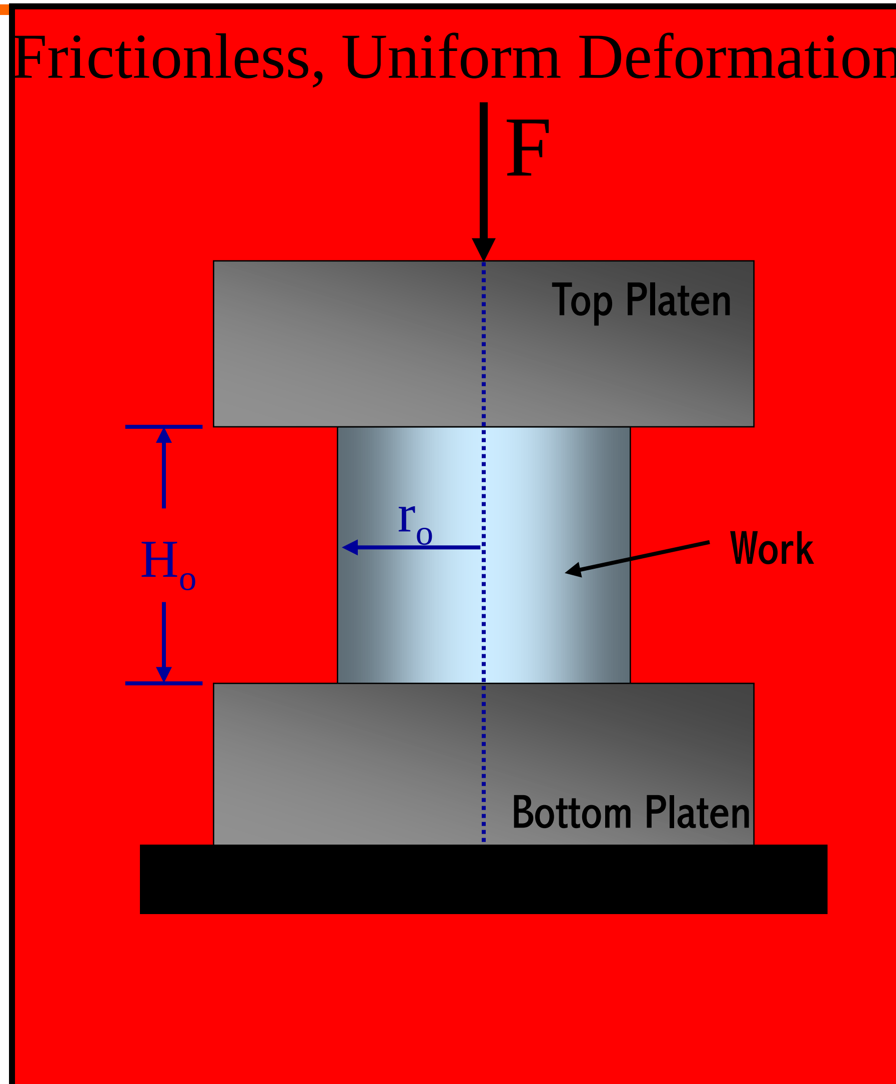
$H_o = 40$ mm

$D_o = 50$ mm

$H_f = 30$ mm (final height)

use $Y_f = K\varepsilon^n$

with $K = 60$ MPa & $n = 0.12$



Forging Calculations

An Example

$$F = K_f Y_f A$$

with $K_f = 1 + \dfrac{\mu D}{3H}$

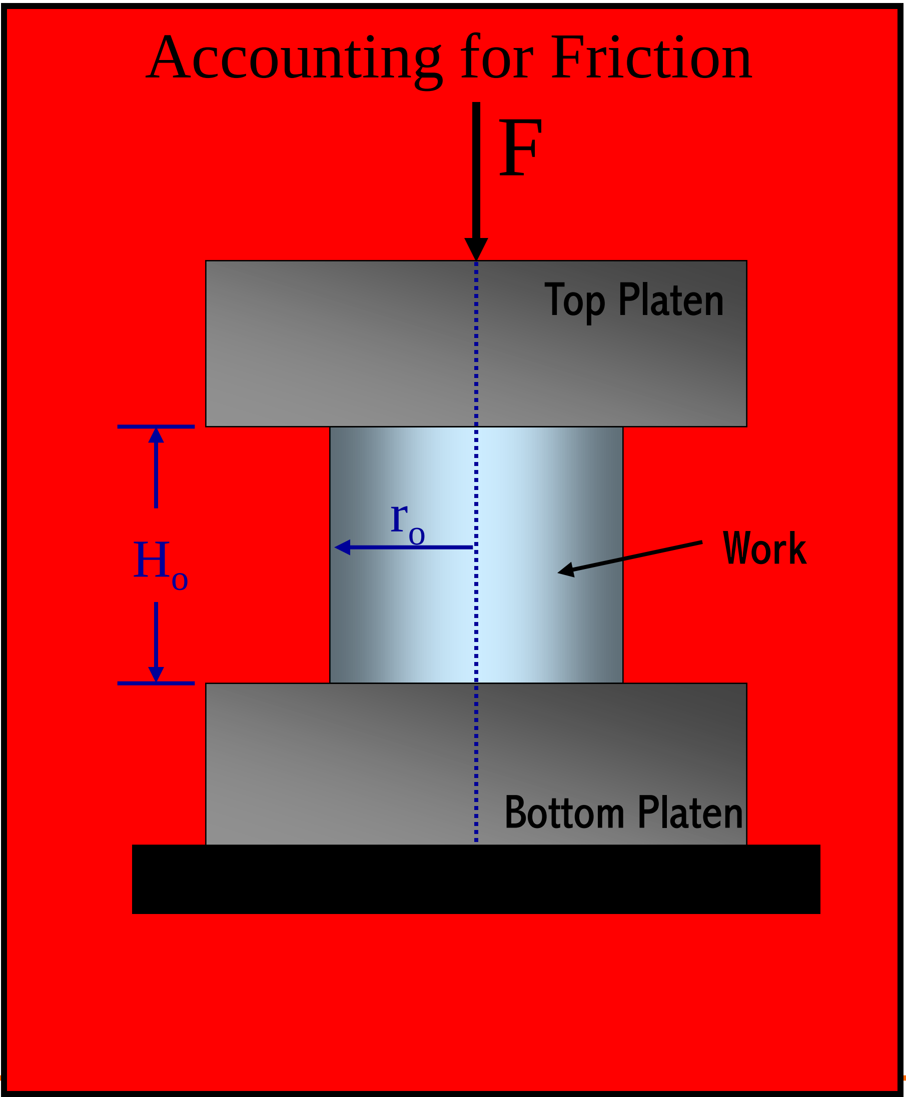
Given:

$H_o = 40$ mm

$D_o = 50$ mm

$H_f = 30$ mm (final height)

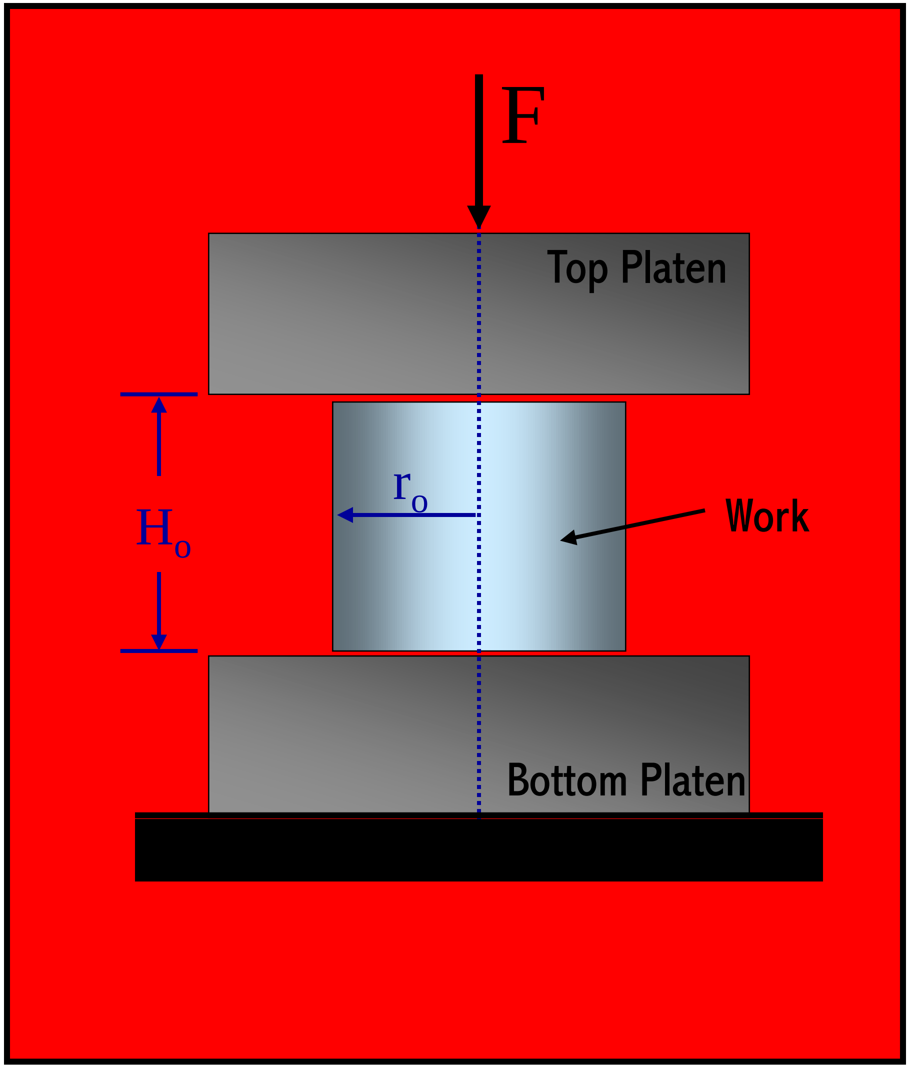
Assume $\mu = 0.1$



Forging Calculations

Note:

- Maximum force always occurs at the end of forging
- Effect of friction is to increase the required force



Forging Calculations

Slab Method Analysis

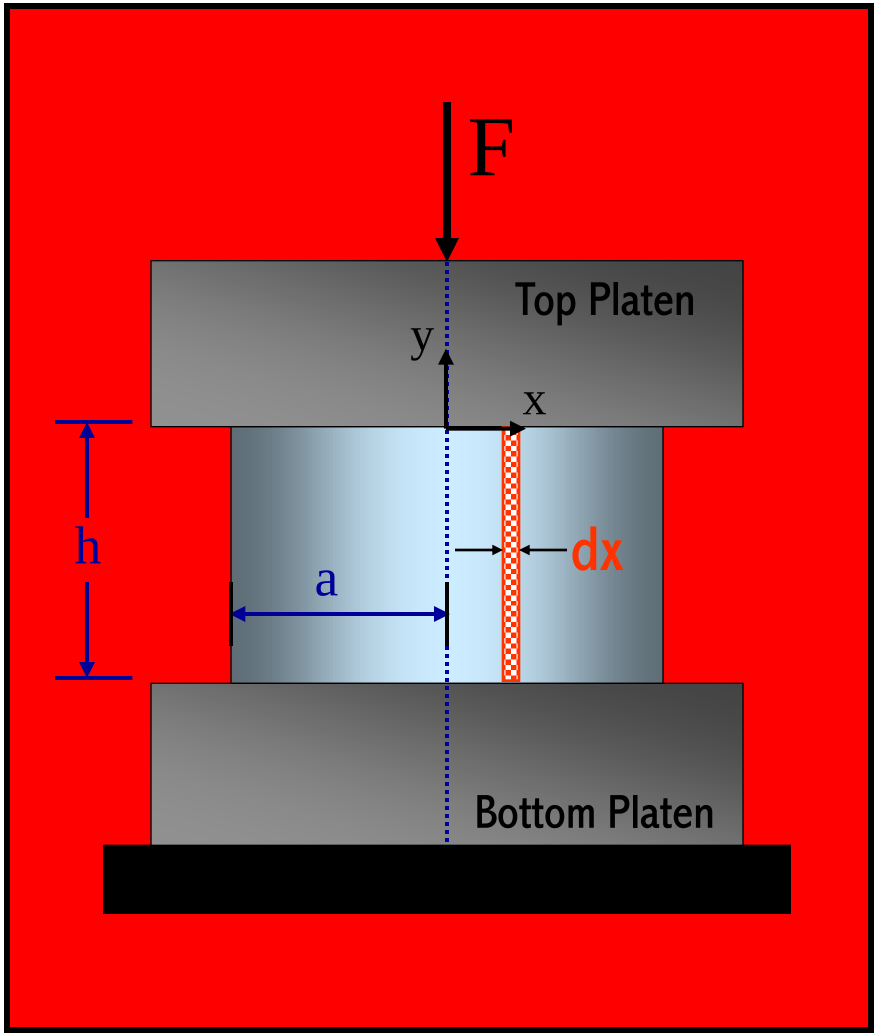
Rectangular cross-section

Assumptions:

Slab Width = unity

Incompressible solid ($\nu = 0.5$)

Plain Strain ($\varepsilon_z = 0$)



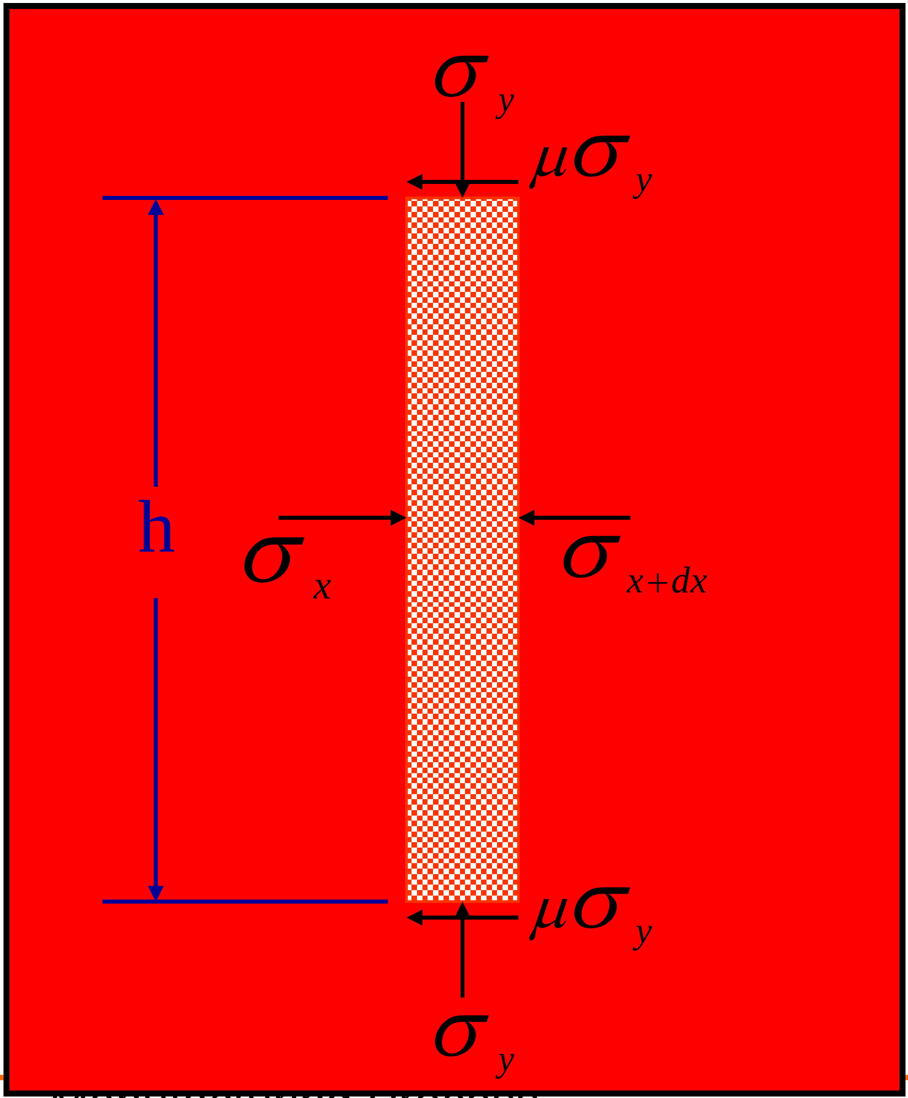
Forging Calculations

Rectangular Slab

Elemental Strip

$$\sum F_x = 0$$

$$\sum F_y = 0$$



Forging Calculations

Rectangular Slab

Assumption:

Yield in tension and yield in compression occur at same stress

- Force balance on slab x-dir

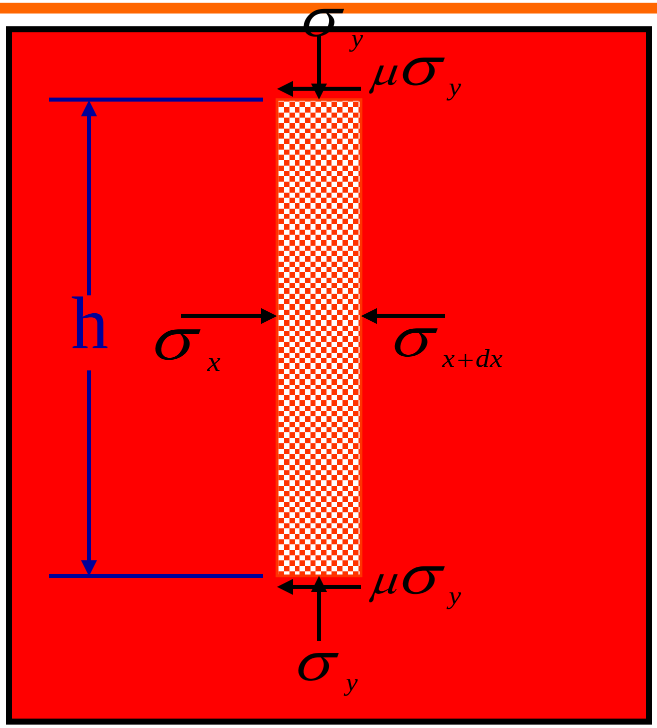
$$(\sigma_x + d\sigma_x)h + 2\mu\sigma_y dx - \sigma_x = 0$$

$$d\sigma_x + \frac{2\mu\sigma_y}{h} dx = 0$$

- 1 eqn., 2 unknowns
- Use yield criterion
  - von Mises for plane strain

$$\sigma_y - \sigma_x = \frac{2}{\sqrt{3}} Y = Y'$$

$$d\sigma_y = d\sigma_x$$



Von Mises Yield Criteria (Distortion Energy Criterion):

$$\overline{\sigma}_Y = \overline{\sigma} = \sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]}$$

Forging Calculations

Rectangular Slab

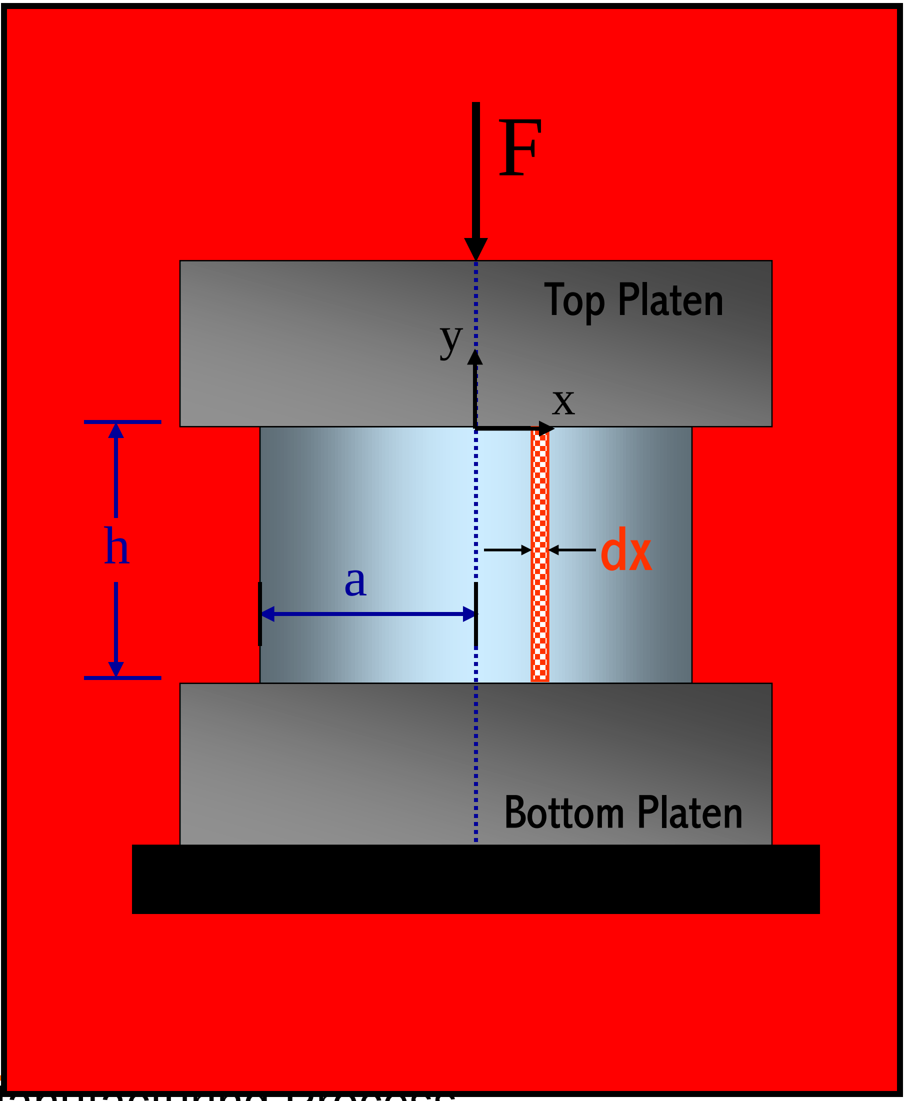
General Solution:

$$\sigma_Y = Ce^{\left(\frac{-2\mu x}{h}\right)}$$

With boundary condition

$\sigma_x = 0$ at $x = a$

And therefore $\sigma_y = Y'$



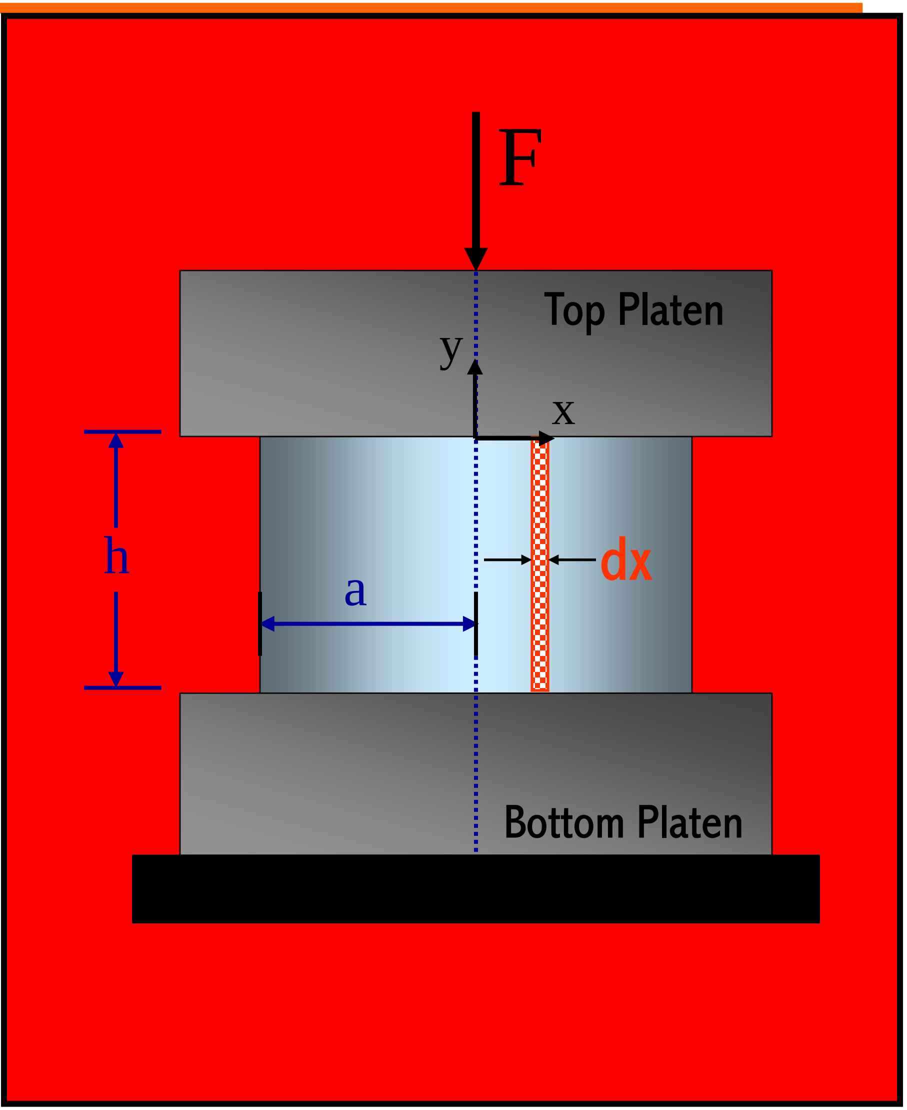
Forging Calculations

Rectangular Slab

Final Solution:

$$P = \sigma_Y = Y' e^{\left(\frac{2\mu(a-x)}{h}\right)}$$

$$\sigma_X = Y'\left[e^{\left(\frac{2\mu(a-x)}{h}\right)} - 1\right]$$



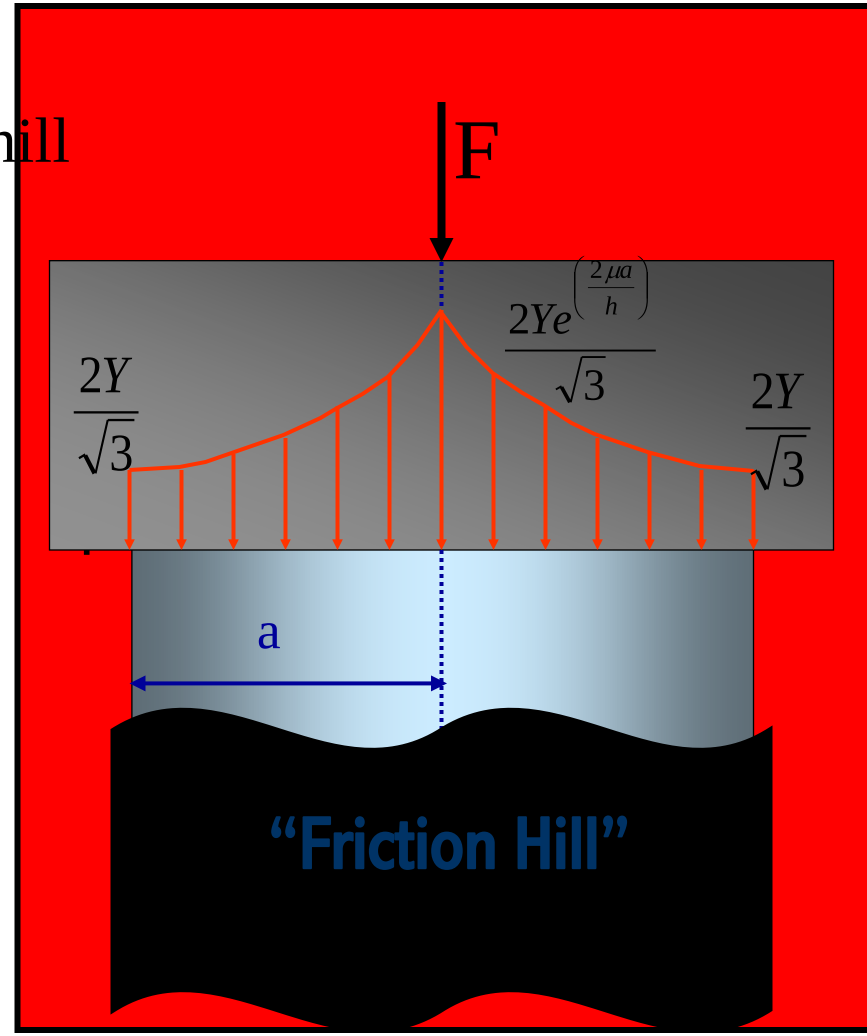
Forging Calculations

Rectangular Slab

pressure highest at center=friction hill

Final Solution:

$$P = \sigma_y = \frac{2Ye^{\left(\frac{2\mu(a-x)}{h}\right)}}{\sqrt{3}}$$



Note that…

$$Y = K\varepsilon^n$$

(For strain hardening material)

Forging Calculations

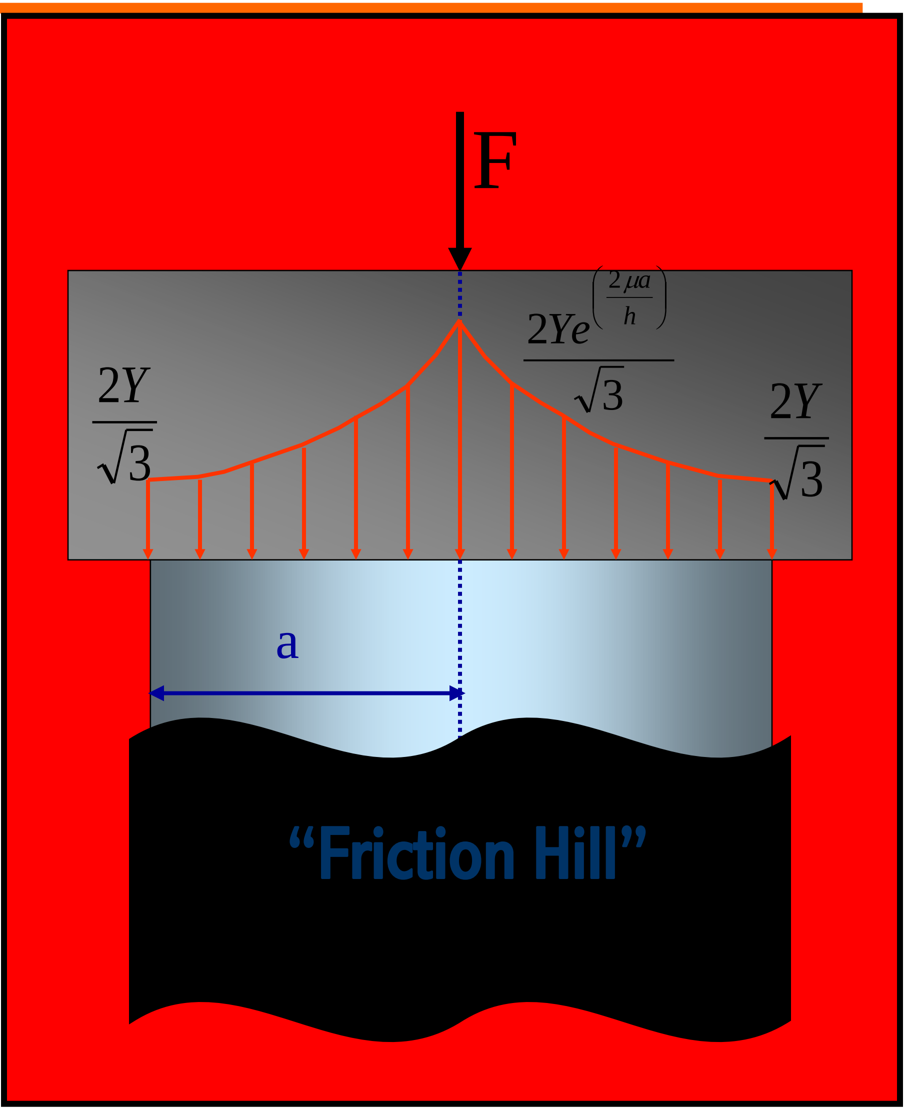
Rectangular Slab

Average Pressure:

$$P_{avg} \approx \frac{2Y}{\sqrt{3}}\left(1+\frac{\mu a}{h}\right)$$

Forging Force:

$$F = (P_{avg})(2a)(width)$$



Forging Calculations

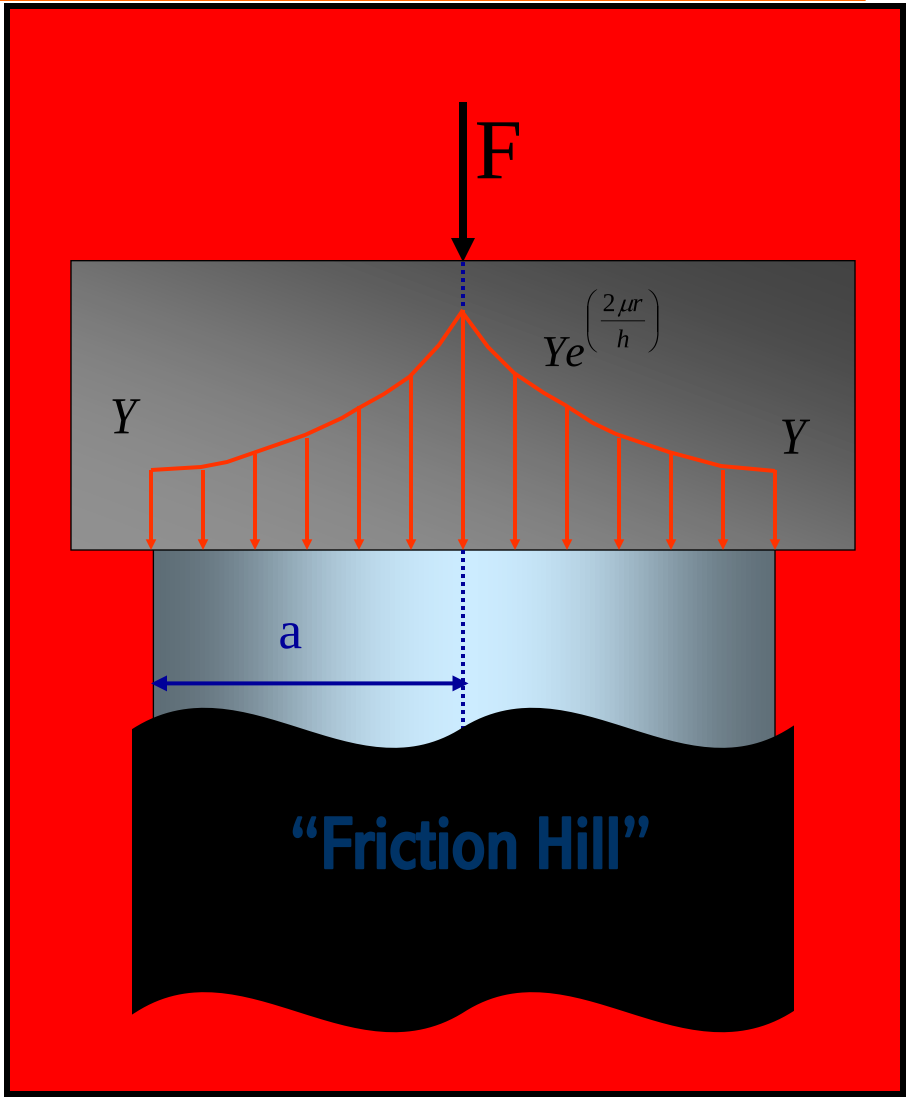
Similarly for a Cylinder…

Pressure:

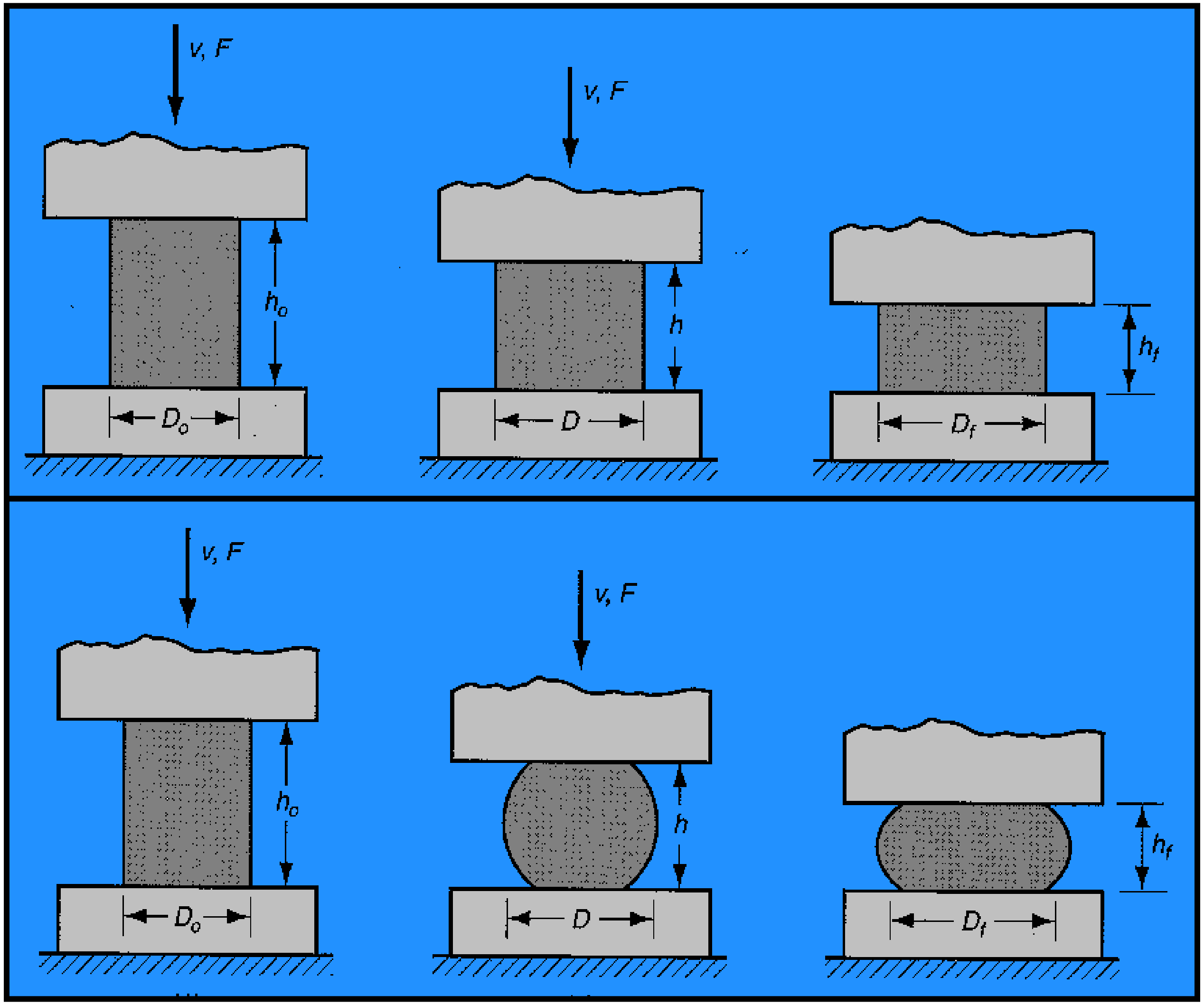
$$P = Ye^{\left(\frac{2\mu(r-x)}{h}\right)}$$

Average Pressure:

$$P_{avg} \approx Y\left(1+\frac{2\mu r}{3h}\right)$$



Barreling During Open Die Forging

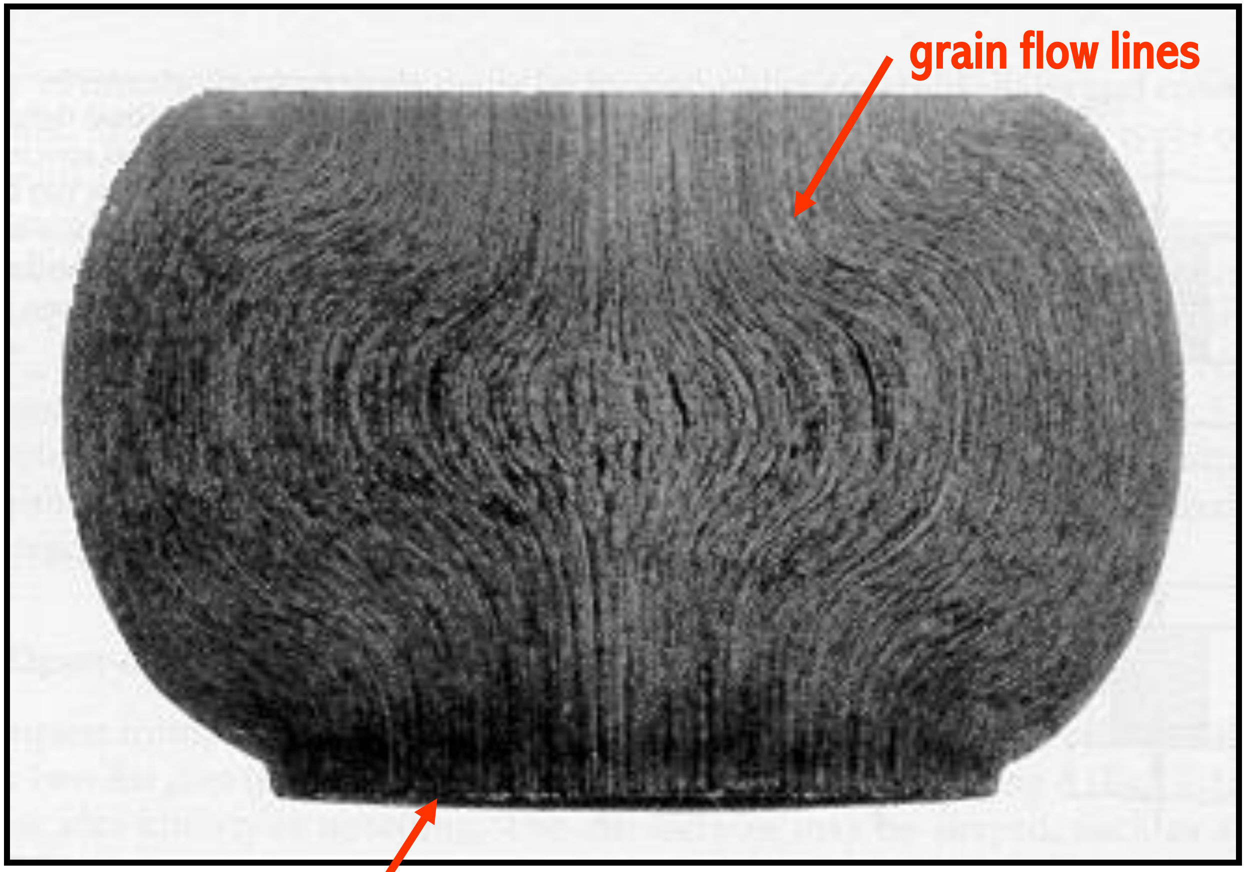


Frictionless contact - workpiece free to expand

Workpiece constrained by friction - can't expand

Glass frit used to reduce friction

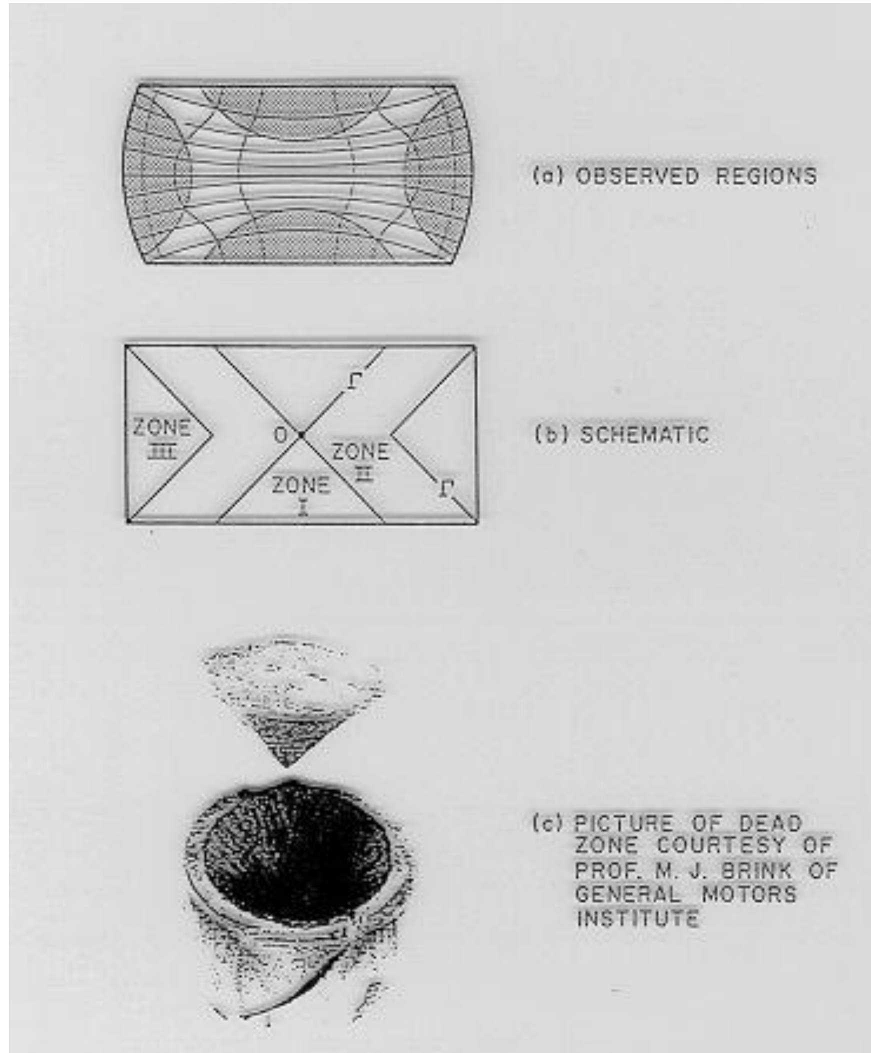
Grain Orientation & Barreling



Kalpakjian, S., *Manufacturing Processes for Engineering Materials*, 1997, p. 298

Dead Zones

Areas of no material deformation



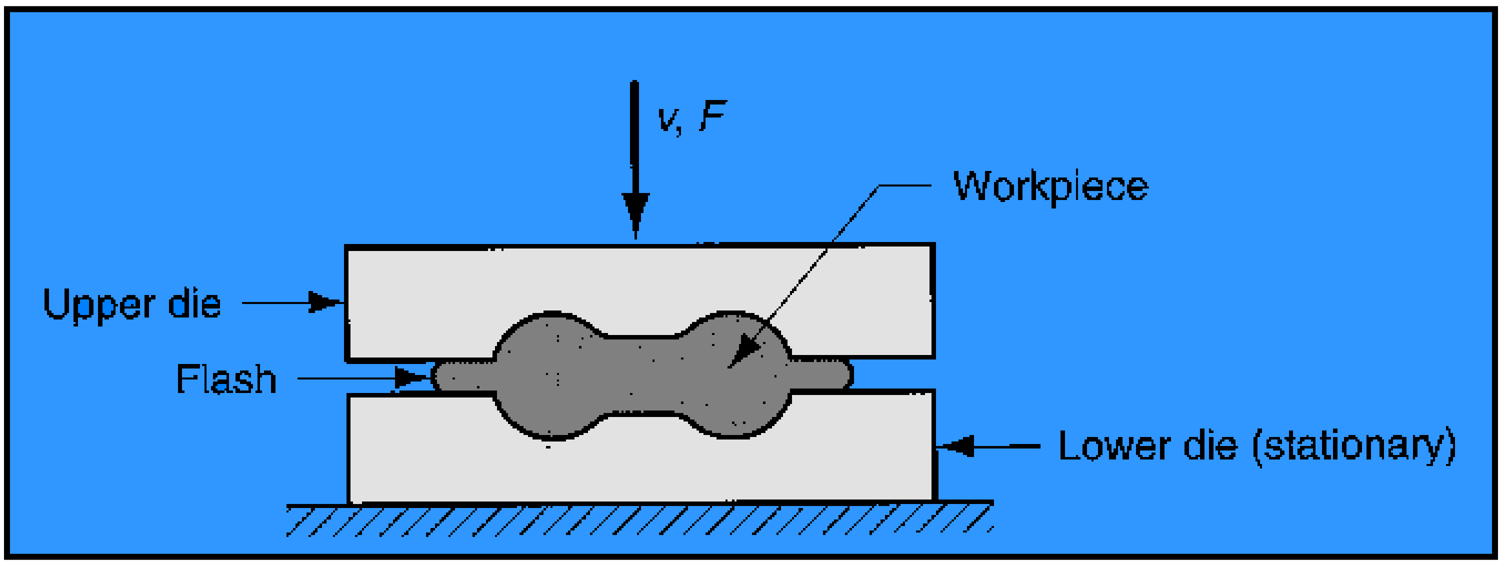
Main Types of Forging

Upset (Open Die) Forging

Main Types of Forging

Closed Die - Impression Die Forging

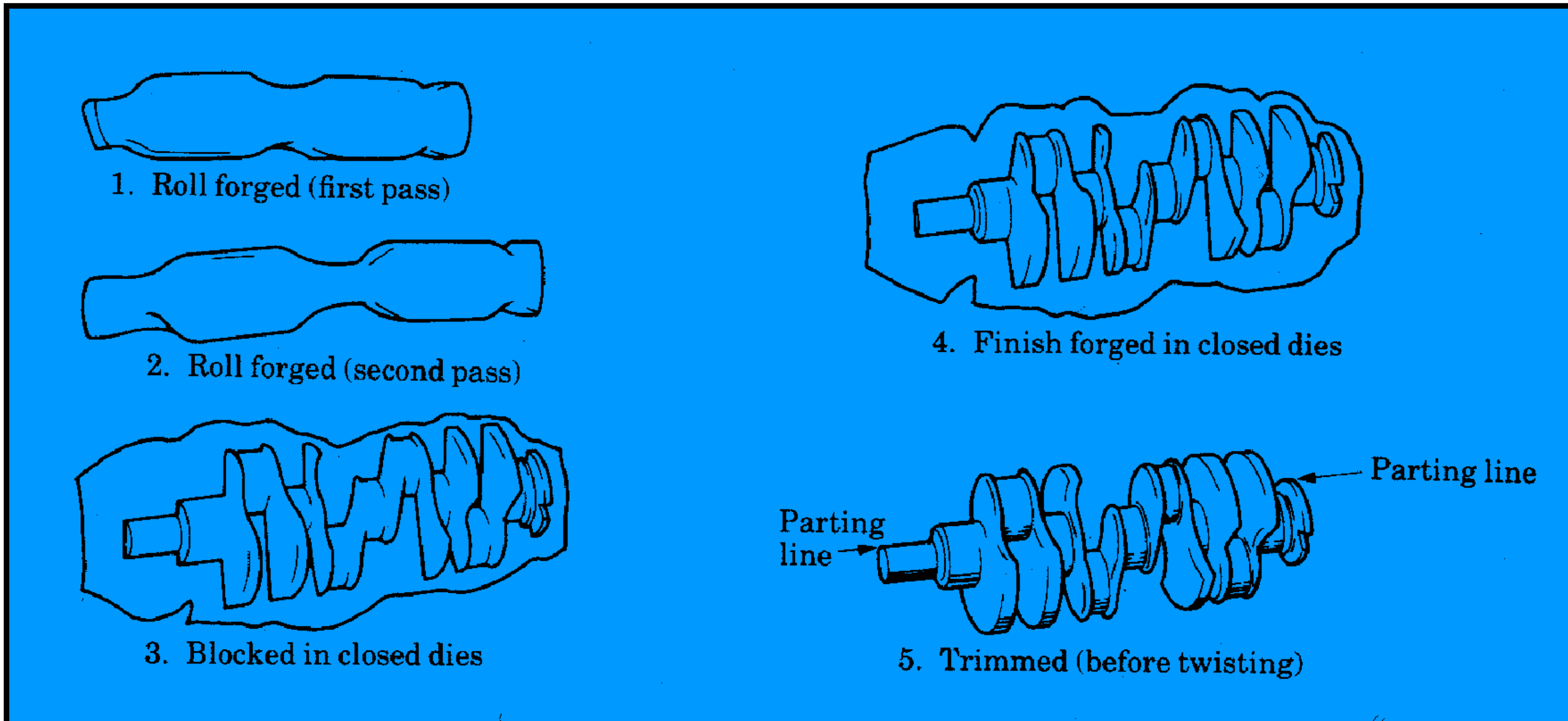
- Dies with inverse shape of part used
- Flash created helps control "back-pressure" in cavity
- Draft angle needed in order to get part out of mold
- More complex shapes obtained



Main Types of Forging

Closed Die - Impression Die Forging

- Multiple forging steps or multiple hammer blows often employed



Kalpakjian, S., *Manufacturing Processes for Engineering Materials*, 1997, p. 320

Main Types of Forging

Closed Die - Impression Die Forging

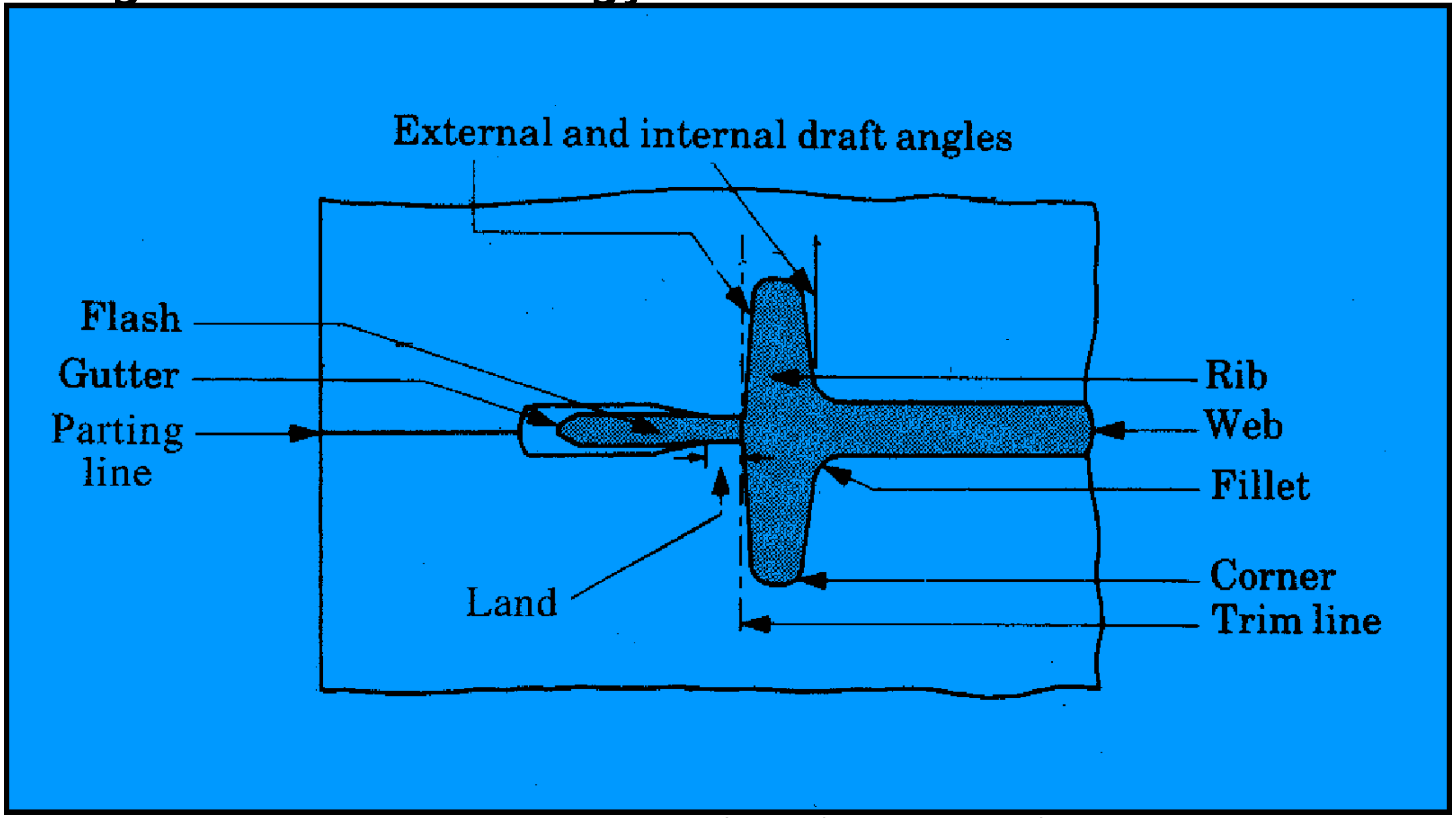
Die for Aircraft Landing Gear

Ostwald, P., *Manufacturing Processes & Systems*, 1997, p. 331

Main Types of Forging

Closed Die - Impression Die Forging

Forged Part Terminology

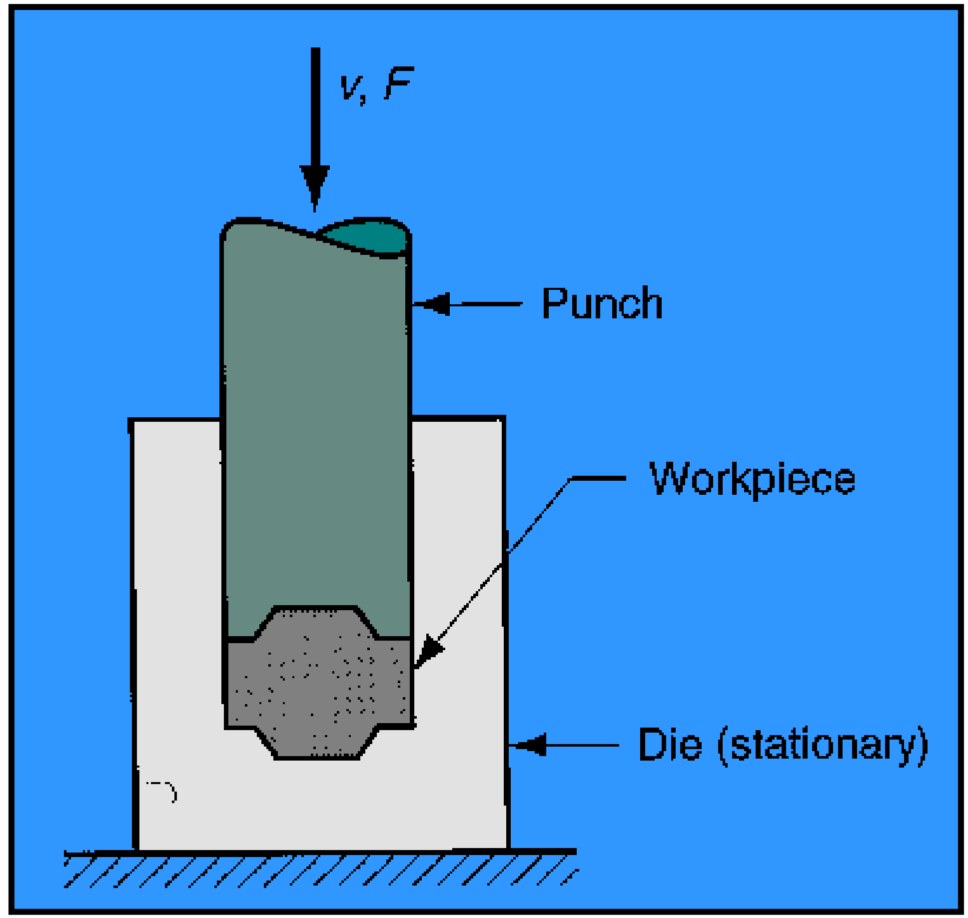


Kalpakjian, S., *Manufacturing Processes for Engineering Materials*, 1997, p. 320

Main Types of Forging

Closed Die - Flashless Forging

- Work completely constrained within die
- No flash produced
- Volume of metal must be controlled closely
- Best for simple, symmetric geometries



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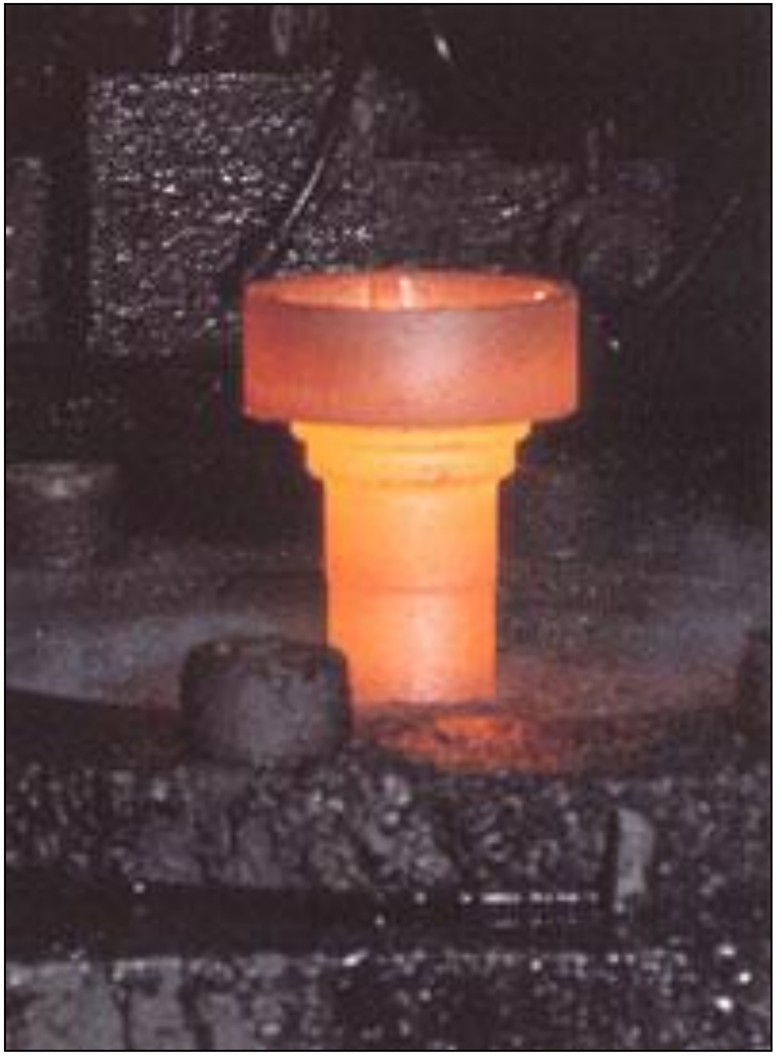

Forging

Material selection is also important

Metal or Alloy	Approximate Forging Temperature Range (C)
Aluminum Alloys	400 - 550
Magnesium Alloys	250 - 350
Copper Alloys	600 - 900
Carbon & Low-Alloy Steels	850 - 1150
Martensitic Stainless Steels	1100 - 1250
Austenitic Stainless Steels	1100 - 1250
Titanium Alloys	700 - 950
Iron-base Superalloys	1050 - 1180
Cobalt-base Superalloys	1180 - 1250
Tantalum Alloys	1050 - 1350
Molybdenum Alloys	1150 - 1350
Nickel-base Superalloys	1050 - 1200
Tungsten Alloys	1200 - 1300

Inspection of Forgings

Inspection Methods

- X-ray
- Ultrasonic

Can NOT make defect-free forgings…

- Must be concerned with defect size and quantity

Questions?????