2. Extrusion Processes

Introduction:

- Extrusion is a compressive process in which the w.p. is forced to flow through a die opening (aperture) to produce a desired cross-sectional shape.
- The process can be likened to squeezing toothpaste out of a toothpaste tube.
- It can be done cold, warm and hot working based on w.p. characteristics and desired properties of the final product.
- Advantages of extrusion process are: (1) a variety of shapes are possible especially with hot extrusion, (2) grain structure and strength properties are enhanced in cold and warm extrusion, (3) fairly close tolerances are possible, especially in cold extrusion, (4) in some extrusion operations, little or no wasted material is created.
- Disadvantage of extrusion process: a limitation is that the cross section of the extruded part must be uniform throughout its length.

Types of Extrusion:

- There are various ways to classify of extrusion operations:
  1- By physical configuration into: **Direct Extrusion** and **Indirect Extrusion.**
  2- By working temperature into: **Cold Extrusion, Warm Extrusion and Hot Extrusion.**
  3- Extrusion is performed as either a **continuous process** or a **discrete process**

Direct Extrusion:

- It is also called “Forward Extrusion”.
- A metal billet is located into a container and a ram compresses it, forcing the metal to flow through one or more apertures in a die. Figure (3-22) explains the direct extrusion.
- The ram force required in direct extrusion is substantially increased because of the significant friction that exists between the w.p. surface and the walls of the container and die itself.

- In hot extrusion, the friction problem is aggravated by the presence of an oxide layer on the surface of the billet.
- To address these problems, a dummy block is often used between the ram and the w.p. The diameter of dummy block is slightly smaller than the billet diameter so that a narrow ring of w.p. metal (mostly the oxide layer) is left in the container.
- This process is also used to produce a hallow sections (e.g., tubes) where starting billet is prepared with a hole, this allows passage of a mandrel that is attached to the dummy block. Figure (3-23) states producing hollow sections by direct extrusion.
- Semi-hollow sections are usually extruded in the same way as shown in figure (3-23).

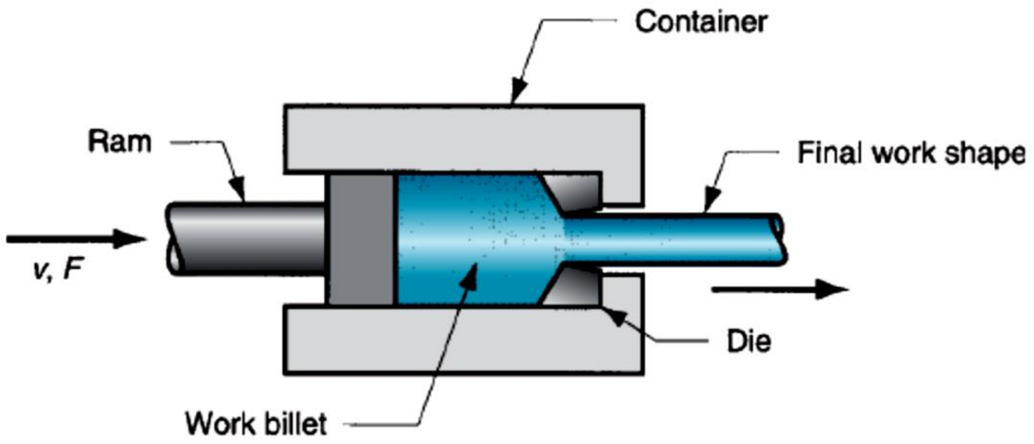


Figure (3-22) direct extrusion

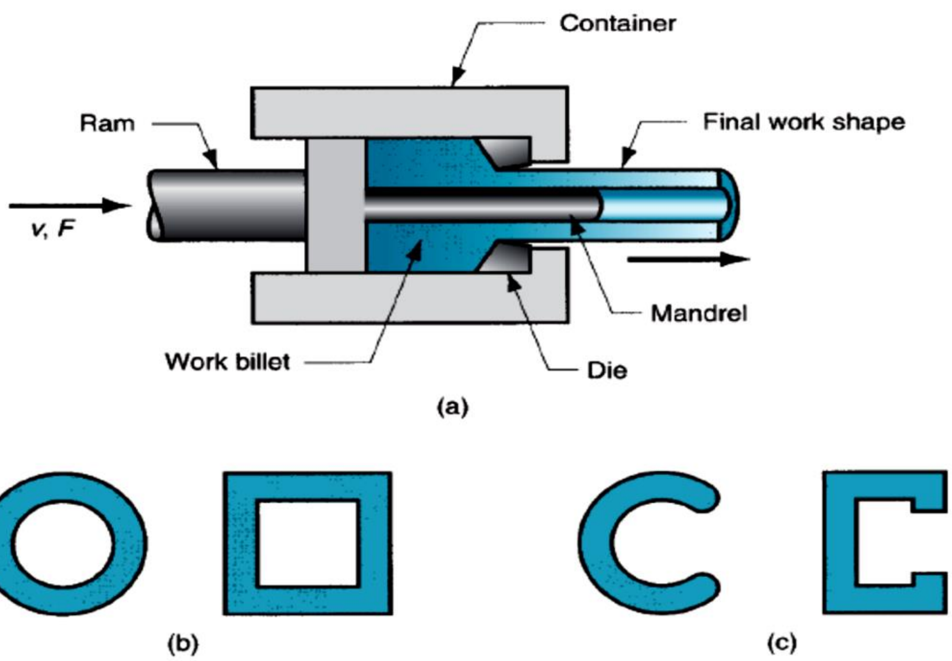
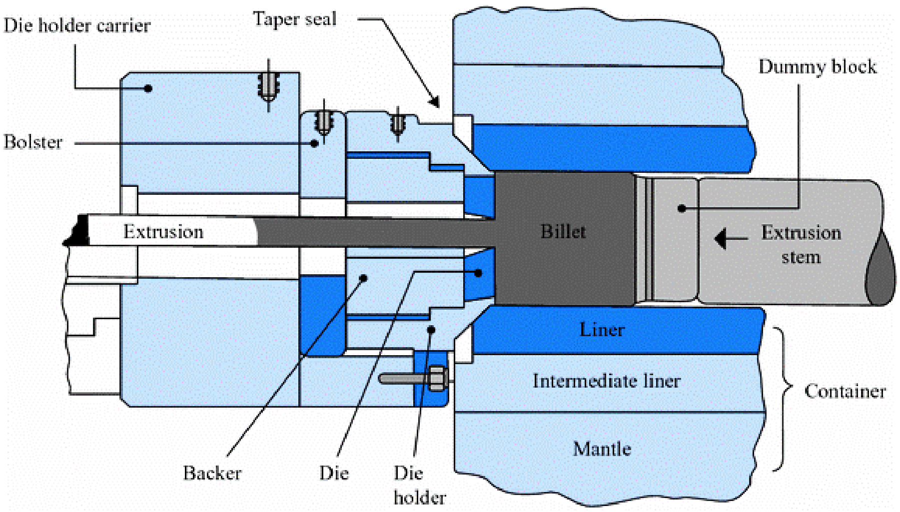
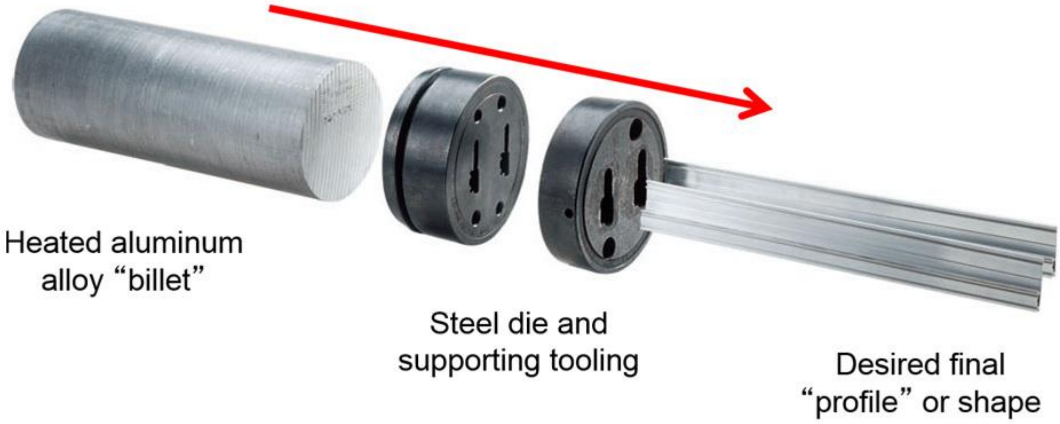


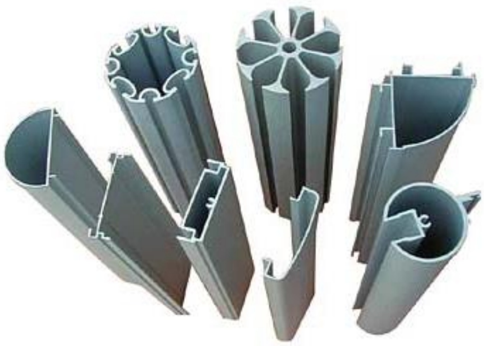
Figure (3-23) (a) direct extrusion to produce hollow or semi-hollow cross-sections, (b) hollow and (c) semi-hollow cross-sections



Die holder carrier
Taper seal
Dummy block
Bolster
Extrusion
Billet
Extrusion stem
Liner
Intermediate liner
Container
Mantle
Backer
Die
Die holder



Heated aluminum alloy “billet”
Steel die and supporting tooling
Desired final “profile” or shape



Indirect Extrusion:

- It is also called "backward extrusion and reverse extrusion".
- The die is mounted to the ram.
- The metal is forced to flow through the clearance in a direction opposite to motion of the ram.
- The ram force is lower than in direct extrusion because there is no friction at the container walls, since the billet is not forced to move relative to the container.
- It can produce hollow (tubular) cross sections.
- Figure (3-24) illustrates the indirect extrusion.
- Disadvantages of indirect extrusion are: 1- lower rigidity of the hollow ram, 2- difficulty in supporting the extruded product as it exit the die (length limitations), 3- support of ram becomes a problem as work length increases.

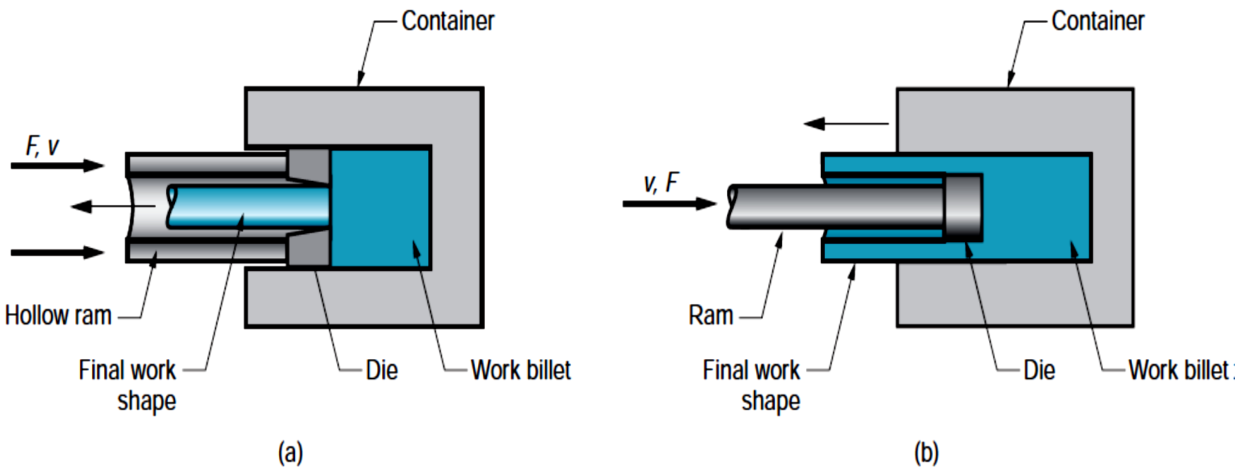


Figure (3-24) indirect extrusion; (a) solid cross-section, (b) hollow cross-section.

Continuous Extrusion:

- It which a very long sections in one cycle are produced, but this operation is limited by the size of the billet that supplied into the container.
- In nearly all cases, the long section is cut into smaller lengths in a subsequent sawing or shearing operation.

Discrete Extrusion:

- In which a single part is produced in each extrusion cycle. Impact extrusion is an example of the discrete extrusion.

Analysis of Extrusion:

1- Extrusion Ratio or Reduction Ratio:

From figure (3-25), the extrusion ratio is:

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

This ratio is applied for both direct and indirect extrusion.

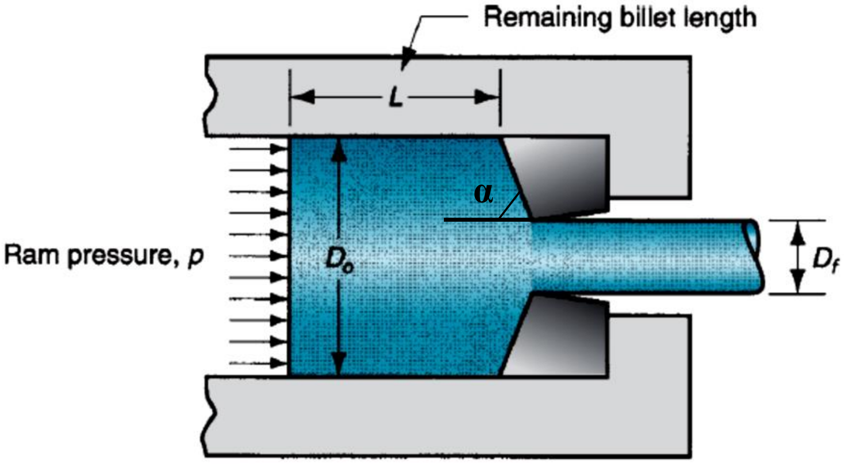


Figure (3-25) pressure and other variables in direct extrusion.

$$A_o = \frac{\pi}{4} D_o^2$$

$$A_f = \frac{\pi}{4} D_f^2$$

Where;

r_x: extrusion ratio

α: die angle

A_o: cross-sectional area of starting billet

A_f: cross-sectional area of extruded section

2- True Strain:

- For ideal deformation case (no friction and no redundant work), the true strain can be write as:

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

3- Ram Pressure:

- Also under the assumption of ideal deformation (no friction and no redundant work), the ram pressure for both direct and indirect extrusion can be written as:

$$p = k_x \bar{Y}_f \varepsilon = k_x \bar{Y}_f \ln\frac{A_o}{A_f}$$

$$\bar{Y}_f = \frac{K\varepsilon^n}{1+n}$$

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

C_x: perimeter of extruded cross-section

C_c: perimeter of a circle of same area as extruded shape

k_x: die shape factor (empirical relation) and it valid for values ($\frac{C_x}{C_c}$) from 1 to 6, k_x=1 for circular shapes and something else for other shapes.

$\bar{Y}_f$: average flow stress

4- Extrusion Strain or Actual True Strain:

- In real case, the friction is existed between die and billet and between billet surface and container wall.
- The effect of friction is to increase the strain experienced by the w.p.
- Thus the actual ram pressure is greater than that given by the above equations.
- The extrusion strain-actual strain (Johnson formula) is given by:

$$\boldsymbol{\varepsilon_x = a + b\varepsilon = a + b\ln r_x}$$

ε_x: extrusion strain (take into account friction and redundant cases)

a, b: empirical constants for a given die angle.

<u>Note:</u> values of *a* and *b* tend to increase with increasing die angle.

- Low die angle ⟹ increase surface area ⟹ increase friction ⟹ increase ram force.
- Large die angle ⟹ more turbulence in metal flow during reduction ⟹ increase ram force.

5- Actual Ram Pressure in Indirect Extrusion:

$$p_1 = k_x \bar{Y}_f \varepsilon_x$$

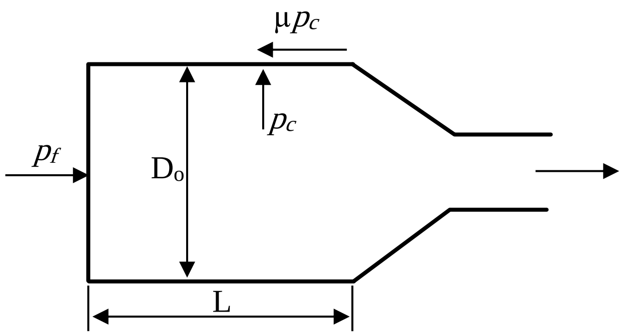
$$\bar{Y}_f = \frac{K\varepsilon^n}{n+1} \qquad \text{where} \quad \varepsilon = \ln r_x$$

6- Actual Ram Pressure in Direct Extrusion:

- The effect of friction between container walls and billet causes the ram pressure to be greater than for indirect extrusion, thus:

$$p_2 = k_x \bar{Y}_f \varepsilon_x + k_x p_f$$

- The following analysis explains the friction force in the container:



$$\sum F_x = 0$$

$$p_f \frac{\pi D_o^2}{4} = \mu p_c \pi D_o L$$

p_f: additional pressure required to overcome billet-container friction

p_c: pressure of billet against the container wall

μ: friction coefficient

$\mu p_c \pi D_o L$: billet-container friction force

$p_f \frac{\pi D_o^2}{4}$: additional ram force to overcome billet-container friction

- In case sticking occurs at the container wall, so that:
  friction stress = shear yield strength of w.p., then:

$$\mu p_c \pi D_o L = Y_s \pi D_o L \qquad \text{and} \qquad Y_s = \frac{\bar{Y}_f}{2}$$

$$\therefore \frac{\bar{Y}_f}{2}\pi D_o L = \mu p_c \pi D_o L = p_f \frac{\pi D_o^2}{4}$$

$$\therefore p_f = \bar{Y}_f \frac{2L}{D_o}$$

$$\therefore p_2 = k_x \bar{Y}_f \left(\varepsilon_x + \frac{2L}{D_o}\right)$$

Where;

Y_s: shear yield strength

L: remaining billet length to be extruded

7- Ram Force:

1- Indirect Extrusion: $F_1 = p_1 A_o$
2- Direct Extrusion: $F_2 = p_2 A_o$

8- Power Required for Extrusion:

1- Indirect Extrusion: $Power = F_1 V_o$
2- Direct Extrusion: $Power = F_2 V_o$

V_o: ram velocity (m/s)

Example (4):

A billet 75mm long and 25mm in diameter is to be extruded in a direct extrusion operation with r_x=4 (circular die). Take the following data: K=415MPa, n=0.18, a=0.8, b=1.5. Determine the ram pressure at the billet lengths: L=75mm, 50mm, 25mm and L=0mm.

Solution:

For the direct extrusion: $p_2 = k_x \bar{Y}_f \left(\varepsilon_x + \frac{2L}{D_o}\right)$

k_x=1.0 for circular die

$\bar{Y}_f = \frac{K\varepsilon^n}{n+1}$ $\varepsilon = \ln r_x = \ln 4 = 1.386$

$$\therefore \bar{Y}_f = \frac{415(1.386)^{0.18}}{0.18+1} = 373MPa$$

$\varepsilon_x = a + b\ln r_x = 0.8 + 1.5(1.386) = 2.879$

At L=75mm, ➡ $p_2 = 1(373)\left(2.879 + \frac{2(75)}{25}\right) = 3312MPa$ **Answer**

At L=50mm, ➡ $p_2 = 1(373)\left(2.879 + \frac{2(50)}{25}\right) = 2566MPa$ **Answer**

At L=25mm, ➡ $p_2 = 1(373)\left(2.879 + \frac{2(25)}{25}\right) = 1820MPa$ **Answer**

At L=0.0mm, ➡ $p_2 = 1(373)\left(2.879 + \frac{0}{25}\right) = 1074MPa$ **Answer**

At L=0.0mm (this is a hypothetical result minimum value of ram pressure)

- The following figure explains relationship between ram pressure vs ram stroke.

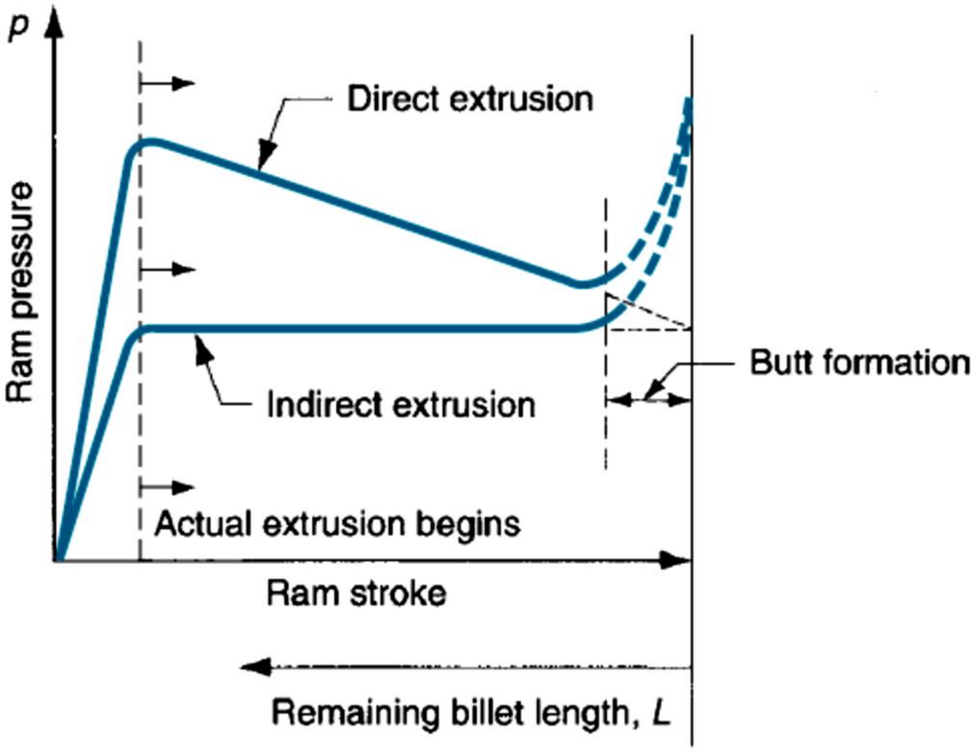


Figure (3-26) relationship between ram pressure vs ram stroke

Example (5):

A 3.0-in-long cylindrical billet whose diameter = 1.5 in is reduced by indirect extrusion to a diameter = 0.375 in (circular die). Die angle = 90°. In the Johnson equation, *a* = 0.8 and *b* = 1.5. In the flow curve for the work metal, *K* = 75,000 lb/in^2 and *n* = 0.25. Determine (a) extrusion ratio, (b) true strain (homogeneous deformation), (c) extrusion strain, (d) ram pressure, (e) ram force, and (f) power if the ram speed = 20 in/min.

Solution:

(a) $r_x = \frac{A_o}{A_f} = \frac{D_o^2}{D_f^2} = \frac{1.5^2}{0.375^2} = 16$ **Answer**

(b) $\varepsilon = \ln r_x = \ln 16 = 2.773$ **Answer**

(c) $\varepsilon_x = a + b\varepsilon = 0.8 + 1.5(2.773) = 4.959$ **Answer**

(d) For indirect extrusion:

$p_1 = k_x \bar{Y}_f \varepsilon_x$ k_x=1.0 (circular die)

$$\bar{Y}_f = \frac{K\varepsilon^n}{n+1} = \frac{75000(2.773)^{0.25}}{1+0.25} = 77424\, Ib/in^2$$

$\therefore p_1 = 1(77424)(4.959) = 383946\, Ib/in^2$ **Answer**

(e) $F_1 = p_1 A_o = 383946 \frac{\pi}{4}(1.5)^2 = 678433\, Ib$ **Answer**

(f) $Power = F_1 v = 678433(20) = 13568660\ in - Ib/min$ **Answer**

or HP = 13568660 / 396000 = 34.26 hp

Example (6):

A billet that is 75 mm long with diameter = 35 mm is direct extruded to a diameter of 20 mm (circular die). The extrusion die has a die angle = 75°. For the work metal, *K* = 600 MPa and *n* = 0.25. In the Johnson extrusion strain equation, *a* = 0.8 and *b* = 1.4. Determine (a) extrusion ratio, (b) true strain (homogeneous deformation), (c) extrusion strain, and (d) ram pressure and force at *L* = 70, 60, 50, 40, 30, 20, and 10 mm.

Solution:

$(a) r_x = \frac{A_o}{A_f} = \frac{D_o^2}{D_f^2} = \frac{35^2}{20^2} = 3.0625$ **Answer**

$(b) \varepsilon = \ln r_x = \ln 3.0625 = 1.119$ **Answer**

(c) $\varepsilon_x = a + b\varepsilon = 0.8 + 1.4(1.119) = 2.367$ **Answer**

(d) For direct extrusion:

$$p_2 = k_x \bar{Y}_f \left(\varepsilon_x + \frac{2L}{D_o} \right) \quad , \quad k_x = 1.0 \text{ (circular die)}$$

$$F_2 = p_2 A_o$$

$$A_o = \frac{\pi}{4} D_o^2 = \frac{\pi}{4} (35)^2 = 962.1 mm^2$$

$$\bar{Y}_f = \frac{K\varepsilon^n}{n+1} = \frac{600(1.119)^{0.25}}{1+0.25} = 493.7 MPa$$

At L=70mm, ➡ $p_2 = 1(493.7)\left(2.367 + \frac{2(70)}{35}\right) = 3143.4 MPa$ **Answer**

$F_2 = 3143.4(962.1) = 3024265 N$ **Answer**

At L=60mm, ➡ $p_2 = 1(493.7)\left(2.367 + \frac{2(60)}{35}\right) = 2861.3 MPa$ **Answer**

$F_2 = 2861.3(962.1) = 2752856 N$ **Answer**

At L=50mm, ➡ $p_2 = 1(493.7)\left(2.367 + \frac{2(50)}{35}\right) = 2579.2 MPa$ **Answer**

$F_2 = 2579.2(962.1) = 2481448 N$ **Answer**

At L=40mm, ➡ $p_2 = 1(493.7)\left(2.367 + \frac{2(40)}{35}\right) = 2297.1 MPa$ **Answer**

$F_2 = 2297.1(962.1) = 2210039 N$ **Answer**

At L=30mm, ➡ $p_2 = 1(493.7)\left(2.367 + \frac{2(30)}{35}\right) = 2014.9 MPa$ **Answer**

$F_2 = 2014.9(962.1) = 1938535 N$ **Answer**

At L=20mm, ➡ $p_2 = 1(493.7)\left(2.367 + \frac{2(20)}{35}\right) = 1732.8 MPa$ **Answer**

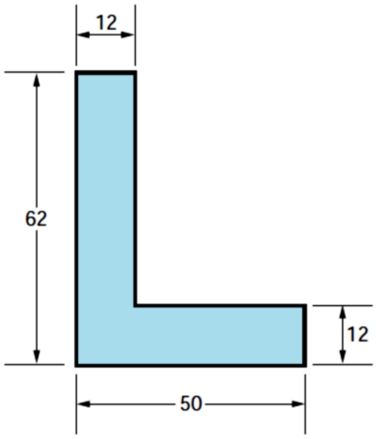
$F_2 = 1732.8(962.1) = 1667126 N$ **Answer**

At L=10mm, ➡ $p_2 = 1(493.7)\left(2.367 + \frac{2(10)}{35}\right) = 1450.7 MPa$ **Answer**

$F_2 = 1450.7(962.1) = 1395718 N$ **Answer**

Example (7):

An L-shaped structural section is direct extruded from an aluminum billet in which L_o = 500 mm and D_o = 100 mm. Dimensions of the cross section are given in the figure below. Die angle = 90°. Determine (a) extrusion ratio, (b) shape factor, and (c) length of the extruded section if the butt remaining in the container at the end of the ram stroke is 25 mm.



(All dimensions are in mm)

Solution:

$$(a) r_x = \frac{A_o}{A_f} = \frac{\frac{\pi}{4}D_o^2}{(38x12)+(12x62)} = \frac{\frac{\pi}{4}100^2}{1200} = 6.545$$ **Answer**

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

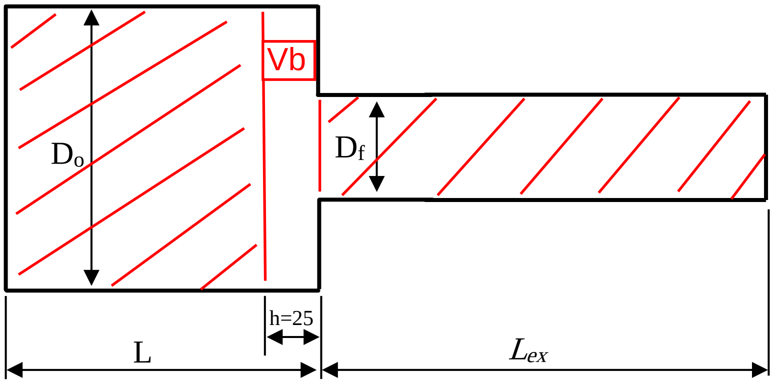
C_x = (50+62+12+50+38+12) = 224mm

A_f=1200=$\frac{\pi}{4}D_f^2$ ➡ $D_f = 39.1mm$

$\therefore C_c = \pi D_f = \pi(39.1) = 122.836mm$

$$\therefore k_x = 0.98 + 0.02\left(\frac{224}{122.836}\right)^{2.25} = 1.057$$ **Answer**

(c) From the constancy of volume:

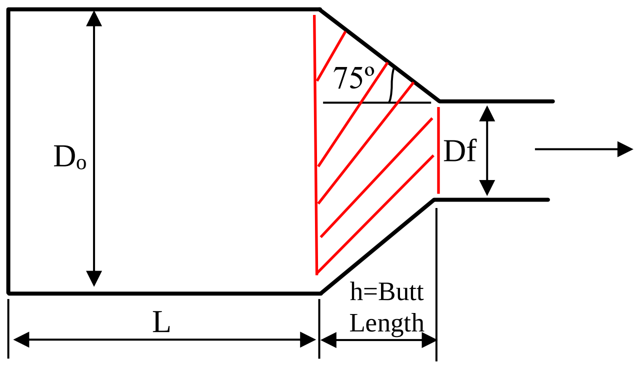


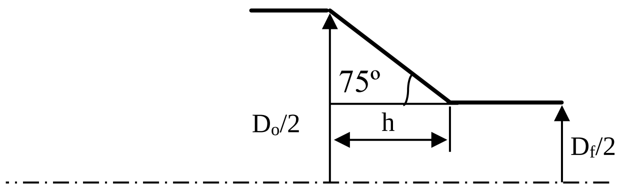
$A_o (L-h)=A_f L_{ex}$ ➡ $L_{ex}= A_o (L-h) / A_f = \frac{\frac{\pi}{4}100^2(500-25)}{1200} = 3108.9mm$ **Answer**

L_{ex}: extruded length

Note:

- If the die angle is 75°, determine the extruded length.





Thus;

$$tan75 = \frac{\frac{D_o}{2} - \frac{D_f}{2}}{h} \Rightarrow h = \frac{\frac{100}{2} - \frac{39.1}{2}}{tan75} = 8.159mm$$

Volume of frustum (butt) is: $V_b = \frac{\pi h}{3}\left[(\frac{D_o}{2})^2 + \frac{D_o}{2}\frac{D_f}{2} + \left(\frac{D_f}{2}\right)^2\right]$

$$\therefore V_b = \frac{8.159\pi}{3}\left[(\frac{100}{2})^2 + \frac{100}{2}\frac{39.1}{2} + \left(\frac{39.1}{2}\right)^2\right] = 32977.6mm^2$$

Volume of original metal: $V_{ori} = \frac{\pi D_o^2}{4} L = \frac{\pi 100^2}{4}(500) = 3926990.8mm^2$

$$\therefore V_{ori} - V_b = A_f L_{ex} \Rightarrow L_{ex} = \frac{3926990.8 - 32977.6}{1200} = 3245mm$$

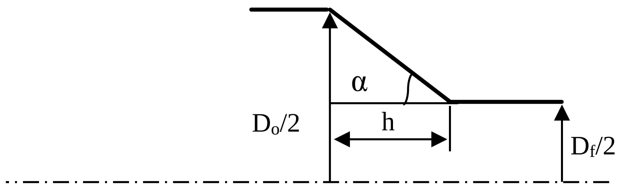
9- Forces in Hot Extrusion:

- Due to the strain-rate sensitivity of metals at elevated temperatures, the force in hot extrusion is difficult to calculate accurately.
- Thus, the average true-strain rate of the material is used to estimate force in hot extrusion as follows:

$$\dot{\varepsilon} = \frac{\varepsilon}{t} = \frac{\ln r_x}{t}$$

Volume flow rate of metal (Q) = $V_o A_o = \frac{volume\ of\ frustum\ butt\ (V_b)}{t}$

$$\therefore t = \frac{volume\ of\ frustum\ butt\ (V_b)}{V_o A_o} = \frac{V_b}{V_o A_o}$$



$$V_b = \frac{\pi h}{3}\left[(\frac{D_o}{2})^2 + \frac{D_o}{2}\frac{D_f}{2} + \left(\frac{D_f}{2}\right)^2\right]$$

$$tan\alpha = \frac{\frac{D_o}{2} - \frac{D_f}{2}}{h} \Longrightarrow h = \frac{\frac{D_o}{2} - \frac{D_f}{2}}{tan\alpha} = \frac{D_o - D_f}{2\ tan\alpha}$$

$$V_b = \frac{\pi\ (D_o - D_f)}{6\ tan\alpha}\left[(\frac{D_o}{2})^2 + \frac{D_o}{2}\frac{D_f}{2} + \left(\frac{D_f}{2}\right)^2\right] = \frac{\pi}{24\ tan\alpha}(D_o^3 - D_f^3)$$

$$\therefore t = \frac{\frac{\pi}{24\ tan\alpha}(D_o^3 - D_f^3)}{V_o \frac{\pi}{4} D_o^2} = \frac{(D_o^3 - D_f^3)}{6\ V_o\ D_o^2\ tan\alpha}$$

$$\therefore \dot{\bar{\boldsymbol{\varepsilon}}} = \frac{\ln r_x}{t} = \frac{6\ V_o\ D_o^2\ tan\alpha}{(D_o^3 - D_f^3)} \ln r_x$$

- At high extrusion ratios ($D_o >> D_f$), die angle=45º (square die), and poor lubrication, the true strain-rate is:

$$\dot{\bar{\boldsymbol{\varepsilon}}} = \frac{6\ V_o\ D_o^2\ tan\alpha}{(D_o^3 - D_f^3)} \ln r_x = \frac{6\ V_o\ D_o^2\ tan45}{D_o^3} \ln r_x = \frac{6\ V_o}{D_o} \ln r_x$$

Where;
V_o: ram velocity (metal speed in container)
$\dot{\bar{\varepsilon}}$**:** average true-strain rate

- **Flow Stress:**
  $\boldsymbol{\sigma = C\dot{\varepsilon}^m}$, **assume that:** $\boldsymbol{\bar{Y}_f = \sigma = C\dot{\varepsilon}^m}$

- **Ram Pressure:**
  $\boldsymbol{p_2 = k_x \bar{Y}_f \left(\varepsilon_x + \frac{2L}{D_o}\right)}$ **For Direct Extrusion**

  $\boldsymbol{p_1 = k_x \bar{Y}_f \varepsilon_x}$ **For Indirect Extrusion**

- **Ram Force:**
  Indirect Extrusion: $\boldsymbol{F_1 = p_1 A_o}$
  Direct Extrusion: $\boldsymbol{F_2 = p_2 A_o}$

- **Power Required for Extrusion:**
  Indirect Extrusion: $\boldsymbol{Power = F_1 V_o}$
  Direct Extrusion: $\boldsymbol{Power = F_2 V_o}$

  V_o: ram velocity (m/s)

Example (8):

A copper billet 5in in diameter and 10in long is direct extruded to 2in final diameter (circular die) at 1500ºF with a ram speed of 10in/s. Using a square die and poor lubrication, estimate (a) pressure, (b) force and (c) power. Take: a=0.8, b=1.4, C=19000 Ib/in^2, m=0.06.

Solution:

19000 Ib.s/in2

(a) $p_2 = k_x \bar{Y}_f \left(\varepsilon_x + \frac{2L}{D_o}\right)$

K_x=1.0 circular die. L=10in, D_o=5in

$\bar{Y}_f = C\dot{\varepsilon}^m$

$\dot{\varepsilon} = \frac{6\,V_o}{D_o} \ln r_x = \frac{6(10)}{5} \ln \frac{5^2}{2^2} = 22$ ← 1/s

$\therefore \bar{Y}_f = C\dot{\varepsilon}^m = 19000(22^{0.06}) = 22872\ Ib/in^2$

$\varepsilon_x = a + b \ln r_x = 0.8 + 1.4 \ln \frac{5^2}{2^2} = 3.366$

$p_2 = k_x \bar{Y}_f \left(\varepsilon_x + \frac{2L}{D_o}\right) = 22872\left(3.366 + \frac{2(10)}{5}\right) = 168475.2\ Ib/in^2$ **Answer**

(b) $F_2 = p_2 A_o = 168475.2\ \frac{\pi}{4} 5^2 = 3308002.8\ Ib$ **Answer**

(c) $Power = F_2 V_o = 3308002.8\ (10) = 33080028\ Ib - in/s$ **Answer**

Or HP = 33080028 / 6600 = 5012 hp

Example (9):

A direct extrusion operation is performed on a cylindrical billet with an initial diameter of 2.0in and an initial length of 4.0in. The die angle = 60° and orifice diameter is 0.5in (circular die). In the Johnson extrusion strain equation, a = 0.8 and b = 1.5. The operation is carried out hot and the hot metal yields at 13,000 lb/in2 (which is flow stress $\bar{Y}_f$) and does not strain harden when hot (n=0.0). (a) What is the extrusion ratio? (b) Determine the ram position at the point when the metal has been compressed into the cone of the die and starts to extrude through the die opening. (c) What is the ram pressure corresponding to this position? (d) Also determine the length of the final part if the ram stops its forward movement at the start of the die cone.

Solution:

(a) $r_x = \frac{A_o}{A_f} = \frac{D_o^2}{D_f^2} = \frac{2^2}{0.5^2} = 16$ **Answer**

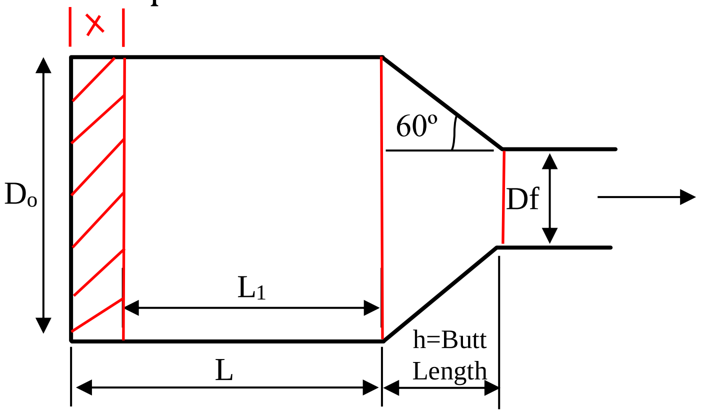
(b) To determine the ram position when extrusion starts, the volume of the frustum must be calculated firstly:

$$V_b = \frac{\pi}{24\, tan\alpha}\left(D_o^3 - D_f^3\right) = \frac{\pi}{24\, tan60}(2^3 - 0.5^3) = 0.595\ in^3$$

The volume of billet compressed forward to fill the frustum V_1 is given by:

$V_1 = \frac{\pi}{4} D_o^2 (L - L_1)$ this volume is equal to V_b, then:

$$\frac{\pi}{4} D_o^2 (L - L_1) = V_b = 0.595$$



$\frac{\pi}{4} 2^2 (4 - L_1) = 0.595$ ➡ $L_1 = 3.811\ in$ **Answer**

(c) $p_2 = k_x \bar{Y}_f \left(\varepsilon_x + \frac{2L}{D_o}\right)$ k_x = 1.0 (circular die)

$\varepsilon_x = a + b \ln r_x = 0.8 + 1.5 \ln 16 = 4.959$

$L=L_1$, $\bar{Y}_f = 13000\ Ib/in^2$

$\varepsilon = \ln 16 = 2.773$

$$\therefore p_2 = 13000\left(4.959 + \frac{2(3.811)}{2}\right) = 114010\ Ib/in^2$$ **Answer**

(d) $V_{ori} - V_b = A_f L_{ex}$ $\Rightarrow$

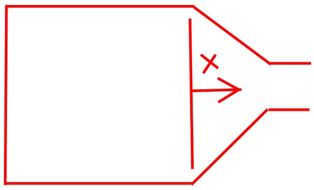
$$L_{ex} = \frac{V_{ori} - V_b}{A_f} = \frac{\frac{\pi}{4}D_o^2 L - V_b}{\frac{\pi}{4}D_f^2} = \frac{\frac{\pi}{4}2^2(4) - 0.595}{\frac{\pi}{4}0.5^2} = 60.97\ in$$ **Answer**

Home Work:

Show that the true strain rate in extruding a round billet of radius r_o as a function of distance x from the entry of a conical die can be given as:

$$\dot{\varepsilon} = -\frac{2V_o r_o^2 tan\alpha}{(r_o - x tan\alpha)^3}$$

where; V_o: ram velocity



Other Extrusion Processes:

Impact Extrusion:

- It is performed at higher speeds and shorter strokes than conventional extrusion.
- It is used to make individual components.
- It can be carried out as forward extrusion, backward extrusion or combination of these as shown in figure (3-27).
- It is usually done cold and backward extrusion impact is the most common.
- Products made by this method: toothpaste tubes and battery cases. Also very thin walls products are possible.
- It is important commercial process because of high speed characteristics of impacting which permit large reductions and high production rates.

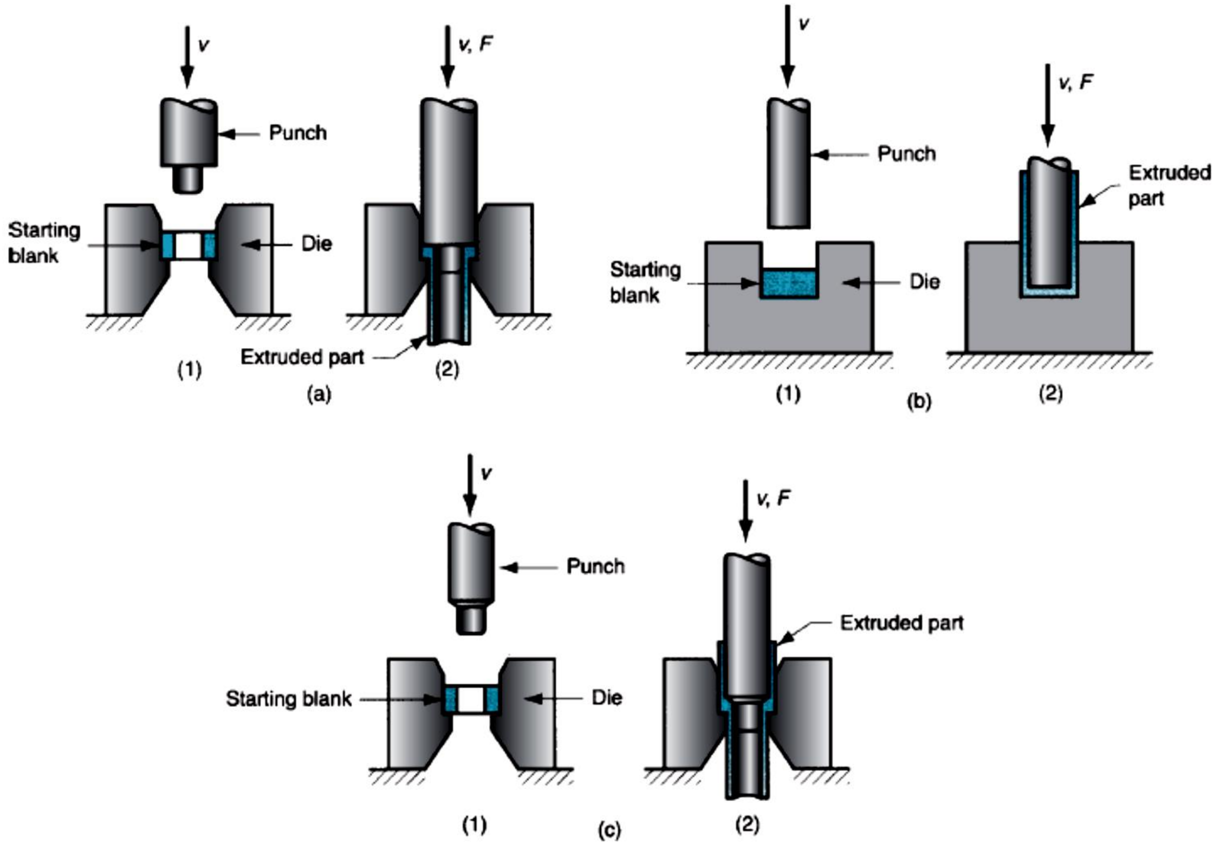


Figure (3-27) impact extrusion: (a) forward, (b) backward, and (c) combination of forward and backward

Hydrostatic Extrusion:

- Friction problem can be addressed by surrounding the billet with fluid inside the container as shown in figure (3-28).
- This way, there is no friction inside the container and the friction at the die opening is reduced.
- Consequently, ram force is significantly lower than in direct extrusion.
- It can be carried out at room temperature or at elevated temperatures, therefore, special fluids and procedures must be used in this case.
- Hydrostatic extrusion is an adaptation of direct extrusion.
- Hydrostatic pressure on the w.p. increases the material's ductility.
- Accordingly, this process can be used on metals that would be too brittle for conventional extrusion.
- Ductile metals can also be hydrostatically extruded, and high reduction ratios are possible.
- The billet must be formed with a taper at one end to fit snugly into the die entry angle. This is one of the disadvantages of this process.

- This establishes a seal to prevent fluid from squirting out the die hole when the container is initially pressurized.

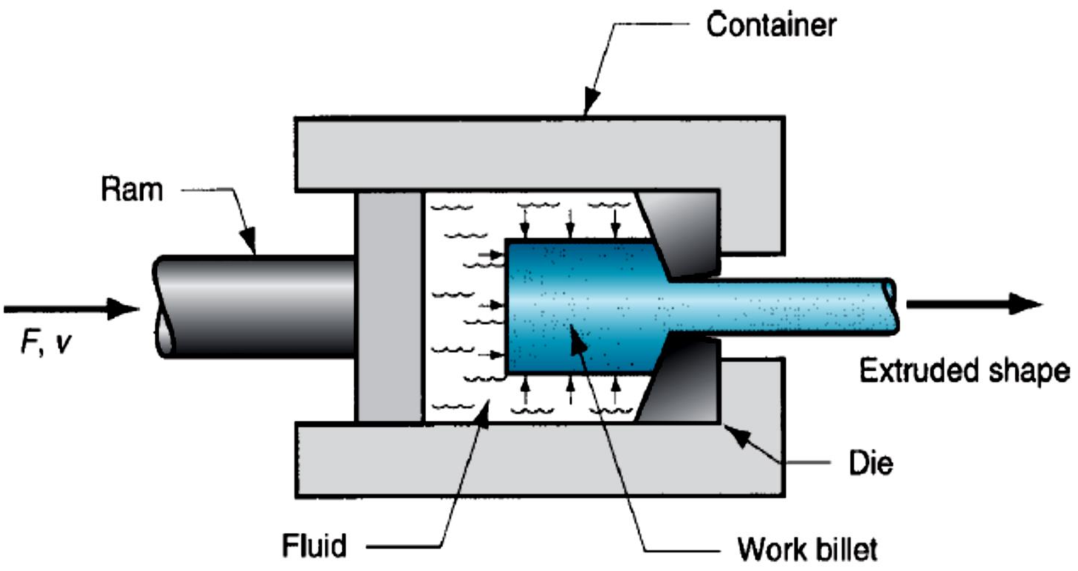


Figure (3-28) hydrostatic extrusion

Defects in Extruded Products:

Figure (3-29) explains some extrusion defects.

(a) Centerburst:

- Other names sometimes used for this defect include arrowhead fracture, center cracking, and chevron cracking.
- This defect is an internal crack that develops as a result of tensile stresses along the centerline of the w.p. during extrusion.
- The significant material movement in outer regions stretches the material along the center of the w.p.. If stresses are great enough, bursting occurs.
- Conditions that promote centerburst are high die angles, low extrusion ratios, and impurities in the w.p. that serve as starting points for crack defects.

(b) Piping:

- It is a defect associated with direct extrusion.
- It is the formation of a sink hole in the end of the billet.
- The use of a dummy block whose diameter is slightly less than that of the billet helps to avoid piping. Other names given to this defect include tailpipe and fishtailing.

(c) Surface Cracking:

- This defect results from high w.p. temperatures that cause cracks to develop at the surface.
- They often occur when extrusion speed is too high, leading to high strain rates and associated heat generation.
- Additional factors contributing to surface cracking are high friction and surface chilling.

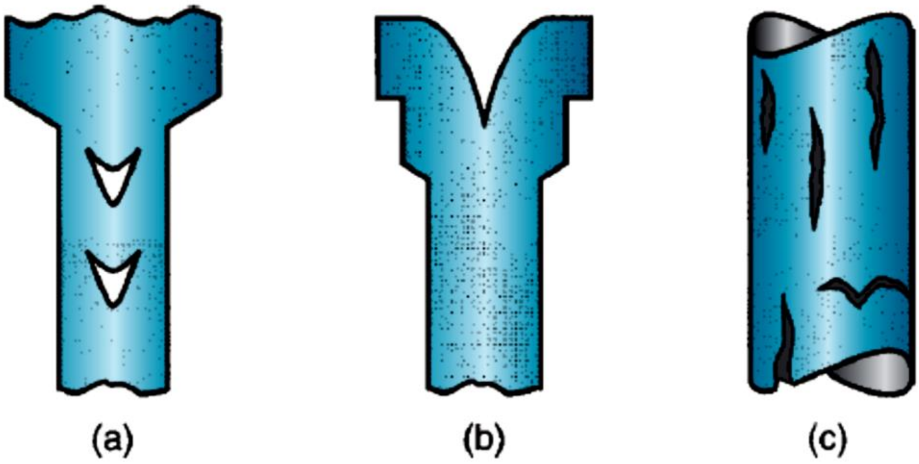


Figure (3-29) extrusion defects; (a) centerburst, (b) piping, and (c) surface cracking