Drawing

ME 206: Manufacturing Processes I
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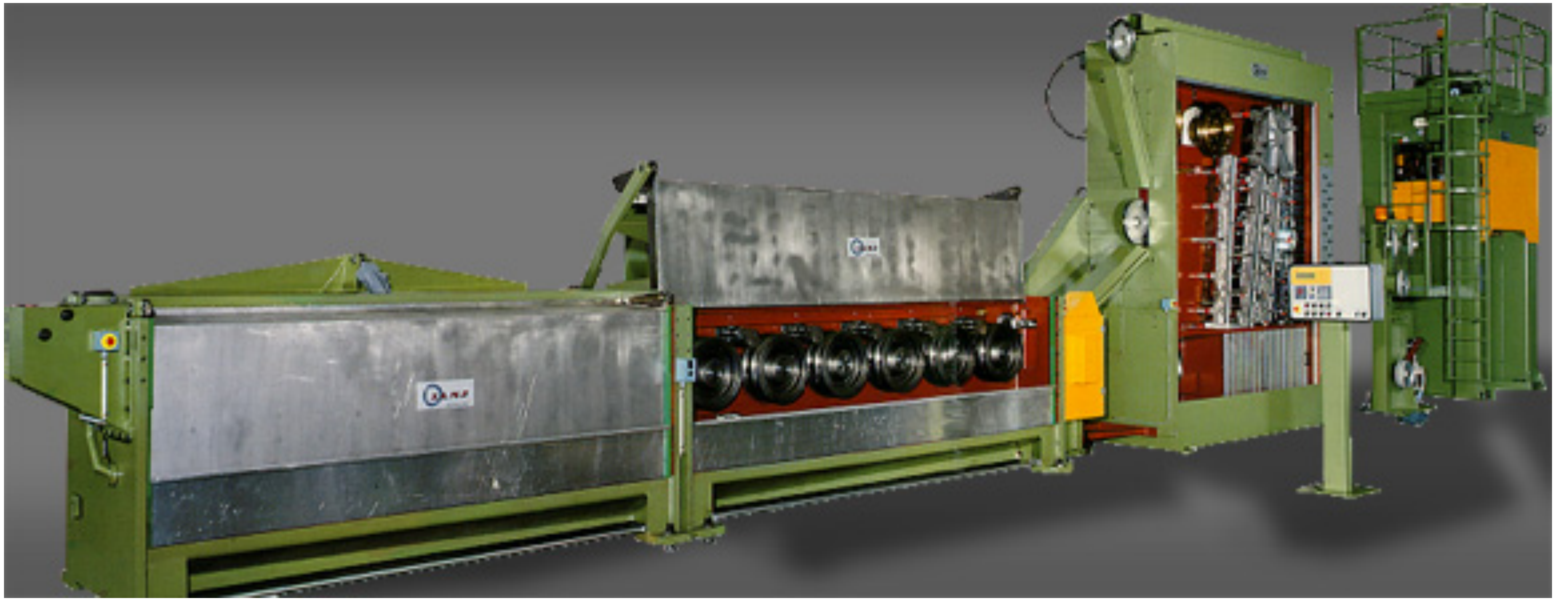
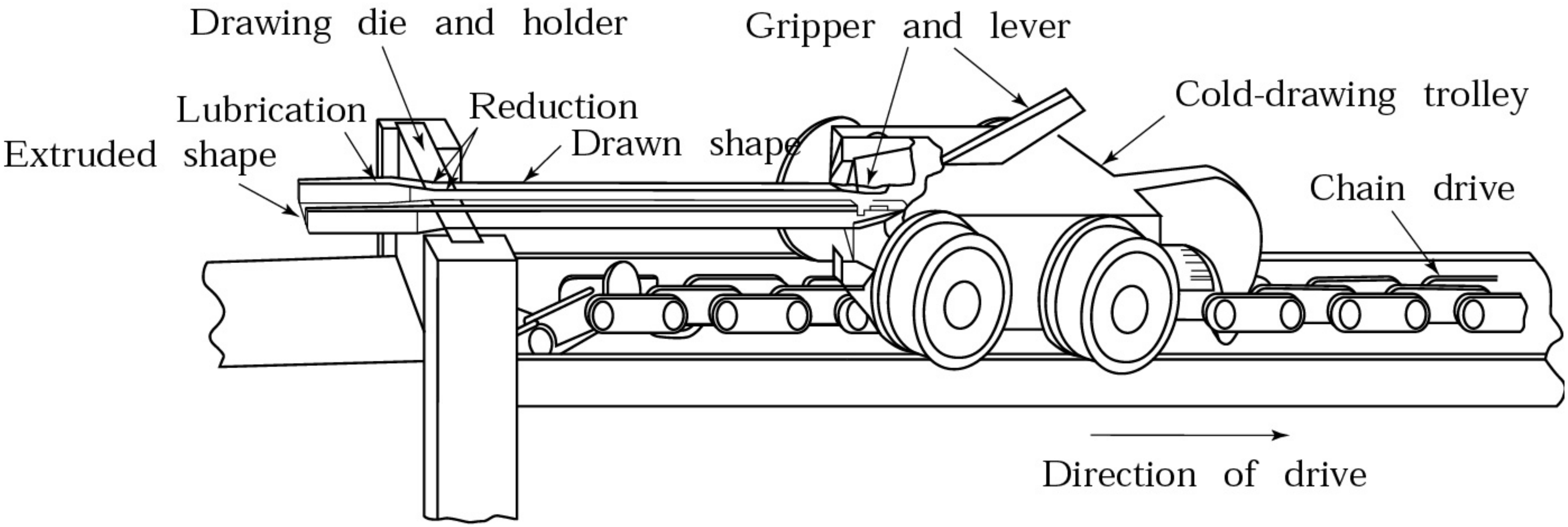
Outline

- Rod/Wire Drawing Introduction
- Rod/Wire Drawing Analysis
- Rod/Wire Drawing Defects

Equipment



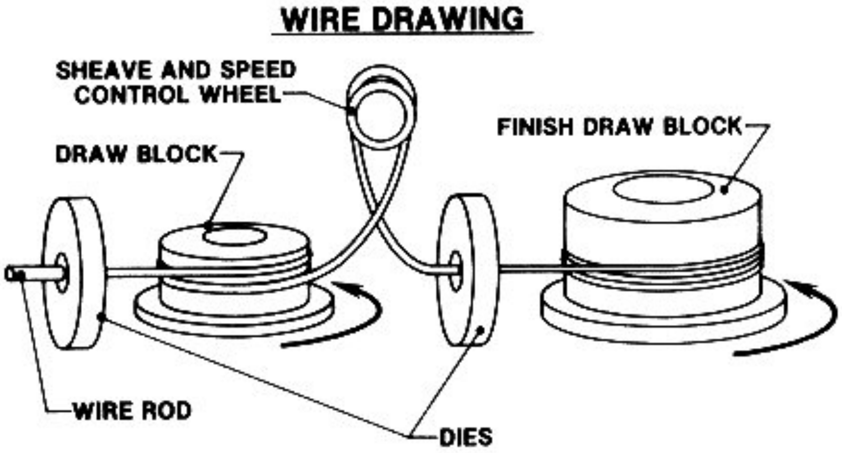
Cold Drawing

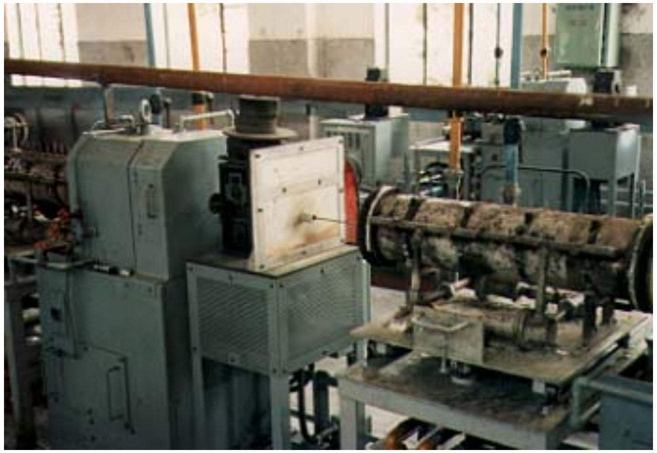


A. Durer - Wire Drawing Mill (1489) (copper wire)

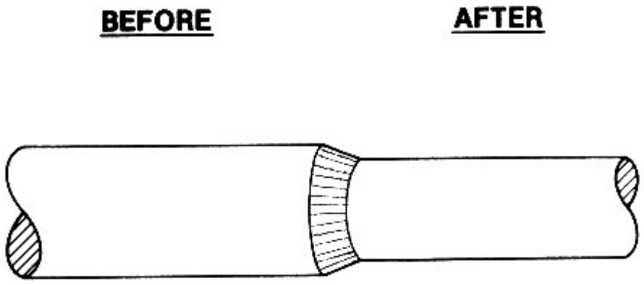
Rod/Wire Drawing Introduction

- <u>Basic Process</u>: A metal rod is pulled through a die by application of a tensile force at die exit





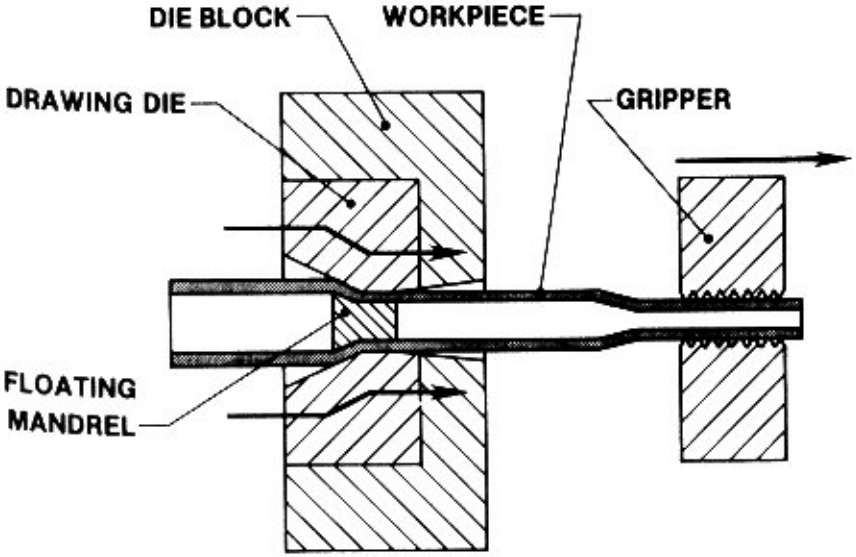
Wire Drawing Machine

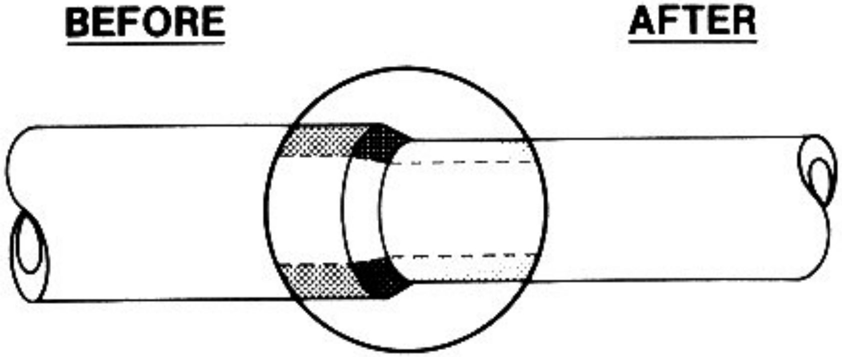


ENLARGED VIEW OF WIRE REDUCTION

Process Variations

- Tube drawing

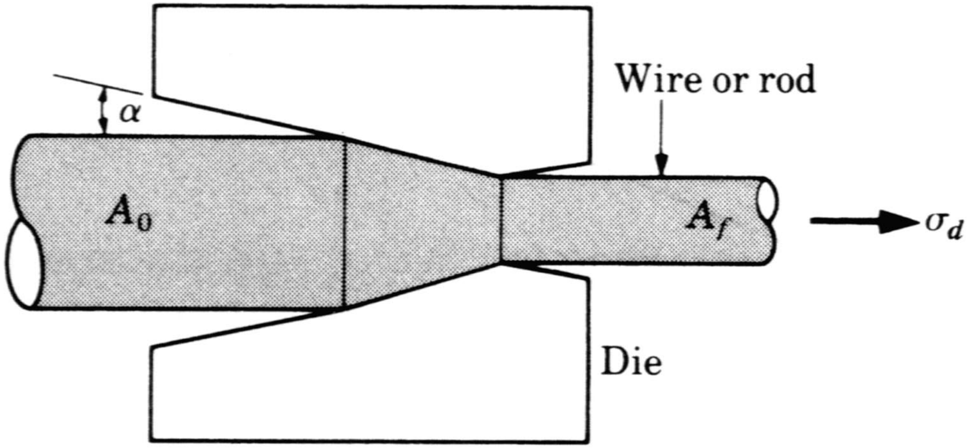




Source: Todd, Allen, Alting, 1994

Rod/Wire Drawing Introduction

- Deformation mechanism: most of the plastic flow is caused by compression force which arises from the reaction of the metal with the die



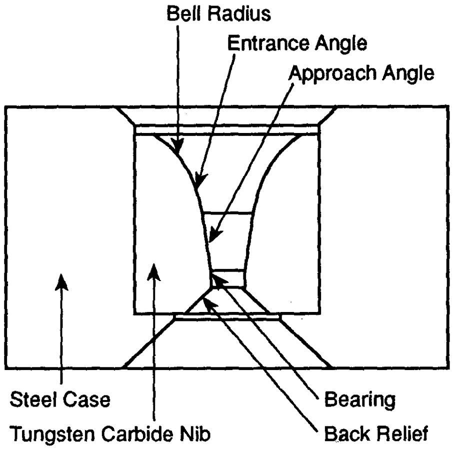
Bar, wire and tube drawing are usually carried out at room temperature. Temperature rise is considerable during the process because of large deformations

Rod/Wire Drawing Introduction

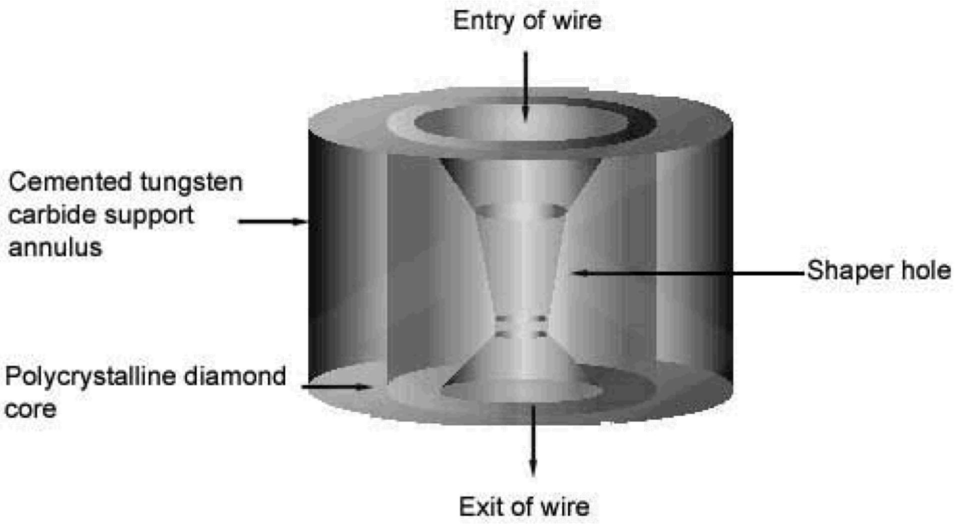
- Drawing Practice:

  fine wires: 15-25% reduction
  coarse wires: 20-50% reduction
  drawing speeds: 30-300ft/min; up to 10,000ft/min
  drawing loads: up to 300,000lb

- Dies: tool steels and carbide; coatings SCD/PCD



– Section through wire drawing die.

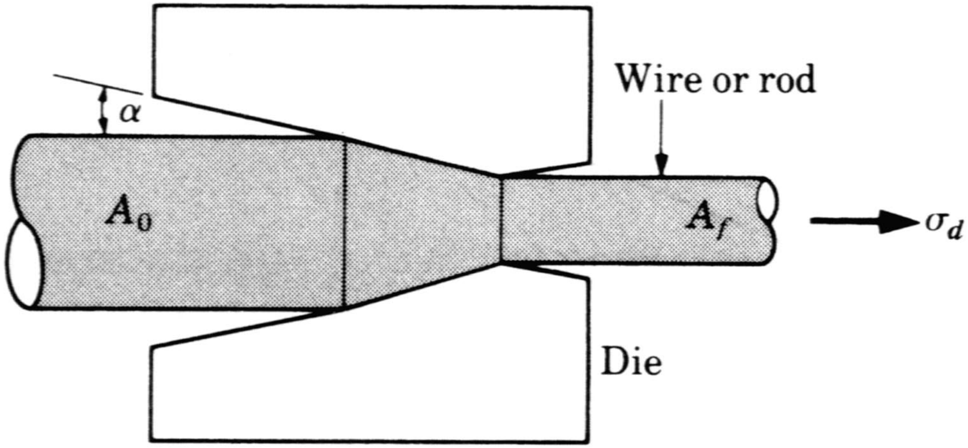


Key Process Variables

- Reduction:

$$\frac{A_o - A_f}{A_o} = 1 - \frac{A_f}{A_o}$$

- Die angle (usually 6°-15°)
- Interfacial friction
- Drawing speed, V_f



Source: S. Kalpakjian & S. Schmidt, 4th ed. 2003

Lubrication

- Lubrication:

  soft metal coatings for dry drawing

  grease, powder, soap

  entire die immersed in lubricating fluid for wet drawing

Rod/Wire Drawing Analysis

- Objectives
  - Find the drawing stress, force and power required under ideal deformation conditions
  - Find drawing stress, force, power including effects of friction and redundant work of deformation

Rod/Wire Drawing Analysis

- Ideal deformation

  External work = Work of ideal plastic deformation

$$\sigma_d\left(A_f L\right)=u\left(A_f L\right)$$

$$\sigma_d = u = \int_0^{\varepsilon_t} \sigma_t d\varepsilon_t$$

for $\sigma_t = K\varepsilon_t^n$

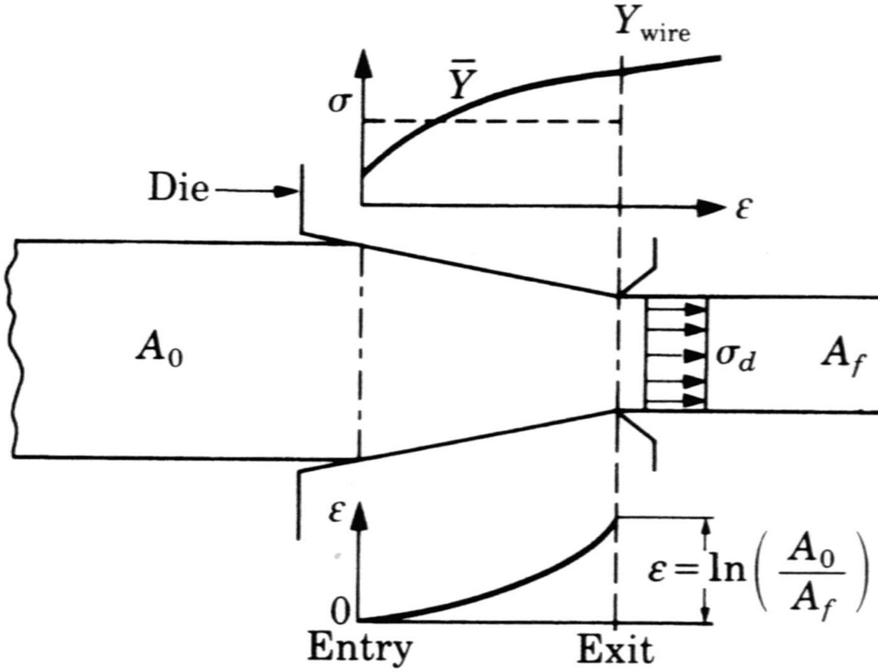
$$\boxed{\sigma_d = \frac{K\varepsilon_t^n}{n+1}\varepsilon_t = \bar{Y}_f \varepsilon_t = \bar{Y}_f \ln\left(\frac{A_0}{A_f}\right)}$$

Rod/Wire Drawing Analysis

- Ideal deformation

  Drawing force, $F_d = \sigma_d A_f$

  Drawing power, $P_d = F_d V_f$



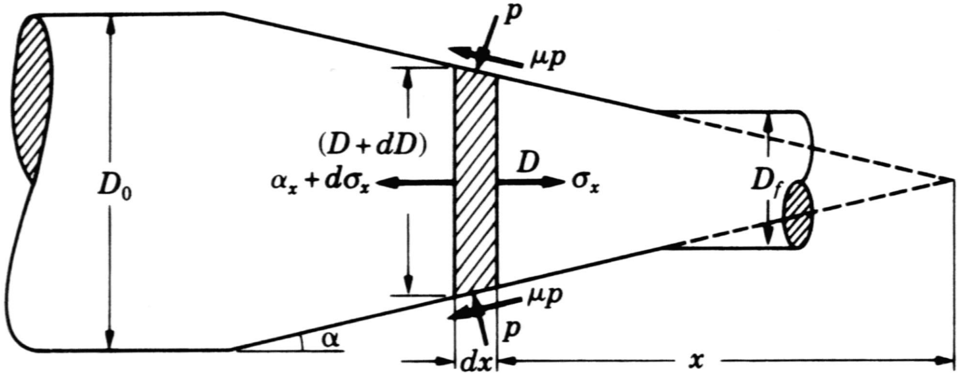
Source: S. Kalpakjian & S. Schmidt, 4th ed. 2003

Rod/Wire Drawing Analysis

- Ideal deformation + friction

  Assumptions of “slab” analysis apply

  Using slab analysis we get



$$\sigma_d = \bar{Y}_f \left(1 + \frac{\tan\alpha}{\mu}\right)\left[1 - \left(\frac{A_f}{A_0}\right)^{\mu \cot\alpha}\right]$$

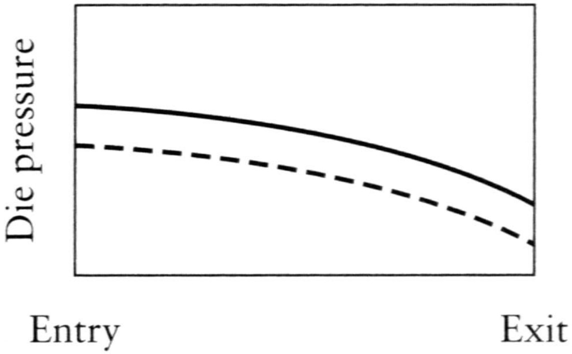
Source: S. Kalpakjian & S. Schmidt, 4th ed. 2003

Rod/Wire Drawing Analysis

- Ideal deformation + friction + redundant deformation

$$\sigma_d = \bar{Y}\left\{\left(1+\frac{tan\,\alpha}{\mu}\right)\left[1-\left(\frac{A_f}{A_o}\right)^{\mu cot\alpha}\right]+\frac{4}{3\sqrt{3}}\alpha^2\left(\frac{1-r}{r}\right)\right\}$$

$$\sigma_d = \bar{Y}\left\{\left(1+\frac{\mu}{\alpha}\right)ln\left(\frac{A_o}{A_f}\right)+\frac{2}{3}\alpha\right\}$$ for small α

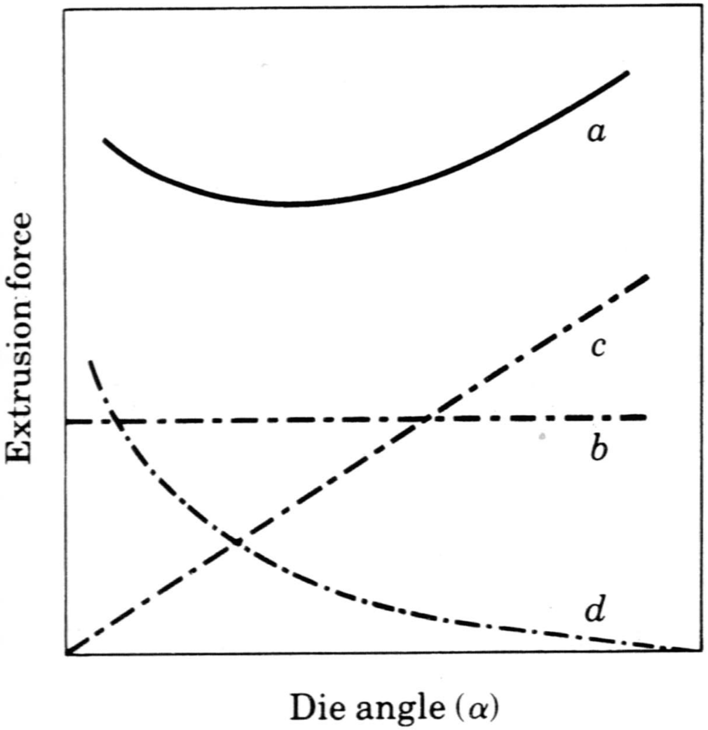


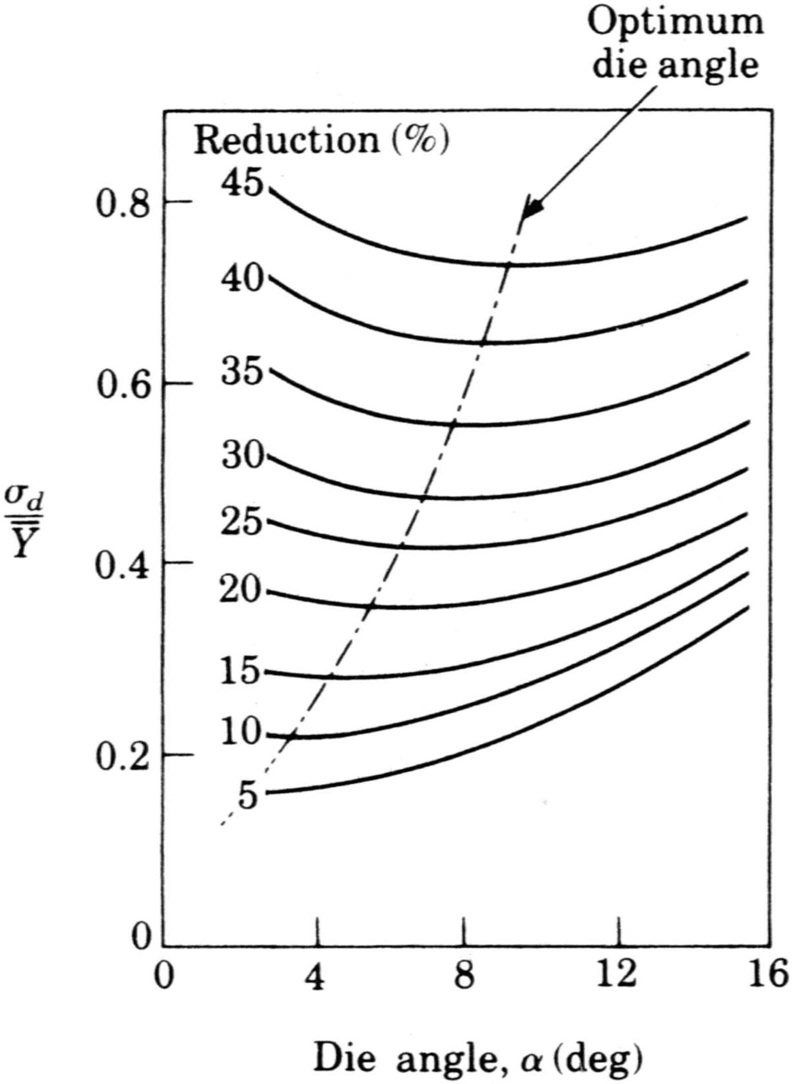
- Die pressure, $p = Y_f - \sigma_d$

Source: S. Kalpakjian & S. Schmidt, 4th ed. 2003

Rod/Wire Drawing Analysis

- Effect of die angle





Source: S. Kalpakjian & S. Schmidt, 4th ed. 2003

Rod/Wire Drawing Analysis

- Main factor limiting maximum reduction per pass in drawing:
  - Yield of material at die exit
  - Drawing limit is reached when $\sigma_d = Y_f$

Drawing Limit

- Ideal deformation of a perfectly plastic material

$$\sigma_d = Y \cdot ln\left(\frac{A_o}{A_f}\right)$$

$$\sigma_\varepsilon = Y$$

$$\sigma_d = \sigma_\varepsilon \Rightarrow ln\left(\frac{A_o}{A_f}\right) = 1 \Rightarrow \frac{A_o}{A_f} = e$$

Maximum reduction per pass

$$= \frac{A_o - A_f}{A_o} = 1 - \frac{1}{e} = 0.63 = 63\%$$

Drawing Limit

- Ideal deformation of a strain hardening material

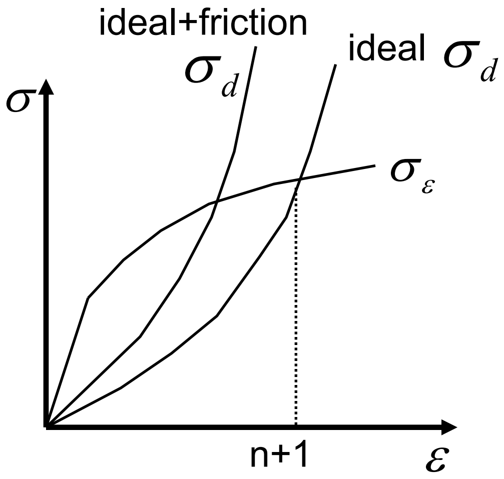
$$\sigma_d = \overline{Y} \cdot ln\left(\frac{A_o}{A_f}\right) = \frac{K\varepsilon^{n+1}}{n+1}$$

$$\sigma_\varepsilon = K\varepsilon^n$$

$$\sigma_d = \sigma_\varepsilon \quad \Rightarrow \quad \varepsilon = n+1$$

$$Maximum\ reduction\ per\ pass$$

$$= \frac{A_o - A_f}{A_o} = 1 - e^{-(n+1)}$$



Example Problem

Assuming zero redundant work and frictional work to be 20% of the ideal work, derive an expression for the maximum reduction in area per pass for a wire drawing operation for a material with a true-stress strain curve of $\sigma = K\varepsilon^n$

Total work = Ideal work + frictional work + $\cancelto{0}{\text{redundant work}}$

Total work = Ideal work + 0.2 x Ideal work = 1.2 x Ideal work

Or, Total work of deformation = 1.2 [*u* x *volume*] … (1)

In drawing, external work of deformation = σ_d x *volume* … (2)

Equating (1) and (2), we get

$\sigma_d = 1.2u$ or $$\sigma_d = 1.2\int_0^{\varepsilon_1} \sigma_t \, d\varepsilon_t = 1.2\int_0^{\varepsilon_1} K\varepsilon_t^n \, d\varepsilon_t = 1.2\,\frac{K\varepsilon_1^{n+1}}{n+1}$$

$$\sigma_d = 1.2\bar{Y}\varepsilon_1 \quad \text{where} \quad \varepsilon_1 = \ln\left(\frac{A_0}{A_f}\right) \qquad \dots (3)$$

Example Problem

Max reduction occurs when total drawing stress, σ_d = Flow stress of material at die exit, *Y*

$$\sigma_d = Y$$

$$1.2\overline{Y}\varepsilon_1 = K\varepsilon_1^n$$

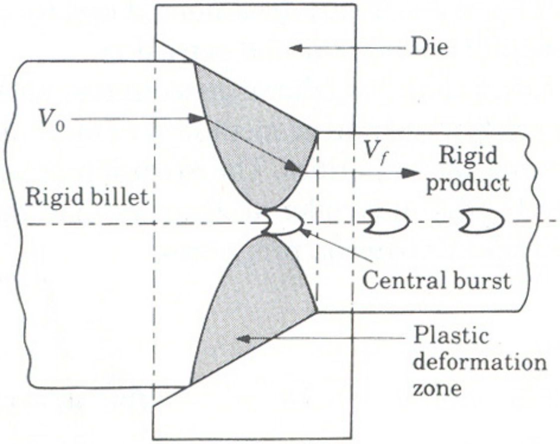
$$1.2\,\frac{K\varepsilon_1^{n+1}}{n+1} = K\varepsilon_1^n$$

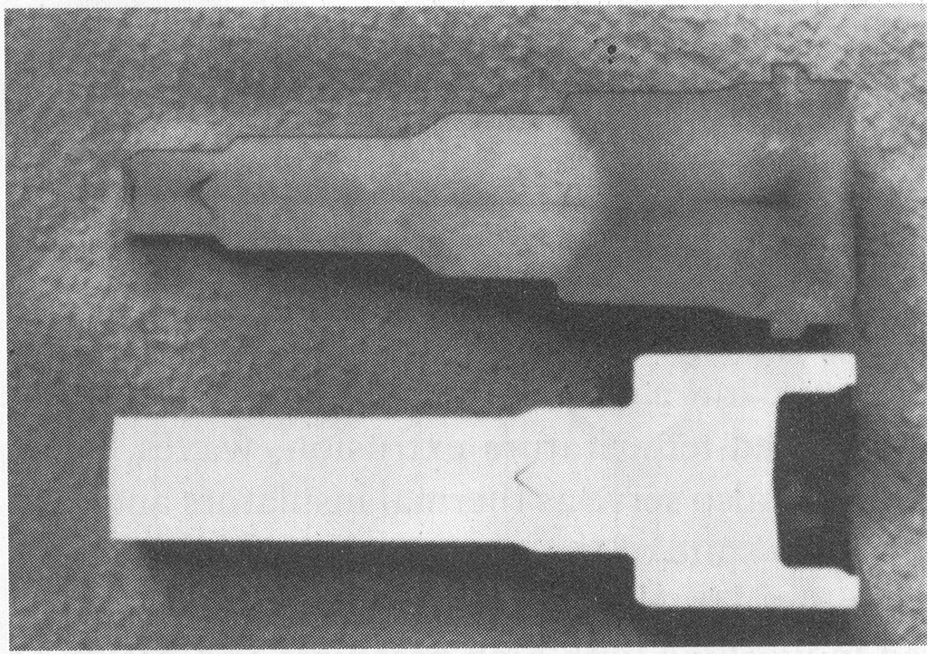
$$\varepsilon_1 = \frac{n+1}{1.2} \Rightarrow \ln\frac{A_0}{A_f} = \frac{n+1}{1.2} \Rightarrow \frac{A_0}{A_f} = e^{\frac{n+1}{1.2}}$$

$$\therefore \text{max reduction per pass} = \frac{A_0 - A_f}{A_0} = 1 - e^{-\left(\frac{n+1}{1.2}\right)}$$

Rod/Wire Drawing Defects

- Centerline cracking





Center cracking in extruded bar

Center cracking increases with:

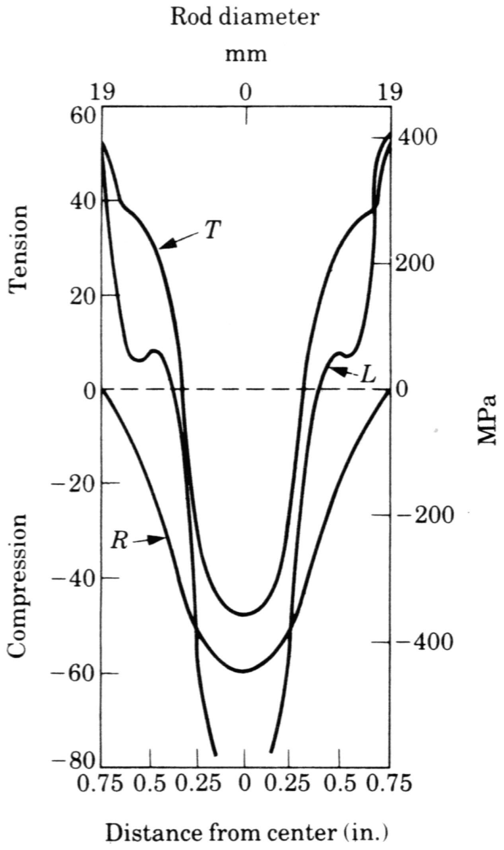
- increasing die angle α
- decreasing reduction per pass
- friction
- presence of inclusions

Source: S. Kalpakjian & S. Schmidt, 4th ed. 2003

Rod/Wire Drawing Defects

- Seams: longitudinal scratches or folds on surface of material

- Residual stresses
  - Common in cold drawn wire/tube
  - Stress pattern a function of amount of reduction/pass
  - Increases with reduction per pass



Source: S. Kalpakjian & S. Schmidt, 4th ed. 2003

Summary

- Rod/Wire drawing basics
- Rod/wire drawing analysis
  - Slab analysis
- Rod/wire drawing defects