

Drawing



ME 206: Manufacturing Processes I
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Outline

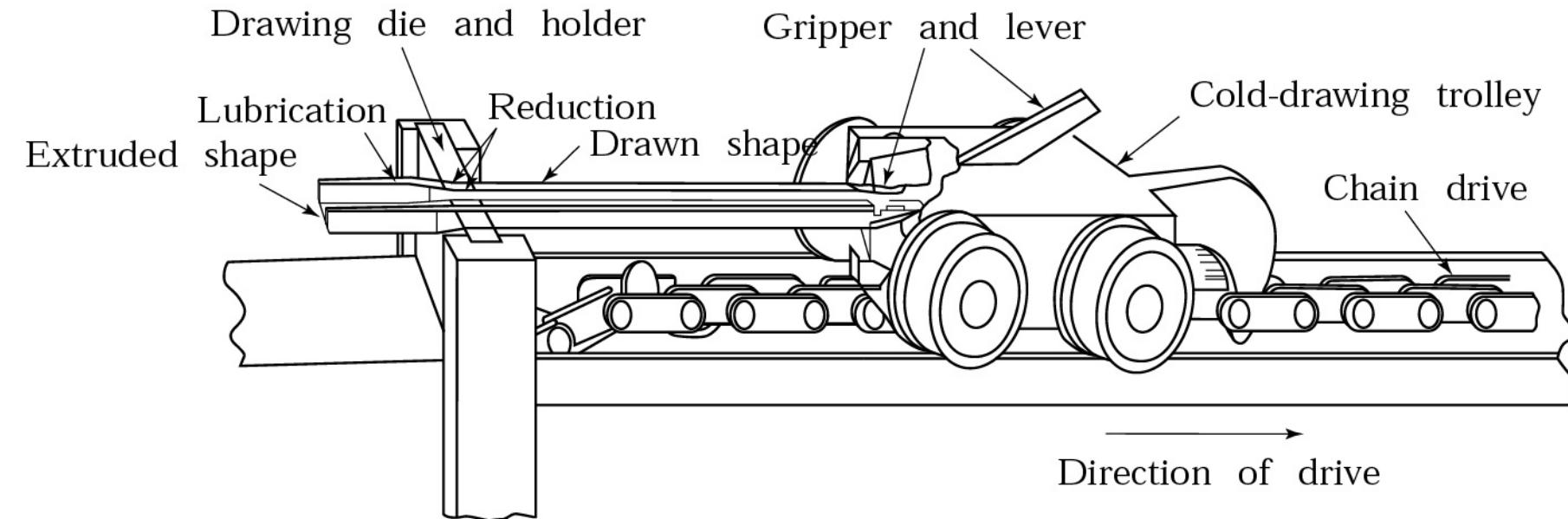
- Rod/Wire Drawing Introduction
- Rod/Wire Drawing Analysis
- Rod/Wire Drawing Defects



Equipment



Cold Drawing

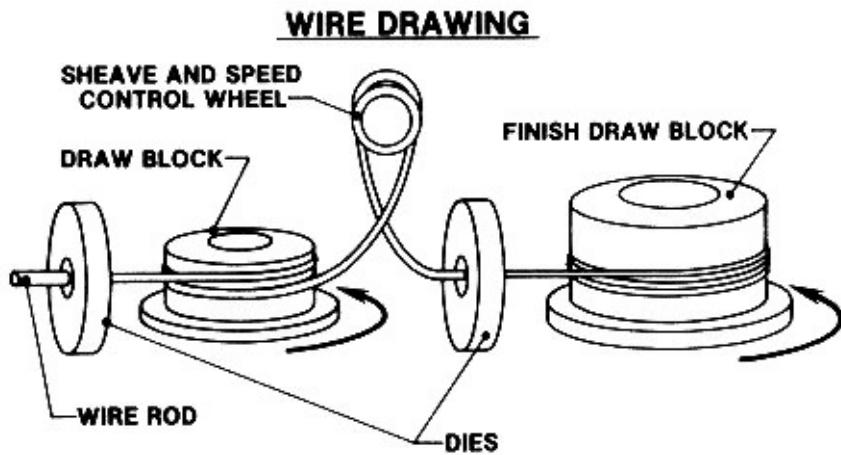


A. Durer - Wire Drawing Mill (1489) (copper wire)



Rod/Wire Drawing Introduction

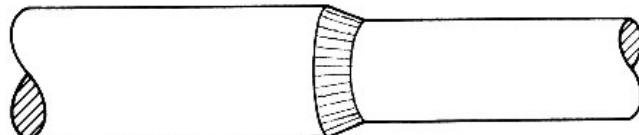
- Basic Process: A metal rod is pulled through a die by application of a tensile force at die exit



Wire Drawing Machine

BEFORE

AFTER

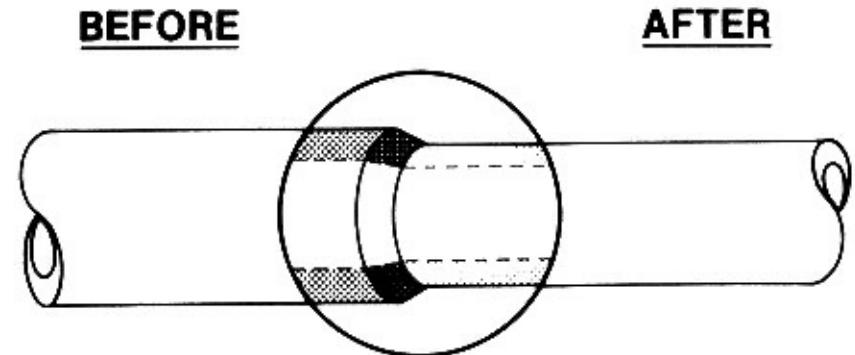
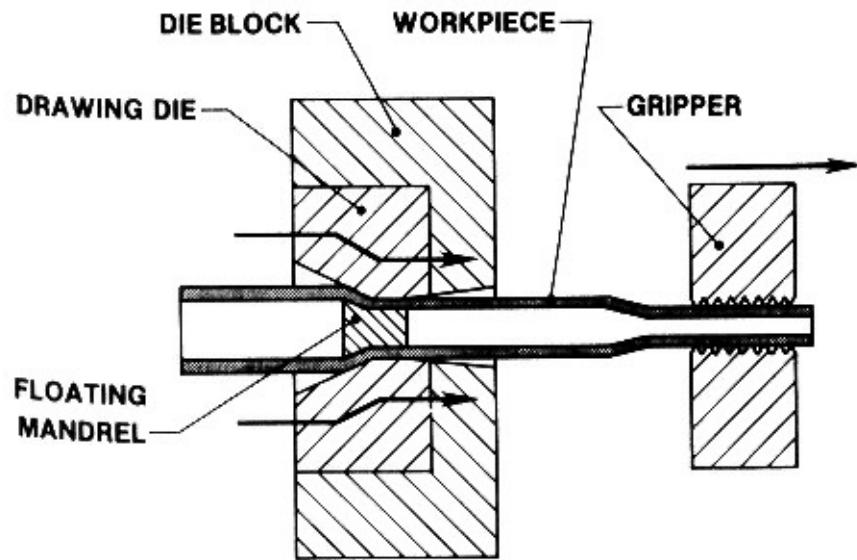


ENLARGED VIEW OF WIRE REDUCTION



Process Variations

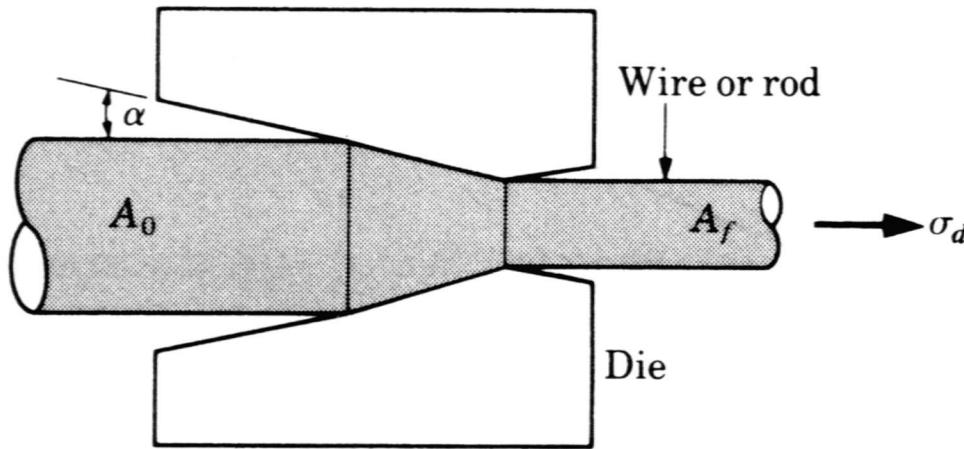
- Tube drawing



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:

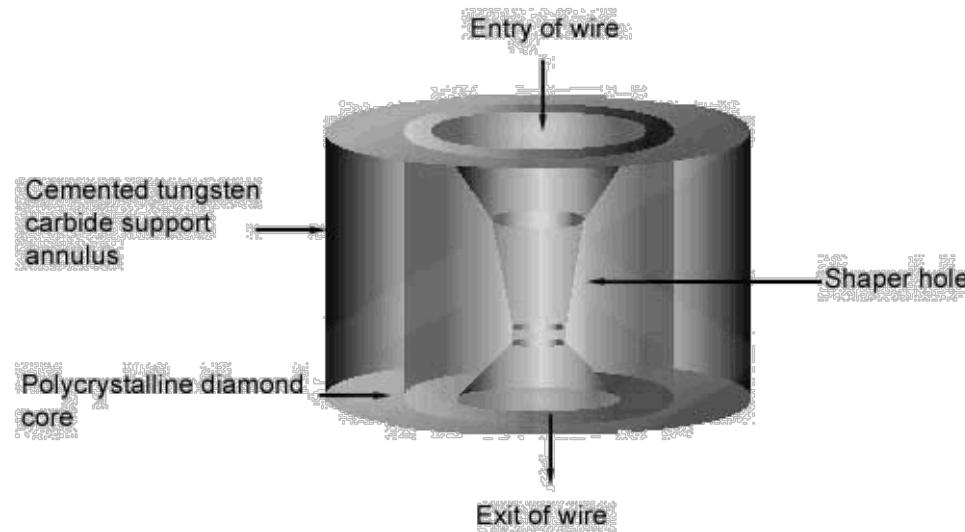
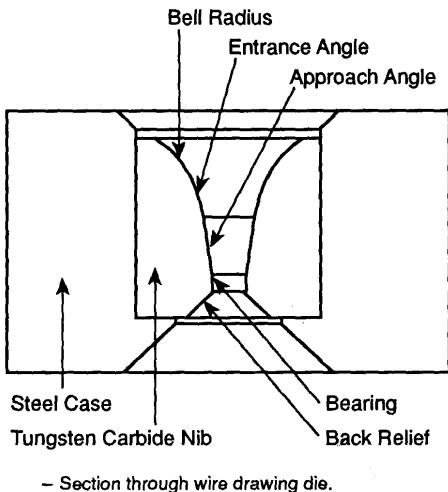
- fine wires: 15-25% reduction

- 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



Key Process Variables

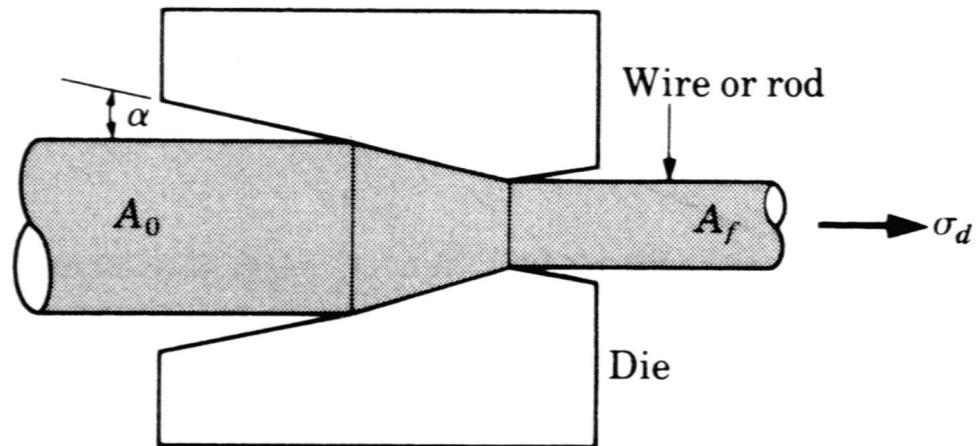
- Reduction:

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

- 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, power, and maximum allowable reduction under ideal deformation conditions
 - Find drawing stress, force, power , and maximum allowable reduction including effects of friction and redundant work of deformation



Rod/Wire Drawing Analysis

- Ideal deformation

External work = Work of ideal plastic deformation

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

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

for $\sigma_t = K\varepsilon_t^n$

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

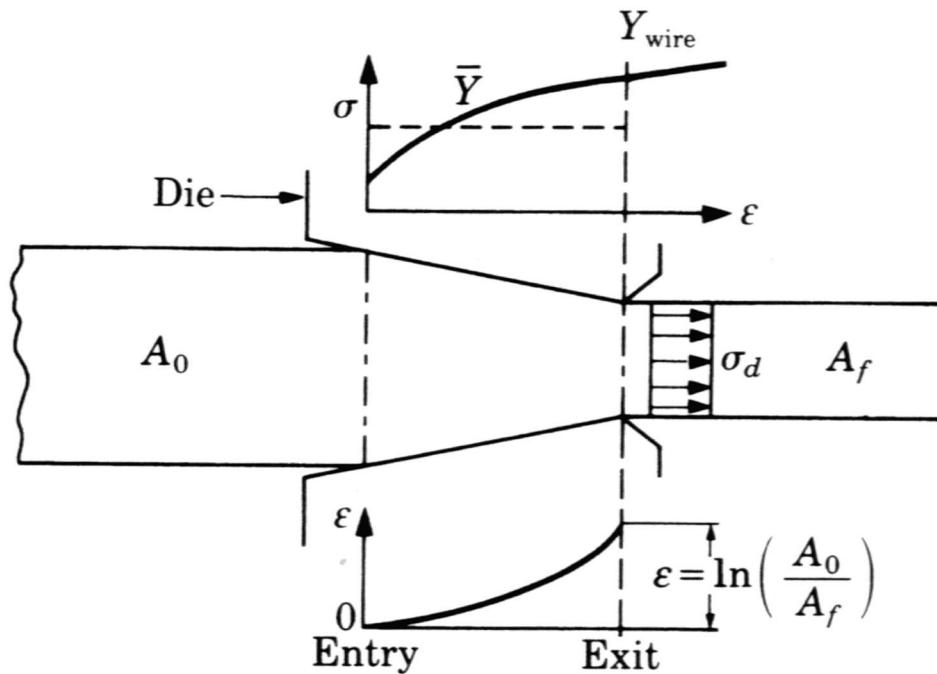


Rod/Wire Drawing Analysis

- Ideal deformation

Drawing force, $F_d = \sigma_d A_f$

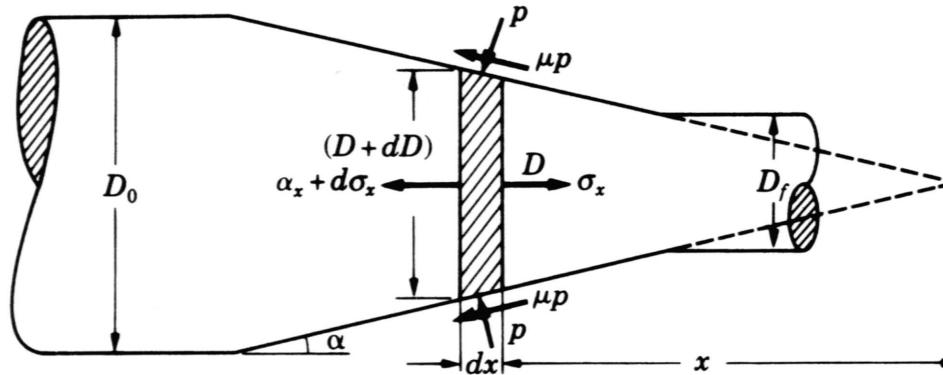
Drawing power, $P_d = F_d V_f$



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

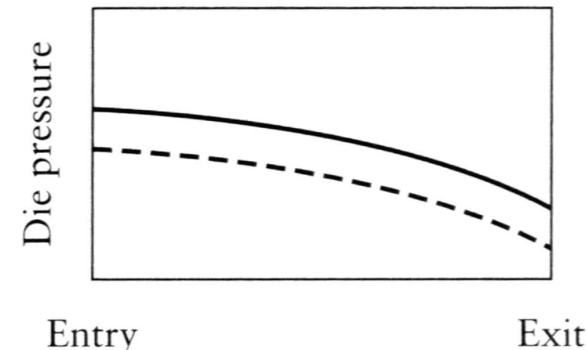
Rod/Wire Drawing Analysis

- 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, $p = Y_f - \sigma_d$

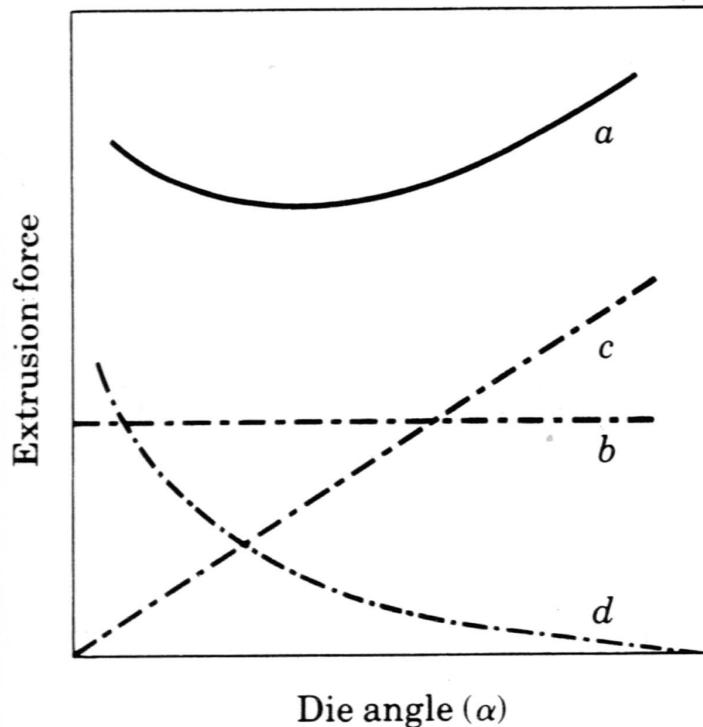


Source: S. Kalpakjian & S. Schmidt, 4th ed. 2003

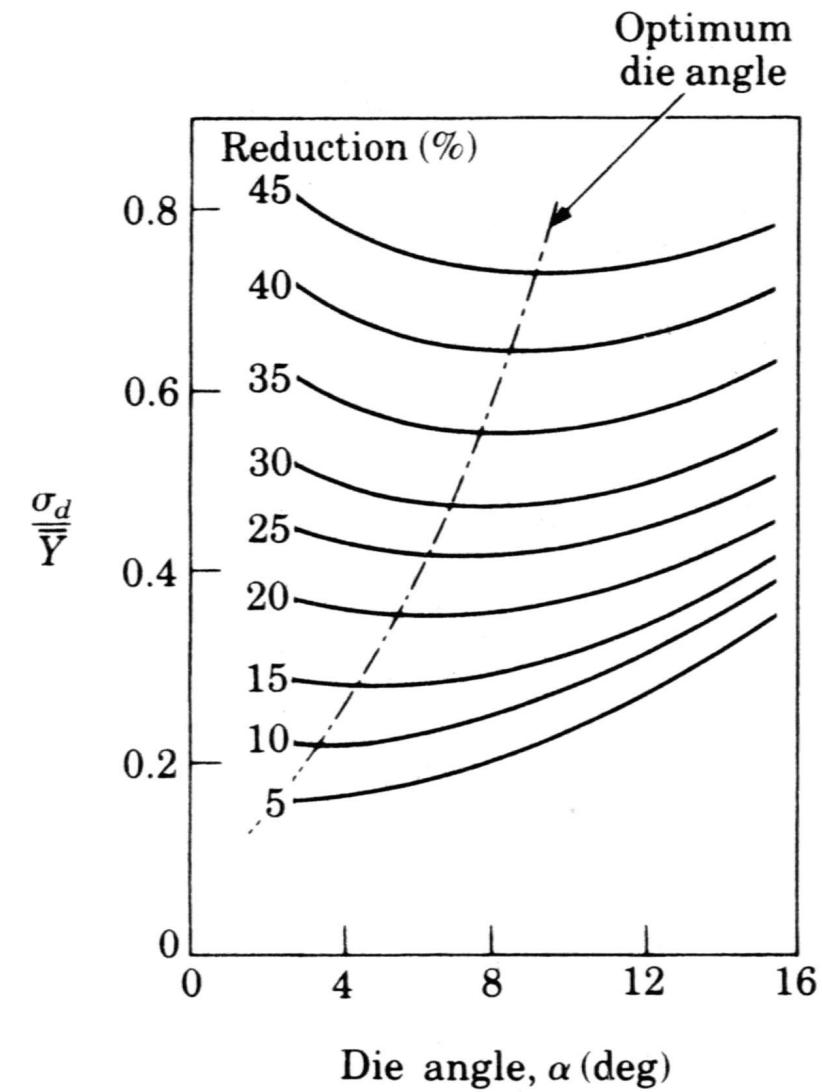
Rod/Wire Drawing Analysis

- Effect of die angle

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



- a. Overall force
- b. Ideal
- c. Force required for redundant deformation
- d. Force to overcome friction



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

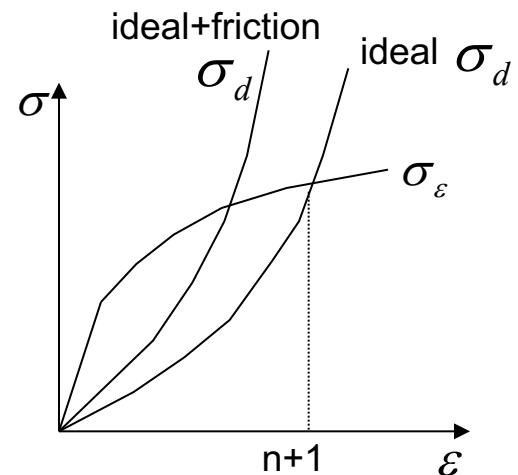
$$\sigma_d = \bar{Y} \cdot \ln \left(\frac{A_o}{A_f} \right) = \frac{K \varepsilon^{n+1}}{n+1}$$

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

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

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 + ~~redundant work~~

Total work = Ideal work + $0.2 \times$ Ideal work = $1.2 \times$ Ideal work

Or, Total work of deformation = $1.2 [u \times \text{volume}] \dots (1)$

In drawing, external work of deformation = $\sigma_d \times \text{volume} \dots (2)$

Equating (1) and (2), we get

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

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



Example Problem

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

$$\sigma_d = Y$$

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

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

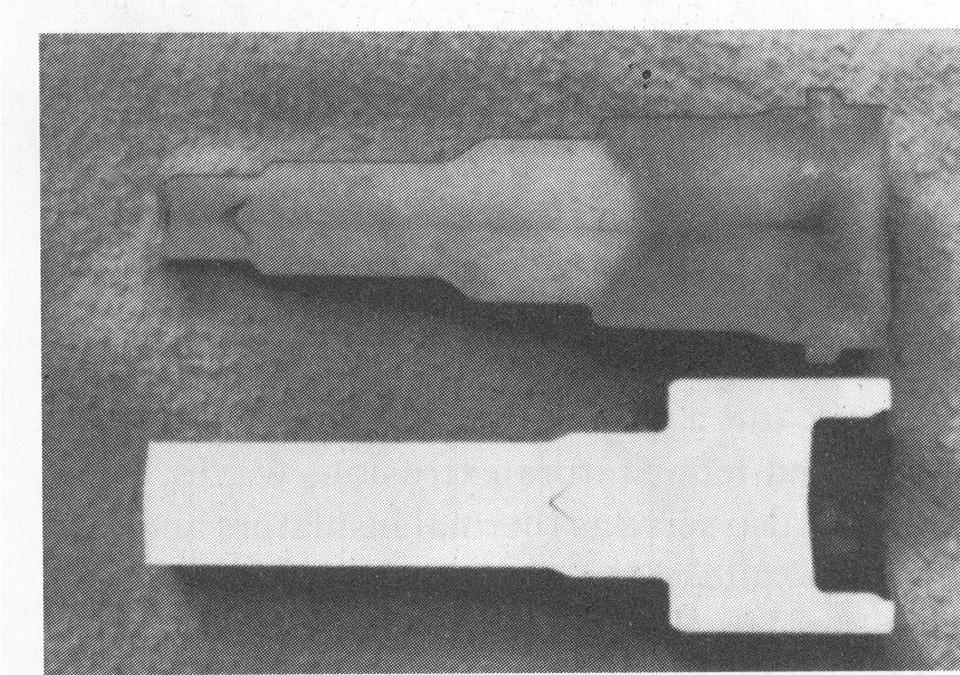
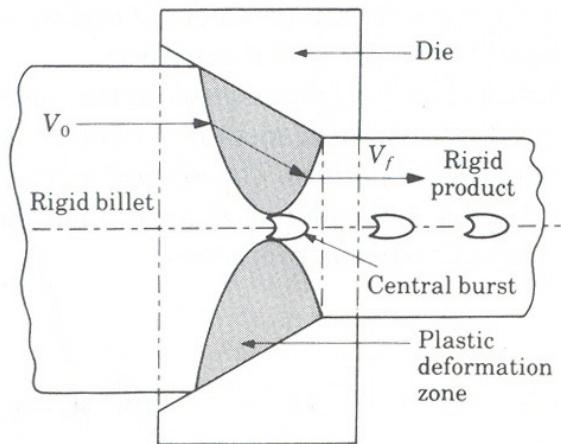
$$\varepsilon_1 = \frac{n+1}{1.2} \Rightarrow \ln \frac{A_0}{A_f} = \frac{n+1}{1.2} \Rightarrow \frac{A_0}{A_f} = e^{\frac{n+1}{1.2}}$$

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



Rod/Wire Drawing Defects

- Centerline cracking



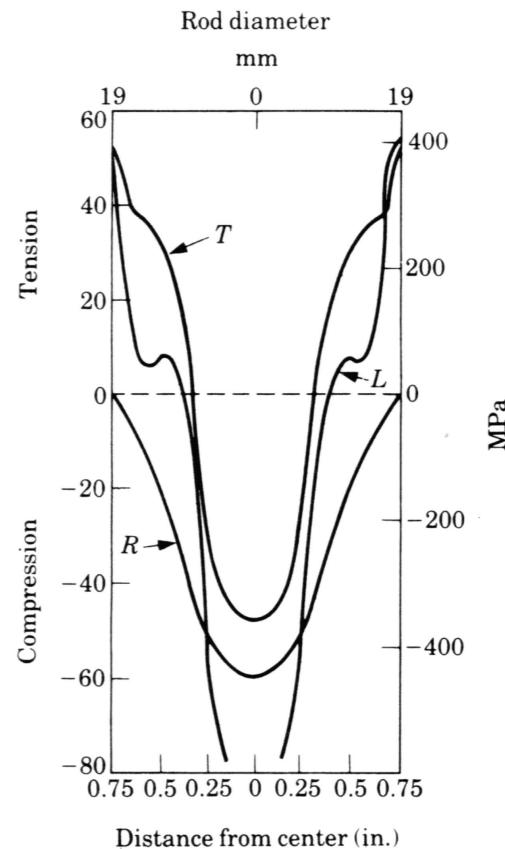
Center cracking increases with: **Center cracking in extruded bar**

- 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

