

# Extrusion and Drawing

IME 240/340

# Extrusion

- A billet, usually round, is forced through a die to create solid or hollow cross-sectional workpieces with elongated grain structures (preferred orientation)
- Common analogy – squeezing toothpaste
- A semi-continuous or batch process
- At room temperature or elevated
- Typical products:
  - Door & window frames
  - Tubing
  - Railings
  - Brackets
- Metals, plastics, and coaxial (i.e. copper clad with silver)

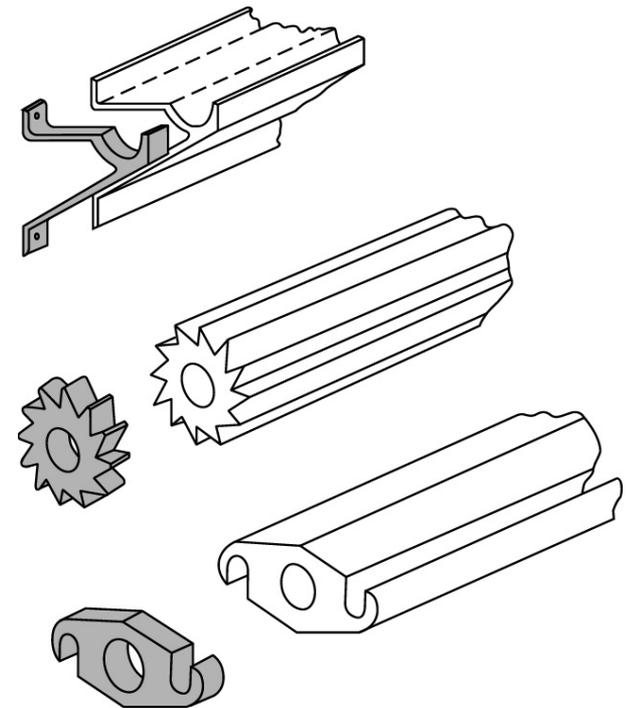
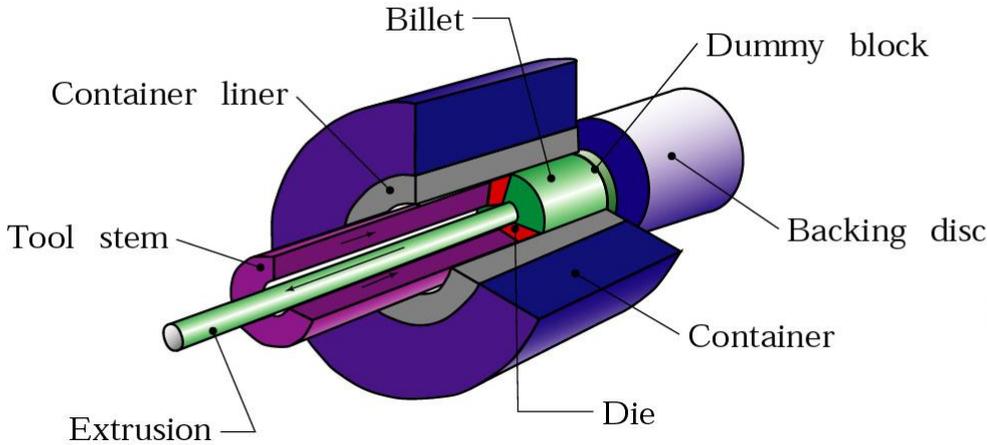
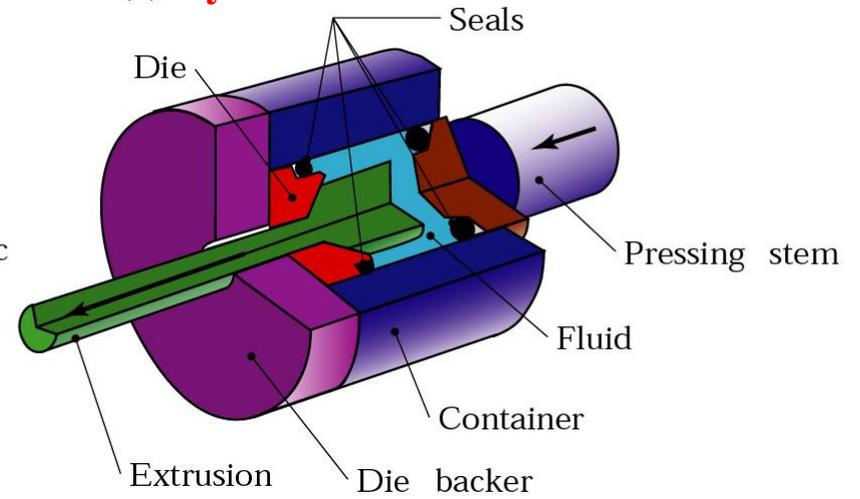


Figure 15.2 Extrusions, and examples of products made by sectioning off extrusions.  
*Source:* Kaiser Aluminum.

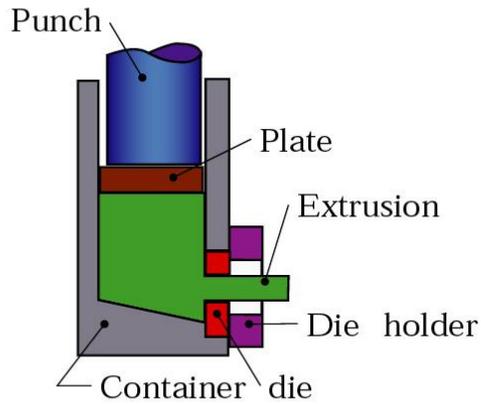
(a) **indirect**



(b) **hydrostatic**

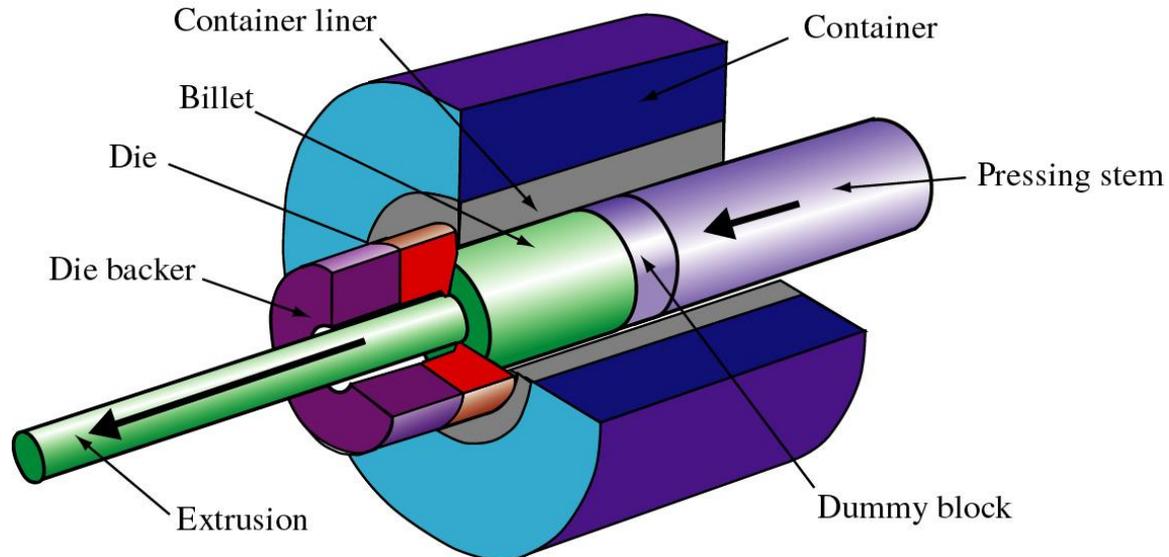


(c) **lateral**



## Extrusion Processes

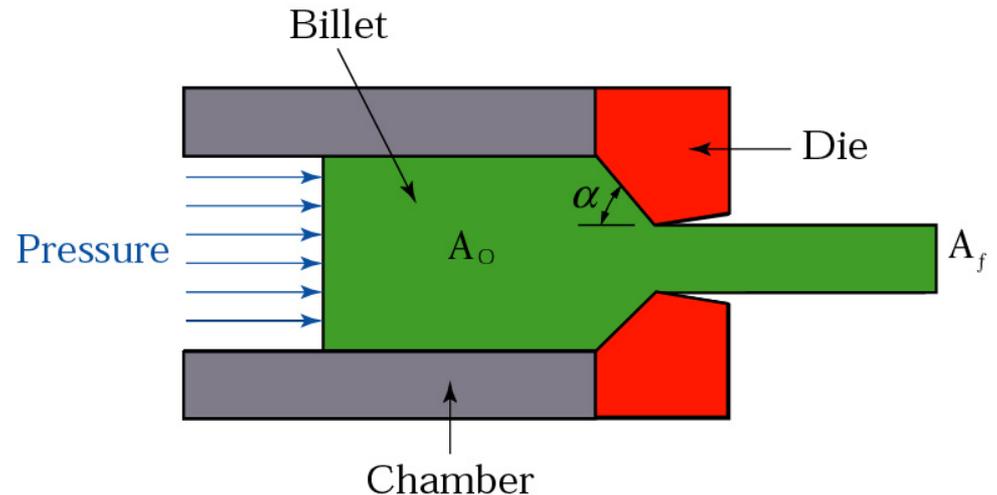
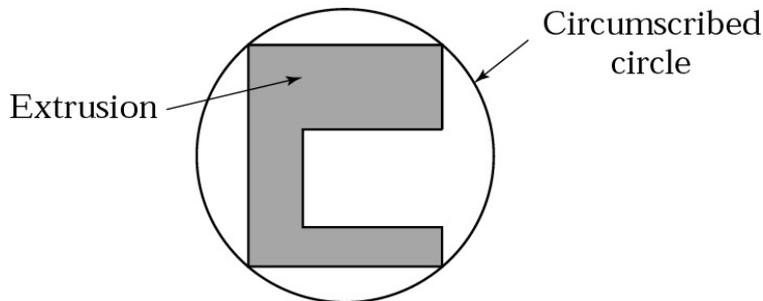
## Direct Extrusion



# Extrusion Parameters

- Parameters include die angle ( $\alpha$ ), extrusion speed, billet temperature, and lubrication
- Extrusion ratio,  $R = A_o/A_f$  (typical values of 10 to 100)
- Circumscribing Diameter (CCD) (for Aluminum 6 mm to 1 m, for steel up to 0.15 m)
- Shape factor = Perimeter/CCD
- Extrusion constant,  $k$
- Typical lengths  $< 7.5$  m

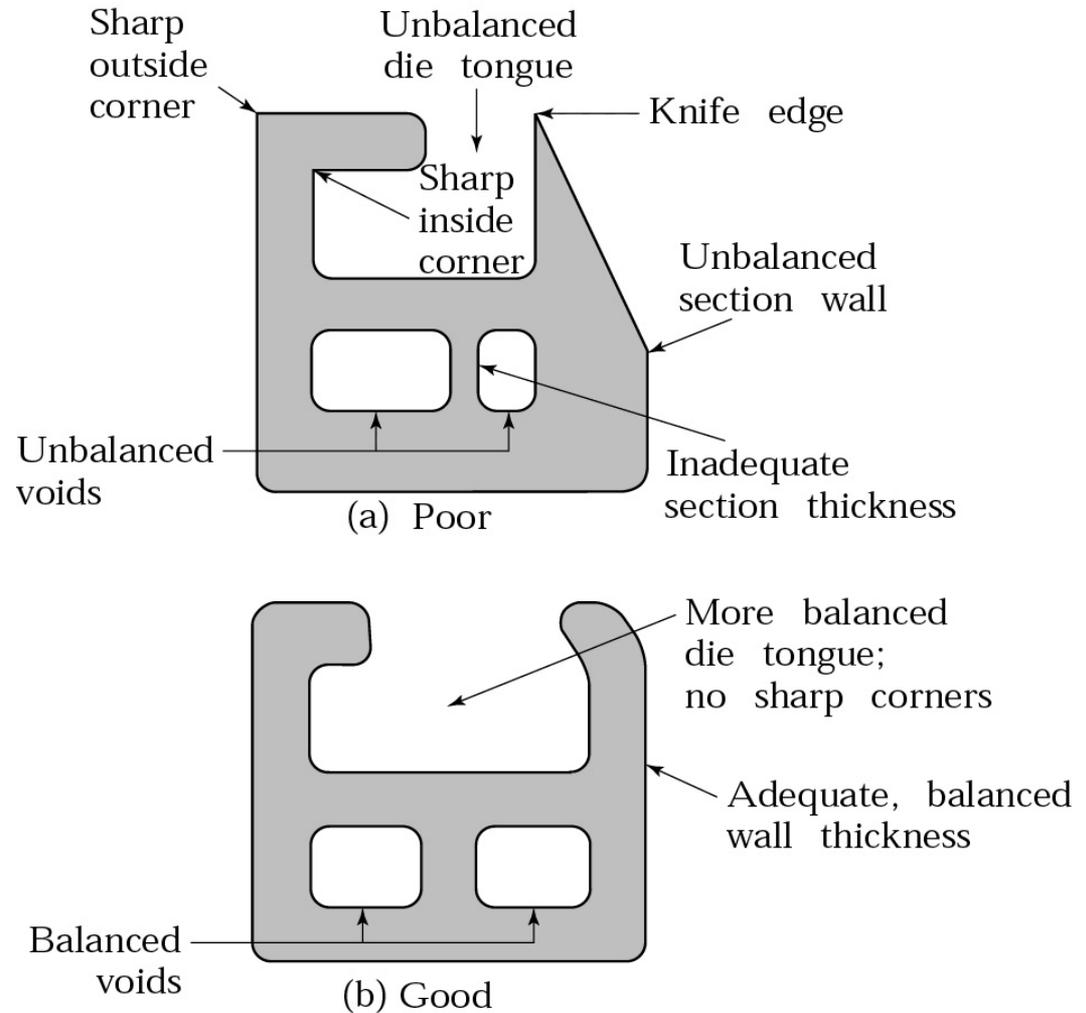
$$F = A_o k \ln \left( \frac{A_o}{A_f} \right)$$



# Extrusion Die Design

Figure 15.10 Poor and good examples of cross-sections to be extruded. Note the importance of eliminating sharp corners and of keeping section thicknesses uniform.

Source: J. G. Bralla (ed.); *Handbook of Product Design for Manufacturing*. New York: McGraw-Hill Publishing Company, 1986. Used with permission.



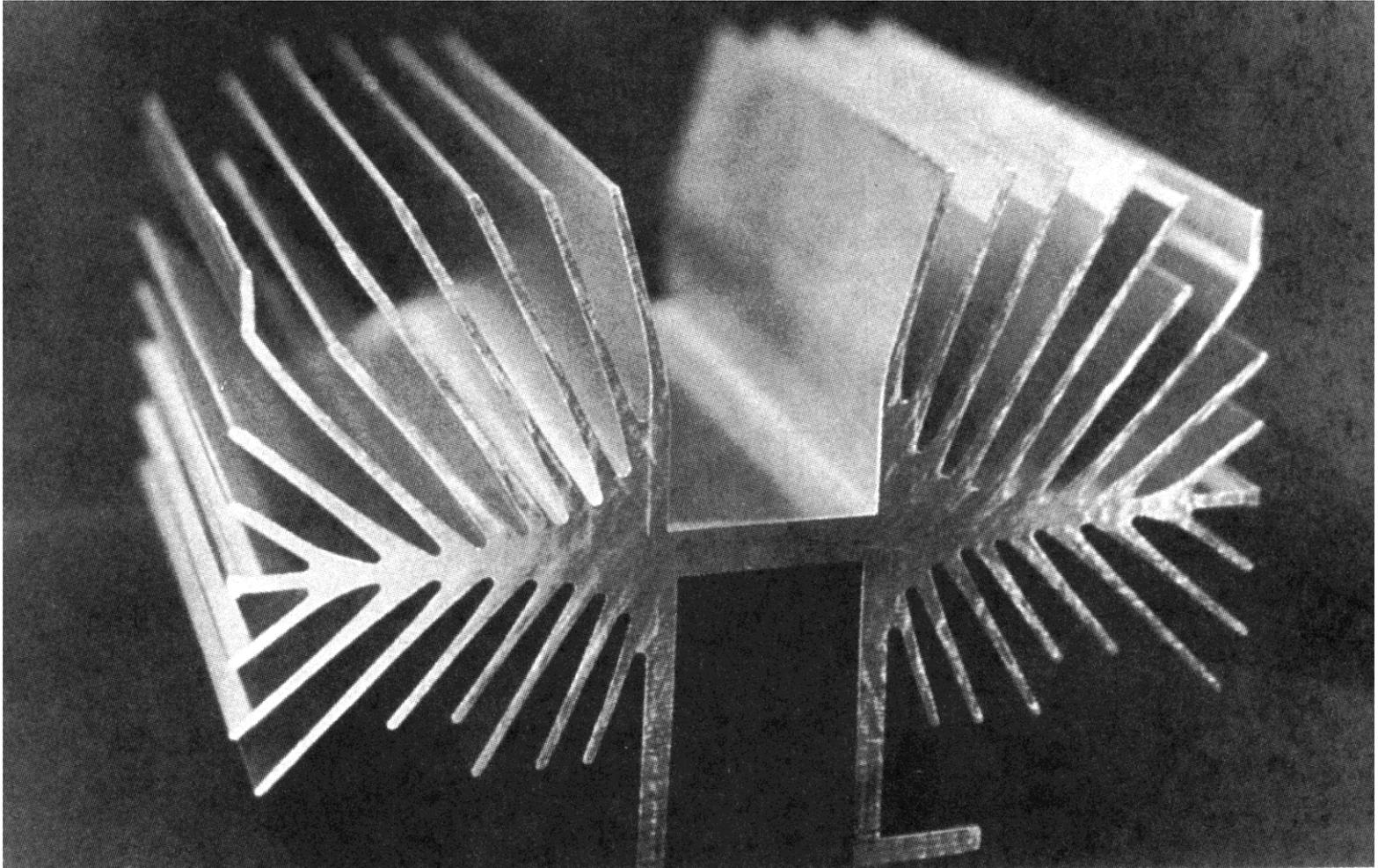
# Hot Extrusion

- For metals and alloys that do not have sufficient ductility at room temperature
- Reduces forces
- Increases die wear
- Preheated billet will develop an abrasive oxide film that affects the material flow pattern, unless it is heated in an inert-atmosphere furnace
- Dummy blocks slightly smaller in diameter than the container will cause only the non-oxidized center core to be extruded, leaving a skull of oxides in the chamber
- Die materials often steels, sometimes coated with zirconia to extend life
- Glass is often used as a lubricant

# Cold Extrusion

- Developed in 1940s
- Often a combination of extrusion and forging
- Used for tools and components of cars, bikes, appliances, farm equipment, motorcycles, etc
- Uses slugs less than 40 mm in diameter
- Work hardening leads to improved properties, as long as frictional heat does not cause recrystallization
- Good dimensional tolerances
- Improved surface finish due to lack of oxide film
- Less energy required (no preheating)
- Disadvantage: higher stresses on tooling
- Lubrication is important for this process

# Aluminum Heat Sink Extrusion

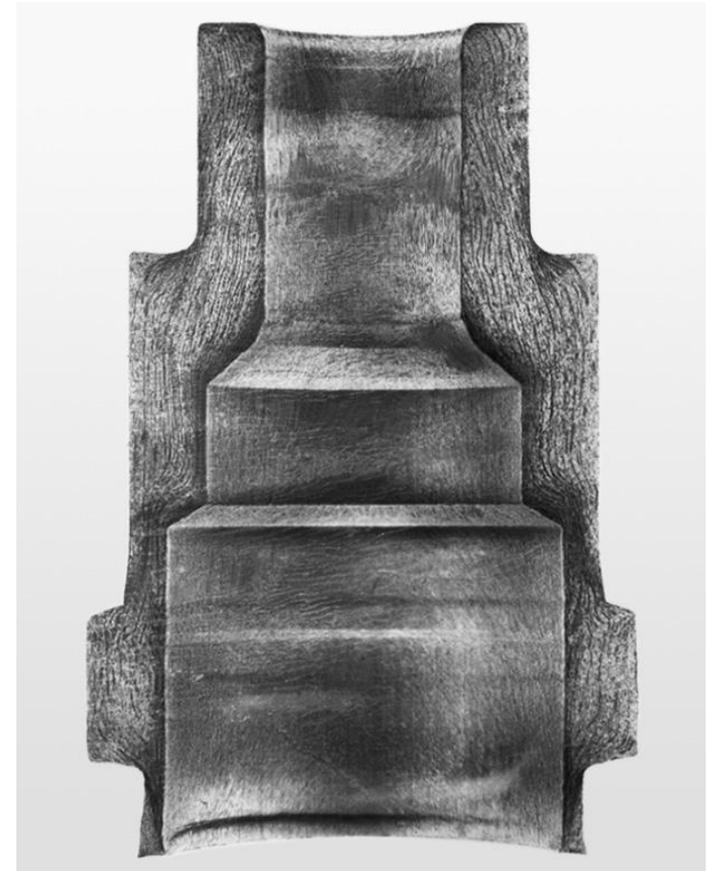


## Cold Extruded Spark Plug

Figure 15.12 Production steps for a cold extruded spark plug. *Source:* National Machinery Company.



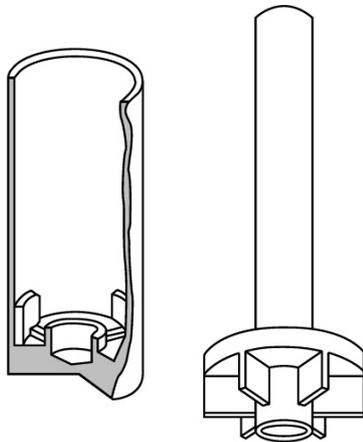
Figure 15.13 A cross-section of the metal part in Fig. 15.12, showing the grain flow pattern. *Source:* National Machinery Company.



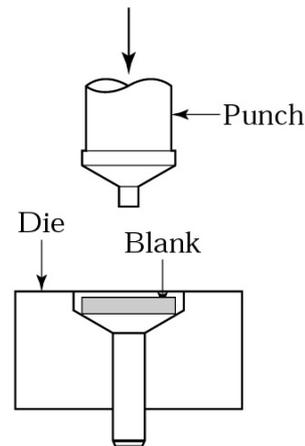
# Impact Extrusion

- Often a combination of indirect and cold extrusion
- Thickness of extruded part depends on clearance between punch and die
- Typical product: collapsible toothpaste tubes

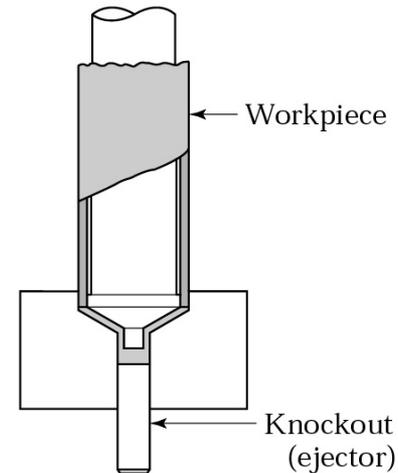
(a)



(b)



(c)



(a) Two examples of products made by impact extrusion. These parts may also be made by casting, forging, or machining; process choice depends on the dimensions and the materials involved and on the properties desired. Economic considerations are also important in final process selection. (b) and (c) Impact extrusion of a collapsible tube by the *Hooker process*.

## Hydrostatic Extrusion

- Advantage: no container-wall friction
- Developed in the 1950s
- Improved fluid-to-fluid extrusion process extrudes into a second fluid-filled chamber
- Fluid is often vegetable oils at room temperature
- Fluid can be waxes, polymers, or glass at elevated temperatures
- Brittle materials can be successfully extruded with this process
- Low friction, small die angles, and high extrusion ratios can be achieved
- This process is less used in industry due to complex tooling, experience needed, and long cycle times

# Extrusion Defects

- Surface cracking (also called hot shortness)
  - If temperature, friction or speed is too high, intergranular cracks occur
  - Common in aluminum, magnesium, and zinc alloys
  - Bamboo defects are periodic surface cracks that develop due to the extruded product sticking to the die land
- Pipe defect (also called tailpipe or fishtailing)
  - Metal flow pattern draws surface oxides and impurities toward the center of the billet, like a funnel
  - To prevent, modify flow pattern to be more uniform, control friction and minimize temperature gradients, remove scale and impurities by machining or chemical etching prior to extrusion
- Internal cracking (also called center-burst, chevron cracking)
  - Due to hydrostatic tensile stress at centerline of deformation zone (similar to necking in a tensile test specimen)
  - Increases with increased die angle, impurities
  - Decreases with increased extrusion ratio and friction

## Chevron Cracking

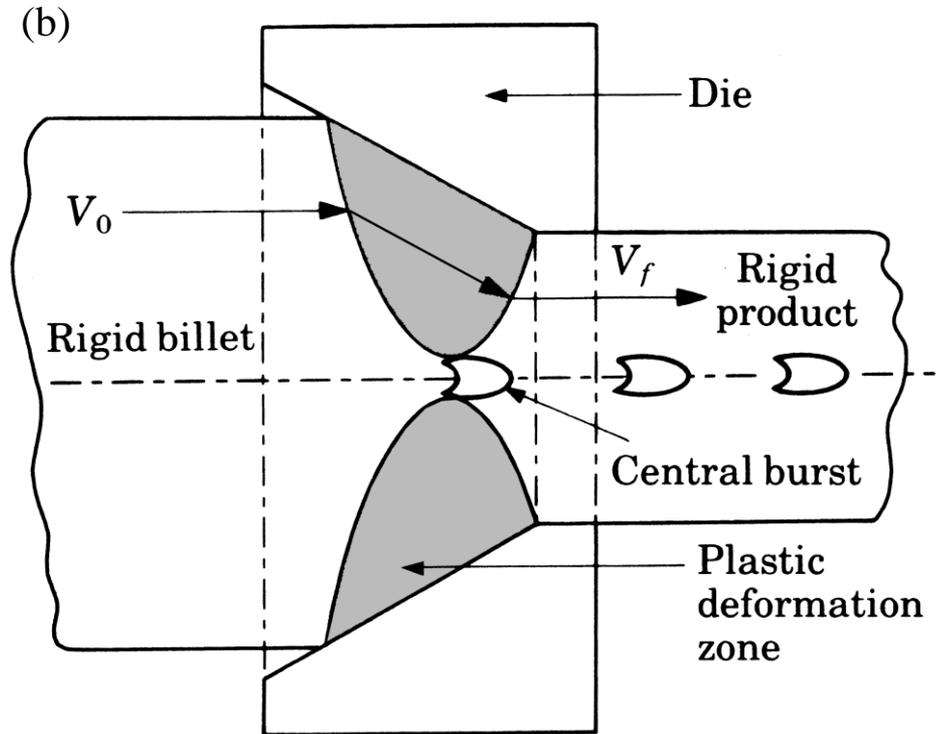
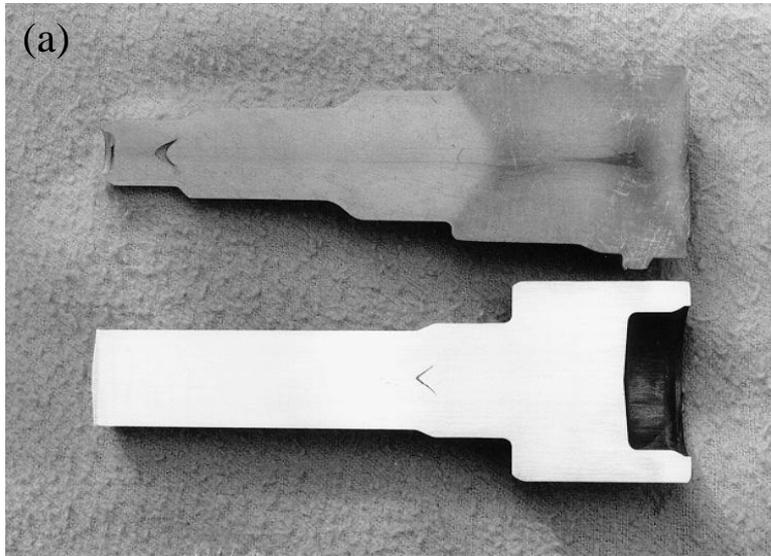


Figure 15.16 (a) Chevron cracking (central burst) in extruded round steel bars. Unless the products are inspected, such internal defects may remain undetected, and later cause failure of the part in service. This defect can also develop in the drawing of rod, of wire, and of tubes. (b) Schematic illustration of rigid and plastic zones in extrusion. The tendency toward chevron cracking increases if the two plastic zones do not meet. Note that the plastic zone can be made larger either by decreasing the die angle or by increasing the reduction in cross-section (or both). *Source*: B. Avitzur.

# Extrusion Equipment

- Horizontal hydraulic press
  - Capable of applying constant force over a long stroke, so long billets can be used and high production rates achieved
  - Up to 120 MN (14000 tons)
  - Used for hot extrusion of large billets
- Vertical hydraulic press for cold extrusion
  - Less capacity, but also less floor space than horizontal machines
- Multi-stage processes also

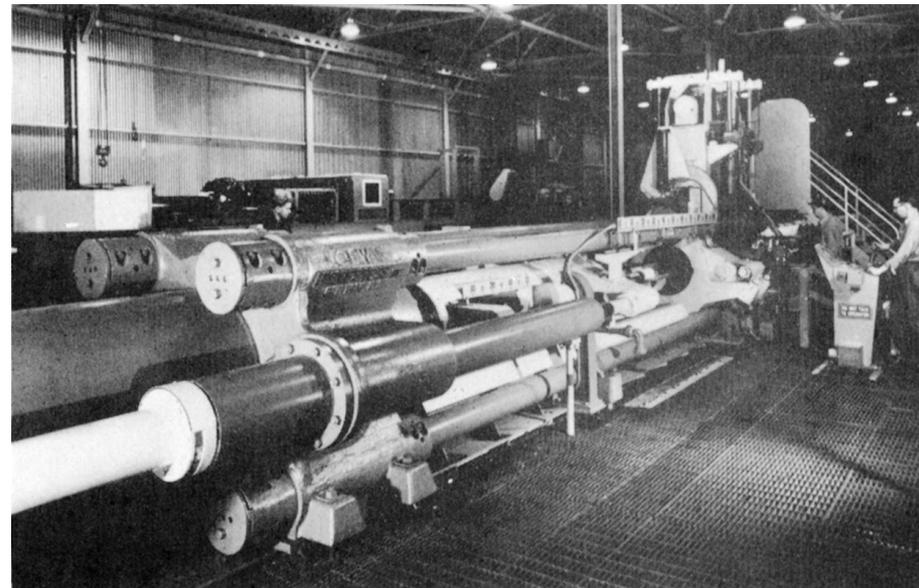


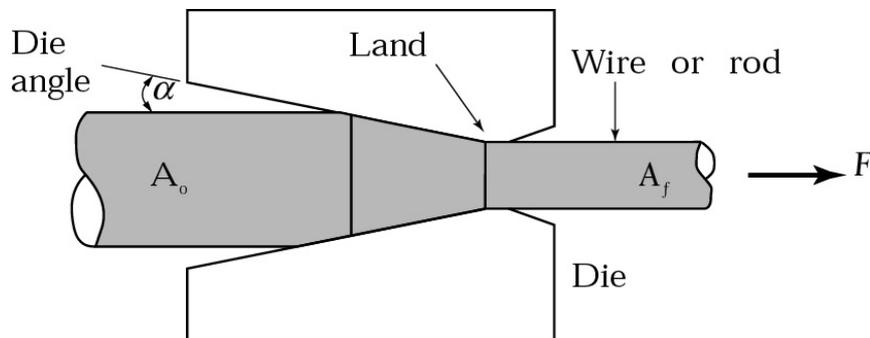
Figure 15.17 General view of a 9-MN (1000-ton) hydraulic-extrusion press. *Source:* Courtesy of Jones & Laughlin Steel Corporation.

# Drawing

- Changing the cross-sectional area or shape of a solid rod, wire, or tubing by pulling it through a die
- Rod is the term for larger cross sections, wire for smaller
- Typical products:
  - Electrical wiring
  - Cables
  - Tension-loaded structural members
  - Welding electrodes
  - Springs
  - Paper clips
  - Bicycle wheel spokes
  - Musical instrument strings
- Die and mandrel materials typically tool steels (chromium plated) and carbides (titanium nitride coated), diamond for fine wire

# Drawing Parameters

- Parameters include die angle ( $\alpha$ ), reduction in cross sectional area, drawing speed, temperature, and lubrication
- For a certain reduction in diameter and friction conditions, there is an optimum die angle
- $Y_{avg}$  is average true stress of the material in the die gap
- Die angle is typically 6-15 degrees
- Maximum reduction per pass is 63%, but more than 45% can cause lubricant breakdown and surface-finish deterioration
- The smaller the initial area, the smaller the reduction per pass percentage that is typically used
- Intermediate annealing may be needed between passes



$$F = Y_{avg} A_f \ln \left( \frac{A_o}{A_f} \right)$$

# Drawing Various Shapes

- Drawing flat strips (ironing) is used in making beverage cans
- Bundle drawing is used to simultaneously draw thousands of wires with final polygonal cross sectional shapes

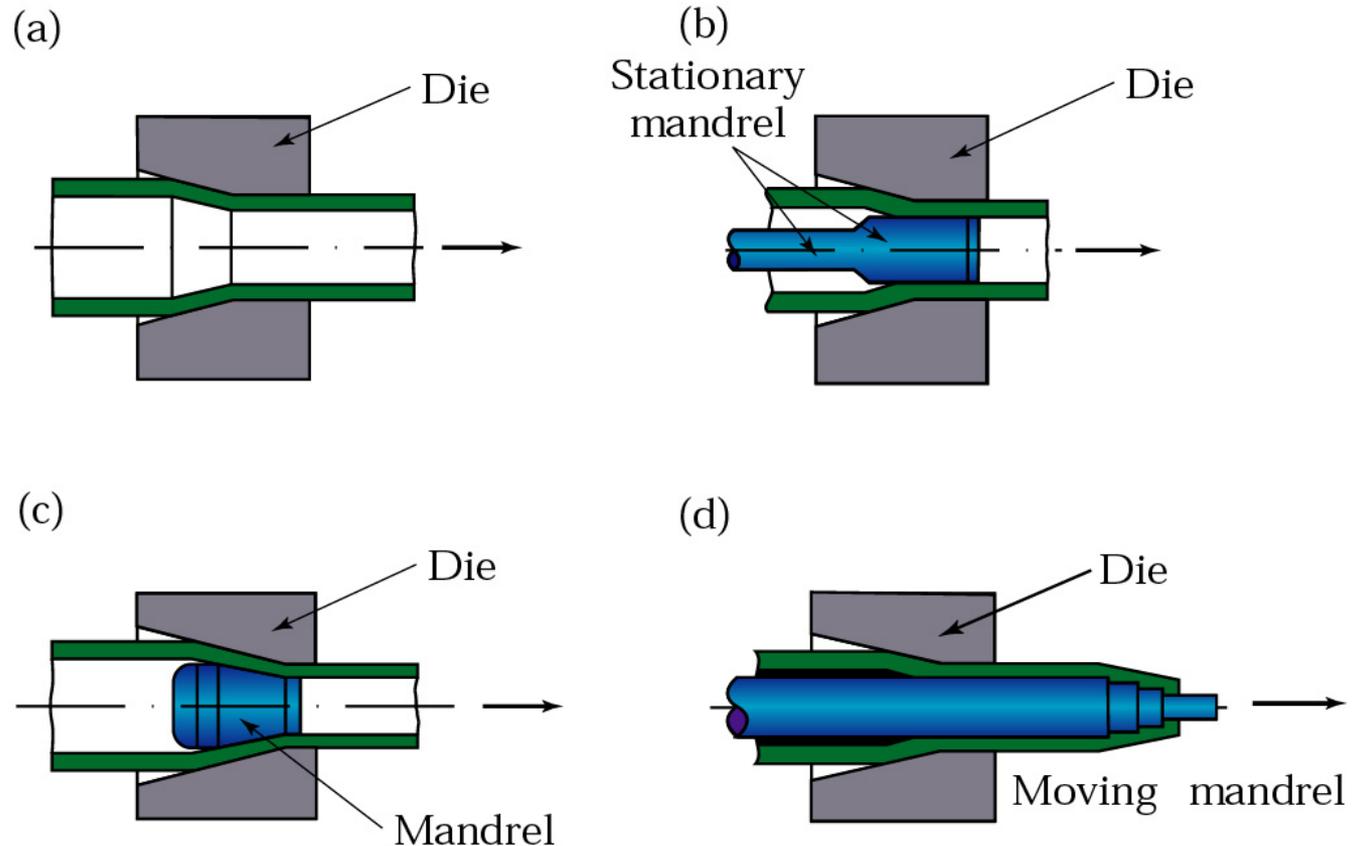


Figure 15.19  
Examples of tube-drawing operations, with and without an internal mandrel. Note that a variety of diameters and wall thicknesses can be produced from the same initial tube stock (which has been made by other processes).

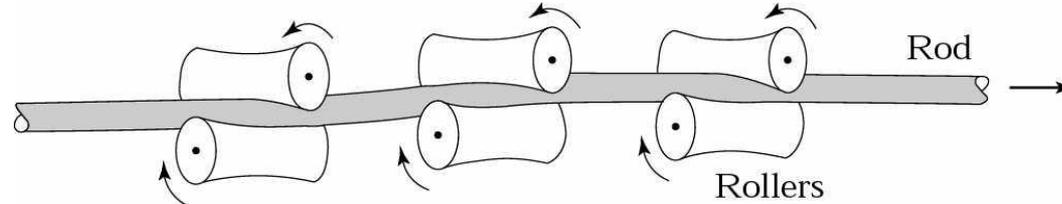
# Lubrication

- Proper lubrication is essential to improve die life, reduce drawing forces and temperature, and improve surface finish
- Lubrication is more difficult between the mandrel and workpiece in tube drawing
- Methods
  - Wet drawing – dies and rod completely immersed in lubricant (oils or emulsions)
  - Dry drawing – surface of rod is coated with a lubricant such as soap by passing it through a box filled with the lubricant (stuffing box)
  - Coating – the rod or wire is coated with a soft metal (copper or tin) that acts as a solid lubricant
  - Ultrasonic vibration of the dies and mandrels – reduces friction and allows larger reductions per pass without failure

# Drawing Defects and Equipment

- Defects

- Similar to those in extrusion
- Also seams, or longitudinal scratches or folds in the material
- Roll straightening used to improve qualities of drawn rods and tubes



- Equipment

- Draw bench
- Bull Block or capstan (rotating drum for drawing very long wire or rod)
- Multi stage drawing

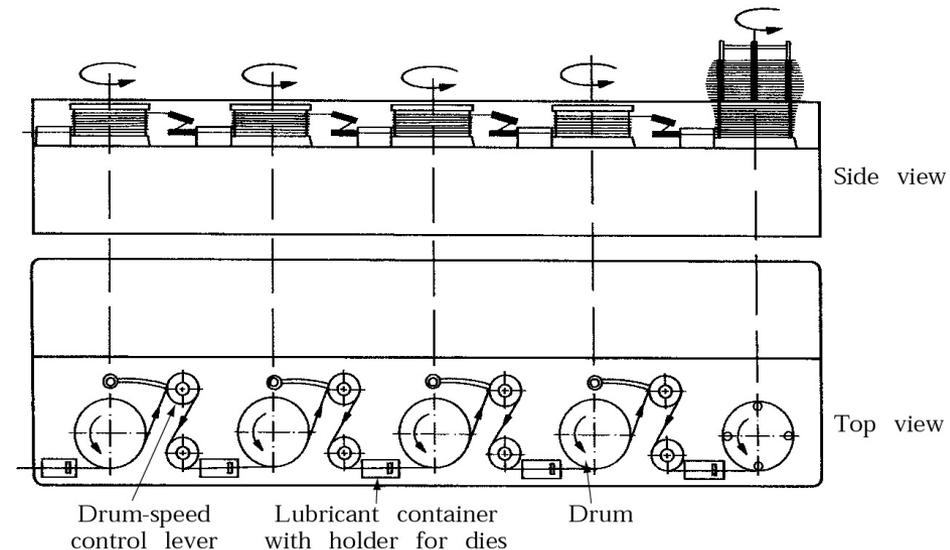


Figure 15.24 Two views of a multistage wire-drawing machine that is typically used in the making of copper wire for electrical wiring. *Source:* H. Auerswald.