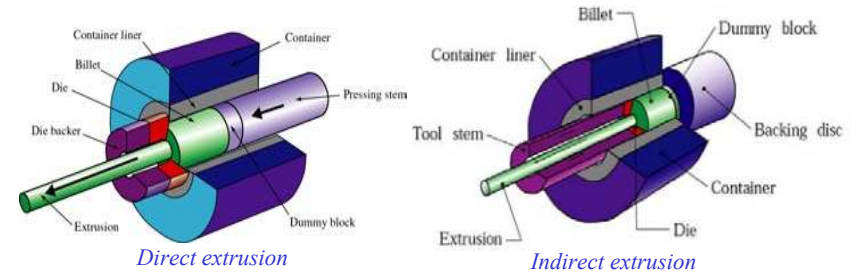


Outline

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

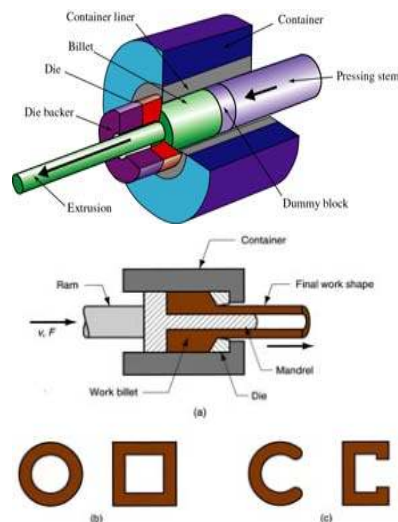
Extrusion



- **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

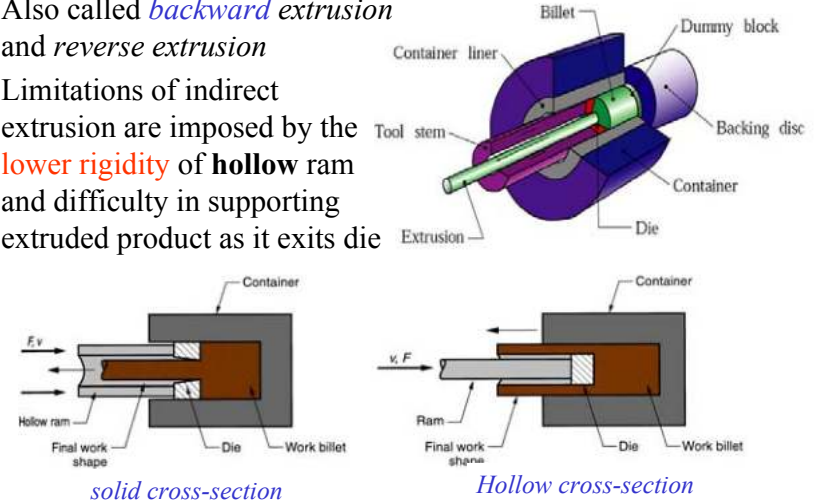
Direct Extrusion

- 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



General Advantages of Extrusion

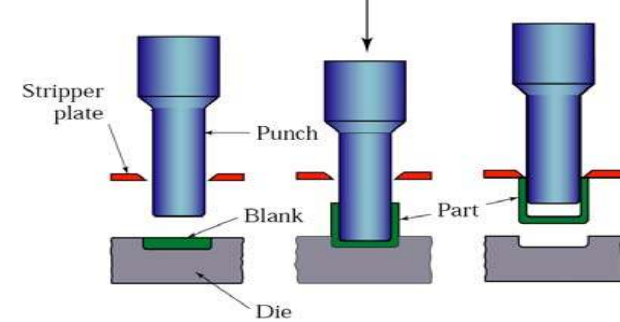
- **Variety** of shapes possible, especially in hot extrusion
 - Limitation: part cross-section **must be uniform** throughout length
- Grain structure and strength in cold and warm extrusion
- **Close tolerances** possible, especially in cold extrusion
- In some operations, **little or no waste** of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

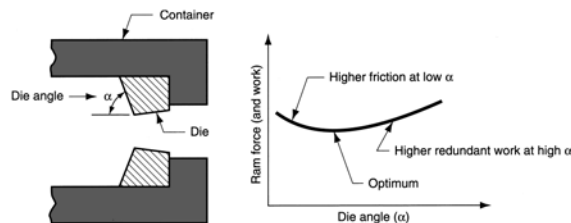
Impact Extrusion

- 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.

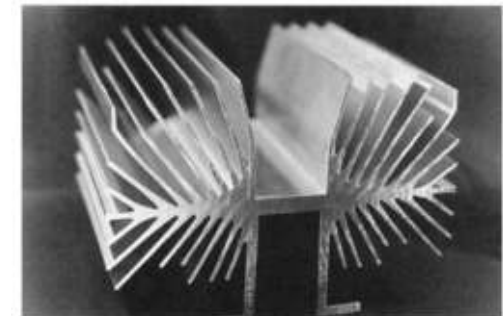
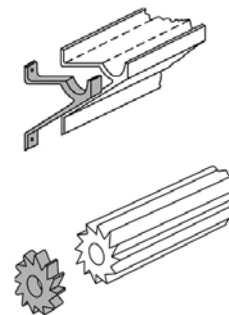
Comments on Die Angle



- **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 **turbulence** in metal flow during reduction
 - Turbulence increases ram force required
- Optimum angle depends on, and

Comments on Orifice Shape of Extrusion Die

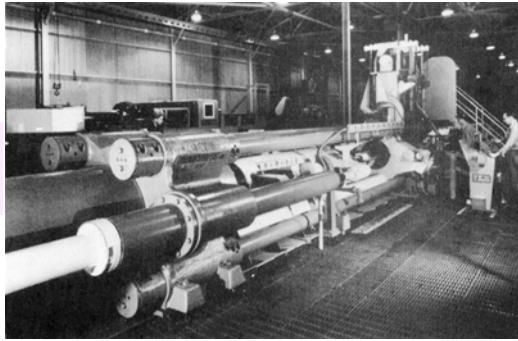
- Simplest cross section shape = **circular** die orifice
- **Shape** of die orifice affects **ram pressure**
- As cross-section becomes more **complex**, pressure and greater force are required



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



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

Extrusion Analysis

- **Reduction (extrusion) ratio**

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

- Extrusion pressure can be calculated from:

$$p_e = Q_e \times \bar{Y}_f \quad \text{Assuming no friction}$$

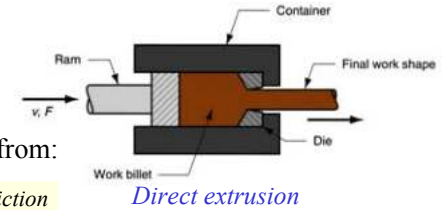
Where Q_e is the multiplying factor for extrusion

- Q_e is related to the **extrusion ratio** according to:

$$Q_e = \varepsilon_x = a + b \ln r_x \quad \text{where } a \text{ } (\sim 0.8) \text{ and } b \text{ } (\sim 1.2-1.5) \text{ increase with dies angle}$$

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

$$P_p = P_e + P_f \quad \text{where: } p_p \text{ is the punch pressure } p_e \text{ is extrusion pressure and } p_f \text{ is the friction pressure}$$



Extrusion Analysis

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)

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

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

$$P_p = \bar{Y}_f \left(\varepsilon_x + \frac{2L}{D_o} \right) \Rightarrow \text{Ram Force, } F_p = P_p A_p$$

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 \rightarrow **strain rate** effects become important

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

Where: $\dot{\varepsilon}_m$ is the mean strain rate

v is the punch velocity

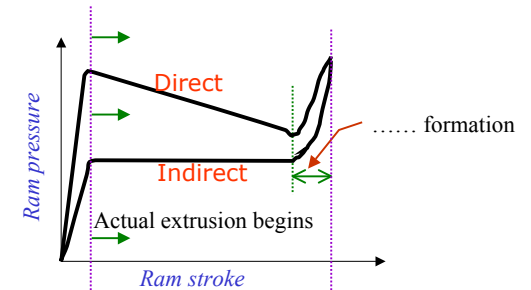
D_o is the diameter of the deformed billet

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

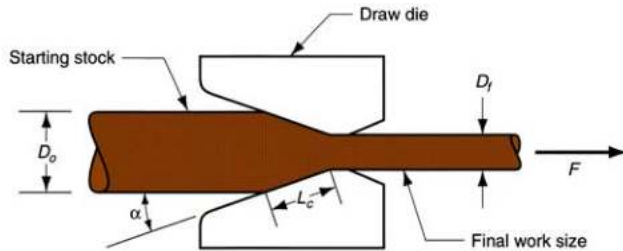
C_c = Perimeter of a circle with the same area

$$p = K_x \bar{Y}_f \varepsilon_x \quad \text{For Indirect}$$

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

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

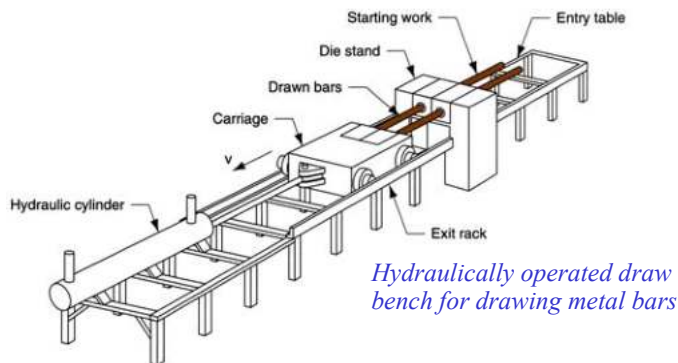


- Cross-section of a bar, rod, or wire is reduced by pulling it through a die opening
- Similar to **extrusion** except work is through die in drawing (it is through in extrusion)
- Although drawing applies **tensile** stress, **compression** also plays a significant role since metal is **squeezed**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

Wire Drawing vs. Bar Drawing

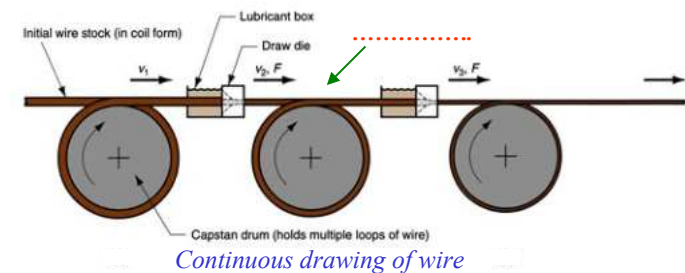
- Difference between bar drawing and wire drawing is
 - **Bar drawing** - large diameter bar and rod stock
 - **Wire drawing** - small diameter stock - wire sizes down to 0.03 mm (0.001 in.) are possible
- Although the mechanics are the **same**, the methods, equipment, and even terminology are **different**
- **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



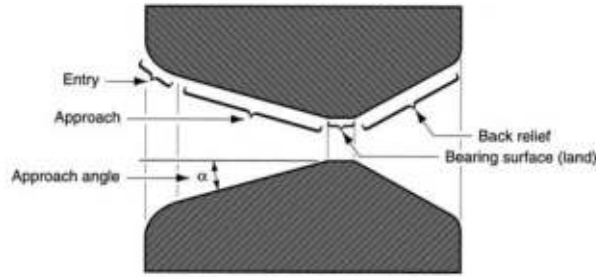
- Accomplished as a **single-draft** operation - the stock is pulled through one die opening
- Beginning stock has large diameter and is a straight cylinder
- This necessitates a **batch** type operation

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:

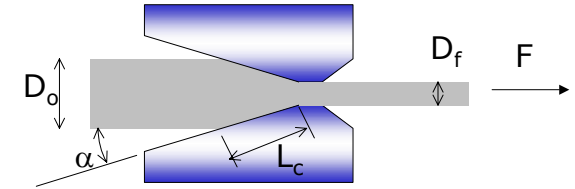
$$d = D_o - D_f$$

Mechanics of Drawing:

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

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

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



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

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

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

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

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