Today’s Lecture

- Drawing Process
- Typical Products by Drawing
- Mechanics of Drawing
- Die Design and Materials
- Process Capability
• **Drawing**: The cross-section of a rod or wire reduced by by pulling it through a die (while push in extrusion).

![Diagram of drawing process](image)

- **Process Variables**: reduction in cross-section area, die angle, friction, and drawing speed
Typical Products

• Solid Cross-Section: rod
Typical Products

- **Solid Cross-Section:** wire
Typical Products

- Hollow Cross-Section:

Without mandrel

Fixed mandrel

Floating mandrel
Mechanics of Drawing

- Drawing Force

**Area Reduction** \[ r = \frac{A_0 - A_f}{A_0} \]

**Draft** \[ d = D_0 - D_f \]

**Strain** \[ \varepsilon = \ln \frac{A_0}{A_f} = \ln \frac{1}{1 - r} \]

**Ideal Drawing Stress** \[ \sigma_d = \overline{\sigma}_f \varepsilon \]

**Actual Drawing Stress** \[ \sigma_d = \overline{\sigma}_f \left( 1 + \frac{\mu}{\tan \alpha} \right) \phi \ln \frac{A_0}{A_f}, \text{ where } \phi = 0.88 + 0.12 \frac{D}{L_c} \]

\[ D = \frac{D_0 + D_f}{2}, \quad L_c = \frac{D_0 - D_f}{2 \sin \alpha} \]

**Force** \[ F = \sigma_d A_f \]
Mechanics of Drawing

• Maximum Reduction Per Pass

\[ \sigma_d = \overline{\sigma}_f \varepsilon, \quad \text{where} \quad \overline{\sigma}_f = \frac{K\varepsilon^n}{1+n} \]

\[ \therefore \sigma_d = \sigma_f = K\varepsilon^n \]

\[ \therefore \frac{K\varepsilon^n}{1+n} \varepsilon = K\varepsilon^n \Rightarrow \varepsilon = 1+n \]

\[ \therefore \varepsilon = \ln \frac{A_0}{A_f} \]

\[ \therefore \ln \frac{A_0}{A_f} = 1+n \]

\[ \Rightarrow \frac{A_0 - A_f}{A_0} = 1 - e^{-(1+n)} \]

and \[ \frac{A_0 - A_f}{A_0} = 1 - \frac{1}{e} = 63.2\% \quad \text{when} \quad n = 0 \quad (\text{perfect plastic}) \]
Die Design and Material

• **Die Design:**

- Bell (angle or radius)
- Entering angle
- Approach angle
- Bearing surface (land)
- Back relief angle

• **Die Material:** tool steels, carbides, and diamond
Process Capability

- Close Dimensional Control
- Good Surface Finish
- Improved Mechanical Properties
- Economical Batch or Mass Production
End

• Questions?