Outline

• Extrusion process
  - Direct extrusion
  - Indirect extrusion
  - Impact extrusion
• Extrusion analysis
• Bar drawing
• Wire drawing
• Drawing analysis

Extrusion

• Compression forming process in which the work metal is forced to flow through a die opening to produce a desired cross-sectional shape
• In general, extrusion is used to produce long parts of .......... cross-sections
• Two basic types of extrusion:
  - .......... extrusion
  - .......... extrusion

Direct Extrusion

• Also called .......... extrusion
• As ram approaches die opening, a small portion of billet remains that cannot be forced through die opening
• This extra portion, called the butt, must be separated from extruded product by cutting it just beyond the die exit
• Starting billet cross section usually round, but final shape is determined by die opening

Indirect Extrusion

• Also called backward extrusion and reverse extrusion
• Limitations of indirect extrusion are imposed by the lower rigidity of hollow ram and difficulty in supporting extruded product as it exits die

solid cross-section
Hollow cross-section
General Advantages of Extrusion

- **Variety** of shapes possible, especially in hot extrusion
  - Limitation: part cross-section must be uniform throughout length
- Grain structure and strength ............ in cold and warm extrusion
- **Close tolerances** possible, especially in cold extrusion
- In some operations, little or no waste of material

Hot vs. Cold Extrusion

- **Hot extrusion** - prior heating of billet to above its recrystallization temperature
  - This reduces strength and increases ductility of the metal, permitting more size reductions and more ................................ shapes
- **Cold extrusion** - generally used to produce discrete parts
  - The term *impact extrusion* is used to indicate high speed cold extrusion

Impact Extrusion

- Similar to indirect extrusion
- Cold extrusion
- Most nonferrous metals at rates of two parts/second
- Thin walled tubular sections possible

Comments on Die Angle

- Low die angle - surface area is large, leading to increased friction at die-billet interface
  - Higher friction results in larger ram force
- Large die angle - more turbulence in metal flow during reduction
  - Turbulence increases ram force required
- Optimum angle depends on ........................., ........................., and .........................

Comments on Orifice Shape of Extrusion Die

- Simplest cross section shape = circular die orifice
- Shape of die orifice affects ram pressure
- As cross-section becomes more complex, ................. pressure and greater force are required

A complex extruded cross-section for a heat sink
Extrusion Presses

- Either horizontal or vertical
  - Horizontal is more common
- Extrusion presses - usually hydraulically driven, which is especially suited to semi-continuous direct extrusion of long sections
- Mechanical drives - often used for cold extrusion of individual parts

Extrusion Analysis

- Reduction (extrusion) ratio

\[ r_s = \frac{A_o}{A_f} \]

- Extrusion pressure can be calculated from:

\[ p_e = Q_e \bar{Y}_f \]  

Assuming no friction

Where \( Q_e \) is the multiplying factor for extrusion

- \( Q_e \) is related to the extrusion ratio according to:

\[ Q_e = a + b \ln r_s \]

where \( a \approx 0.8 \) and \( b \approx 1.2-1.5 \) increase with dies angle

Friction is significant in extrusion and should be considered, so:

\[ p_p = p_e + p_f \]

where: \( p_p \) is the punch pressure, \( p_e \) is extrusion pressure, and \( p_f \) is the friction pressure

Extrusion Dies and Press

Shape factor

\[ K_x = 0.98 + 0.02 \left( \frac{C_x}{C_c} \right)^{2.25} \]

\( C_x = \) perimeter of the extruded cross-section
\( C_c = \) Perimeter of a circle with the same area

Note that in direct extrusion the ram pressure decreases as the billet is extruded further because \( L \) decreases, whereas in indirect extrusion the ram pressure is not a function of the billet length.

Actual extrusion begins

Ram force, \( F_p = p_p A_p \)

\[ \bar{Y} = \frac{2L}{D_o} \]

\[ F_p = \bar{Y} \left( \varepsilon_s + \frac{2L}{D_o} \right) \]

\( \varepsilon_s \) is the mean strain rate
\( \bar{Y} \) is the flow stress

\[ \varepsilon_s = \frac{6vD_o^2 \ln r_s}{D_o^3 - D_s^3} \]

\( D_o \) is the diameter of the deformed billet
\( D_s \) is the diameter of the deformed product

\( v \) is the punch velocity

\( D_s \) is the diameter of the deformed billet

\( D \) is the extruded product diameter

Ram stroke

\[ \varepsilon_s = \ln r_s \]
Wire and Bar Drawing

- Cross-section of a bar, rod, or wire is reduced by pulling it through a die opening
- Similar to extrusion except work is ………… through die in drawing (it is …………. through in extrusion)
- Although drawing applies tensile stress, compression also plays a significant role since metal is squeezed as it passes through die opening

Wire Drawing vs. Bar Drawing

- Difference between bar drawing and wire drawing is …………
  - Bar drawing - large diameter bar and rod stock
  - Wire drawing - small diameter stock - wire sizes down to 0.03 mm (0.001 in.) are possible
- Although the mechanics are the same, the methods, equipment, and even terminology are different
- Drawing practice:
  - Usually performed as cold working
  - Most frequently used for round cross-sections
- Products:
  - Wire: electrical wire; wire stock for fences, coat hangers, and shopping carts
  - Rod stock for nails, screws, rivets, and springs
  - Bar stock: metal bars for machining, forging, and other processes

Bar Drawing

- Accomplished as a single-draft operation - the stock is pulled through one die opening
- Beginning stock has large diameter and is a straight cylinder
- This necessitates a batch type operation

Wire Drawing

- Continuous drawing machines consisting of multiple draw dies (typically 4 to 12) separated by accumulating drums
  - Each drum (capstan) provides proper force to draw wire stock through upstream die
  - Each die provides a small reduction, so desired total reduction is achieved by the series
  - Annealing sometimes required between dies
Features of a Draw Die

- **Entry** region - funnels lubricant into the die to prevent scoring of work and die
- **Approach** - cone-shaped region where drawing occurs
- **Bearing surface** - determines final stock size
- **Back relief** - exit zone - provided with a back relief angle (half-angle) of about 30°
- **Die materials**: tool steels or cemented carbides

Drawing Analysis

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

**Draft:**
\[ d = D_o - D_f \]

**Mechanics of Drawing:**
\[ \varepsilon = \ln \frac{A_o}{A_f} = \ln \frac{1}{1-r} \]
\[ \sigma = \overline{Y} \varepsilon = \overline{Y} \ln \frac{A_o}{A_f} \]

**Draw Force:**
\[ F = A_f \sigma = A_f \overline{Y} \left(1 + \frac{\mu}{\tan \alpha}\right) \phi \ln \frac{A_o}{A_f} \]

Where:
\[ \phi = 0.88 + 0.12 \frac{D}{L_c} \]
\[ D = \frac{D_o + D_f}{2} \text{ and } L_c = \frac{D_o - D_f}{2 \sin \alpha} \]

Maximum Reduction per pass

**Example**

- For a perfect plastic material

\[ \sigma = \overline{Y} \ln \frac{A_o}{A_f} = Y \ln \frac{A_o}{A_f} = Y \ln \frac{1}{1-r} = Y \]

\[ \ln \left( \frac{A_o}{A_f} \right) = \ln \left( \frac{1}{1-r} \right) = 1 \quad \Rightarrow \quad \varepsilon_{\text{max}} = 1 \]

\[ \frac{A_o}{A_f} = \ldots = \ldots \ldots \]

\[ r_{\text{max}} = \frac{e - 1}{e} = \ldots = \ldots \ldots \]

Next time

Review of Bulk Deformation: **Examples**