Bulk Deformation Processes

ME 355 - Introduction to Manufacturing Processes

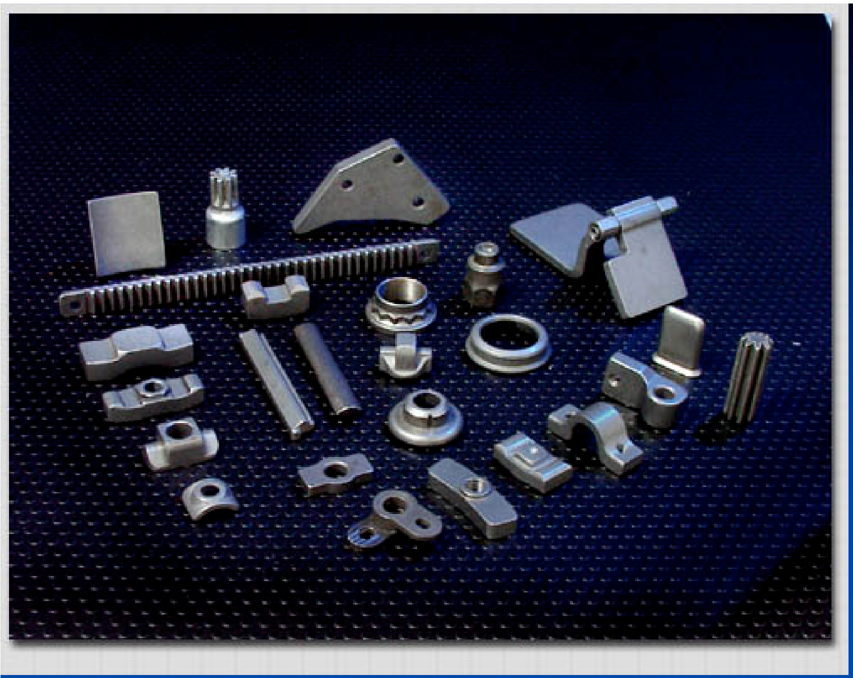
Deformation Processes

- Permanent (plastic) deformation of a material under tension, compression, shear or a combination of loads.
- Types of Deformation
  - Bulk Deformation
  - Sheet Metal Work

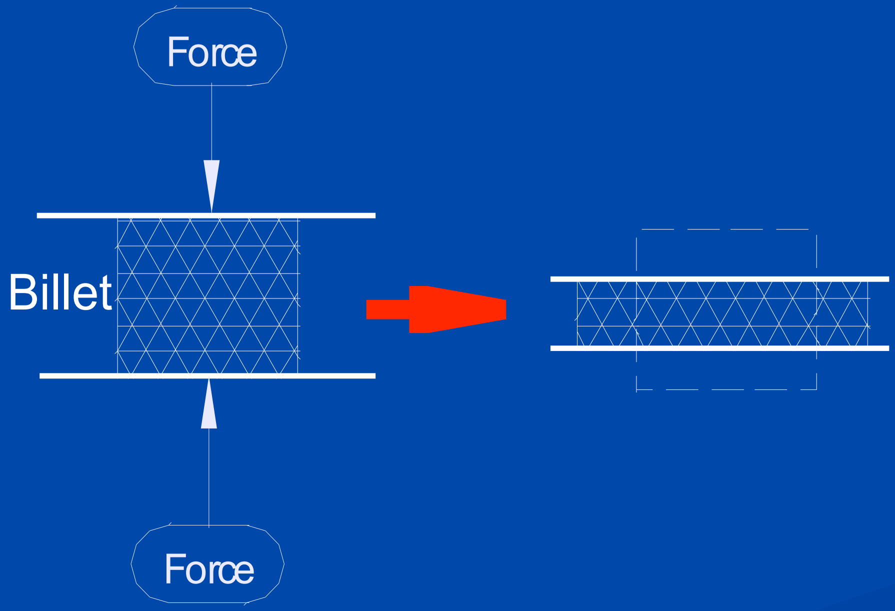
Deformation Processes

- Bulk Deformation - Significant change in surface area, thickness and cross section reduced, and overall geometry changed.
  - Forging
  - Rolling
  - Extrusion
  - Drawing
- Sheet Metal Work - Initial Material Thickness stays the same (hopefully).
  - Bending
  - Shearing

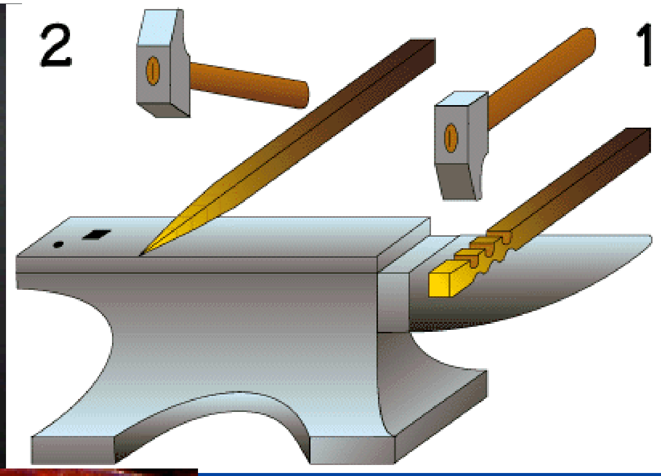
Forging



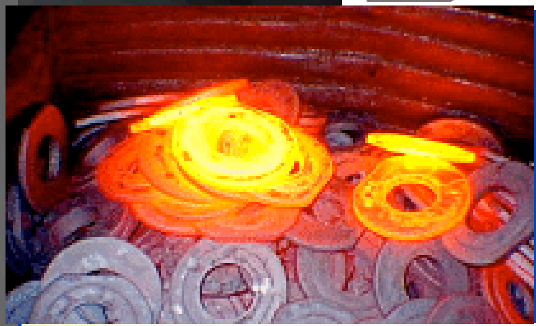
- Metal is pressed into a die and takes on the shape of the die
- Sequential Process - typically multiple pressing steps involved

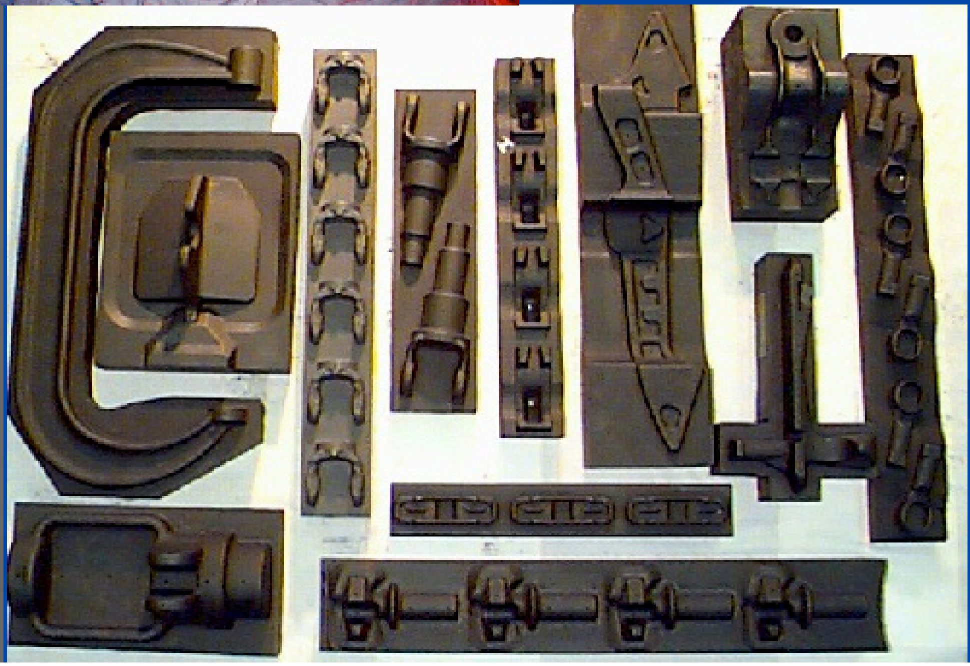


Open Die Forging


2
1


Striker C41-40/C41-65/C41-75B two piece





Forging Advantages/Disadvantages

- Process Advantages
  - Closing of voids
  - Reduced Machining
  - Improved physical properties of starting material
- Process Disadvantages
  - Possible scale inclusions
  - High Tooling Cost
  - Not economical for short production runs

Forging Process Variables

- Independent Variables
  - Material
  - Starting Geometry
  - Tool Geometry
  - Lubrication
  - Starting Temperature
  - Speed of Deformation
  - Amount of Deformation
- Dependent Variables
  - Force and Power
  - Resulting Material Properties
  - Exit Temperature
  - Surface Finish
  - Dimensional Precision
  - Material Flow Details

Force Calculation for Open-Die Forging - Friction Free

1. Calculate the volume of the part
2. Determine the final part dimensions
3. Determine the true strain:

$$\varepsilon = \ln\left(\frac{h_o}{h_i}\right)$$

4. For Hot working - determine the strain rate

$$\dot{\varepsilon} = \frac{v}{h}$$

5. Calculate the Flow Stress

$$cold-working: \sigma_f = K\varepsilon^n$$

$$hot-working: \sigma_f = C\dot{\varepsilon}^m$$

6. Calculate Force

$$Force = \sigma_f A_i$$

7. Energy Calculation

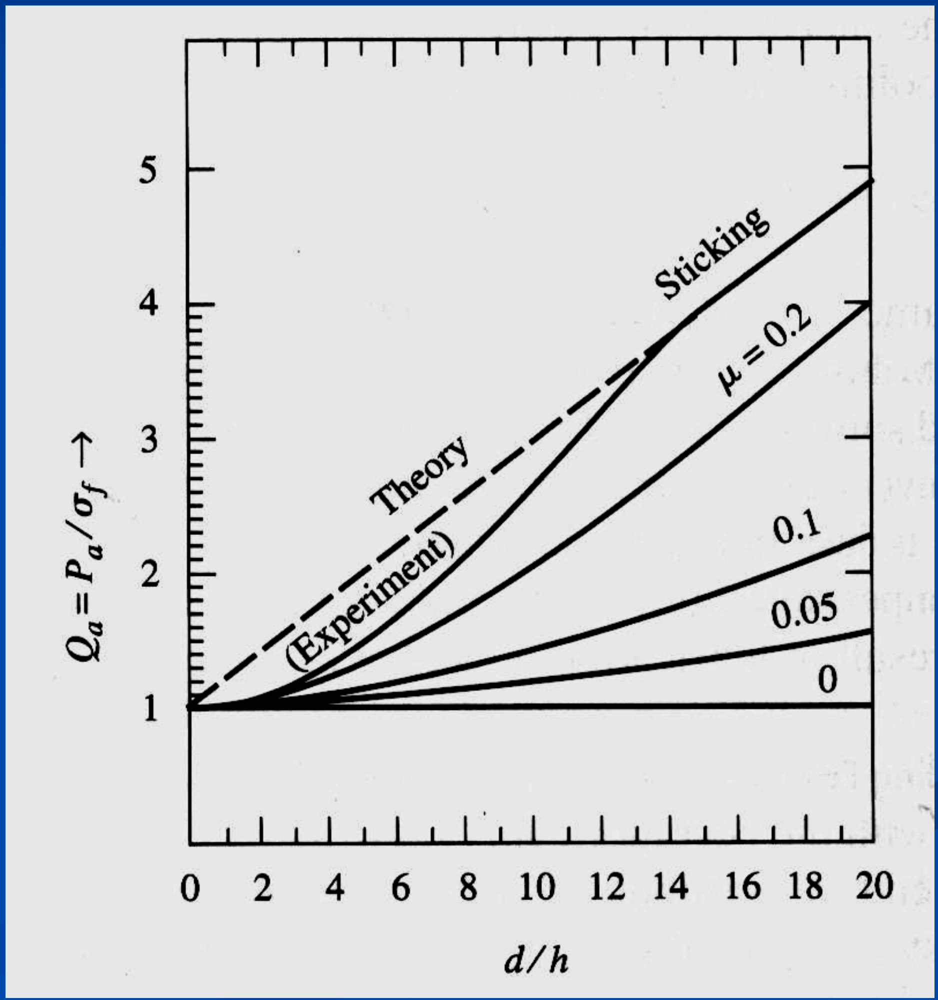
$$Work = \int F \cdot dh$$

$$\Delta T = \frac{Work}{V \rho c}$$

Friction Correction Factor

- Determine correction factor through the use of theoretical calculations, or charts

$$p_{avg} = \sigma_f Q_a$$



Rectangular Workpiece

- Plane Strain condition
  - Constrained by the material in the wider dimension
  - End result is that the applied stress required will be greater than the material flow stress

$$p_p = 1.15\sigma_f$$

  - Apply similar friction correction factor

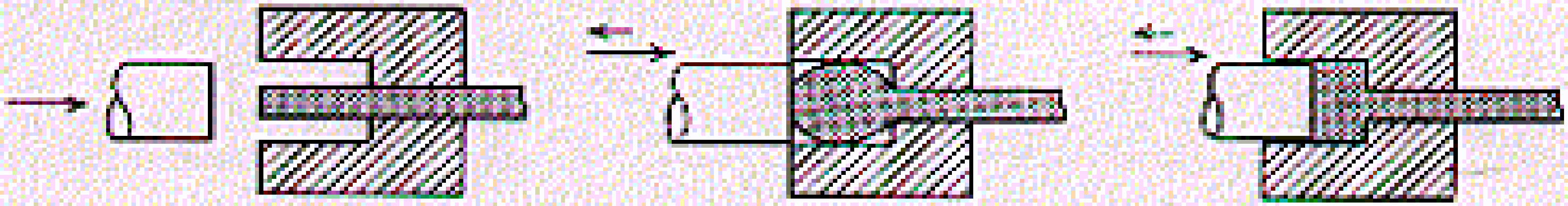
Hot Work vs. Cold Work

- Hot Work
  - Recrystallization takes place
  - > 0.5 * T_m
  - Requires less force
  - Less residual stresses
  - Greater deformation possible
  - Dimensional Variation
  - Poor Surface Finish
  - Oxidation of
- Cold Work
  - NO Recrystallization
  - Less than 0.3 T_m
  - Residual Stresses
  - Strain Hardened
  - Better Surface Finish
  - Less Common
  - Anisotropic Material Properties

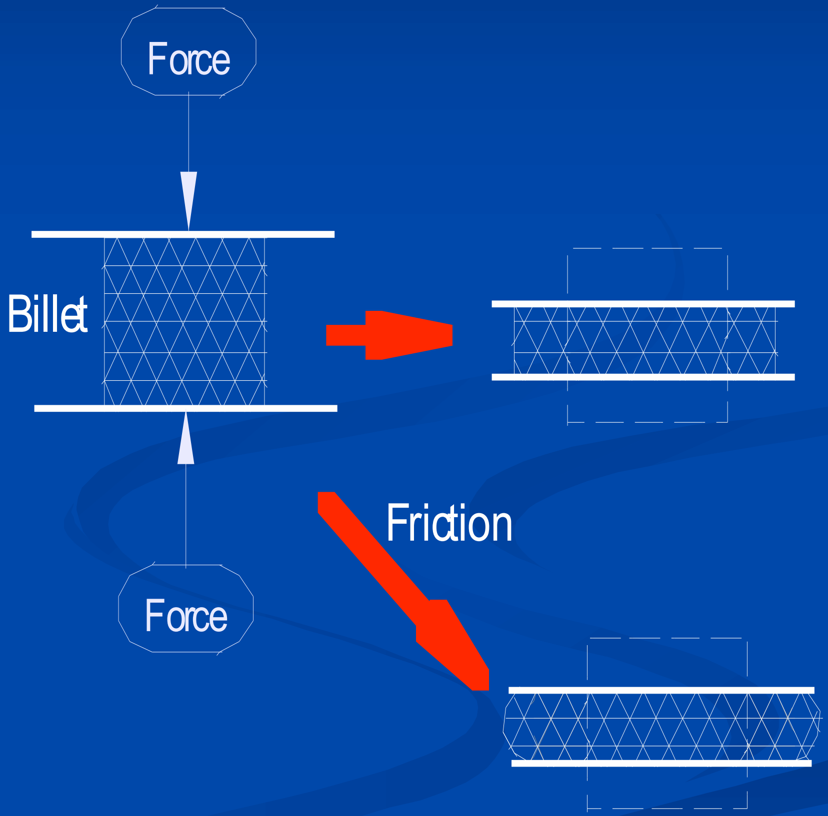
Upset Forging

- Grip a bar—heat the end—forge into desired shape
- Product examples
    - Bolts
    - Nails
    - Engine valves

Figure 12.10 Upset forging.



Open Die Forging



Open Die Forging Defects

- Fracture -
  - exhausted ductility
  - Intergranular fracture in hot working
- Barreling - Friction
- Solution -
  - limited deformation per step
  - Process anneal between steps

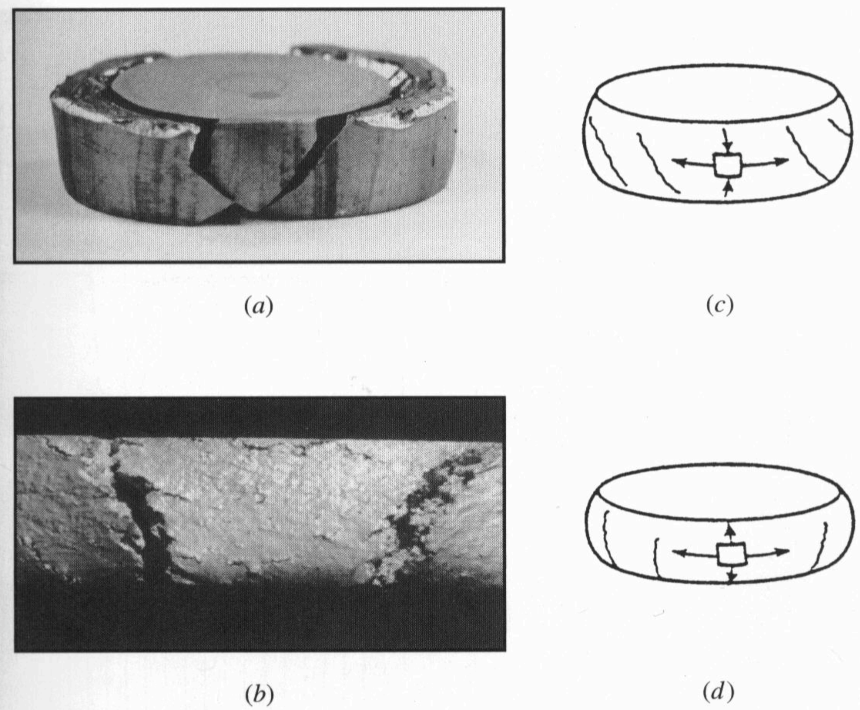
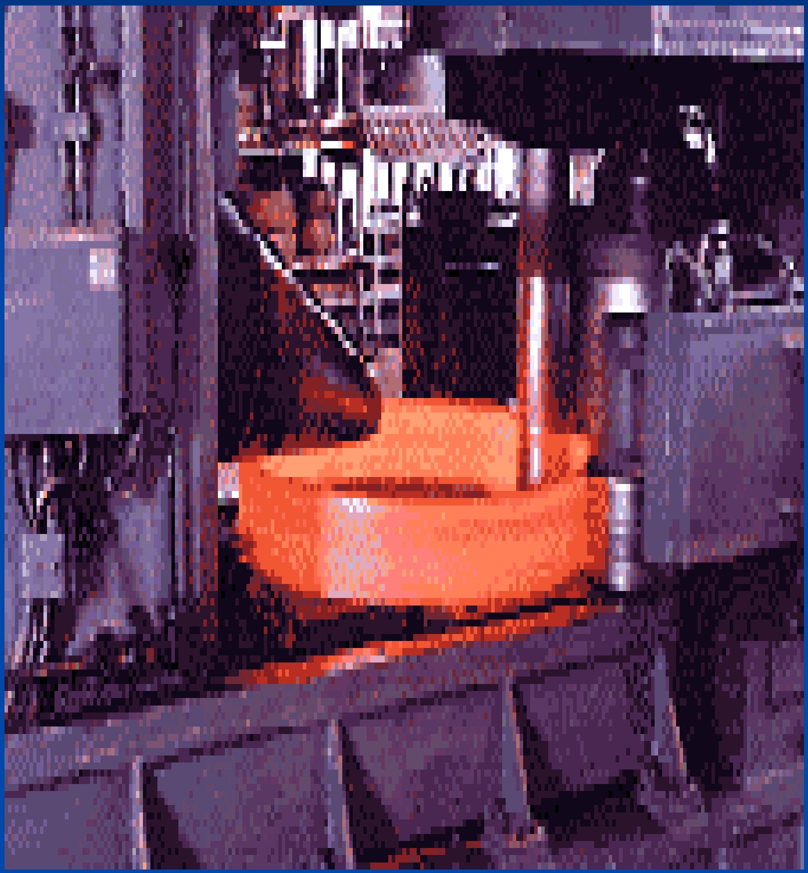
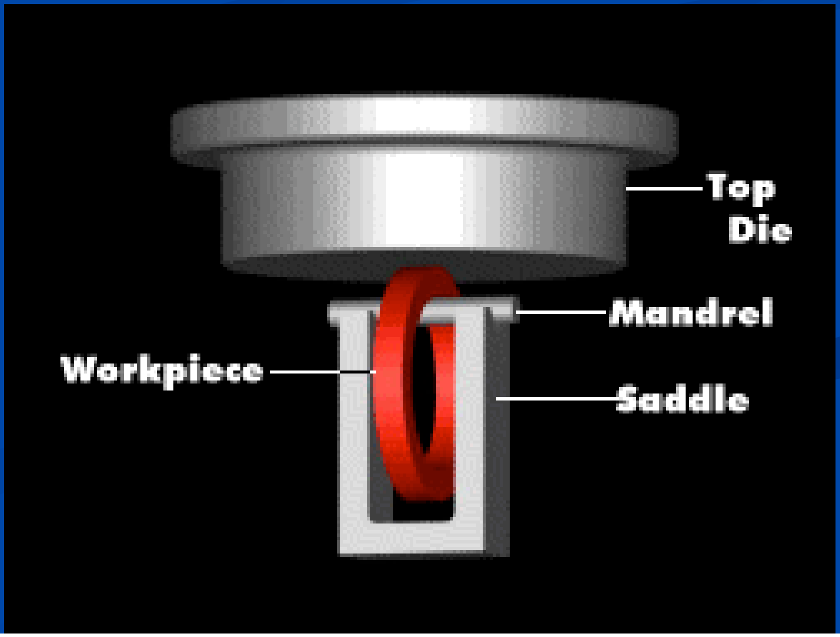


Figure 9–16 Fracture may occur by (*a*) exhausting ductility in cold working or by (*b*) intergranular fracture in hot working. (*c*), (*d*) The direction of cracks depends on the relative magnitudes of secondary tensile stresses generated by bulging.

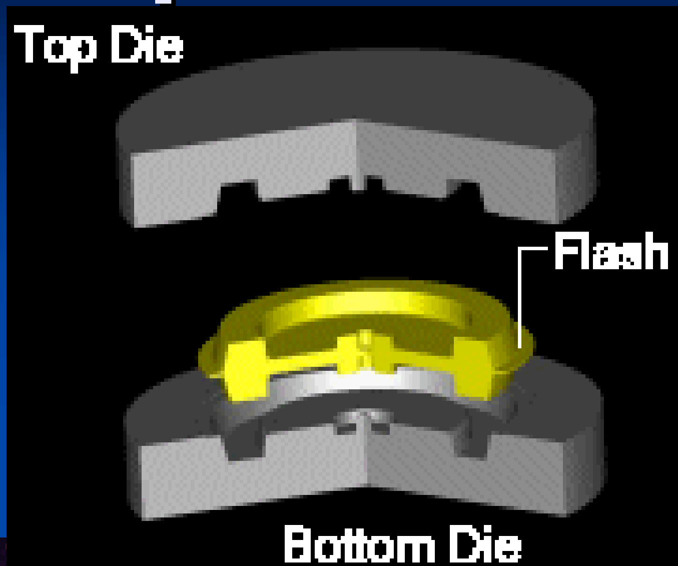
Seamless Ring Forging

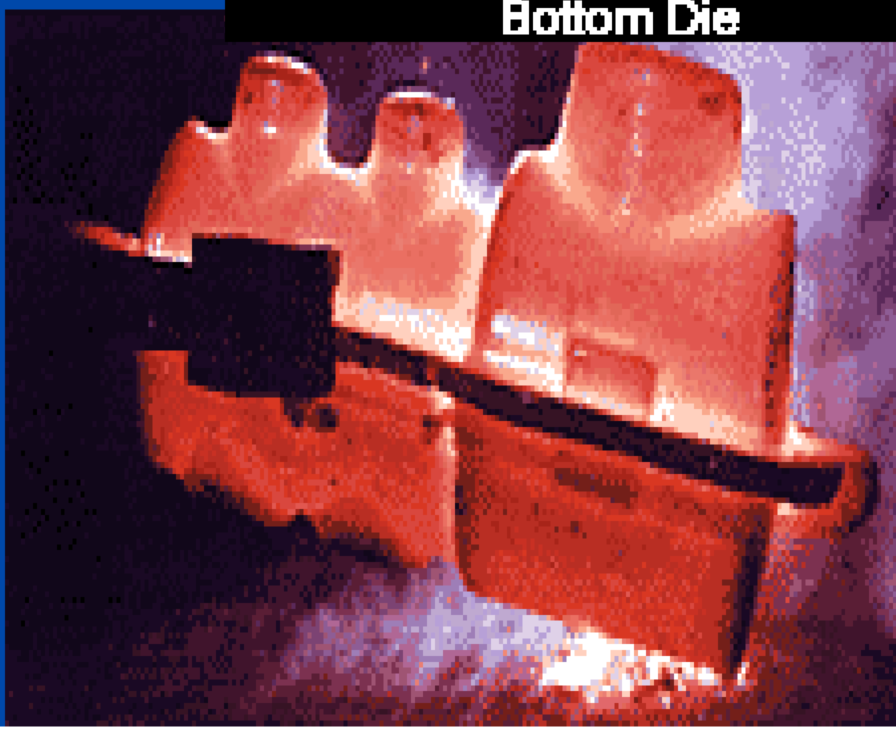


- Most processes are not purely defined. This is a hybrid process -
  - Forge Welding
  - Rolling



Impression Die Forging





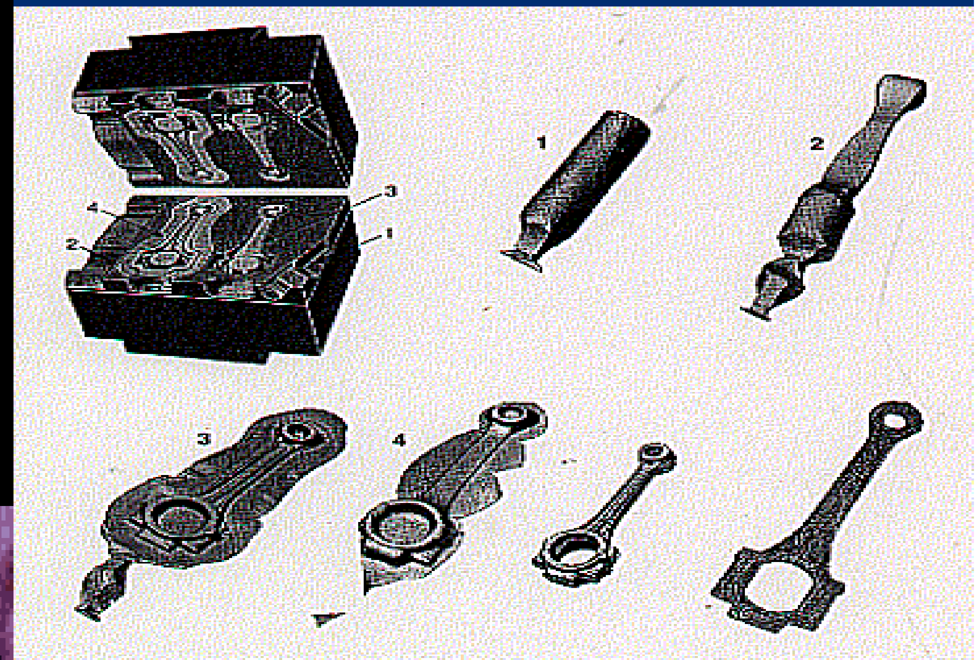


FIGURE 18-10 Impression drop-forging dies and the product resulting from each impression. The flash is trimmed from the finished connecting rod in a separate trimming die. The sectional view shows the grain fiber resulting from the forging process. *(Courtesy of Forging Industry Association, Cleveland, Ohio.)*

Note the presence of Flash!

Impression Die Forging

- Isothermal Forging
  - Die at workpiece temperature
  - Reduced temp cycling of die
  - Very slow forging speeds possible
  - Complex, thin walled parts possible
- Non-isothermal Forging
  - Die cooler than workpiece (~200° C for Al)
  - Less complex part geometry
  - Less expensive process

Impression Die Forging

- Form 3-D complex geometry
- Flash present

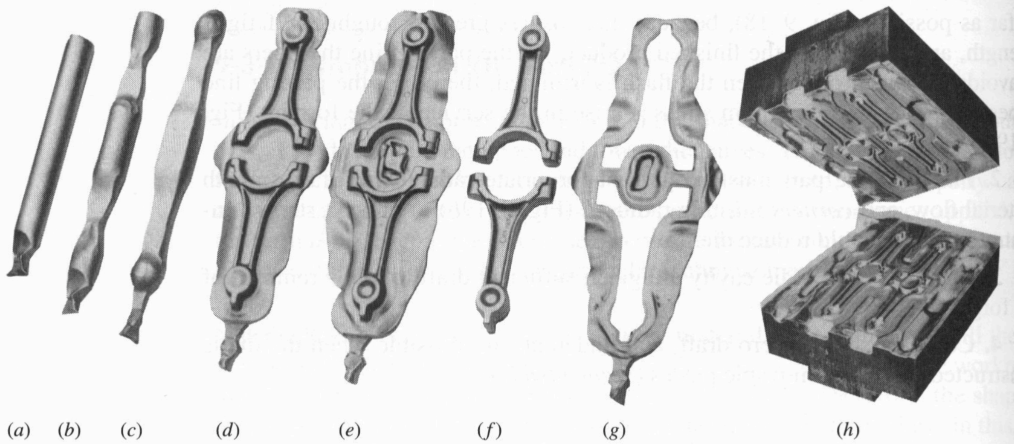


Figure 9–20 Hammer forging two connecting rods: (*a*) bar stock; after (*b*) fullering, (*c*) "rolling," (*d*) blocking, (*e*) finishing, (*f*) trimming; (*g*) the flash; and (*h*) the forging dies. (*Courtesy Forging Industry Association, Cleveland, Ohio.*)

- Material Flow
  - Parting Line - grain flow
  - Fillet corners - flow
  - Draft angle to allow removal from die
  - Undercuts and complex parts - segmented dies

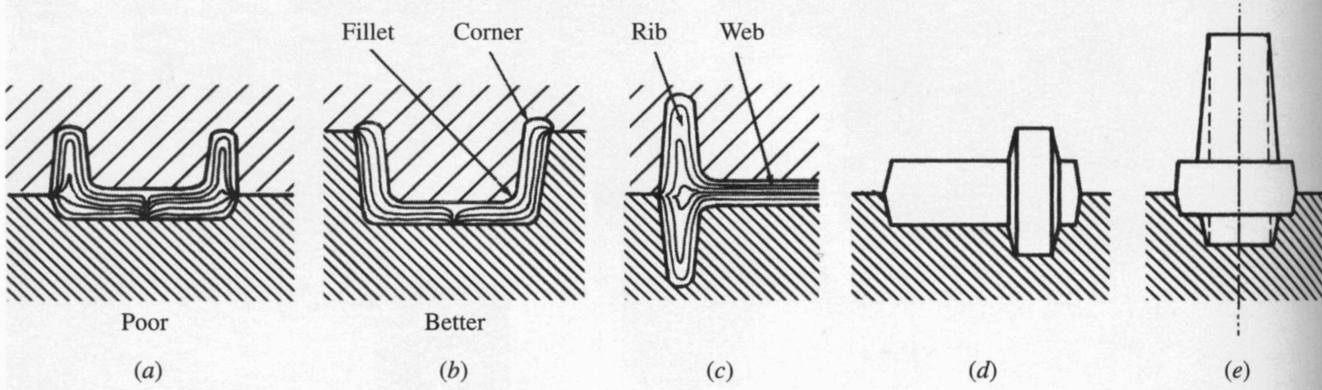
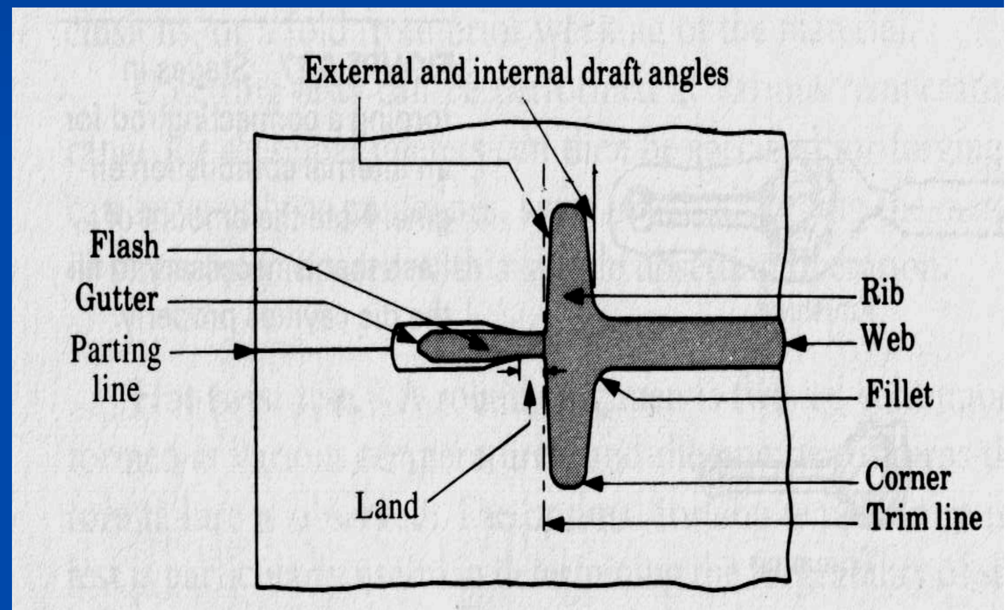


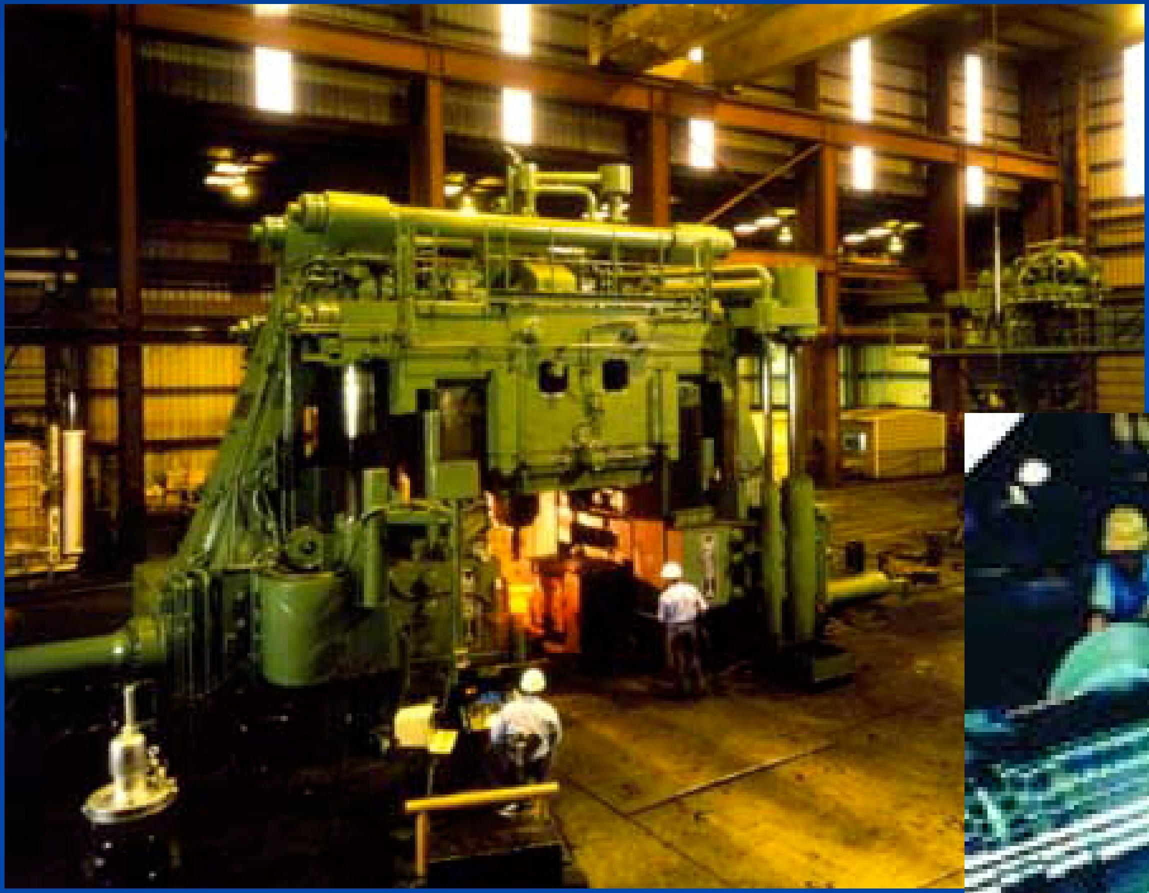
Figure 9–19 Parting lines and draft angles must be chosen to give sound material flow and allow removal of the forging from the die.

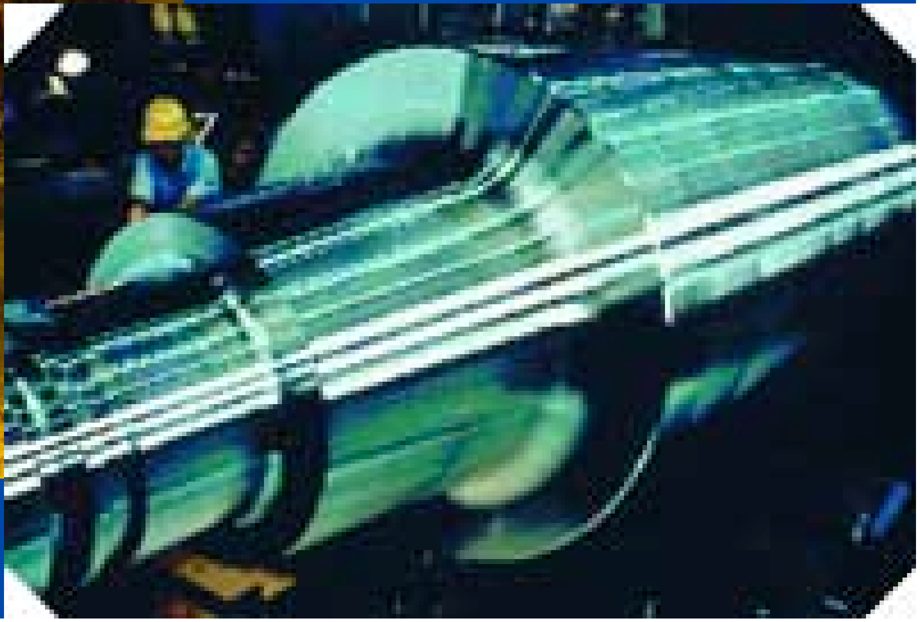
The role of Flash – Impression Forging

- Flash controls the ability to fill the die cavity
- The size of the land controls the friction, which controls the inward force that fills the cavity
- Allows for incoming billet size variation



Closed Die Forging





Closed Die Forging - Coining

- Complex 3-D geometry
- No Flash
- Requires very tight process control

Defects - Impression Die and Closed Die Forging

- Cracking
- End Grains
- Laps
- Incomplete die fill
- Anisotropy

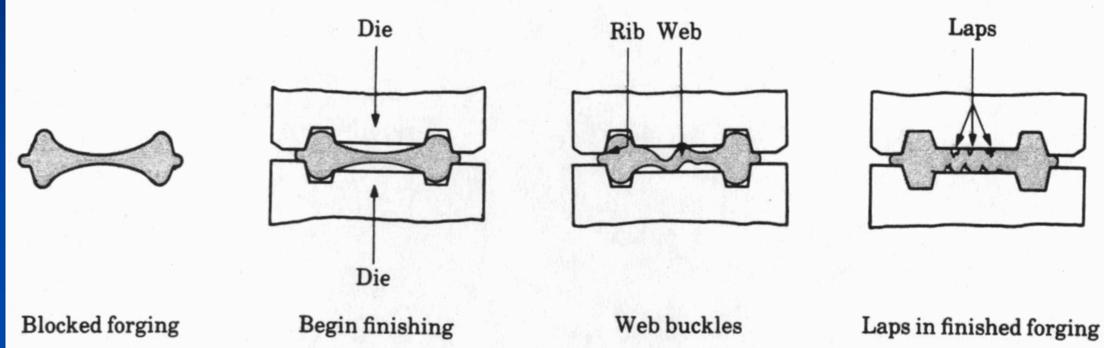
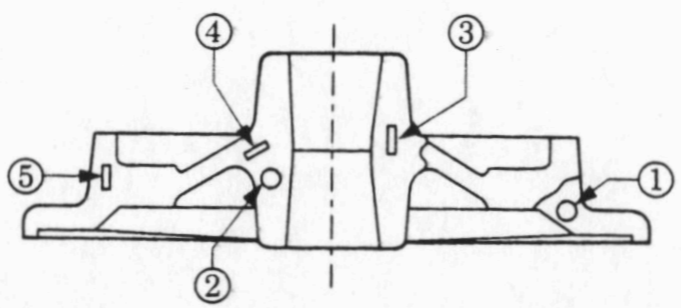


FIGURE 6.23 Laps formed by buckling of the web during forging. The solution to this problem is to increase the initial web thickness to avoid buckling.



Specimen location	Yield strength, psi	Ultimate tensile strength, psi	Elongation, %
1.	26,500	41,200	20.0
2.	23,000	39,400	17.7
3.	13,800	38,000	18.6
4.	25,400	40,400	16.2
5.	17,100	37,500	14.0

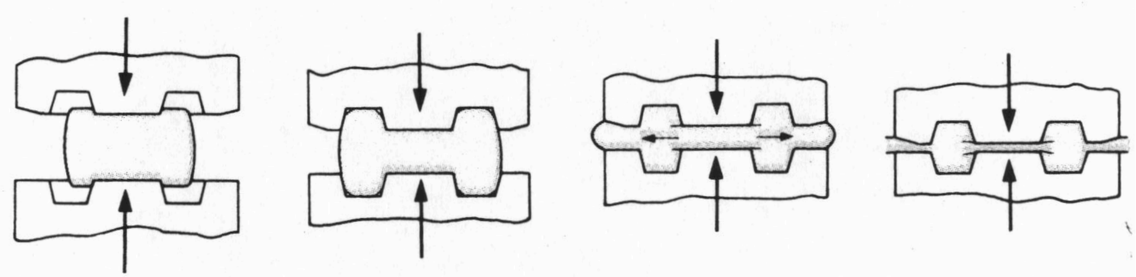
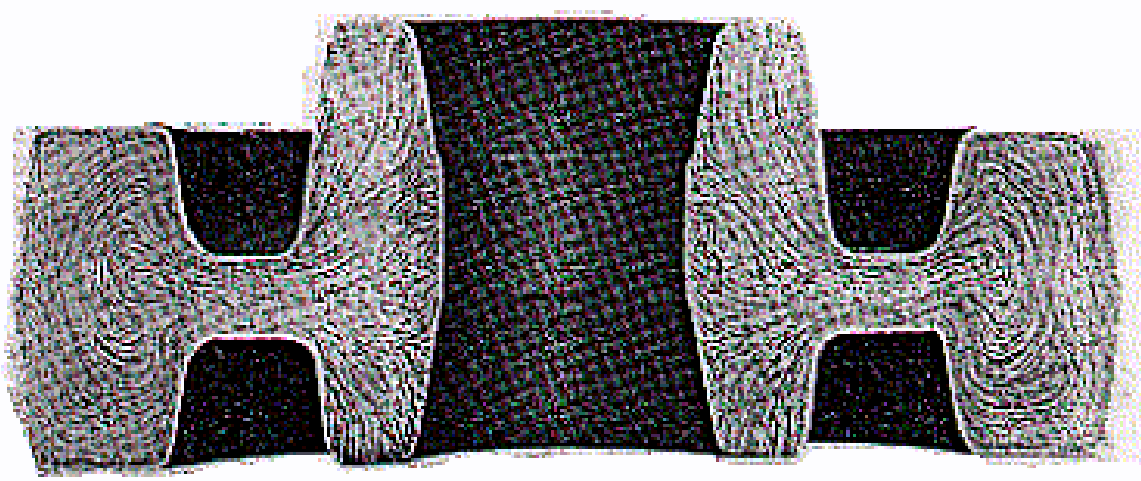


FIGURE 6.24 Internal defects produced in a forging because of an oversized billet. The die cavities are filled prematurely and the material at the center of the part flows past the filled regions as deformation continues.

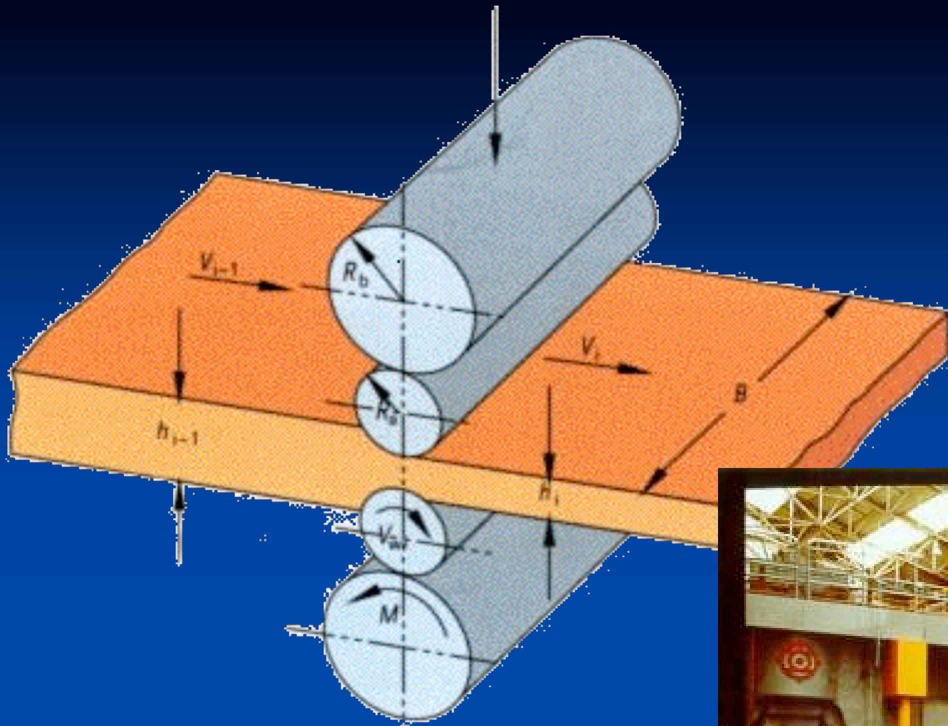
Non-homogeneous Properties

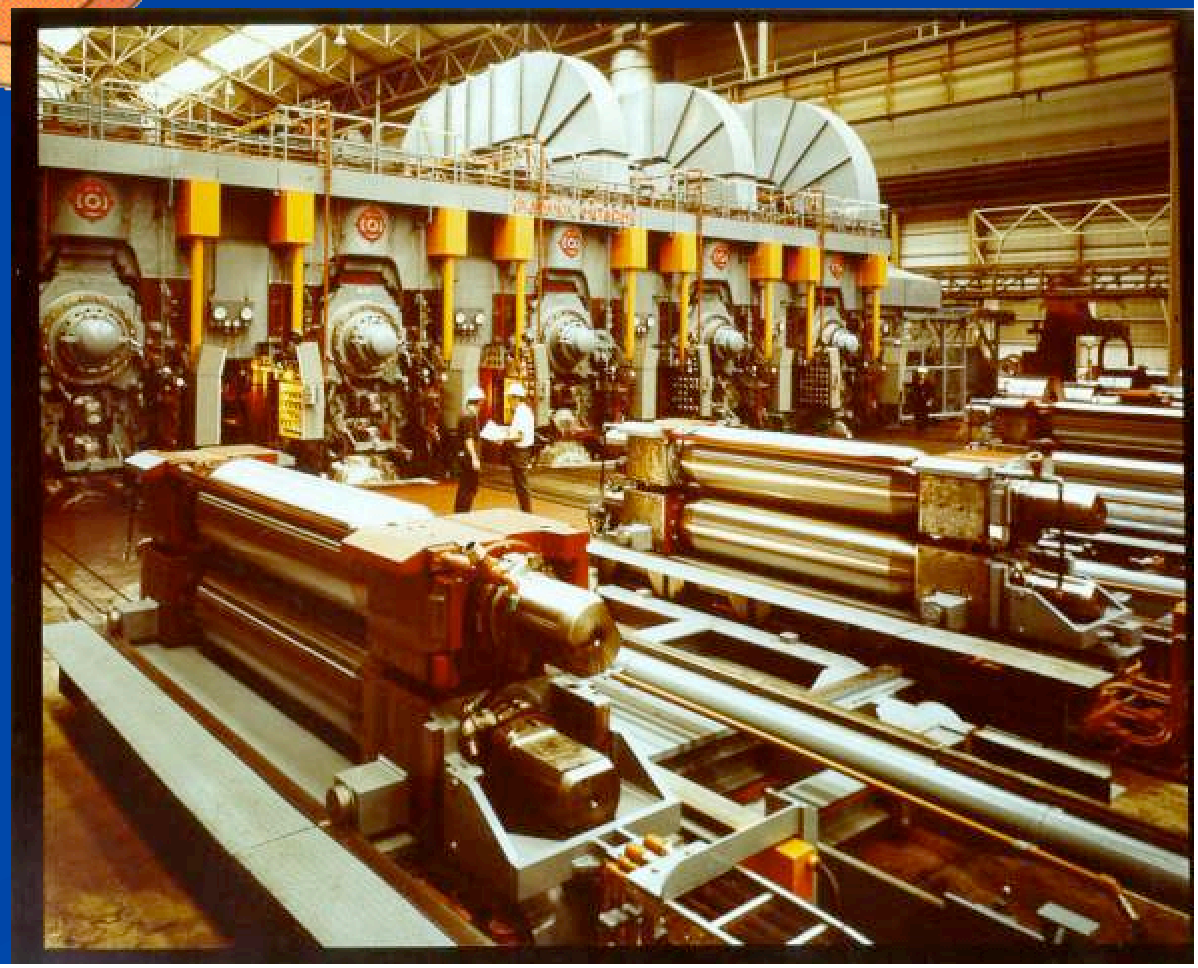
FIGURE 17-4 "Fiber" structure of a hot-formed (forged) transmission gear blank. *(Courtesy of Bethlehem Steel Corporation.)*



- This is good and bad.
  - Generally - reduced fatigue life
    - Can actually increase in some cases.
  - Increased strength
  - Increased wear resistance
  - ANISOTROPY

Rolling



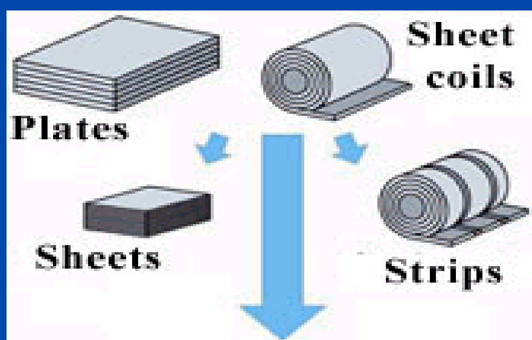


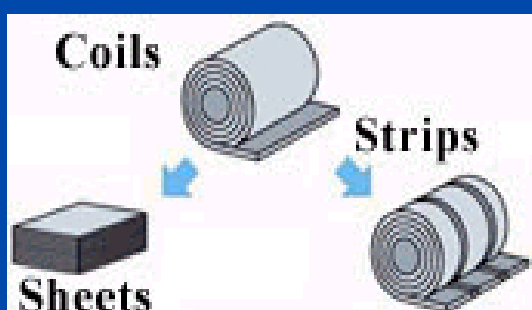
Rolling

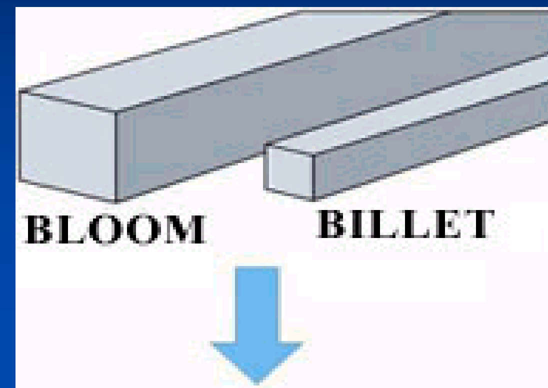
- One of the first primary processes to convert raw material into a finished product.
- Starting material (Ingots) are rolled into blooms, billets, or slabs by feeding material through successive pairs of rolls.
  - Bloom - square or rectangular cross section with a thickness greater than 6” and a width no greater than 2x’s the thickness
  - Billets - square or circular cross section - - smaller than a bloom
  - Slabs - rectangular in shape (width is greater than 2x’s the thickness), slabs are rolled into plate, sheet, and strips.

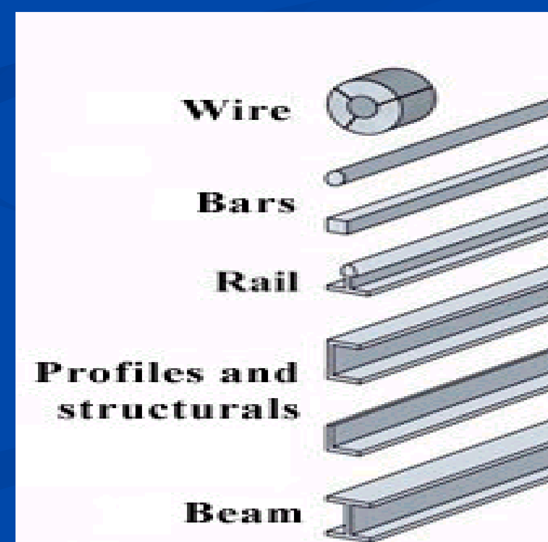
Rolling


SLAB

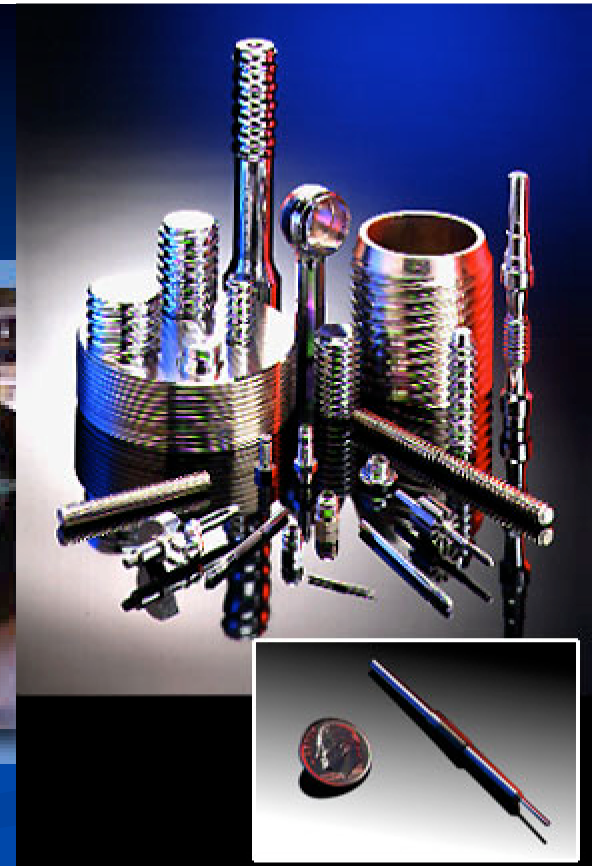

Plates
Sheet coils
Sheets
Strips

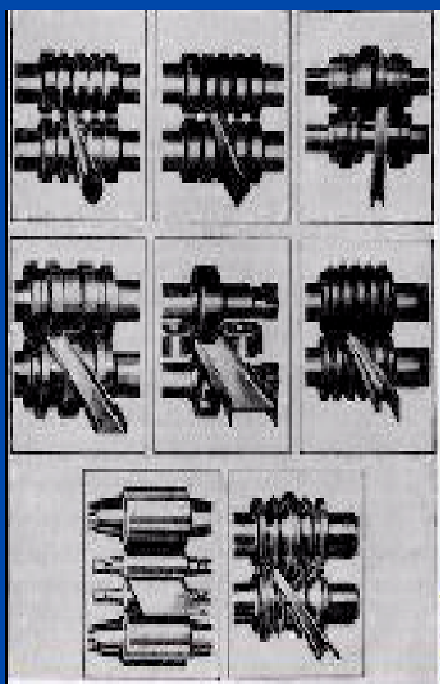

Coils
Strips
Sheets

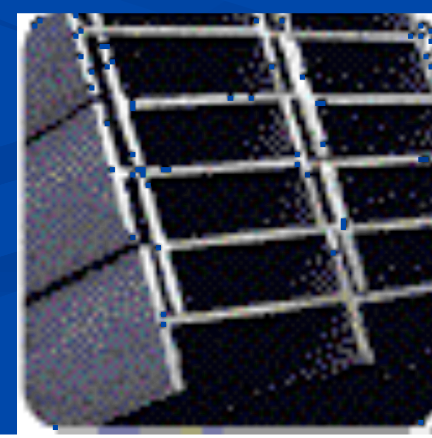

BLOOM
BILLET


Wire
Bars
Rail
Profiles and structurals
Beam

Rolling

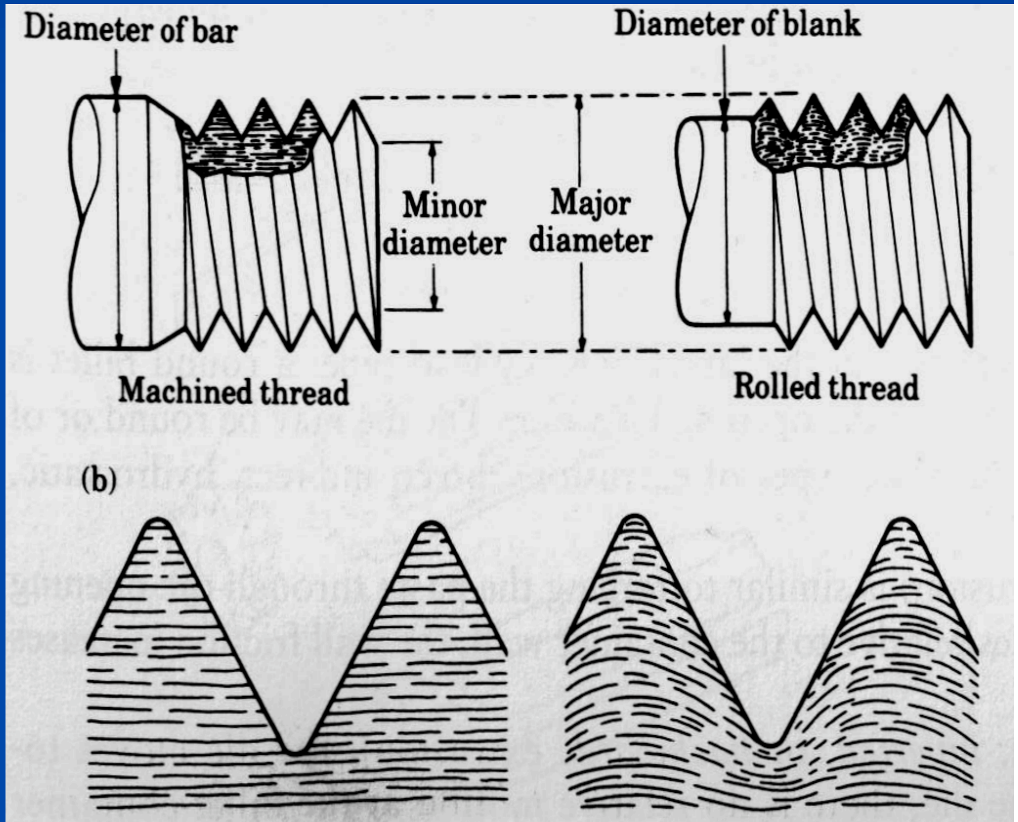






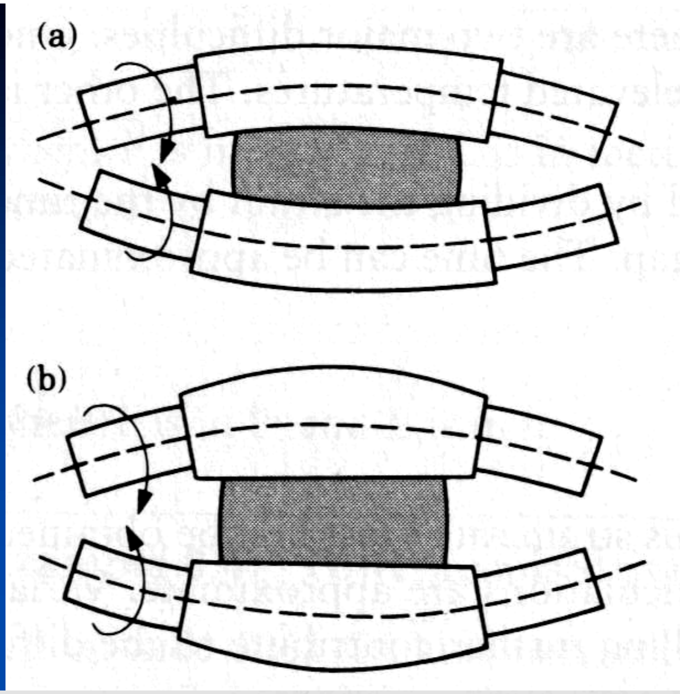
Rolled Threads

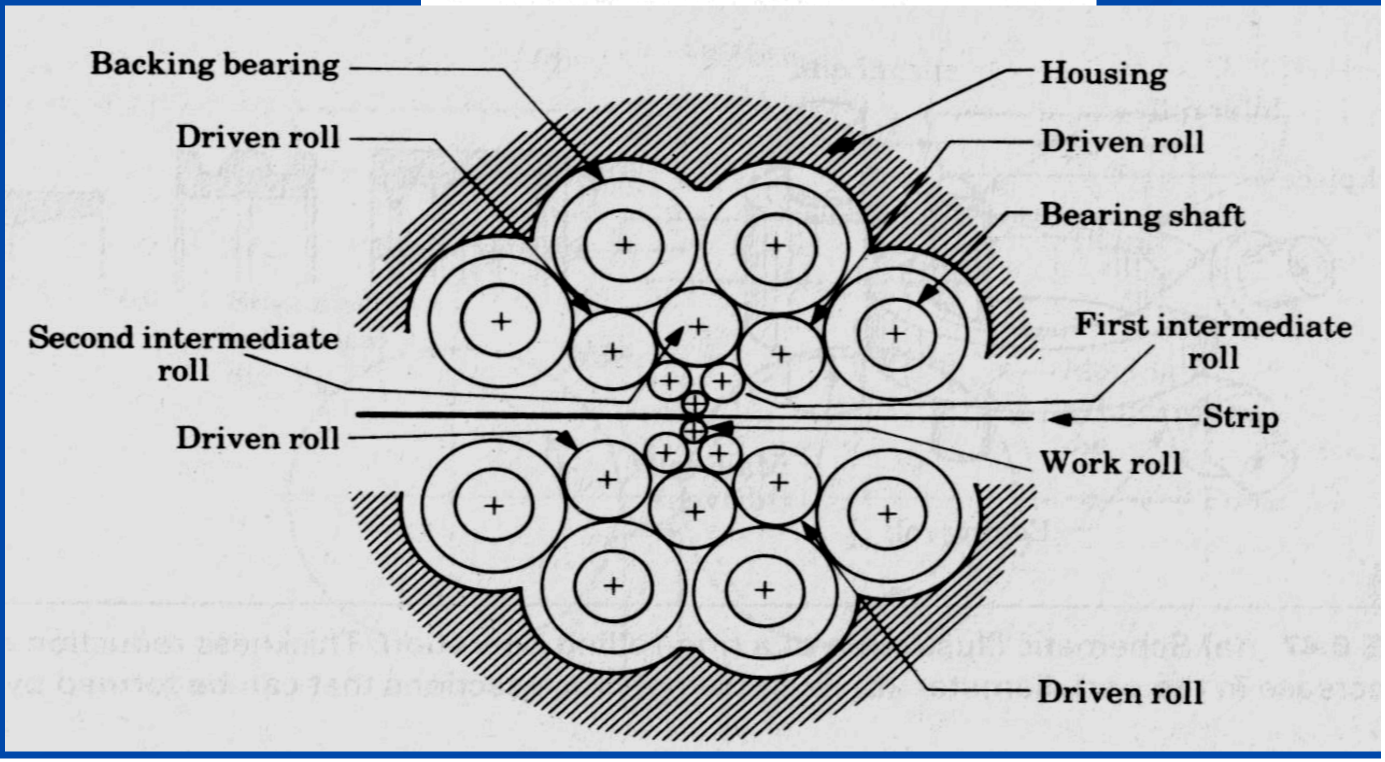
- Superior to machined
- Grain structure promotes longer life over machined threads



Complexities in rolling

- Bending of rolls





Rolling Defects

- Waviness
  - Improper roller speeds
- Zipper cracks
  - Too much rolling in center
- Edge cracks
  - Too much rolling on outside
- Alligator
  - Too much induced tensile stress in the part, or defects

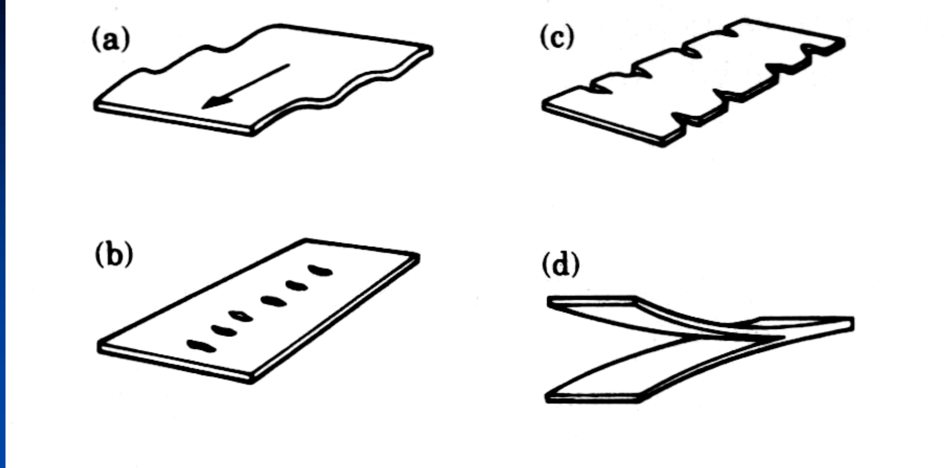


FIGURE 6.41 Schematic illustration of typical defects in flat rolling: (a) wavy edges; (b) zipper cracks in center of strip; (c) edge cracks; (d) alligatoring.

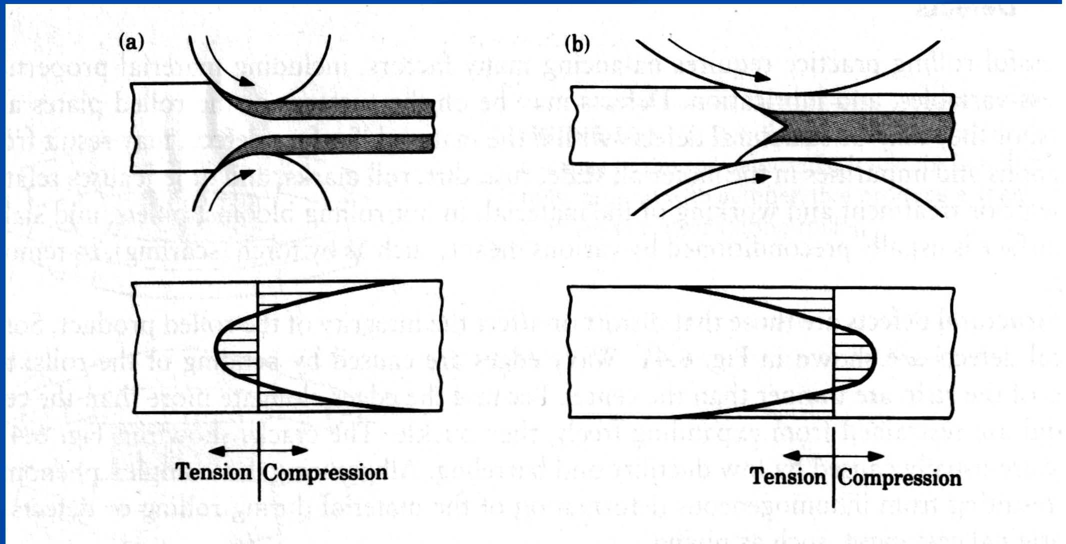
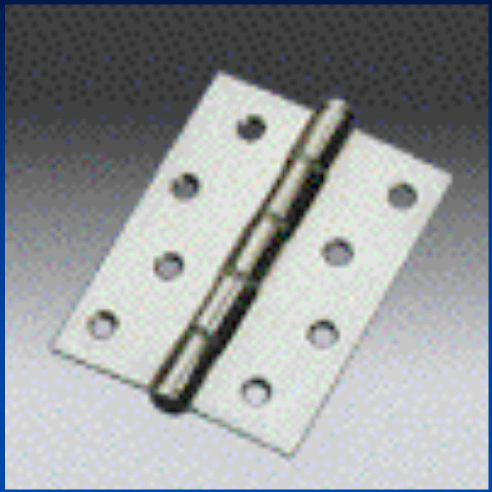


FIGURE 6.42 The effect of roll radius on the type of residual stresses developed in flat rolling: (a) small rolls, or small reduction; and (b) large rolls, or large reduction in thickness.

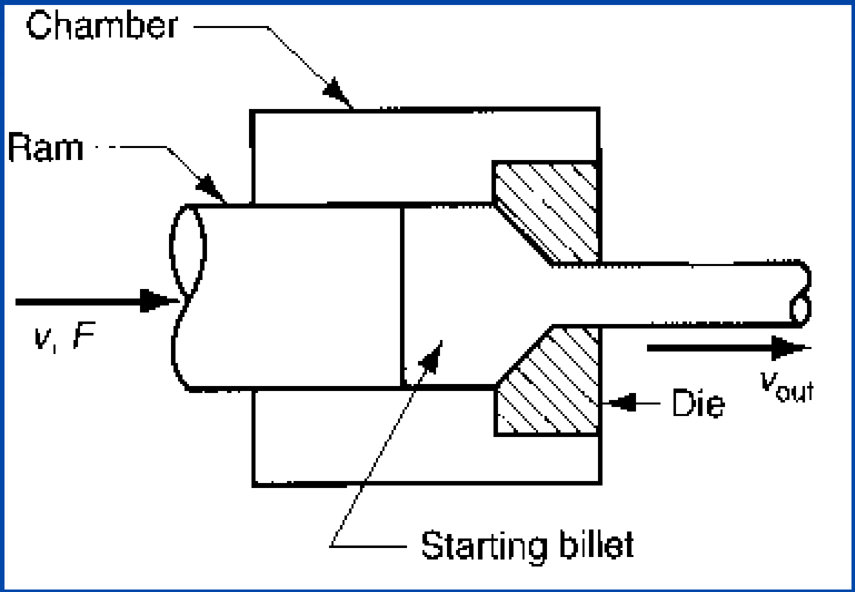
Extrusion



Extrusion

- A plastic deformation process in which metal is forces under pressure to flow through a single, or series of dies until the desired shape is produced.
- Advantages
  - Wide variety of shapes
  - High production rates
  - Improved microstructure and physical properties
  - Close tolerances are possible
  - Economical
  - Design flexibility

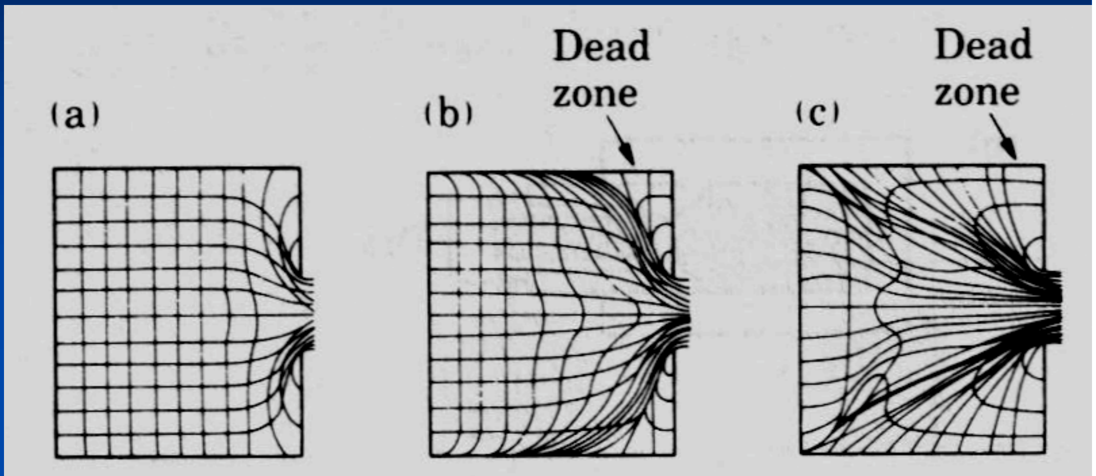
Direct Extrusion

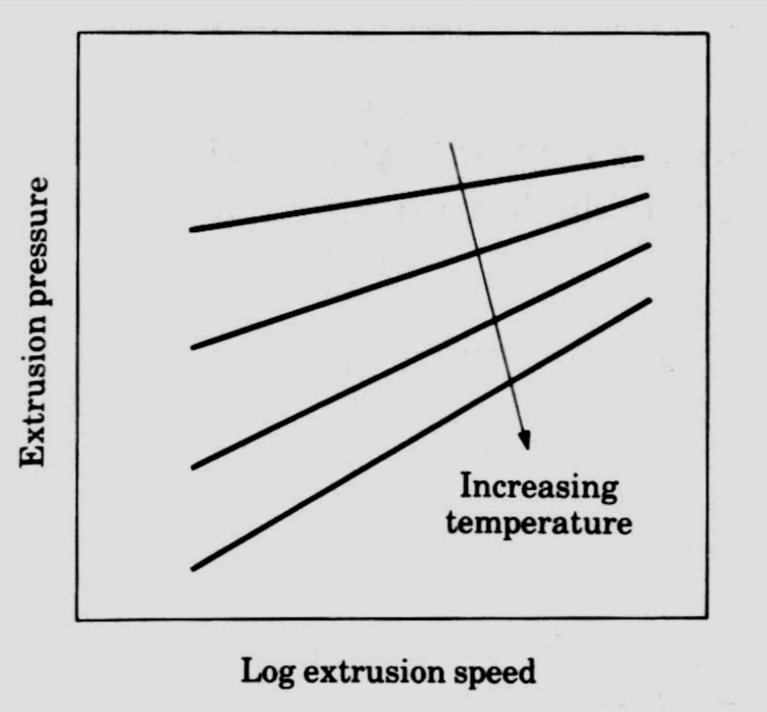


- Billet is forced out of die into desired shape
- Dies are machined to the desired cross-section
- Good process for long 2 _ D parts
- Controlling friction is the key to the process

Controlling Friction in Extrusion

- Friction controls the process
  - Surface Characteristics
  - Forces required
  - Material capability
  - Die Design
  - Die Wear





Complex Extrusion

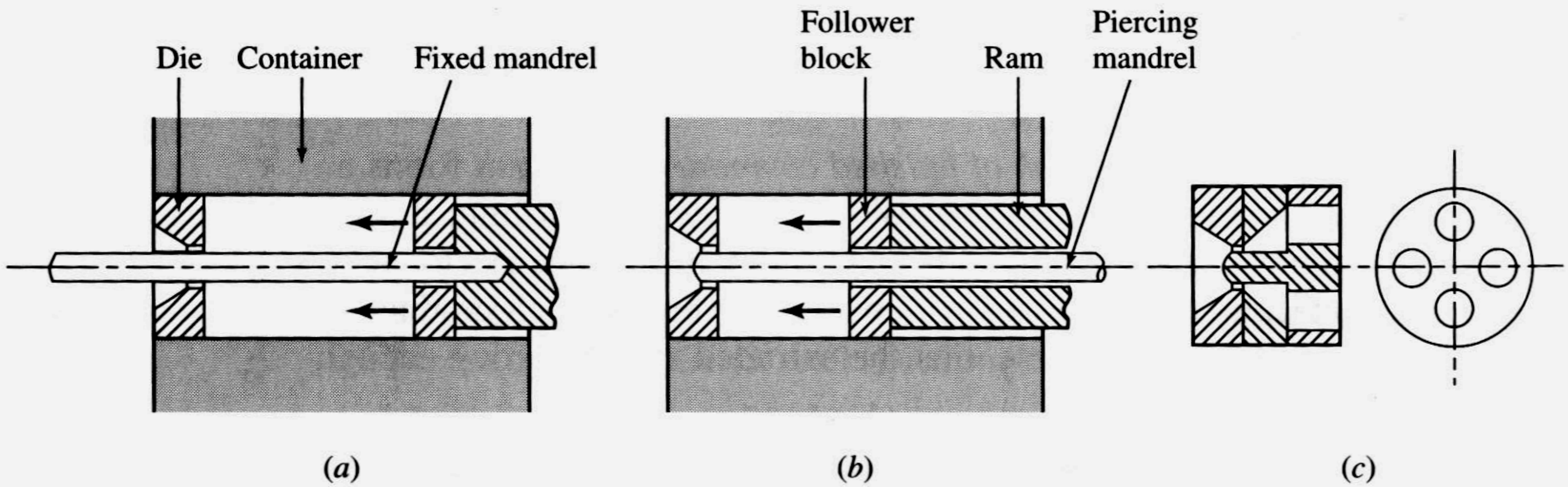
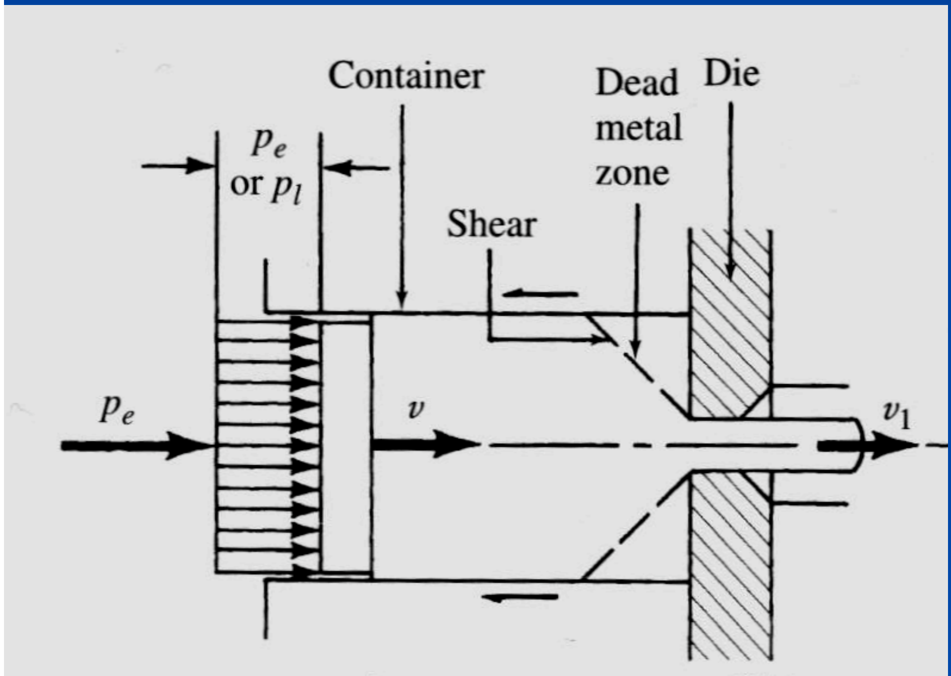


Figure 9–30 Hollow products may be extruded with (a) fixed or (b) piercing mandrels or with (c) bridge- or spider-type dies. [*After J.A. Schey, in Techniques of Metals Research, R.F. Bunshah* (*ed.*), *vol. 1, pt. 3, Interscience, 1968, p. 1494. With permission.*]

- Aluminum almost exclusively
- Hollow shapes possible and common

Dry Extrusion

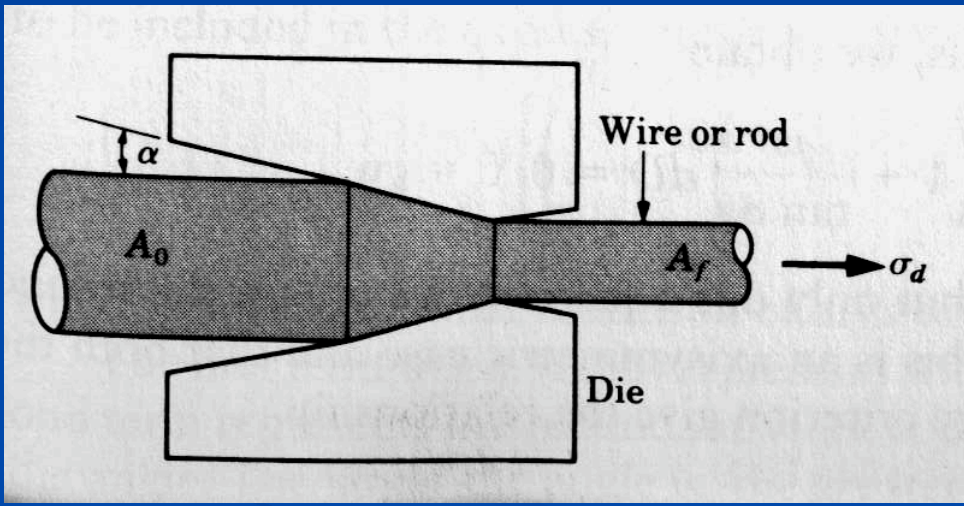


- Aluminum
- The dead metal zone is used to produce the part surface (sheared from bulk material)
- Parts are smooth with good surface finish

Extrusion – Process Control

- Major process control parameters:
  - Temperature
  - Extrusion Speed
  - Die Design

Drawing



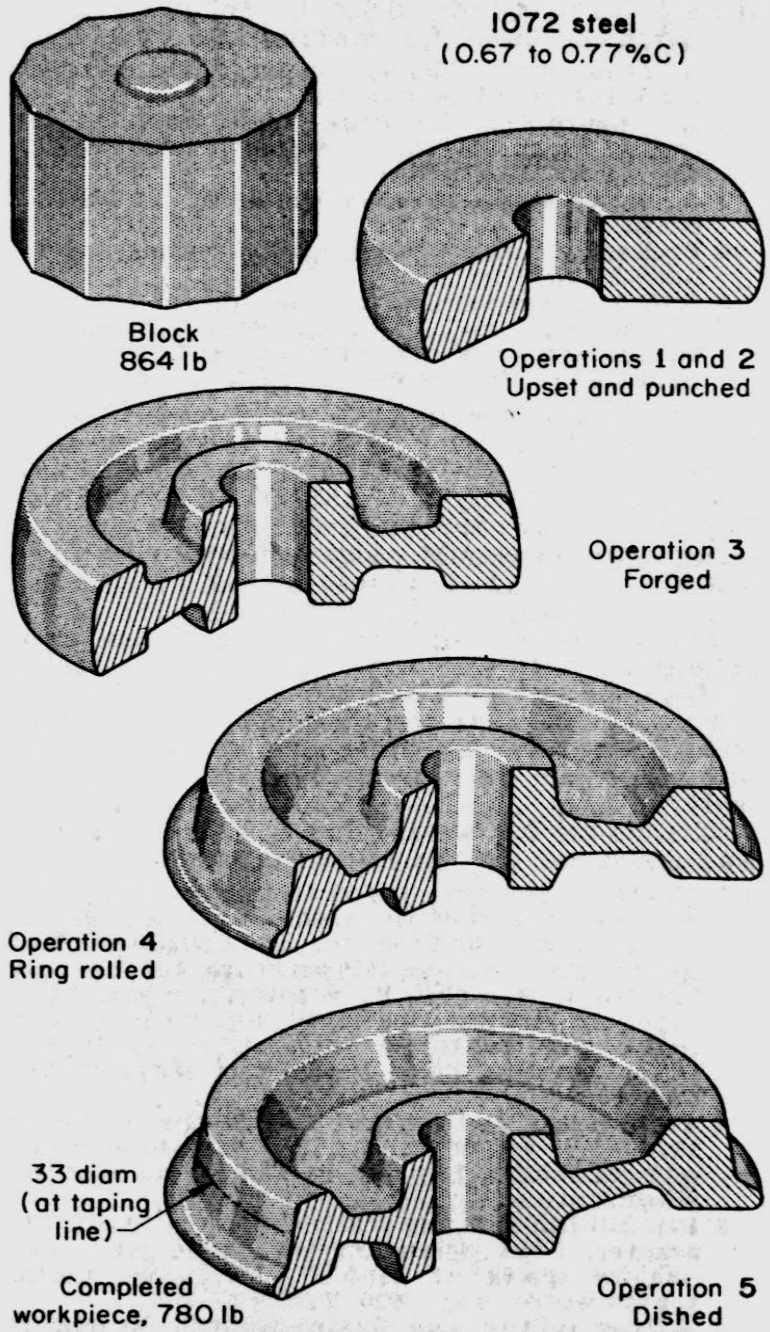


***Fig. 9. Steps in the forging and rolling of a railroad freight-car wheel* (Example 111)**

Summary

- Bulk Deformation is extremely common
- Most products require multiple steps/processes
- Example – Railroad Wheels