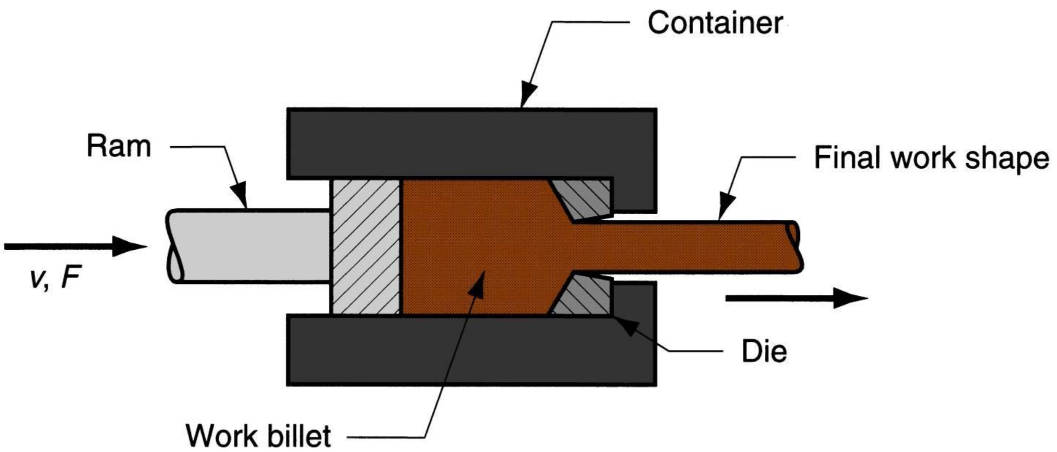
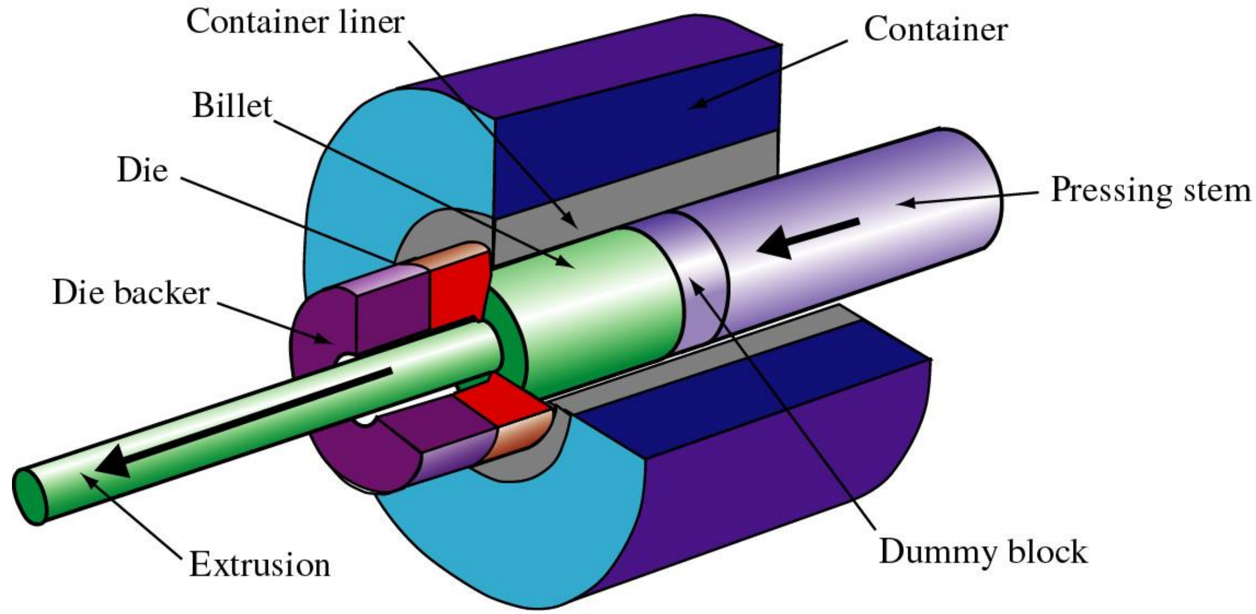
Extrusion

Introduction

- Compression forming process in which work metal is forced to flow through a die opening to produce a desired cross-sectional shape
- Process is similar to squeezing toothpaste out of a toothpaste tube
- In general, extrusion is used to produce long parts of uniform cross sections
- Two basic types:
  - Direct extrusion
  - Indirect extrusion

Direct Extrusion

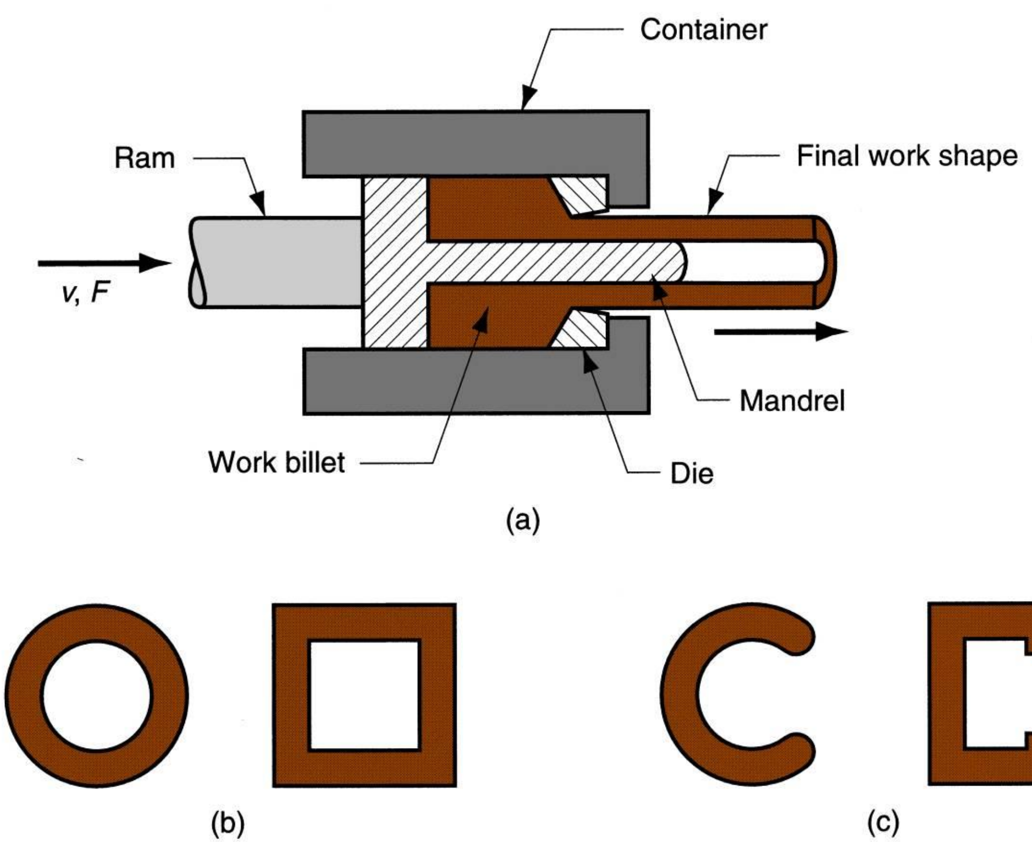




Direct Extrusion

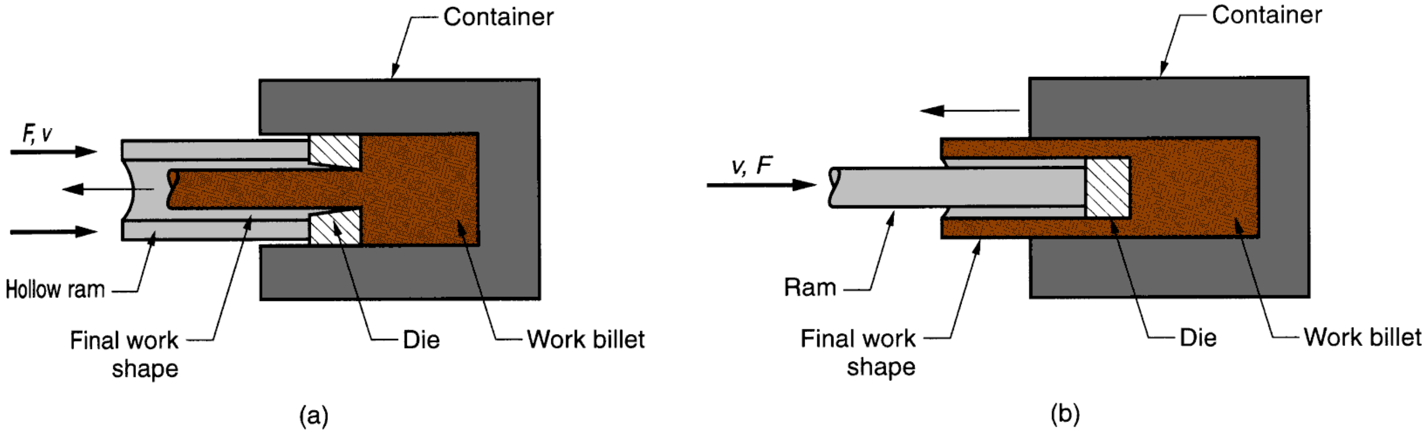
- Also called *forward extrusion*
- A metal billet is loaded into a container and a ram compresses the material, forcing it to flow through one or more openings in a die at the opposite end of the container.
- As ram approaches die opening, a small portion of billet remains that cannot be forced through die opening
- This extra portion, called the *butt*, must be separated from *extrudate* by cutting it just beyond the die exit
- Starting billet cross section usually round
- Final shape of extrudate is determined by die opening

Hollow and Semi-Hollow Shapes



(a) Direct extrusion to produce a hollow or semi-hollow cross sections; (b) hollow and (c) semi-hollow cross sections.

Indirect Extrusion



Indirect extrusion to produce (a) a solid cross section and (b) a hollow cross section.

Comments on Indirect Extrusion

- Also called *backward extrusion* and *reverse extrusion*

- Die is mounted to the ram rather than at the opposite end of the container.

- As the ram penetrates into the work, the metal is forced to flow through the clearance in a direction opposite to the motion of the ram

- Limitations of indirect extrusion are imposed by
  - Lower rigidity of hollow ram
  - Difficulty in supporting extruded product as it exits the die

Advantages of Extrusion

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

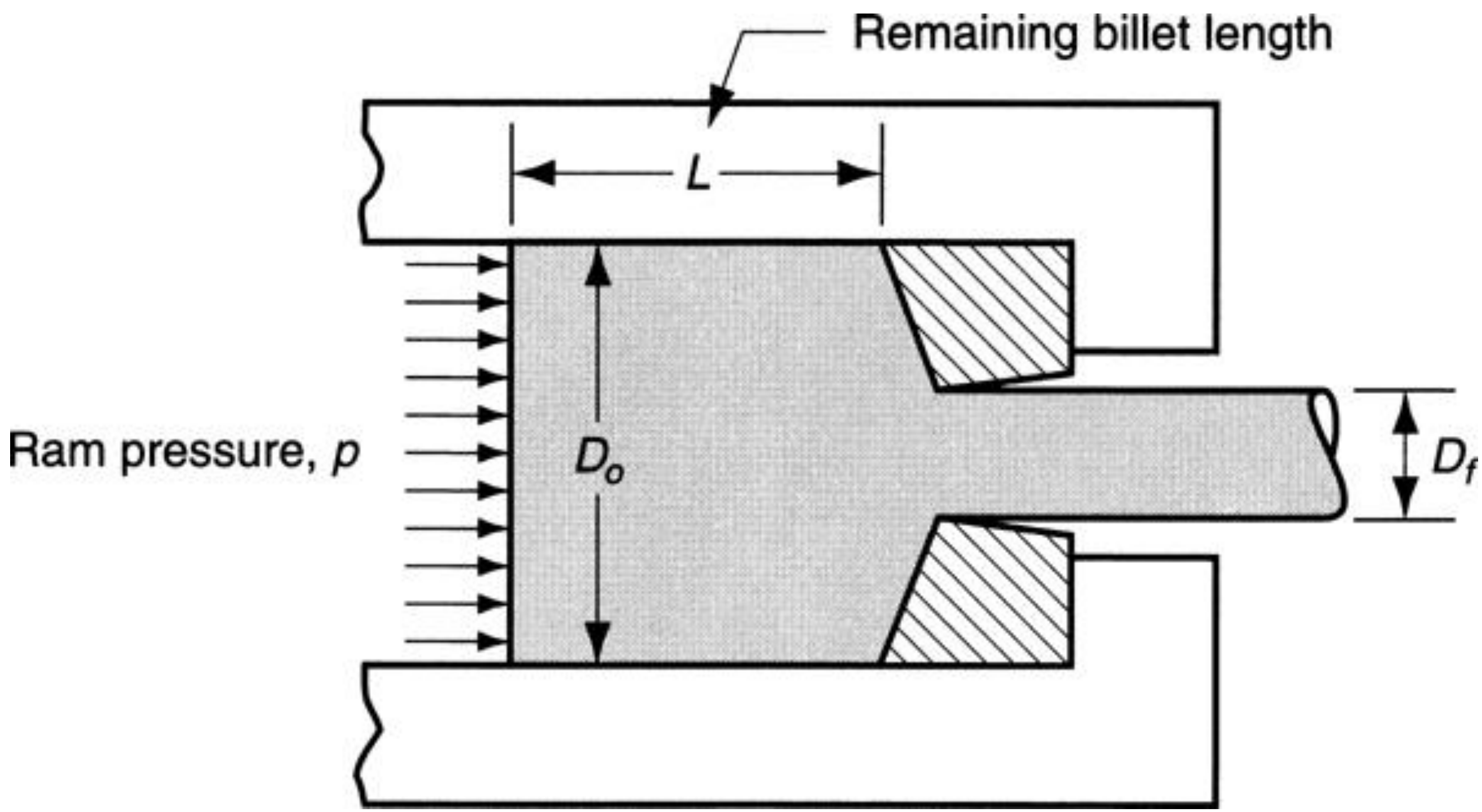
Hot vs. Cold Extrusion

- Can be performed hot or cold, depending on work metal and amount of strain to which it is subjected during deformation.
- Aluminum is probably the most ideal metal for both type.

- Hot extrusion - prior heating of billet to above its recrystallization temperature
  - Reduces strength and increases ductility of the metal, permitting more size reductions and more complex shapes

- Cold extrusion - generally used to produce discrete parts
  - The term impact extrusion is used to indicate high speed cold extrusion

Analysis of extrusion



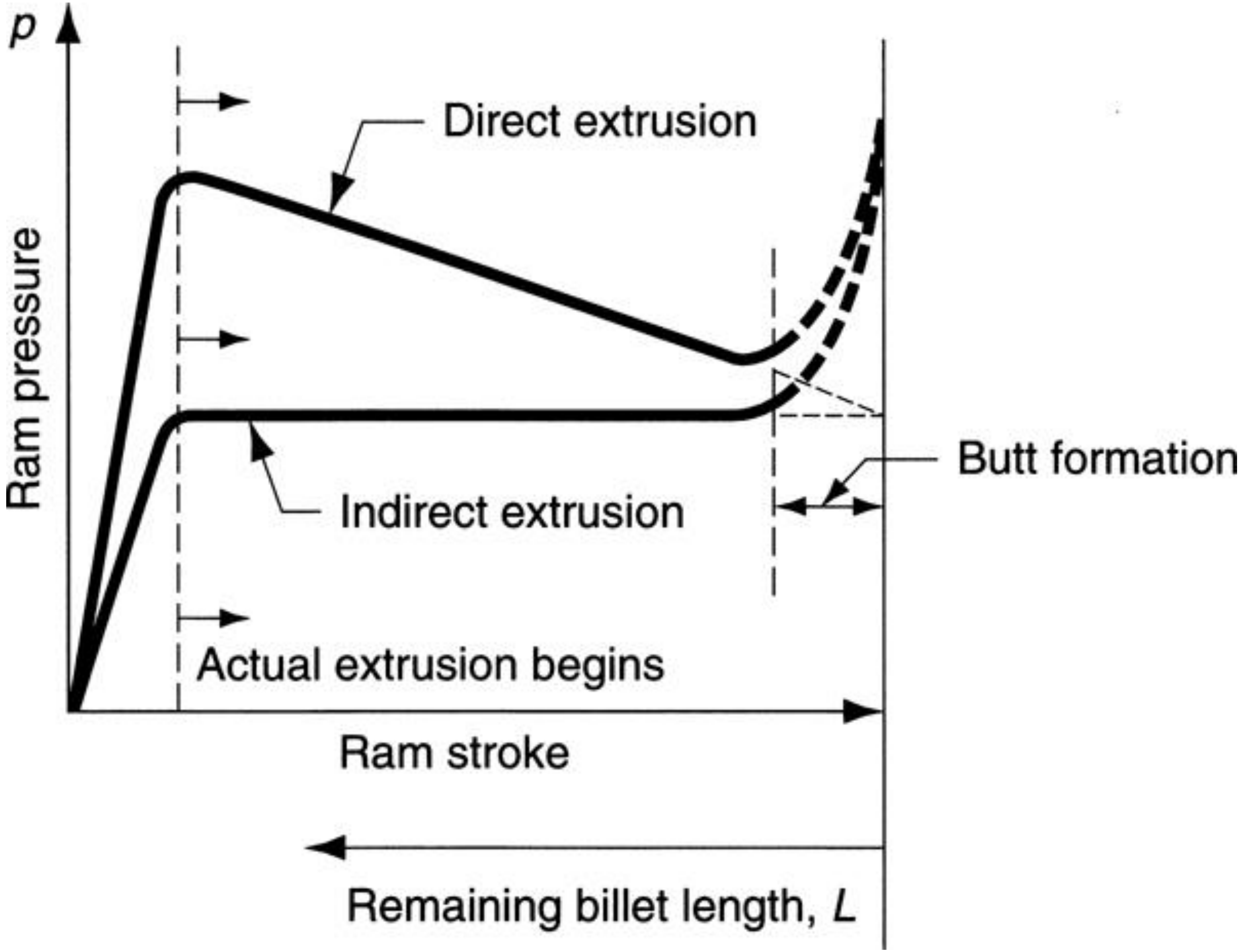
Extrusion Ratio

- Also called the *reduction ratio*, it is defined as

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

where r_x = extrusion ratio; A_o = cross-sectional area of the starting billet; and A_f = final cross-sectional area of the extruded section

- Applies to both direct and indirect extrusion


p
Ram pressure
Direct extrusion
Indirect extrusion
Butt formation
Actual extrusion begins
Ram stroke
Remaining billet length, L

Example

- A cylindrical billet that is 100 mm long and 50 mm in diameter is reduced by indirect (backward) extrusion to a 20 mm diameter. The Johnson equation has *a = 0.8 and b = 1.4, and the flow curve for the work metal has a strength coefficient of 800 MPa and strain hardening exponent of 0.13. Determine (a) extrusion ratio, (b) true strain (homogeneous deformation), (c) extrusion strain, (d) ram pressure, and (e) ram force.*

(a) $r_x = A_o/A_f = D_o^2/D_f^2 = (50)^2/(20)^2 = \mathbf{6.25}$

(b) $\varepsilon = \ln r_x = \ln 6.25 = \mathbf{1.833}$

(c) $\varepsilon_x = a + b \ln r_x = 0.8 + 1.4(1.833) = \mathbf{3.366}$

(d) $Y_f = 800(1.833)^{0.13}/1.13 = 766.0$ MPa

$p = 766.0(3.366) = \mathbf{2578\ MPa}$

(e) $A_o = \pi D_o^2/4 = \pi(50)^2/4 = 1963.5\ mm^2$

$F = 2578(1963.5) = \mathbf{5,062,000\ N}$

Example

- A 3.0 mm long cylindrical billet whose diameter = 1.5 mm is reduced by indirect extrusion to a diameter = 0.375 mm. In the Johnson equation, *a = 0.8 and b = 1.5. In the flow curve for the work metal, K = 75,000 N/mm*^{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 mm/min.*

Solution

(a) $r_x = A_o/A_f = D_o^2/D_f^2 = (1.5)^2/(0.375)^2 = 4^2 = \mathbf{16.0}$

(b) $\varepsilon = \ln r_x = \ln 16 = \mathbf{2.773}$

(c) $\varepsilon_x = a + b \ln r_x = 0.8 + 1.5(2.773) = \mathbf{4.959}$

(d) $Y_f = 75{,}000(2.773)^{0.25}/1.25 = 77{,}423\ N/mm^2$

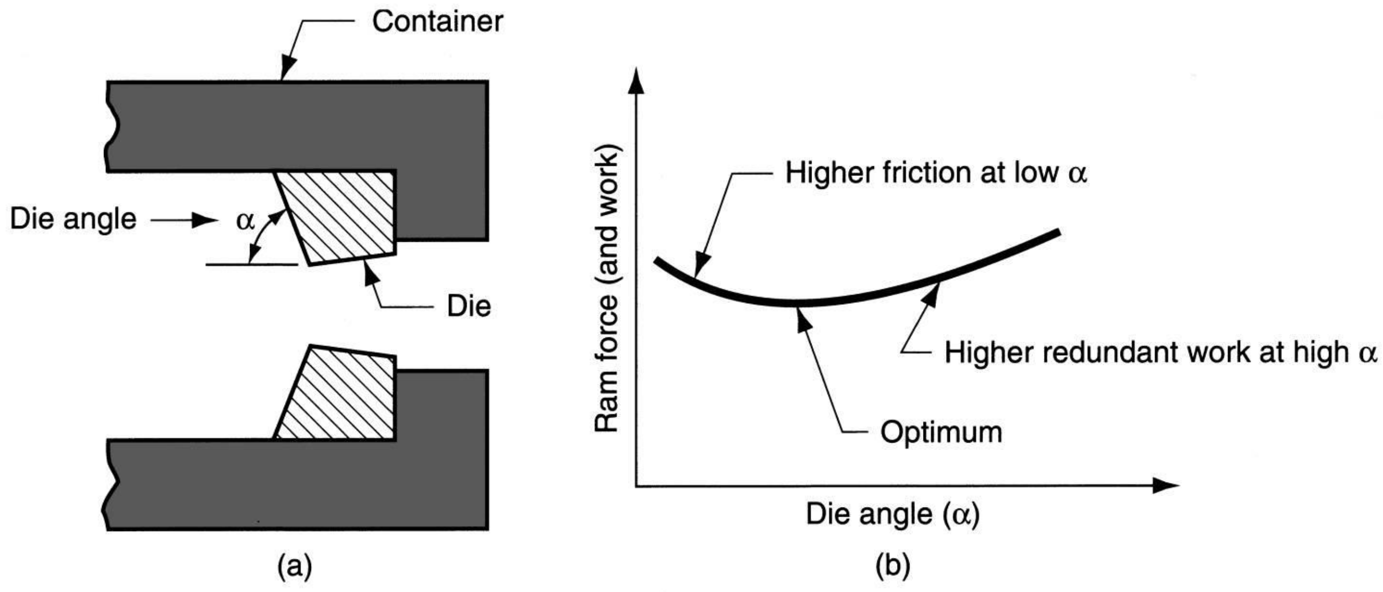
$p = 77{,}423(4.959) = \mathbf{383{,}934\ N/mm^2}$

(e) $A_o = \pi D_o^2/4 = \pi(1.5)^2/4 = 1.767\ mm^2$

$F = (383{,}934)(1.767) = \mathbf{678{,}411\ N.}$

(f) $P = 678{,}411(20) = \mathbf{13{,}568{,}228\ N\text{-}mm/min}$

Extrusion Die Features



(a) Definition of die angle in direct extrusion; (b) effect of die angle on ram force.

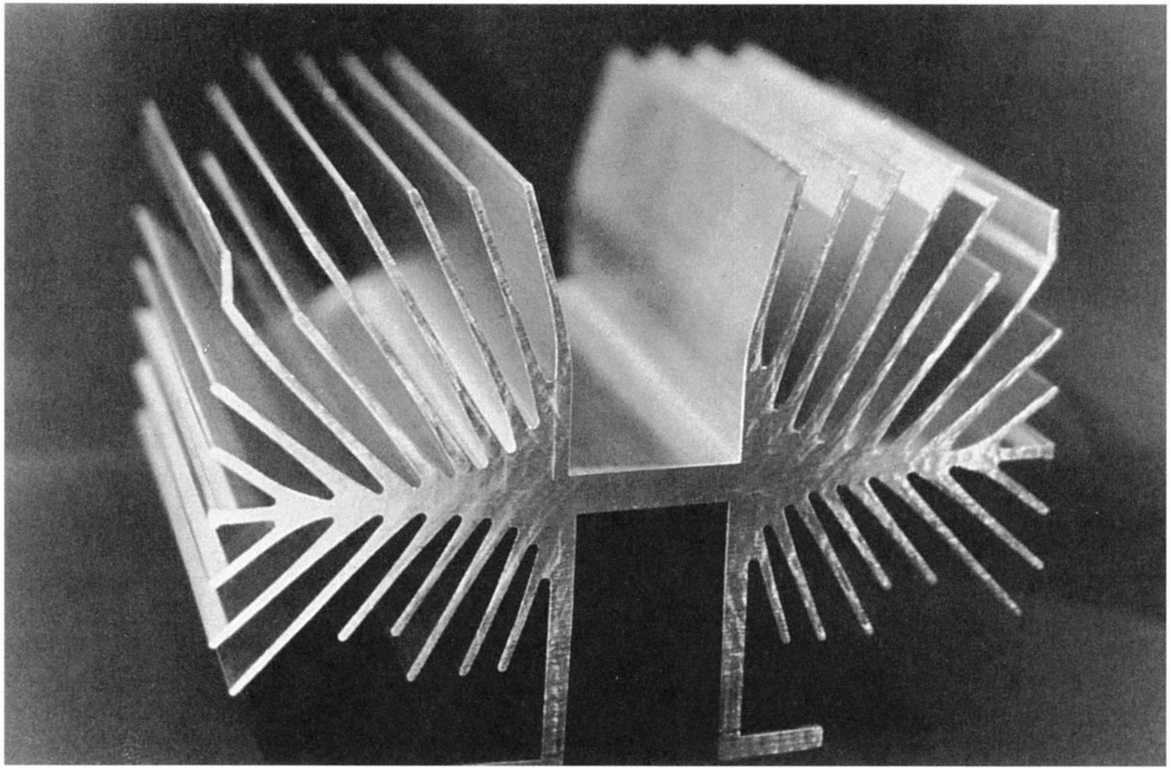
Comments on Die Angle

- Low die angle - surface area is large, which increases 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 work material, billet temperature, and lubrication

Orifice Shape of Extrusion Die

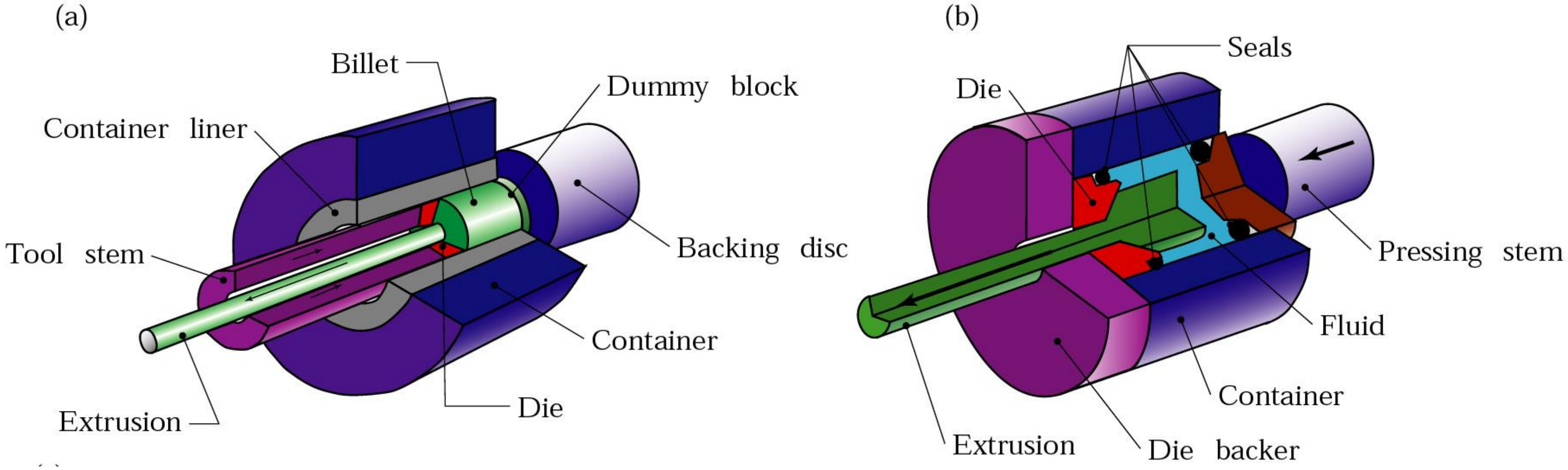
- Simplest cross section shape is circular die orifice
- Shape of die orifice affects ram pressure
- As cross section becomes more complex, higher pressure and greater force are required
- Effect of cross-sectional shape on pressure can be assessed by means the die *shape factor* K_x

Complex Cross Section

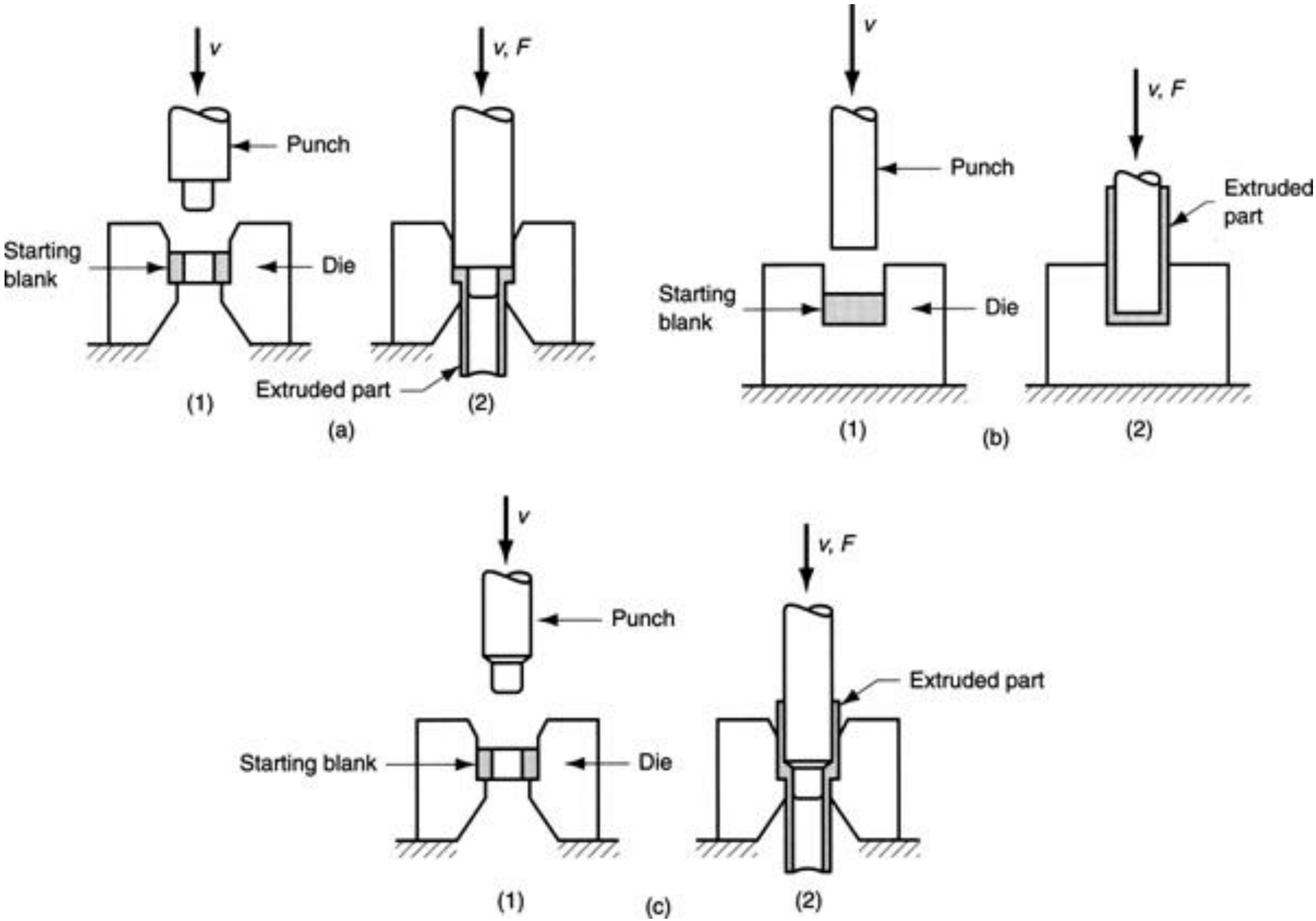


A complex extruded cross section for a heat sink (photo courtesy of Aluminum Company of America)

Types of Extrusion

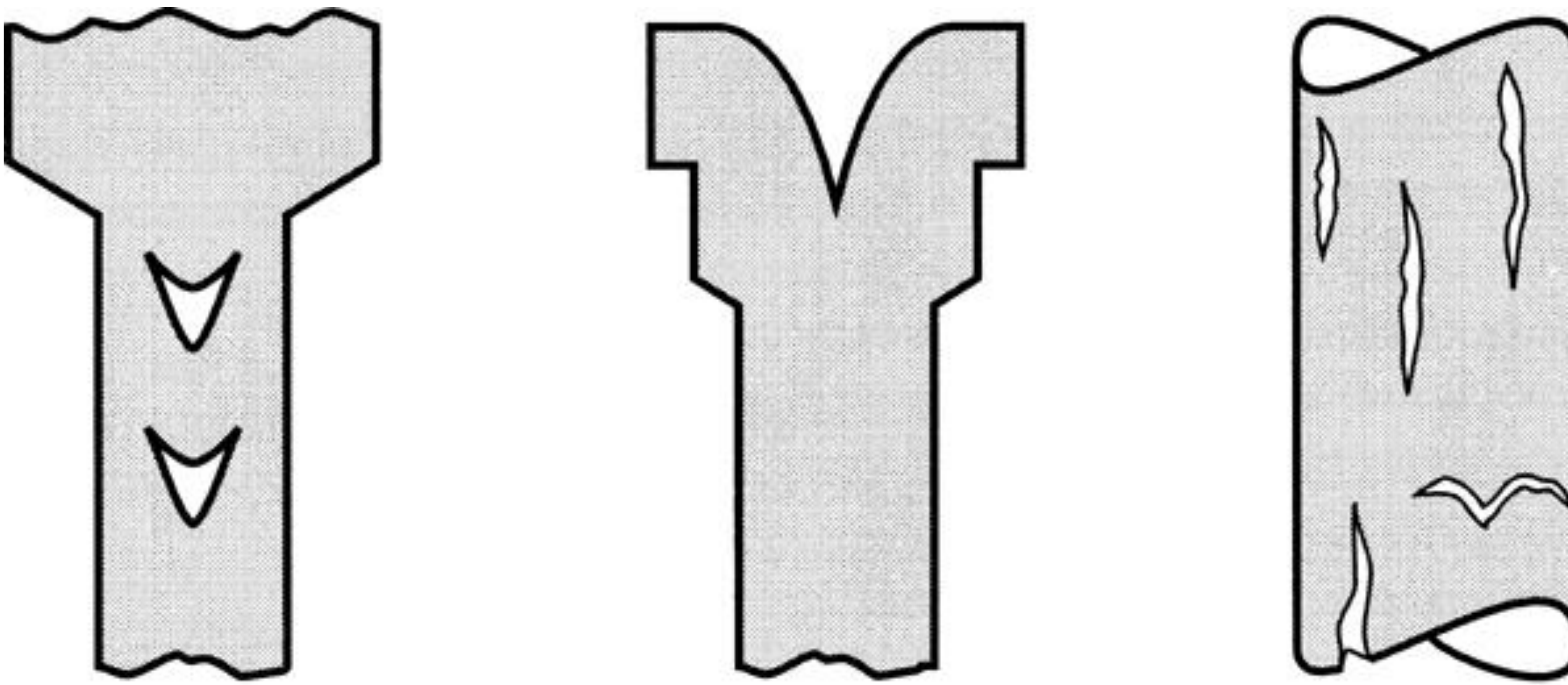


(a) indirect; (b) hydrostatic


v
v, F
Punch
Starting blank
Die
Extruded part
(1)
(2)
(a)
v
v, F
Punch
Extruded part
Starting blank
Die
(1)
(b)
(2)
v
v, F
Punch
Extruded part
Starting blank
Die
(1)
(c)
(2)

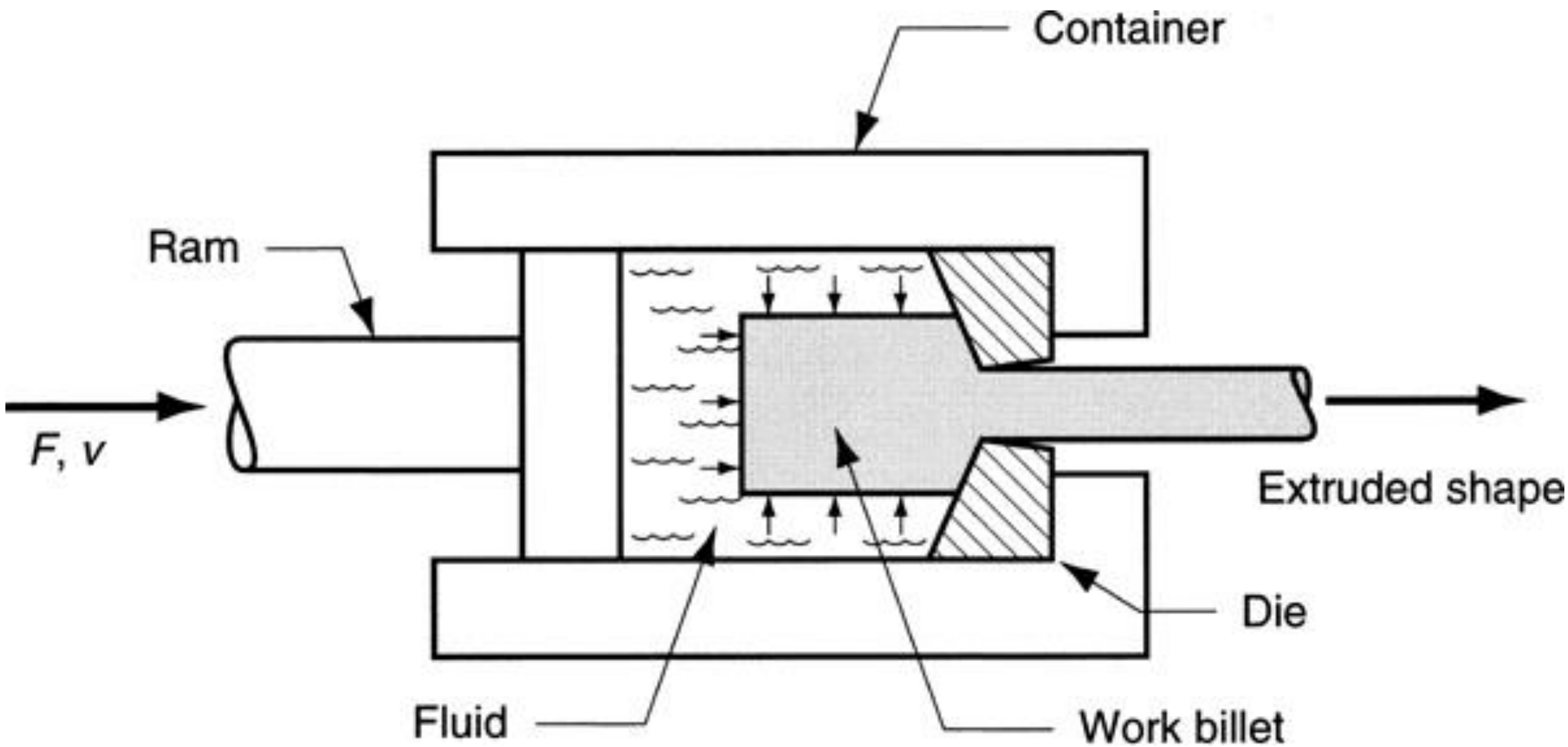
Extrusion Defects

- Surface Cracking
  - Fir-tree cracking or Speed Cracking
- Pipe/tailpipe/fishtailing
- Internal Cracking/Chevron Cracking/ centre-burst/arrowhead fracture

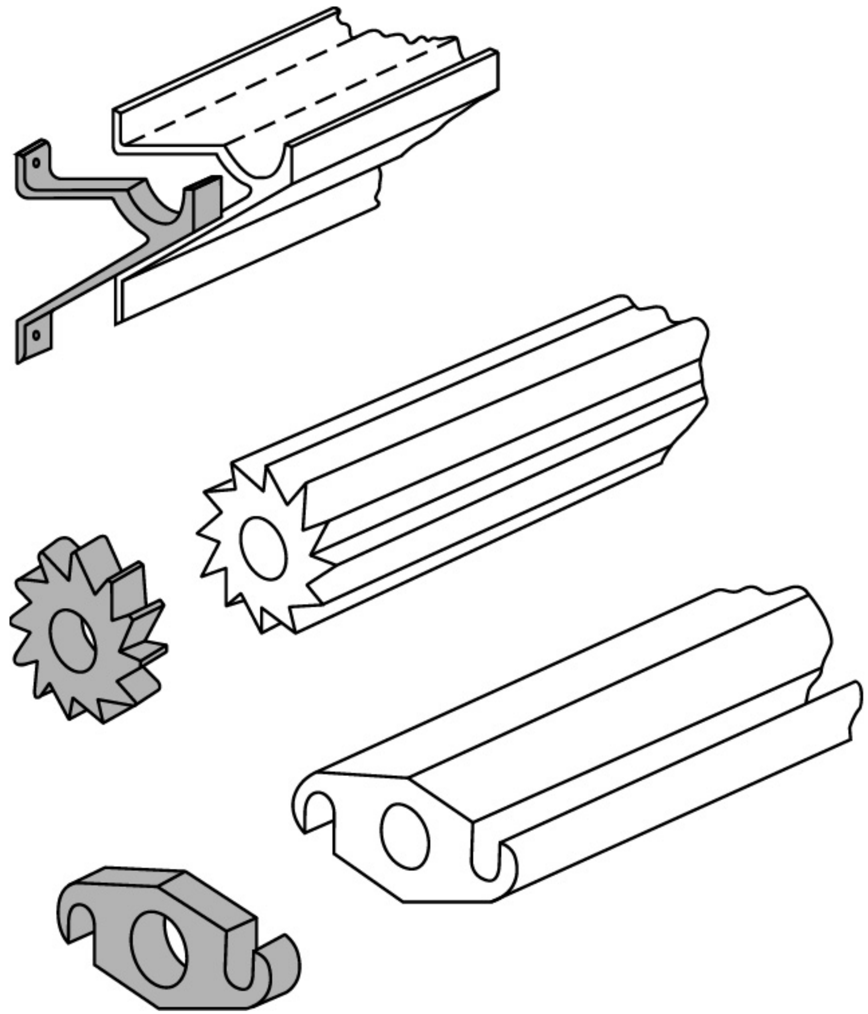


(a) (b) (c)

19-39


Container
Ram
F, v
Extruded shape
Die
Fluid
Work billet

Examples of Extruded Parts



Thanks