3. Extrusion

- A compressive forming process in which the work metal is forced to go through a die opening in a shape of desirable cross-section.
- Direct vs. Indirect
- Hot, warm and cold
- Solid, Hollow and Semi-hollow parts
- Continuous vs. Discrete
- Advantage
  - Variety of shapes but a uniform cross-section
  - no waste of material

Extrusion Analysis I

- Reduction (extrusion) ratio \( r_e = \frac{A_i}{A_f} \)
- Assuming no friction, true strain \( \varepsilon = \ln r_e \)
- Pressure required: \( p = \frac{F}{A_f} \ln r_e \)
- With friction, \( \varepsilon = a + b \ln r_e \), where \( a \sim 0.8 \) and \( b \) (1.2-1.5) increase with dies angle
- Indirect Extrusion: \( p = \pi \frac{D}{2} \varepsilon \)
- Direct Extrusion: \( p = \pi \frac{2L}{D} \varepsilon \)
- Ram Force, \( F = \rho A_o \)
- Power \( P = Fv \)

Extrusion Analysis II

In direct extrusion, there is additional pressure, \( P_f \), to overcome the friction at the container wall.

\[
\frac{P_f D^2}{4} = \mu \pi D L = \frac{\varepsilon_0}{2}
\]

where \( P_f \) = pressure of the billet against the container wall

\( \varepsilon_0 = \frac{Y_p}{2} \)

Extrusion Dies and Press

- Shape factor \( K_r = 0.98 + 0.02 \left( \frac{C_r}{C_o} \right)^{1.25} \)
  - \( C_r \) = perimeter of the extruded cross-section
  - \( C_o \) = Perimeter of a circle with the same area
- Formula
  - For Indirect: \( p = K_r \pi \varepsilon \)
  - For Direct: \( p = K_r \pi \left( \varepsilon + \frac{2L}{D} \right) \)
- Impact & Hydrostatic Extrusion

Die Angle & Orifice Shape

- Optimum angle depends on work material, billet temperature, and lubrication
  - Low die angle - surface area is large, leading to increased friction at die-billet interface, which results in larger ram force
  - Large die angle - More turbulence in metal flow during reduction, which increases ram force required
- Shape of die orifice affects ram pressure
  - Simplest shape = circular die orifice
  - As cross-section becomes more complex, higher pressure and greater force are required
Problem 19.25

A billet that is 75mm long with diameter=35mm is directly extruded to
a diameter of 20mm. The extrusion die has a die angle of 75°. For the
work metal, K=600MPa and n=0.25. In the Johnson’s equation, a=0.8
and b=1.4. Determine (a) extrusion ratio, (b) true strain, (c) extrusion
strain and (d) ram pressure at L=70, 40 and 10mm.

(a) \( r \times A_0/A_f = (35^2)/(20^2) = 3.0625 \)
(b) \( \varepsilon = \ln(r A_0/A_f) = 1.119 \)
(c) \( \varepsilon_x = a + b \ln(r A_0/A_f) = 0.8 + 1.4(1.119) = 2.367 \)
(d) \( \sigma_f = 600(1.119)^{0.25}/1.25 = 493.7MPa \)

To L=70mm, Did extrusion took place?

\( \Delta = (R - R)/\tan 75 \)

\( h = 2.01mm \)

\( V = \frac{1}{3} \pi (R^2 H - R^2 (H-h)) = 1223.4mm^3 \)

\( V_{70mm} = \pi D_0^2 (75-70)/4 = 4810.6mm^3 \)

L=70mm; \( p = 493.7(2.367 + 2(70)/35) = 3143.4MPa \)
L=40mm; \( p = 493.7(2.367 + 2(40)/35) = 2297.0MPa \)
L=10mm; \( p = 493.7(2.367 + 2(10)/35) = 1450.7MPa \)

4. Wire and Bar Drawing

- The cross section of a bar, rod or wire is
  pulled while deforming through a die
  opening.

\( r = \frac{A_0}{A_f} \)
\( h = \Delta \tan \alpha \)
\( F = A_f \sigma = A_f \left( 1 + \frac{\mu}{\tan \alpha} \right) \ln \frac{A_0}{A_f} \)

Problem 19.35

Bar stock of initial diameter =90mm is drawn with a draft=15mm. The draw
Die has an entrance angle=18°, and the coefficient of friction at the work-die
interface =0.08. The metal behave as a perfectly plastic material with yield
stress =105MPa. Determine: (a) area of reduction, (b) draw stress, (c) draw
force required for the operation and (d) power to perform the operation of exit
velocity=1.0m/min.

(a) \( r = \frac{A_0}{A_f} = \frac{(90^2) - (90-15)^2}{90^2} = 0.3056 \)
(b) \( \omega = \ln \frac{A_0}{A_f} = \ln 1.440 = 0.3646 \)
\( \sigma_T = 105MPa \)
\( \phi = 0.88 + 0.12(0.12L) = 1.288 \) where \( D = 0.5(90+75) = 82.5mm \) and
\( L = 0.5(90-75)/\sin 18 = 24.3mm \)
\( \sigma_f = \frac{\Delta}{\Delta D} = 61.45MPa \)
\( (c) F = A_f \sigma = 4117.9(61.45) = 271,475N \)
\( (d) P = 271,475(1m/min) = 4524.6W \)

Drawing practice

- Usually cold working & round cross-sections
- Difference between bar drawing and wire
drawing is stock size
  - 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
- Preparation of the Work
  - Annealing – to increase ductility of stock
  - Cleaning - to prevent damage to work surface and
draw die
  - Pointing – to reduce diameter of starting end to allow
insertion through draw die