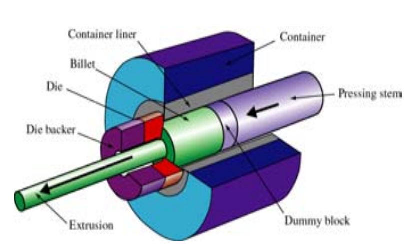
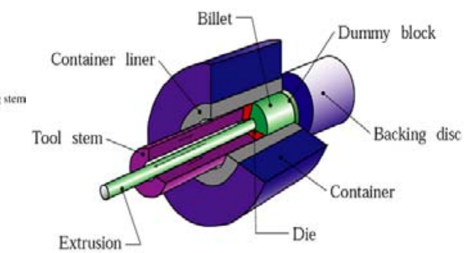
Outline

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

Extrusion



Direct extrusion

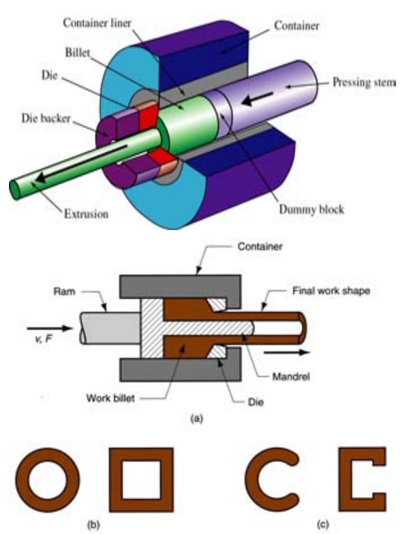


Indirect extrusion

- **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

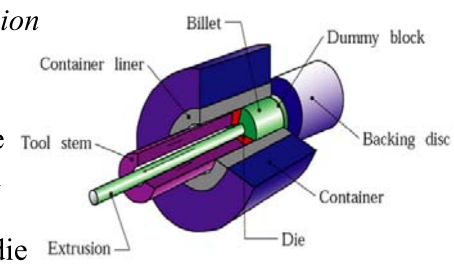
Direct Extrusion

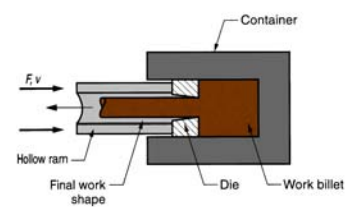
- Also called ………….. *extrusion*
- As ram approaches die opening, a small portion of billet remains that cannot be forced through die opening
- This extra portion, called the *butt*, must be separated from extruded product by cutting it just beyond the die exit
- Starting billet cross section usually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



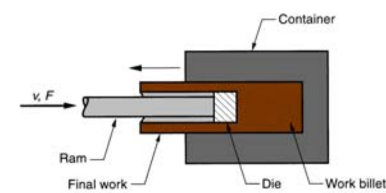
Indirect Extrusion

- 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

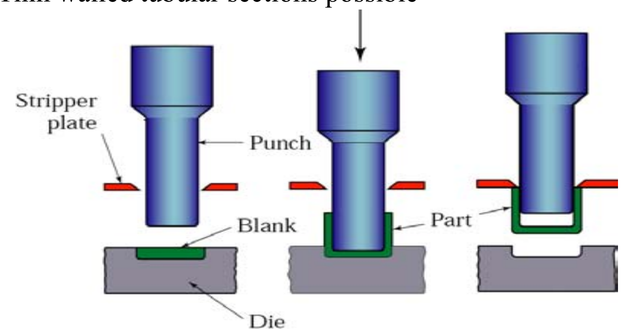
- **Variety** of shapes possible, especially in hot extrusion
  - Limitation: part cross-section **must be uniform** throughout length
- Grain structure and strength **…………** in cold and warm extrusion
- **Close tolerances** possible, especially in cold extrusion
- In some operations, **little or no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

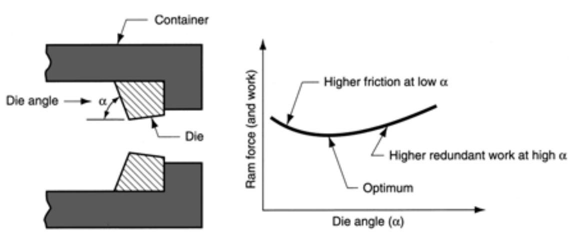
Impact Extrusion

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



The extruded parts are stripped by the use of a stripper plate, because they tend to stick to the punch.

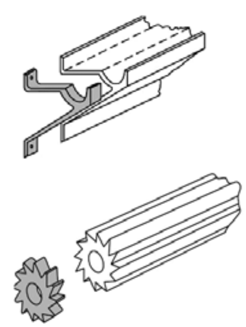
Comments on Die Angle

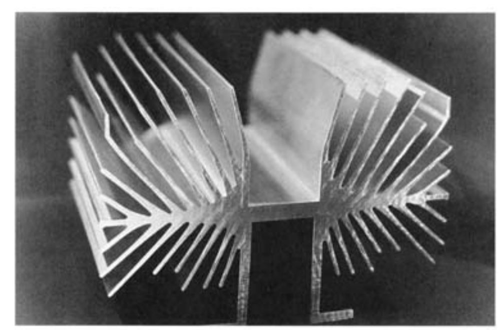


- Low die angle - **surface area** is large, leading to increased **friction** at die-billet interface
  - Higher friction results in larger ram force
- Large die angle - more **turbulenc**e in metal flow during reduction
  - Turbulence increases ram force required
- Optimum angle depends on ………………,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

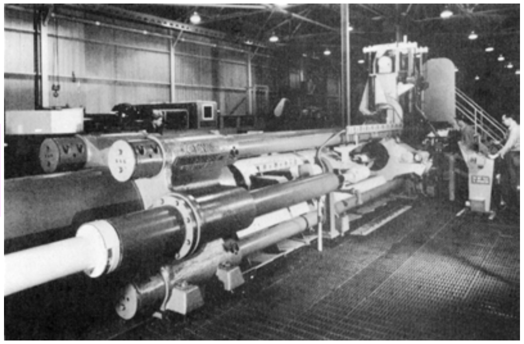




A complex extruded cross-section for a heat sink

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

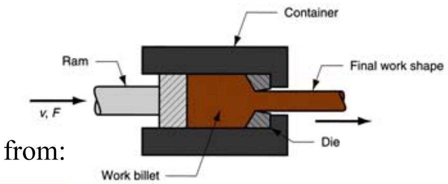


General view of a 9-MN (900-ton) hydraulic-extrusion press

Extrusion Analysis

- Reduction (*extrusion*) ratio

$$r_x = \frac{A_o}{A_f}$$



Direct extrusion

- Extrusion pressure can be calculated from:

$$p_e = Q_e \times \overline{Y}_f$$ *Assuming no friction*

Where Q_e is the multiplying factor for extrusion

- Q_e is related to the extrusion ratio according to:

$$Q_e = \varepsilon_x = a + b \ln r_x$$ where a (~0.8) and b (~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 Analysis

$$F_f = \tau_t \pi D l$$

Where:
τ_t is the shear flow strength
D is the diameter of the deformed billet
l is the length of the frictional resistance
(taking into account the dead metal zone)

Tresca's failure Criterion says: $\tau_t = 0.5\overline{Y}_f$

$$p_p = \overline{Y}_f\left(\varepsilon_x + \frac{2L}{D_o}\right) \Rightarrow$$ Ram Force, $F_p = p_p A_p$ Power $P = F_p v$

L is the billet length

For indirect extrusion friction can be assumed insignificant

Hot extrusion → strain rate effects become important

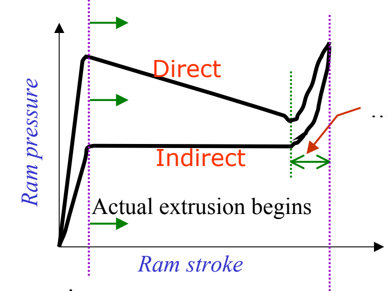
$$\dot{\varepsilon}_m = \frac{6 v D_o^2 \ln r_x}{D_o^{\,3} - D^3}$$

Where: $\dot{\varepsilon}_m$ is the mean strain rate
v is the punch velocity
D_o is the diameter of the deformed billet
D is the extruded product diameter

Extrusion Dies and Press

Shape factor

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



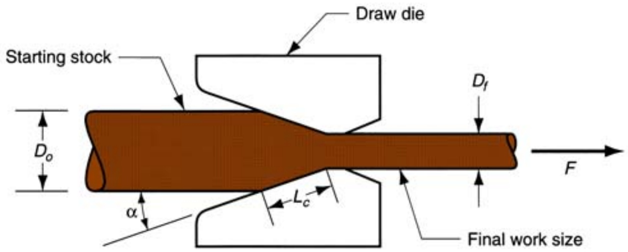
C_x=perimeter of the extruded cross-section
C_c=Perimeter of a circle with the same area

$$p = K_x \overline{Y}_f \varepsilon_x$$ For Indirect

$$p = K_x \overline{Y}_f \left(\varepsilon_x + \frac{2L}{D}\right)$$ For Direct

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.

Wire and Bar Drawing

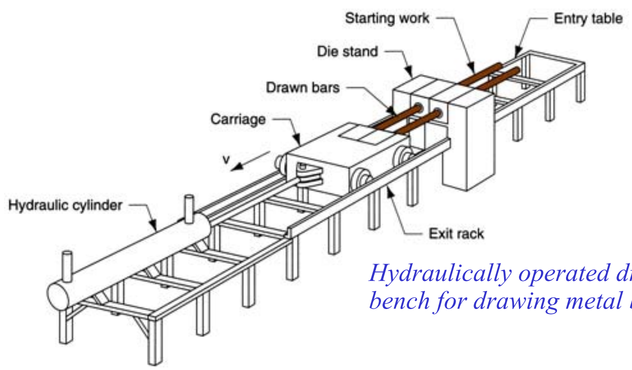


- Cross-section of a bar, rod, or wire is reduced by pulling it through a die opening
- Similar to extrusion except work is ……….. through die in drawing (it is …………. through in extrusion)
- Although drawing applies tensile stress, compression also plays a significant role since metal is squeezed as it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

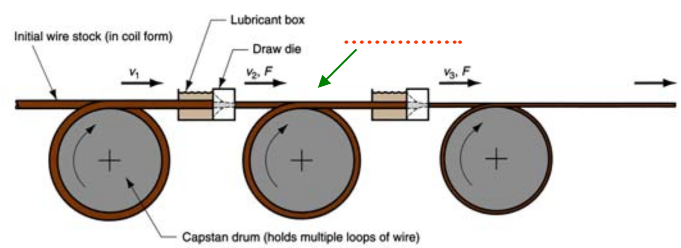
Bar Drawing



Hydraulically operated draw bench for drawing metal bars

- 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

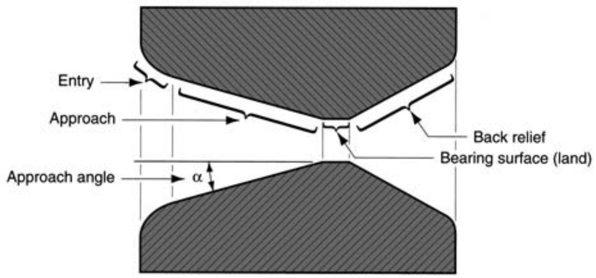
Wire Drawing



Continuous drawing of wire

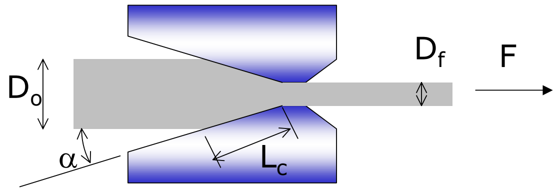
- Continuous drawing machines consisting of multiple draw dies (typically 4 to 12) separated by accumulating drums
  - Each drum (*capstan*) provides proper force to draw wire stock through upstream die
  - Each die provides a **small reduction**, so desired total reduction is achieved by the series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

$$\varepsilon = \ln\frac{A_o}{A_f} = \ln\frac{1}{1-r}$$

$$\sigma = \bar{Y}_f \varepsilon = \bar{Y}_f \ln\frac{A_o}{A_f} \quad \text{Ideal}$$

$$\sigma = \bar{Y}_f \left(1 + \frac{\mu}{\tan\alpha}\right)\phi \ln\frac{A_o}{A_f} \quad \text{Actual}$$

Where:

$$\phi = 0.88 + 0.12\frac{D}{L_c}$$

$$D = \frac{D_o + D_f}{2} \quad \text{and} \quad L_c = \frac{D_o - D_f}{2\sin\alpha}$$

Draw Force:

$$F = A_f \sigma = A_f \bar{Y}_f \left(1 + \frac{\mu}{\tan\alpha}\right)\phi \ln\frac{A_o}{A_f}$$

Maximum Reduction per pass

Example

- For a perfect plastic material

$$\sigma = \bar{Y}_f \ln\frac{A_o}{A_f} = Y \ln\frac{A_o}{A_f} = Y \ln\frac{1}{1-r} = Y$$

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

$$\frac{A_o}{A_f} = ... = ...$$

$$r_{\max} = \frac{e-1}{e} = ...$$

Next time

Review of Bulk Deformation: *Examples*