Global Manufacturing

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Metal Forming Processes [#8]

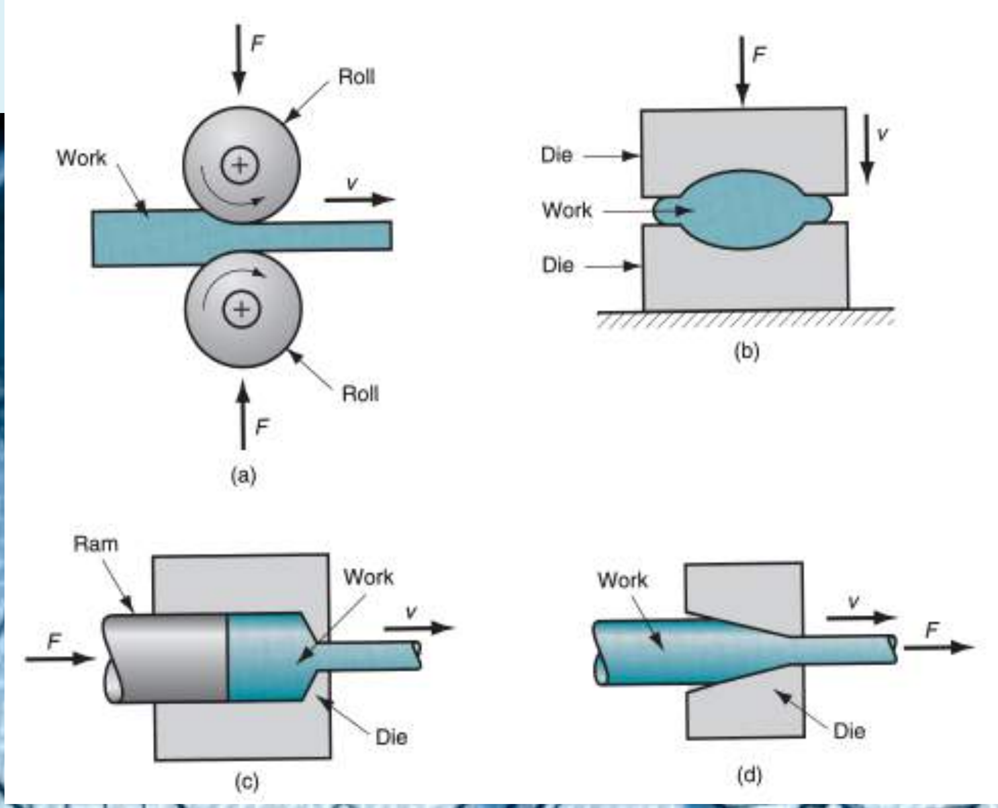
Forming Processes

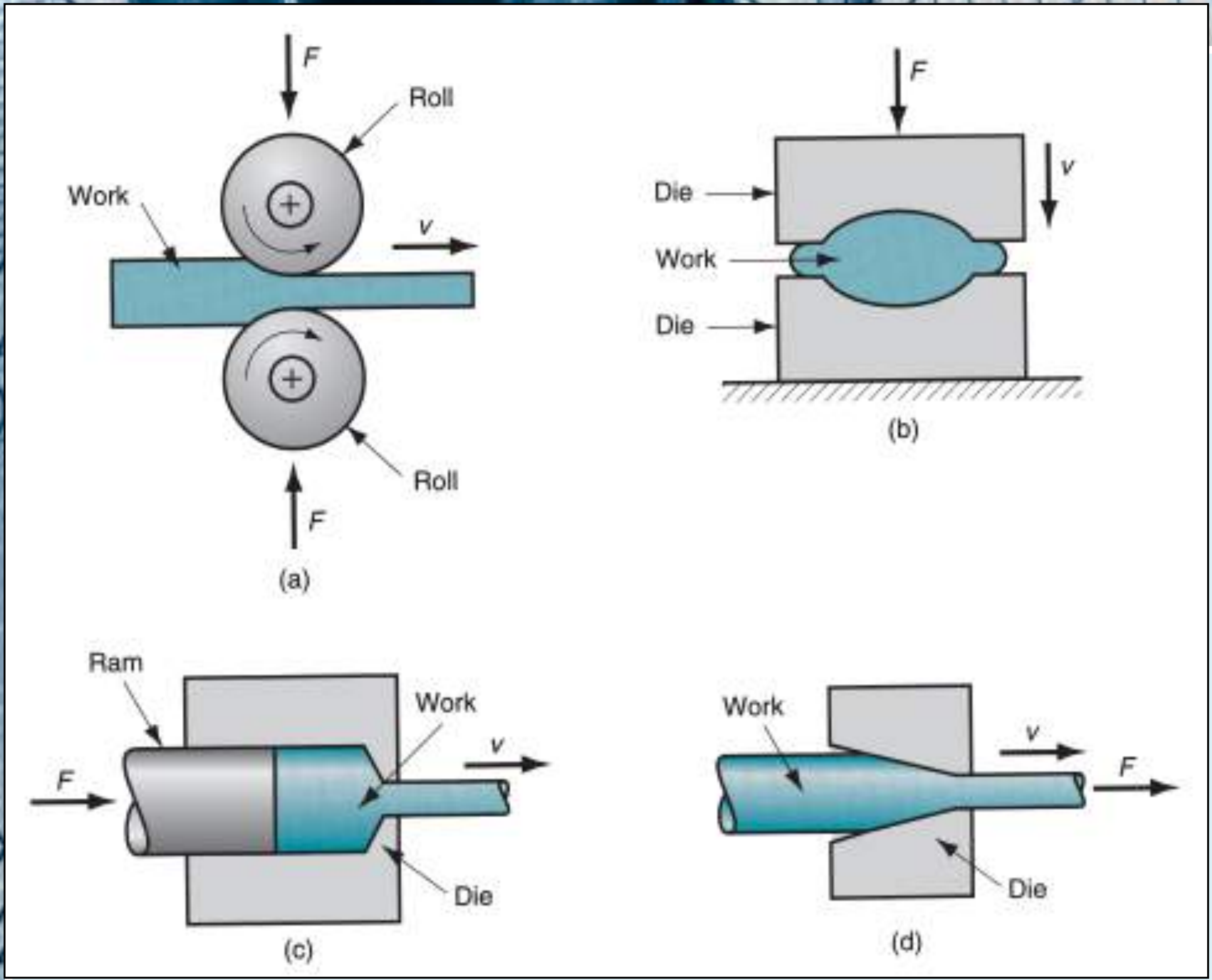
- How materials deforms permanelty?
- What are the differences from forming processes aplied to polymers and metals?
- What are the metal forming processes?
- What is the energy consuming in metal forming?
- How is the final process like?
- What is the production quantity?

"Globalization is the integration and interdependency of world markets and resources in producing consumer goods and services"

Bulk Deformation Processes

- Bulk deformation processes are generally characterized by significant deformations and massive shape changes, and the surface area–to-volume of the work is relatively small. The term bulk describes the workparts that have this low area-to-volume ratio. Starting work shapes for these processes include cylindrical billets and rectangular bars.





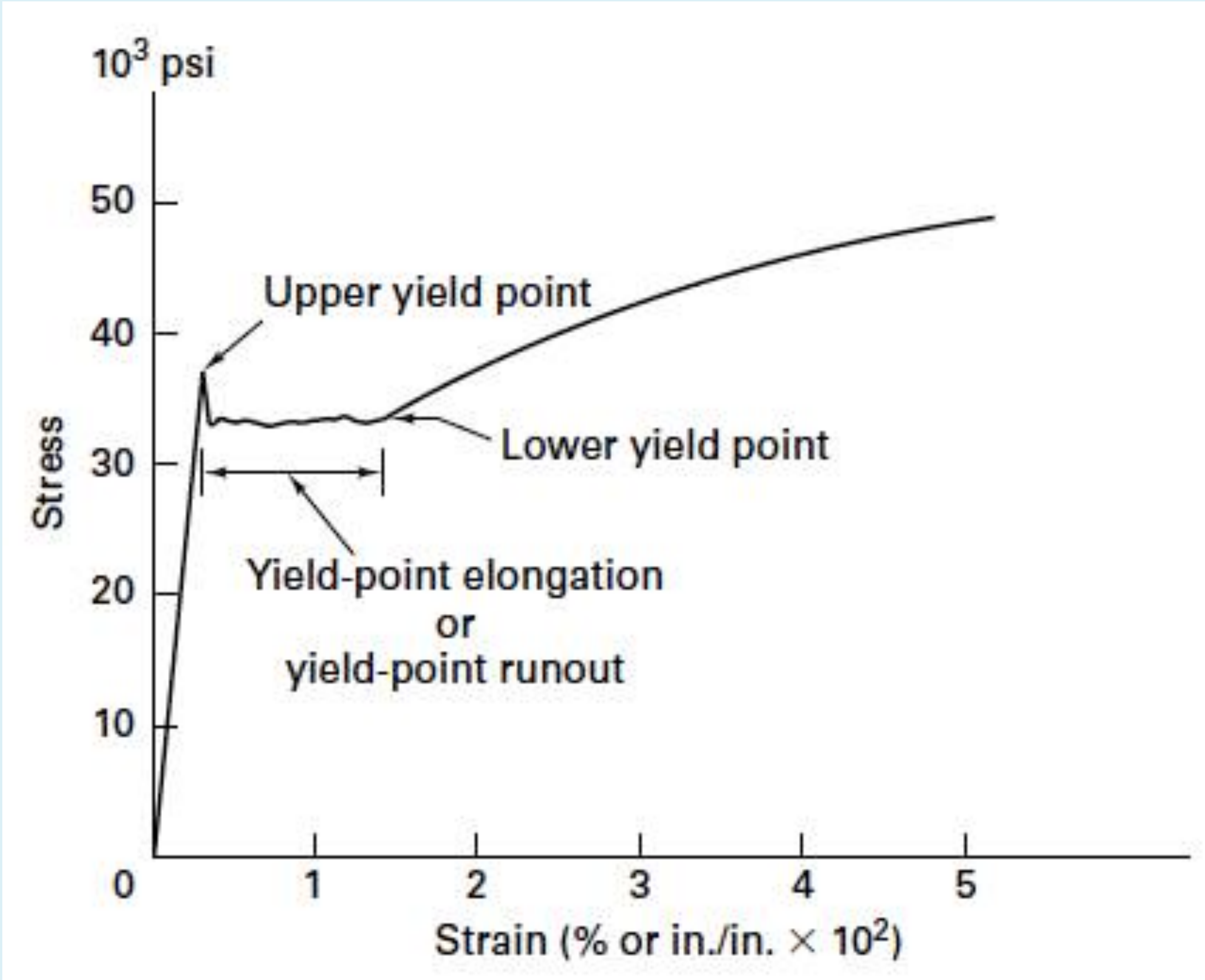
Forging: In forging, a workpiece is compressed between two opposing dies, so that the die shapes are imparted to the work. Forging is traditionally a hot working process, but many types of forging are performed cold.

Drawing: In this forming process, the diameter of a round wire or bar is reduced by pulling it through a die opening.

Extrusion: This is a compression process in which the work metal is forced to flow through a die opening, thereby taking the shape of the opening as its own cross section.

Rolling: This is a compressive deformation process in which the thickness of a slab or plate is reduced by two opposing cylindrical tools called rolls. The rolls rotate so as to draw the work into the gap between them and squeeze it.

Metal Plasticity (Yielding) [Uniaxial stress]



True stress and strain. If the tensile tests are used to predict how the material will behave under other forms of loading, true stress–true strain curves are useful. The true stress is defined as

$$\sigma = F/A, \tag{3.4}$$

where A is the instantaneous cross-sectional area corresponding to the force F. Before necking begins, the true strain is given by

$$\varepsilon = \ln(L/L_o). \tag{3.5}$$

The engineering stress is defined as the force divided by the original area, $s = F/A_o$, and the engineering strain is defined as the change in length divided by the original length, $e = \Delta L/L_o$. As long as the deformation is uniform along the gauge length, the true stress and true strain can be calculated from the engineering quantities. With constant volume, $LA = L_oA_o$, so that

$$A_o/A = L/L_o, \tag{3.6}$$

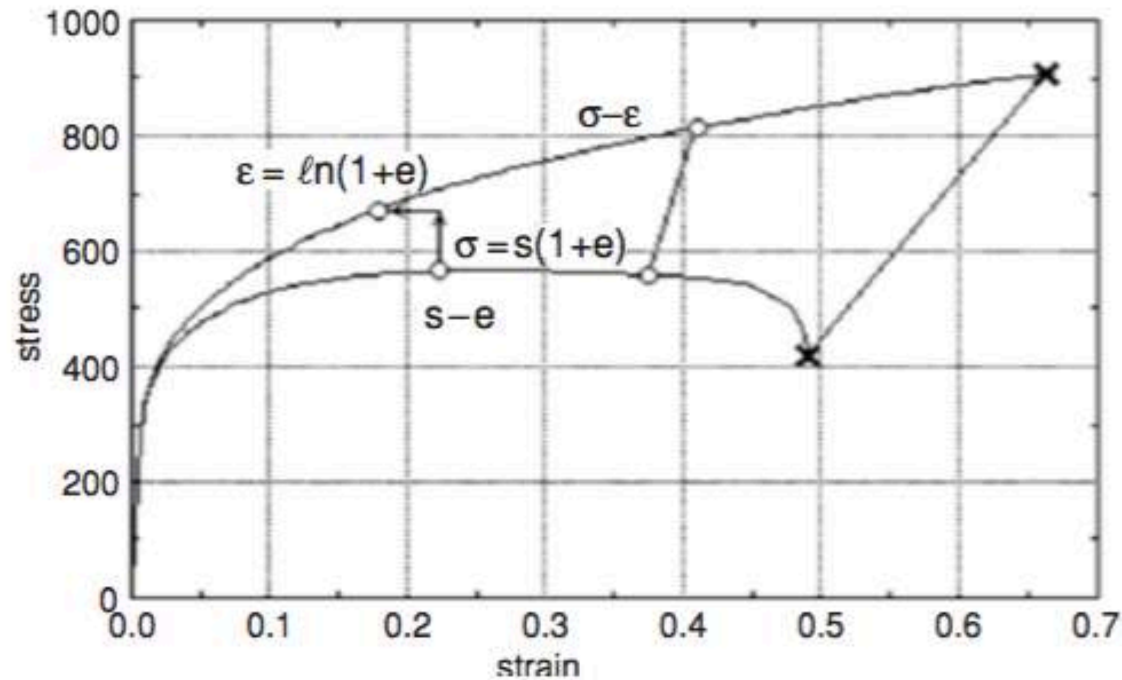
and thus $A_o/A = 1 + e$. Rewriting Equation (3.4) as $\sigma = (F/A_o)(A_o/A)$ and substituting $A_o/A = 1 + e$ and $s = F/A_o$,

$$\sigma = s(1 + e). \tag{3.7}$$

Substitution of $L/L_o = 1 + e$ into Equation (3.5) gives

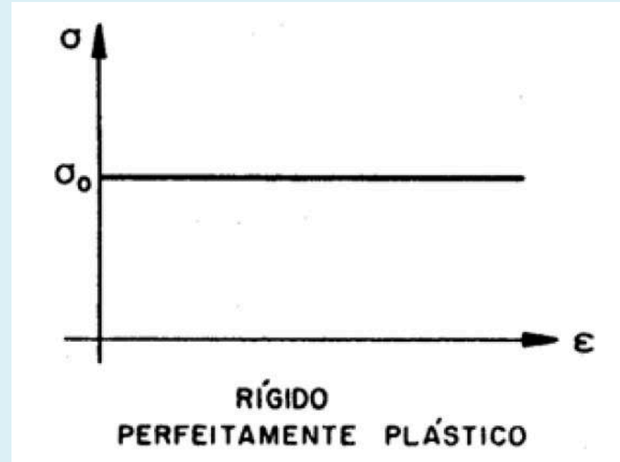
$$\varepsilon = \ln(1 + e). \tag{3.8}$$

Figure 3.9. Comparison of engineering and true stress–strain curves. Before necking, a point on the true stress–strain curve (σ–ε) can be constructed from a point on the engineering stress–strain curve (s–e) with Equations (3.7) and (3.8). After necking, the cross-sectional area at the neck must be measured to find the true stress and strain.

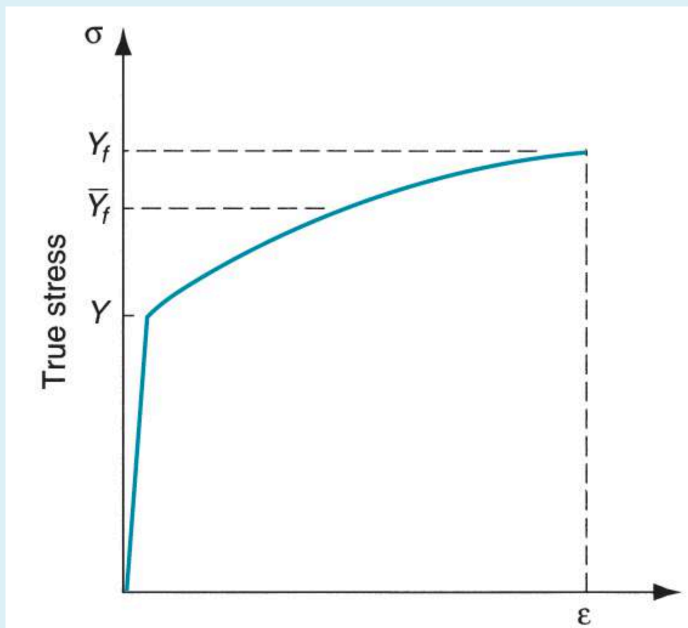


Models for Plasticity

- Rigid Plastic

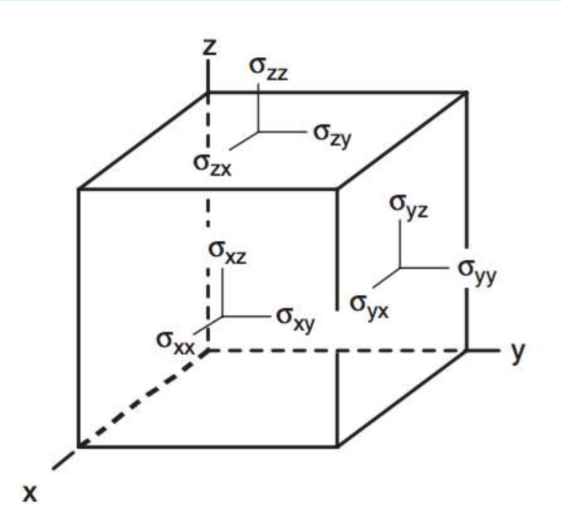


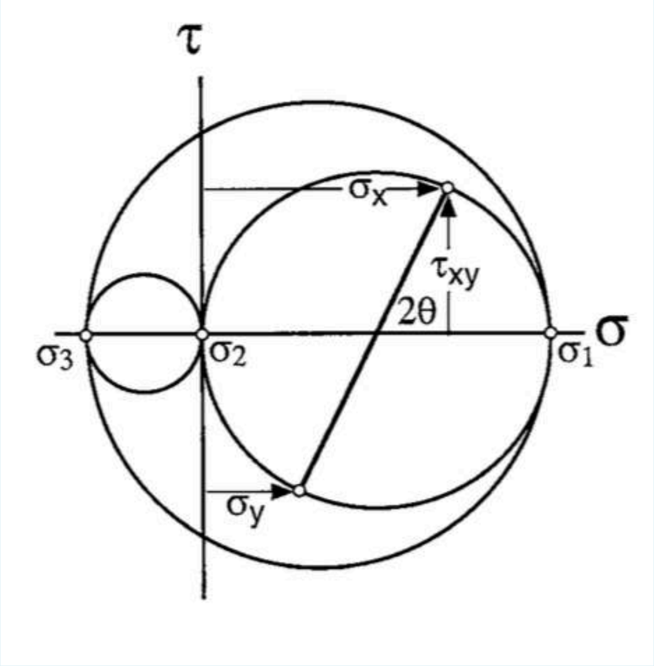
- Hardening



$$\overline{Y}_f = \frac{K\epsilon^n}{1+n}$$

Principal Stresses





Principal stresses. It is always possible to find a set of axes (1, 2, 3) along which the shear stress components vanish. In this case the normal stresses, σ_1, σ_2, and σ_3, are called *principal stresses* and the 1, 2, and 3 axes are the *principal stress axes*. The magnitudes of the principal stresses, σ_p, are the three roots of

$$\sigma_p{}^3 - I_1\sigma_p{}^2 - I_2\sigma_p - I_3 = 0, \tag{1.11}$$

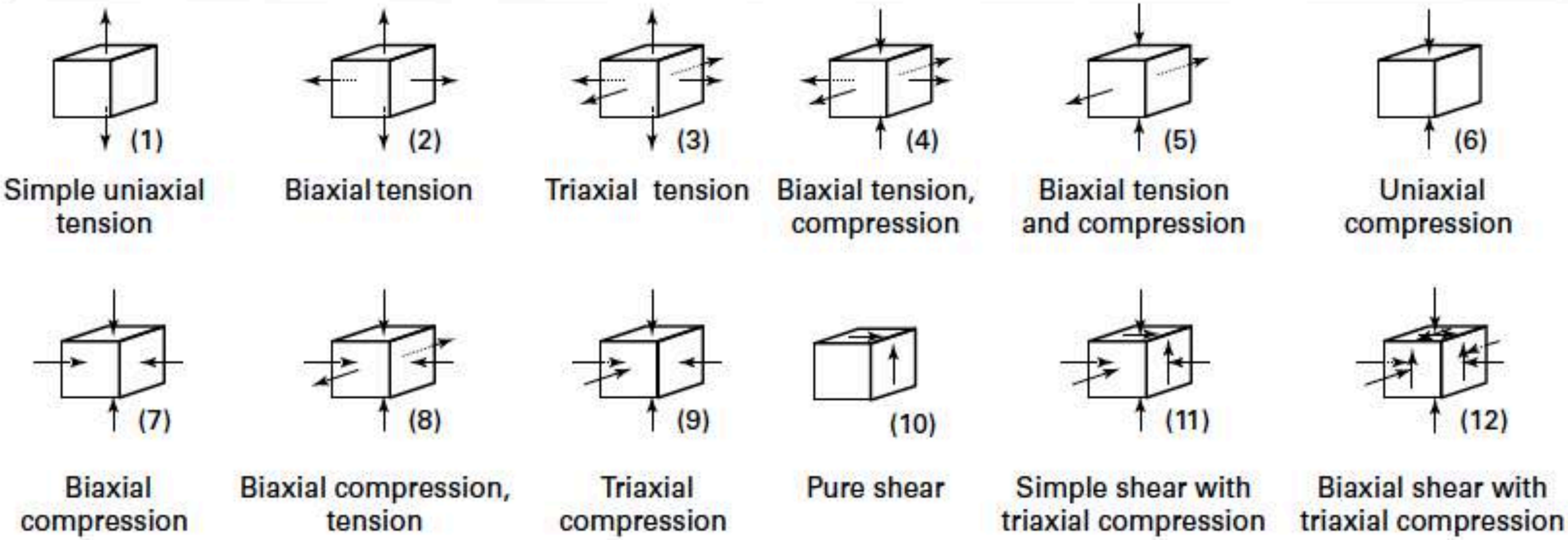
where

$$I_1 = \sigma_{xx} + \sigma_{yy} + \sigma_{zz},$$
$$I_2 = \sigma_{yz}{}^2 + \sigma_{zx}{}^2 + \sigma_{xy}{}^2 - \sigma_{yy}\sigma_{zz} - \sigma_{zz}\sigma_{xx} - \sigma_{xx}\sigma_{yy}, \tag{1.12}$$

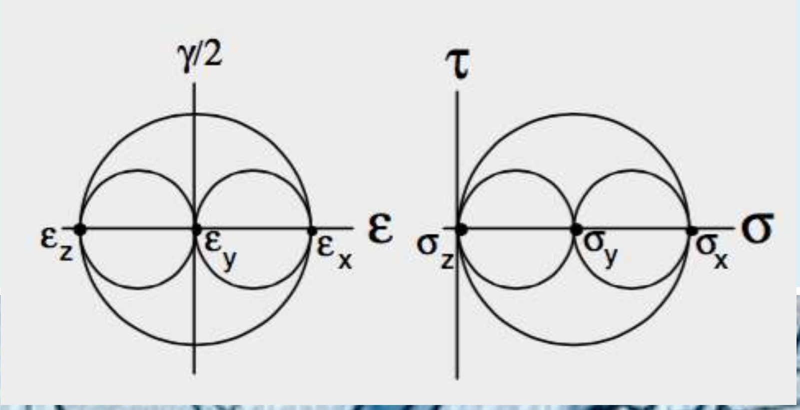
and

$$I_3 = \sigma_{xx}\sigma_{yy}\sigma_{zz} + 2\sigma_{yz}\sigma_{zx}\sigma_{xy} - \sigma_{xx}\sigma_{yz}{}^2 - \sigma_{yy}\sigma_{zx}{}^2 - \sigma_{zz}\sigma_{xy}{}^2.$$

TABLE 15-1 Classification of States of Stress



Plain Strain (ey=0;Sz=0)



Yield criteria

The concern here is to describe mathematically the conditions for yielding under complex stresses. A *yield criterion* is a mathematical expression of the stress states that will cause yielding or plastic flow. The most general form of a yield criterion is

$$f(\sigma_x, \sigma_y, \sigma_z, \tau_{yz}, \tau_{zx}, \tau_{xy}) = C, \tag{6.1}$$

where C is a material constant. For an isotropic material this can be expressed in terms of principal stresses,

$$f(\sigma_1, \sigma_2, \sigma_3) = C. \tag{6.2}$$

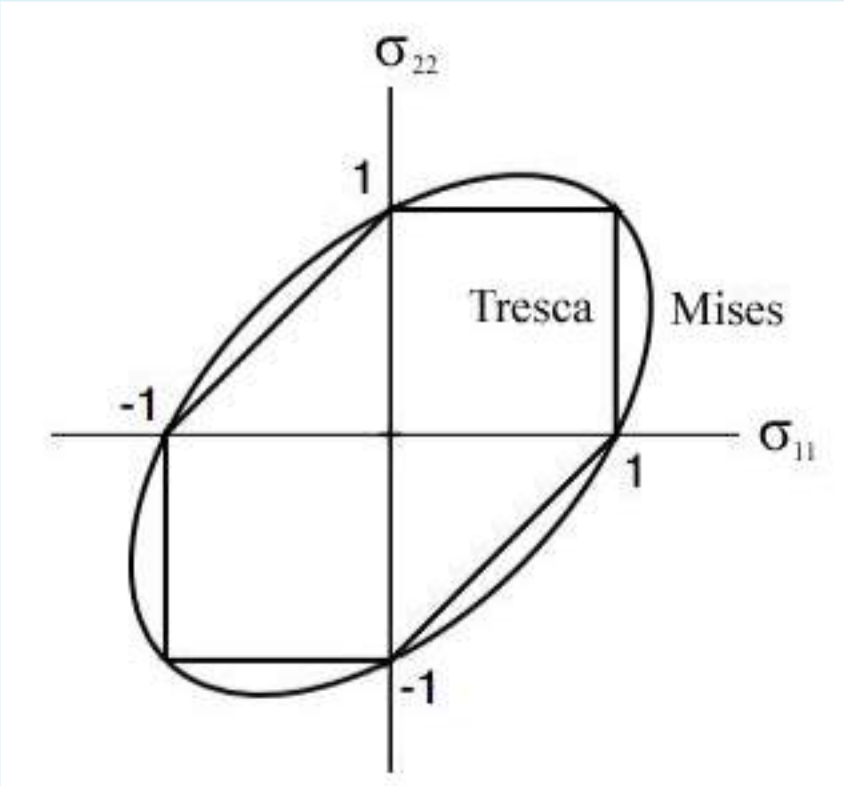
The yielding of most solids is independent of the sign of the stress state. Reversing the signs of all the stresses has no effect on whether a material yields. This is consistent with the observation that for most materials, the yield strengths in tension and compression are equal.* Also, with most solid materials, it is reasonable to assume that yielding is independent of the level of mean normal stress,

$$\sigma_m = (\sigma_1 + \sigma_2 + \sigma_3)/3. \tag{6.3}$$

It will be shown later that this is equivalent to assuming that plastic deformation causes no volume change. This assumption of constancy of volume is certainly reasonable for crystalline materials that deform by slip and twinning because these mechanisms involve only shear. With slip and twinning only the shear stresses are important. With this simplification, the yield criteria must be of the form

$$f[(\sigma_2 - \sigma_3), (\sigma_3 - \sigma_1), (\sigma_1 - \sigma_2)] = C. \tag{6.4}$$

Failure Criteria (Isotropic Materials)



Tresca maximum shear stress criterion:
The simplest yield criterion is one firs proposed by Tresca. It states that yielding wil occur when the largest shear stress reaches a critical value.
The largest shear stress is $\tau_{max} = (\sigma_{max} - \sigma_{min})/2$

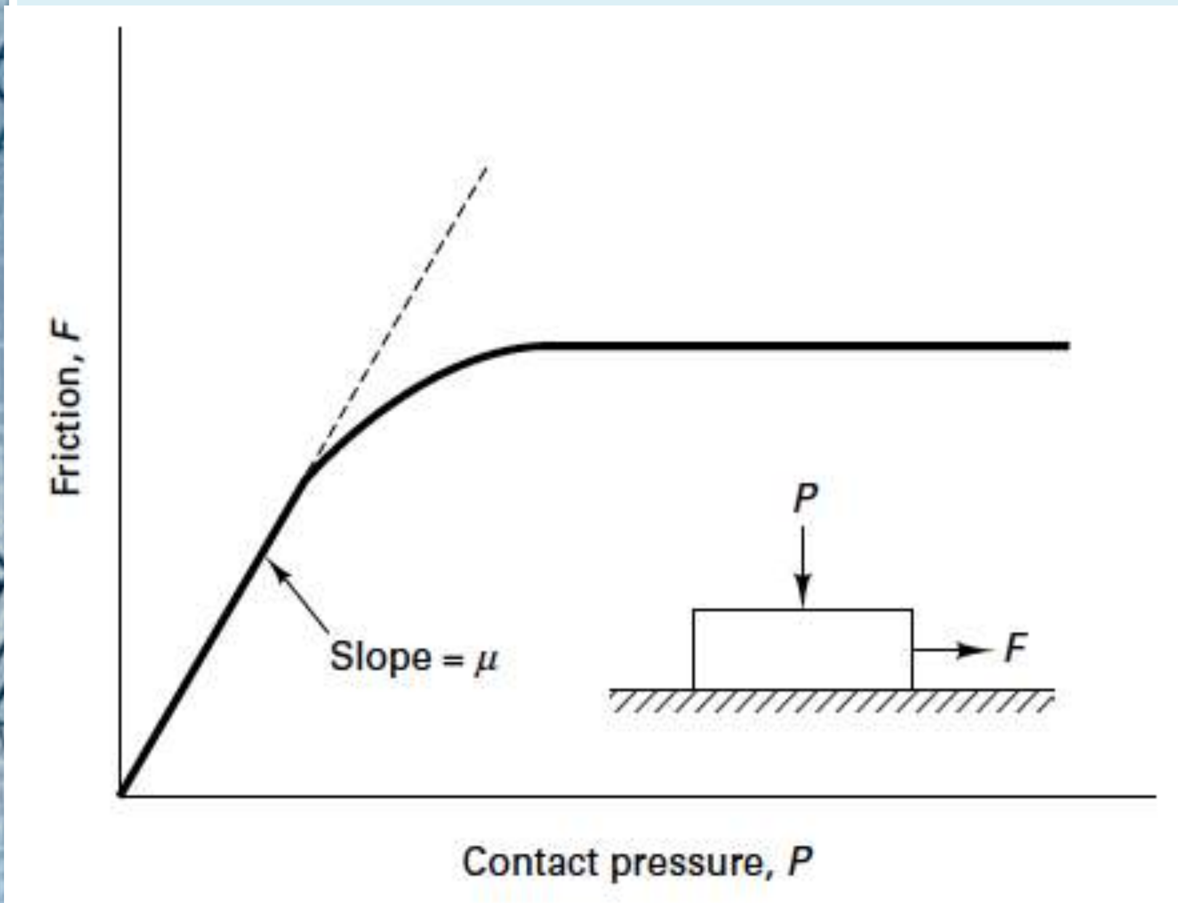
$$\sigma_{\max} - \sigma_{\min} = C.$$

$$\sigma_1 - \sigma_3 = Y.$$

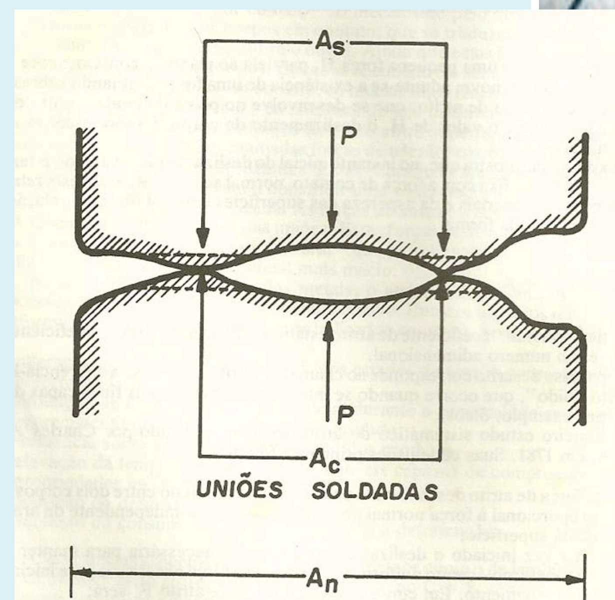
Von Mises criterion: The effect of th intermediate principal stress can be included b assuming that yielding depends on the root mean-square diameter of the three Mohr' circles.

$$\left\{\left[(\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 + (\sigma_1 - \sigma_2)^2\right]/3\right\}^{1/2} = C$$

Friction (Coulomb and Sticking/Adhesion)



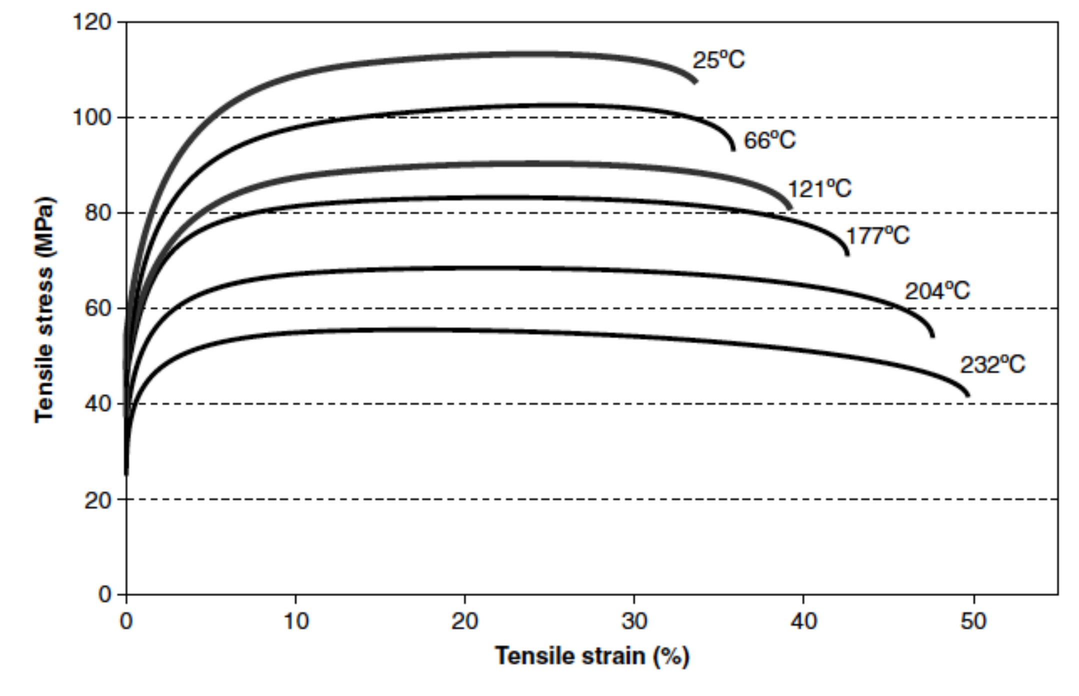
Nominal Contact Area – An
Real Contact Area - As



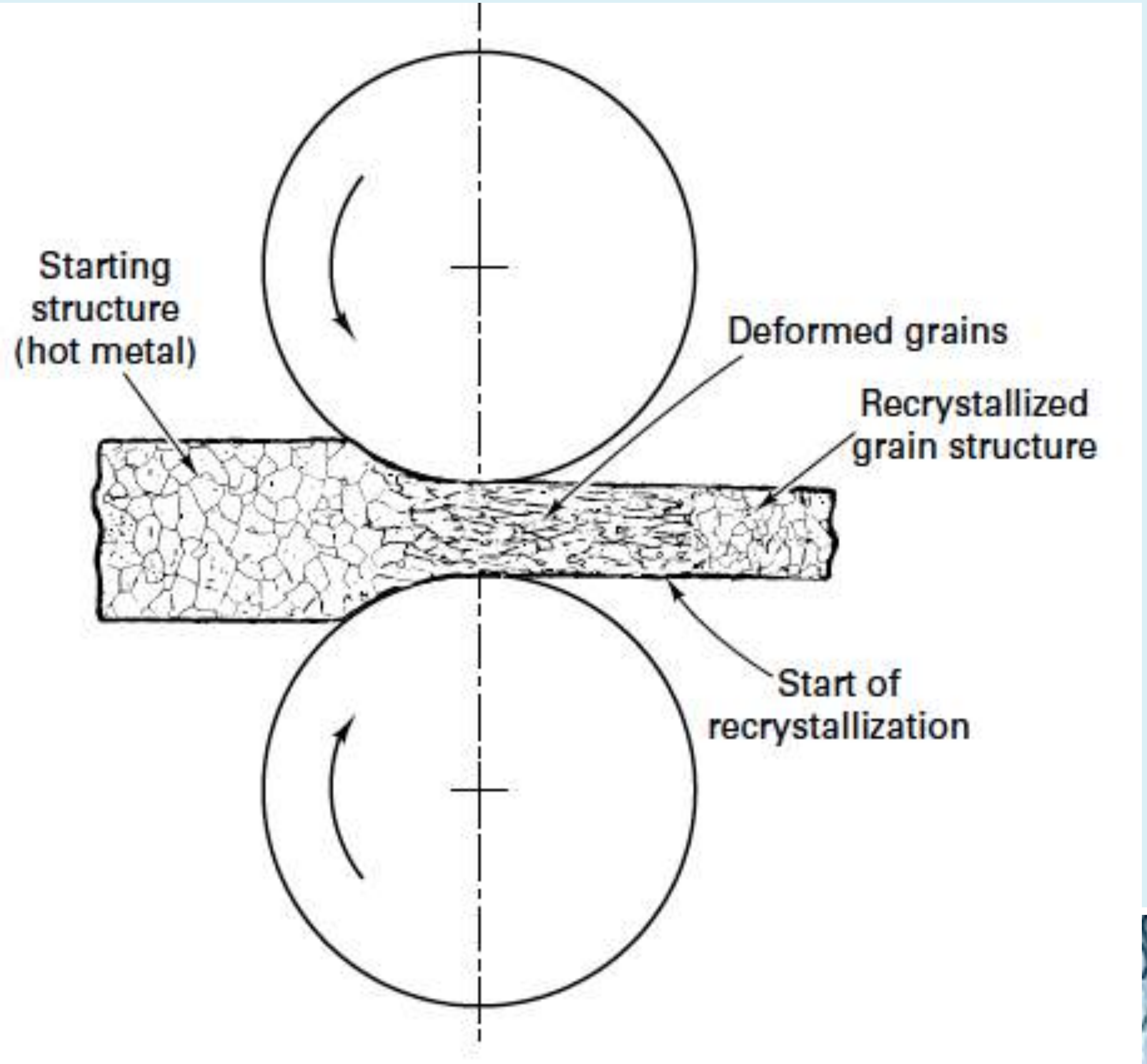
Temperature (Hot and Cold Forming)

TABLE 12.1 Typical values of temperature (relative to melting point T_m) and coefficient of friction in cold, warm, and hot working

Category	Temperature Range	Coefficient of Friction
Cold working	$\leq 0.3T_m$	0.1
Warm working	$0.3T_m$–$0.5T_m$	0.2
Hot working	$0.5T_m$–$0.75T_m$	0.4–0.5



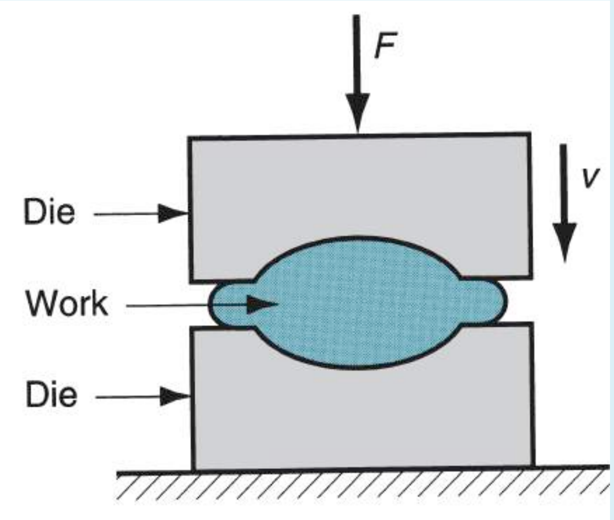
Recrystalization in hot forming

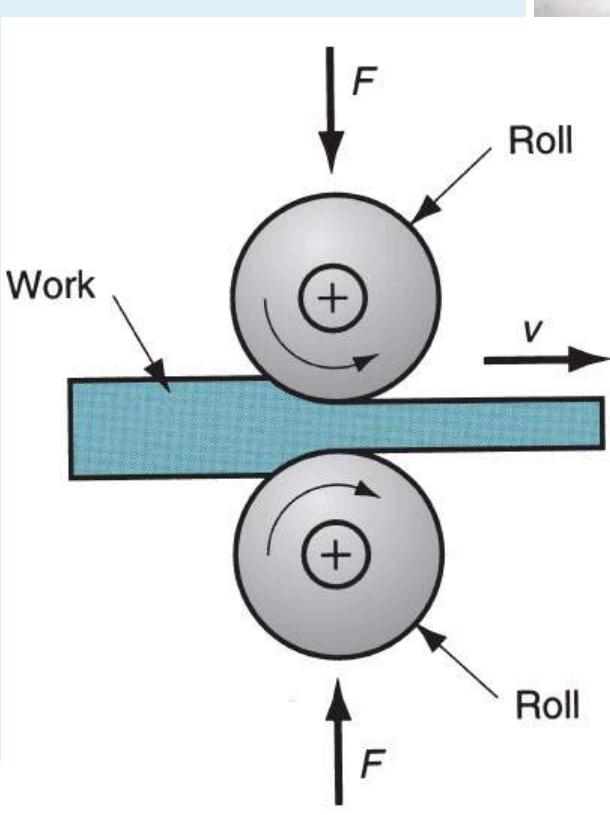


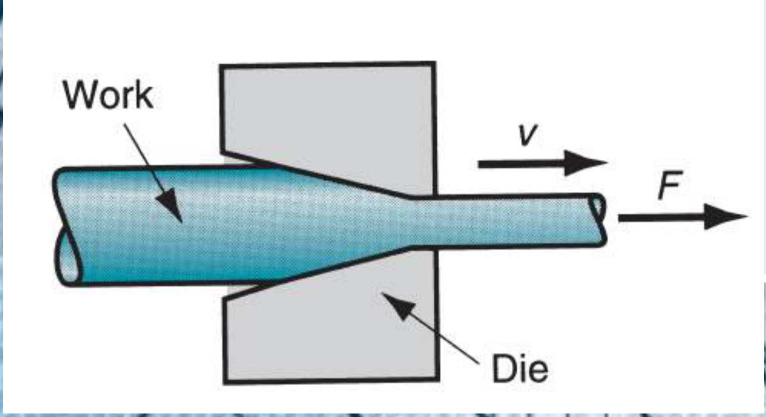
Independent variables	Links	Dependent variables
Starting material		Force or power requirements
Starting geometry	-Experience-	Product properties
Tool geometry		Exit temperature
Lubrication	-Experiment-	Surface finish
Starting temperature		Dimensional precision
Speed of deformation	-Modeling-	Material flow details
Amount of deformation		

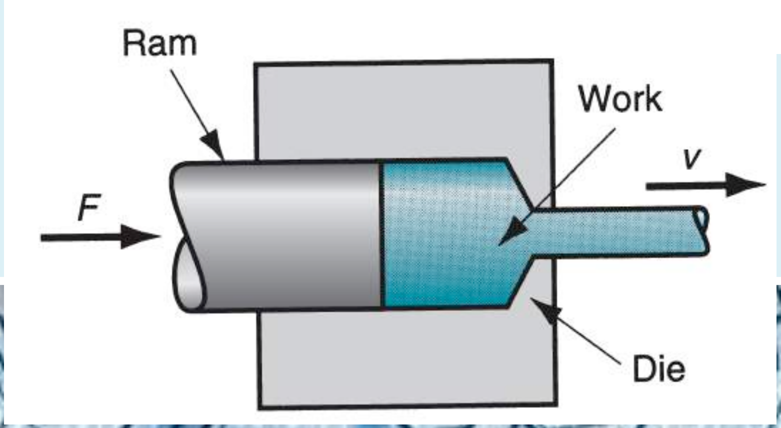
PROCESSOS DE CONFORMAÇÃO VOLUMÉTRICA (BULK PROCESSES)

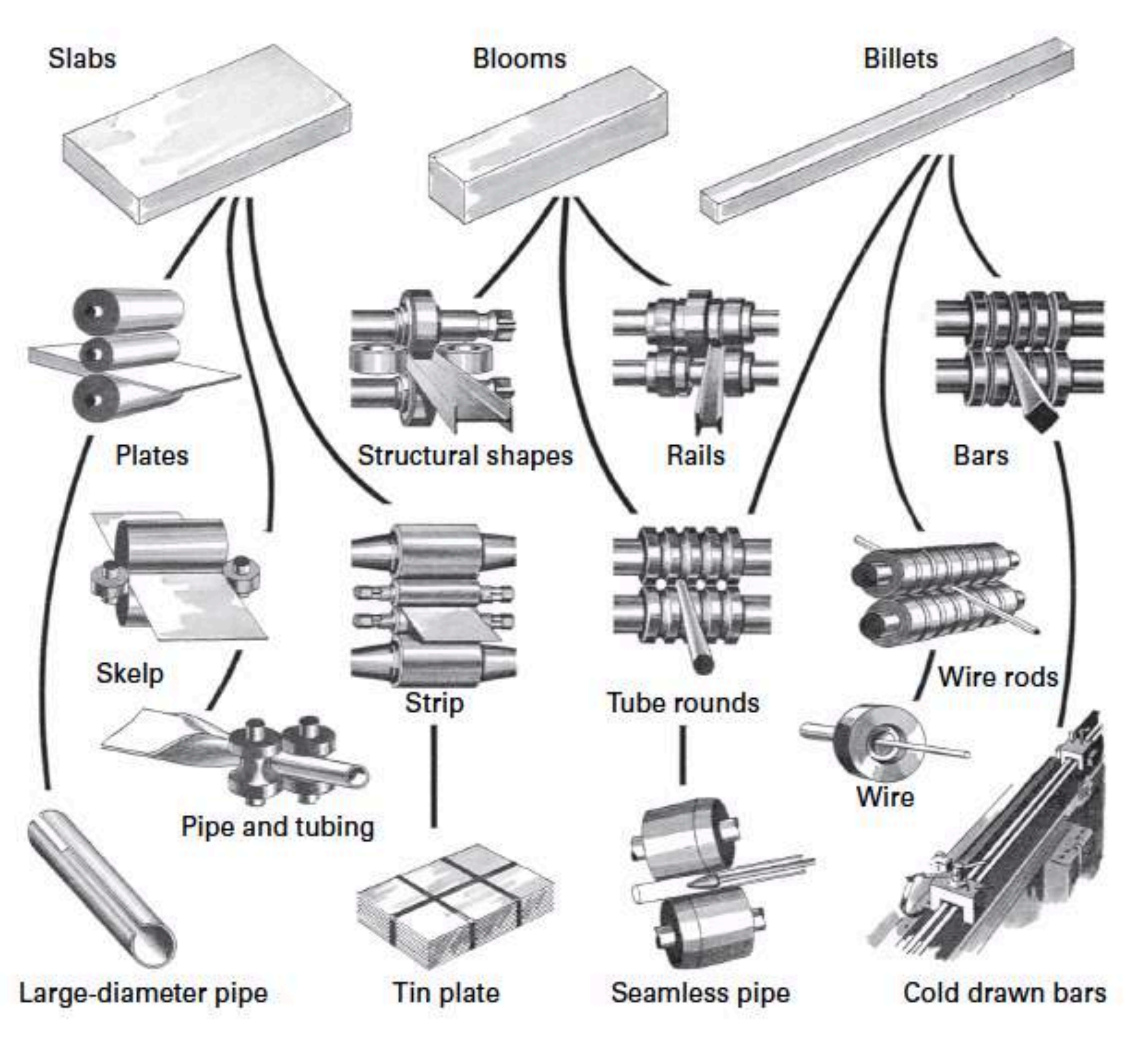
- FORJAMENTO
- LAMINACAO
- TREFILACAO
- EXTRUSAO










Slabs
Blooms
Billets
Plates
Structural shapes
Rails
Bars
Skelp
Strip
Tube rounds
Wire rods
Pipe and tubing
Wire
Large-diameter pipe
Tin plate
Seamless pipe
Cold drawn bars

Forging – Open Die

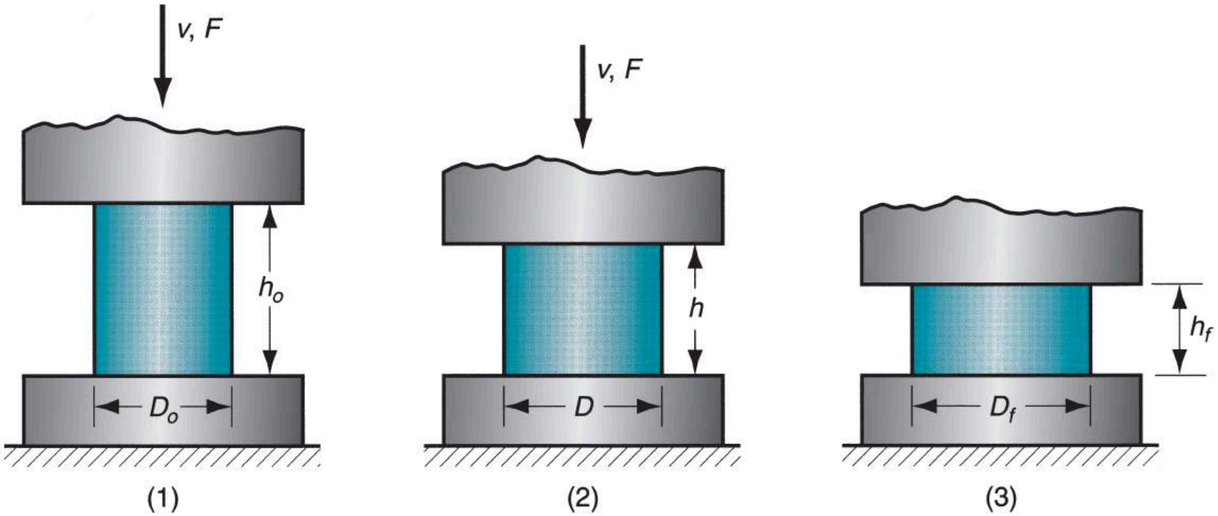


FIGURE 13.10 Homogeneous deformation of a cylindrical workpart under ideal conditions in an open-die forging operation: (1) start of process with workpiece at its original length and diameter, (2) partial compression, and (3) final size. (Credit: *Fundamentals of Modern Manufacturing,* 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

$$\epsilon = \ln \frac{h_o}{h}$$

$$F = Y_f A$$

Forces in Open Die Forming
Homogeneous Strain Method with Friction

$$F = K_f Y_f A$$

$$K_f = 1 + \frac{0.4\mu D}{h}$$

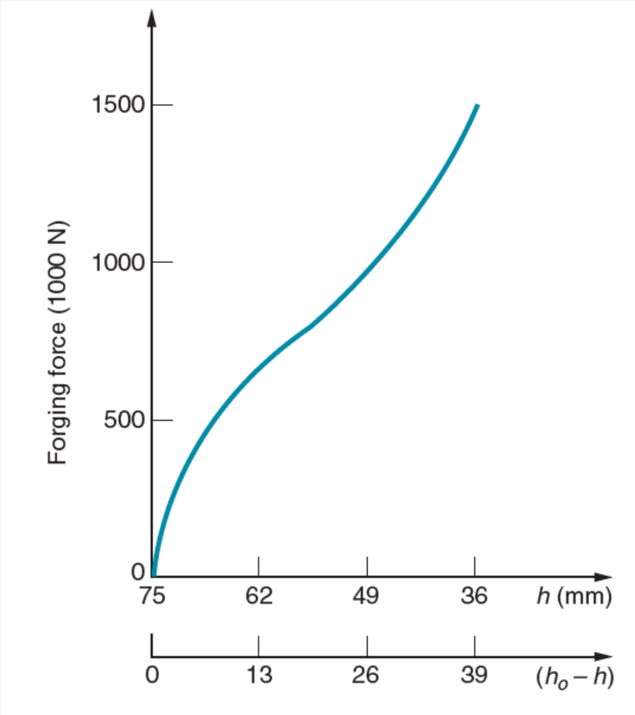


TABLE 13.1 Typical K_f values for various part shapes in impression-die and flashless forging

Impression-die forging	K_f	Flashless forging	K_f
Simple shapes with flash	6.0	Coining (top and bottom surfaces)	6.0
Complex shapes with flash	8.0	Complex shapes	8.0
Very complex shapes with flash	10.0		

Contact / Pressure Distribution on the Die (N/mm)
Coulomb Friction

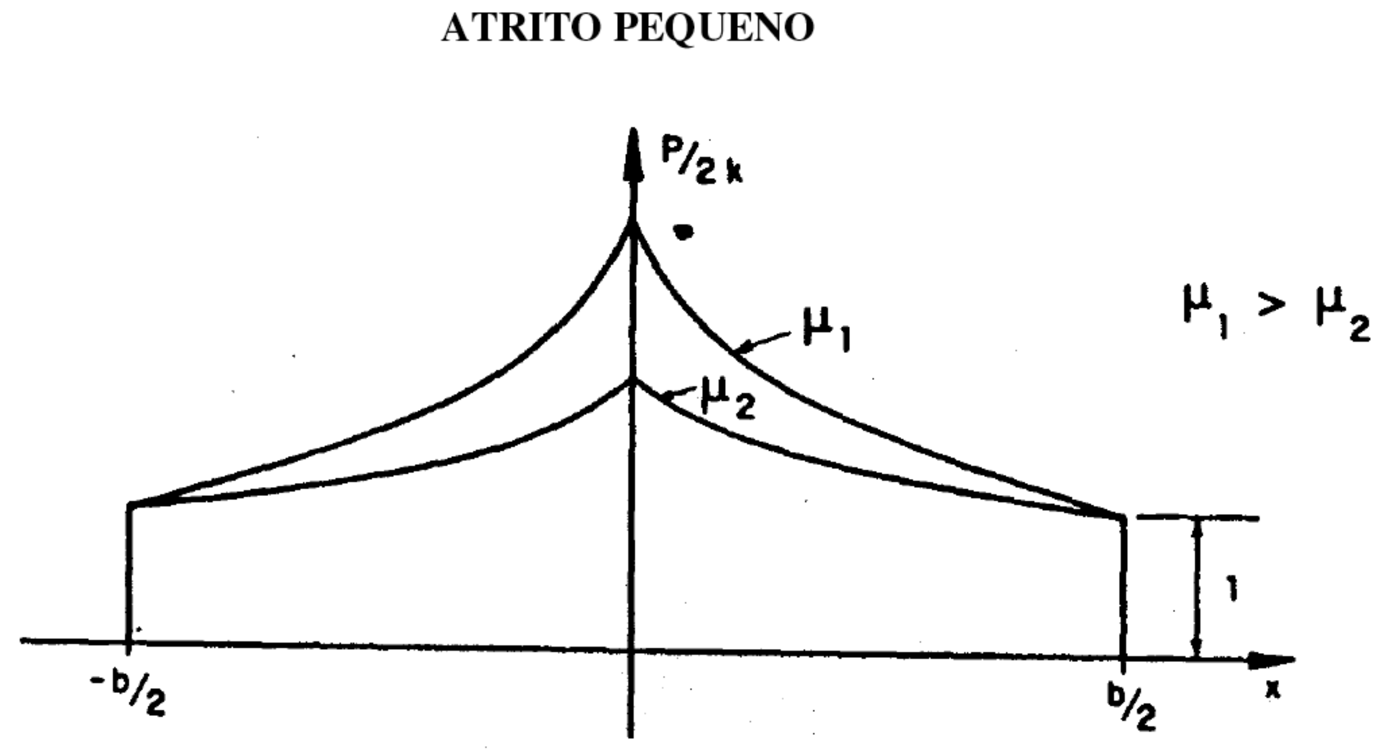


Figura 5.4 - Distribuição da pressão p para um dado instante.

Contact / Pressure Distribution on the Die (N/mm)
Adhesion/Stiking Friction and Partial Adhesion

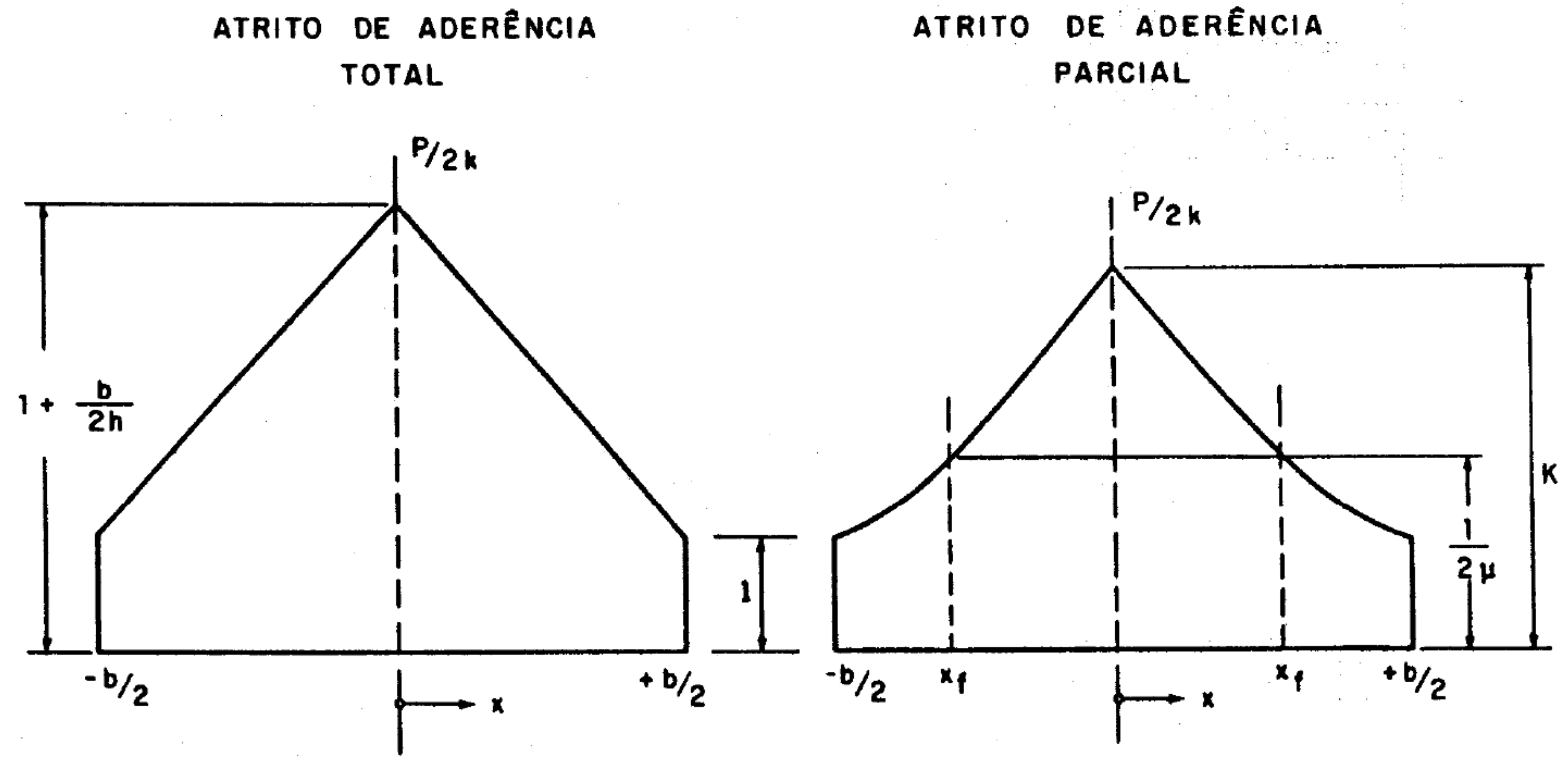
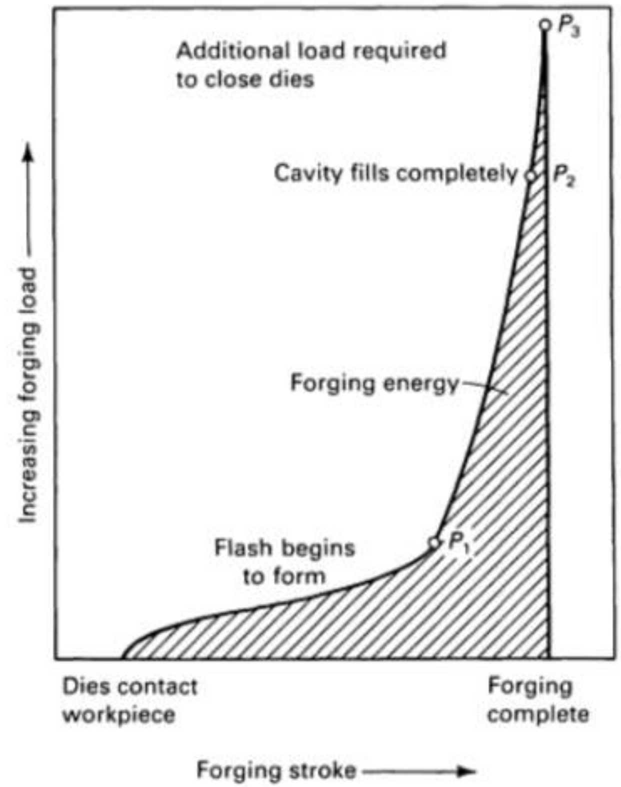


Figura 5.5 - Distribuição de p para as condições de atrito de aderência total e parcial



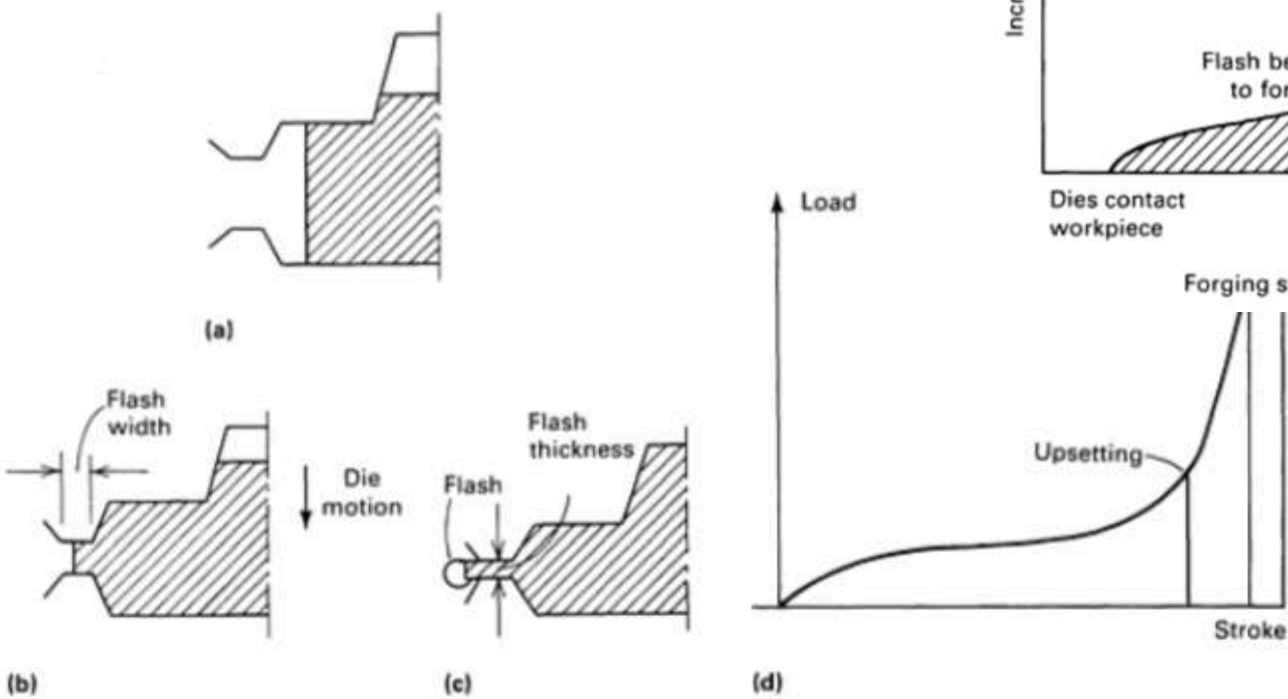


Fig. 7 Metal flow (a to c) and load-stroke curve (d) in closed-die forging. (a) Upsetting. (b) Filling. (c) End

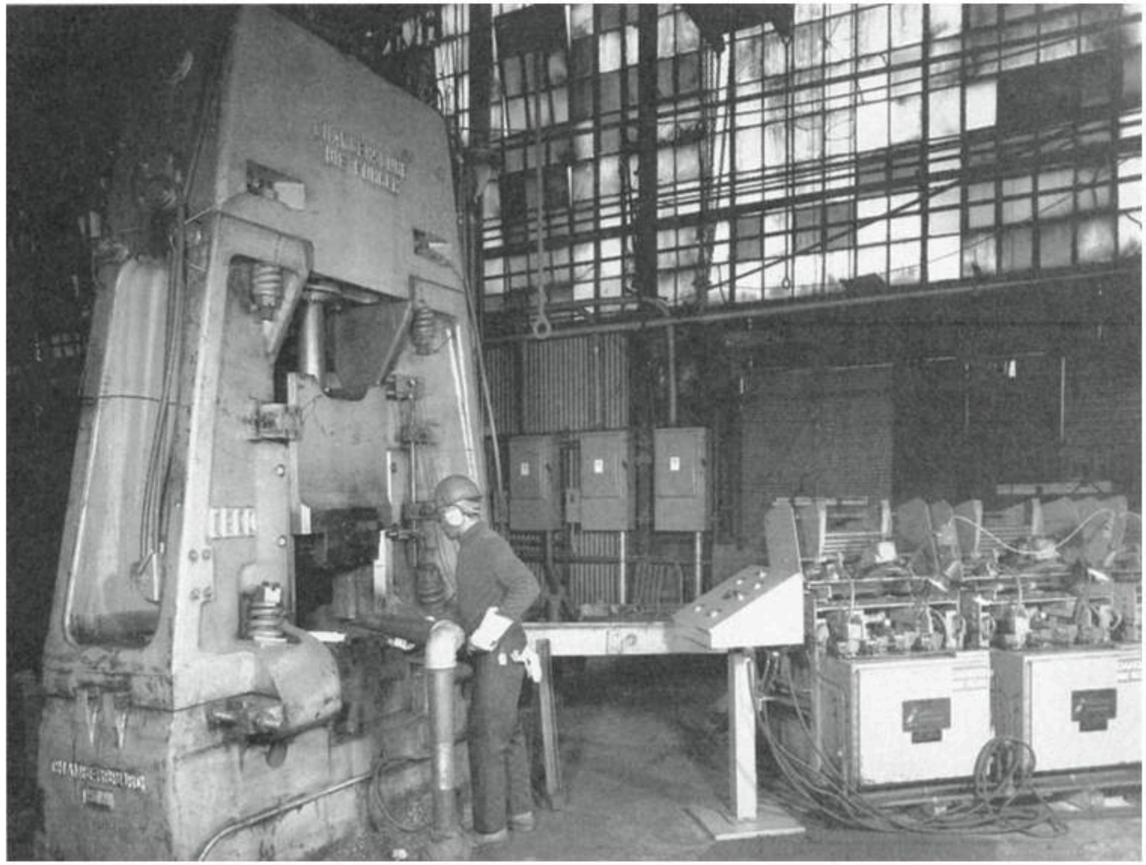
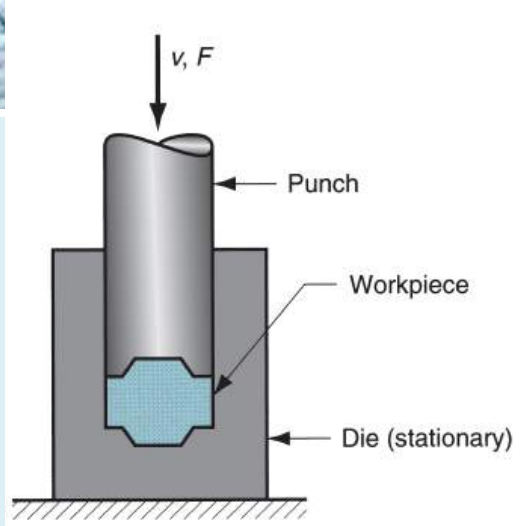
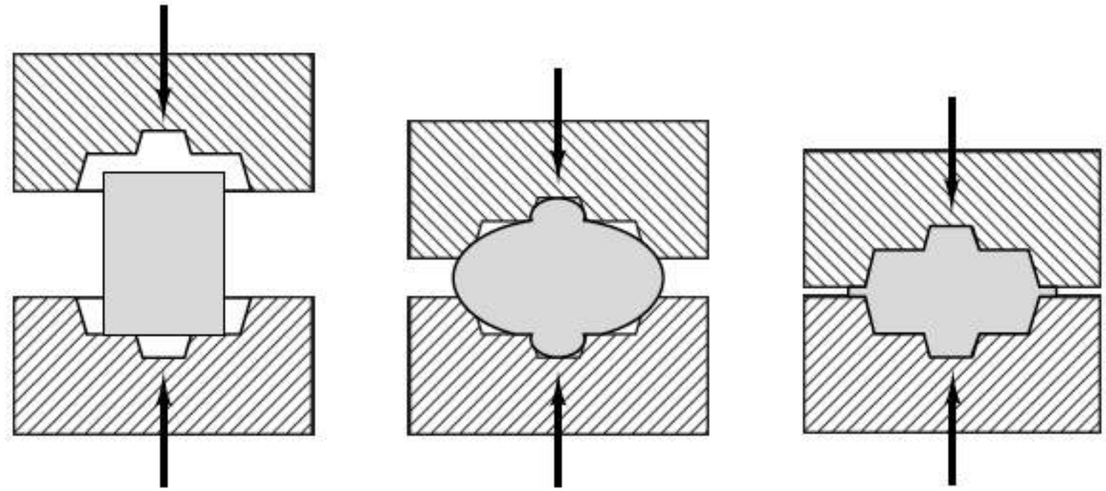
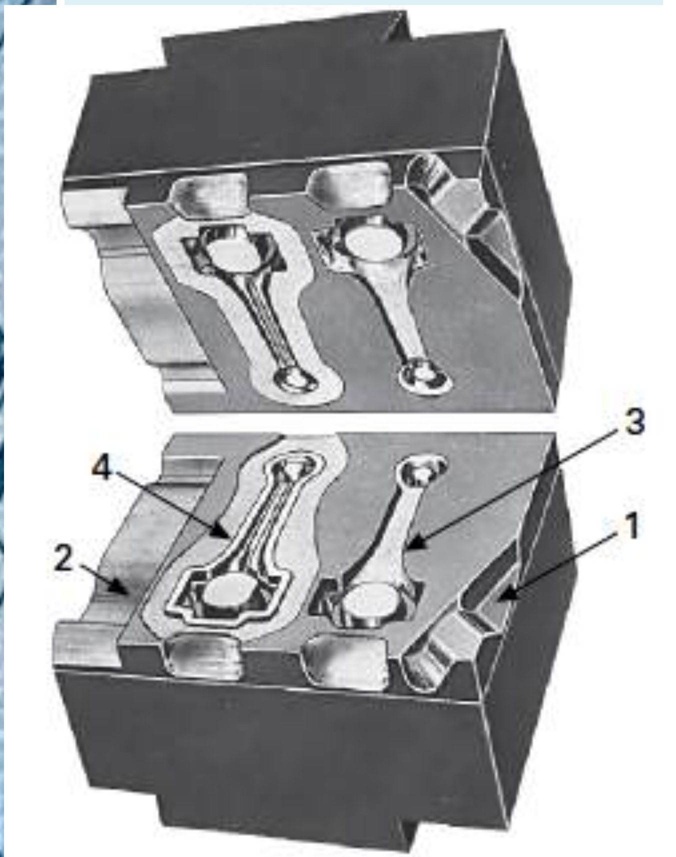


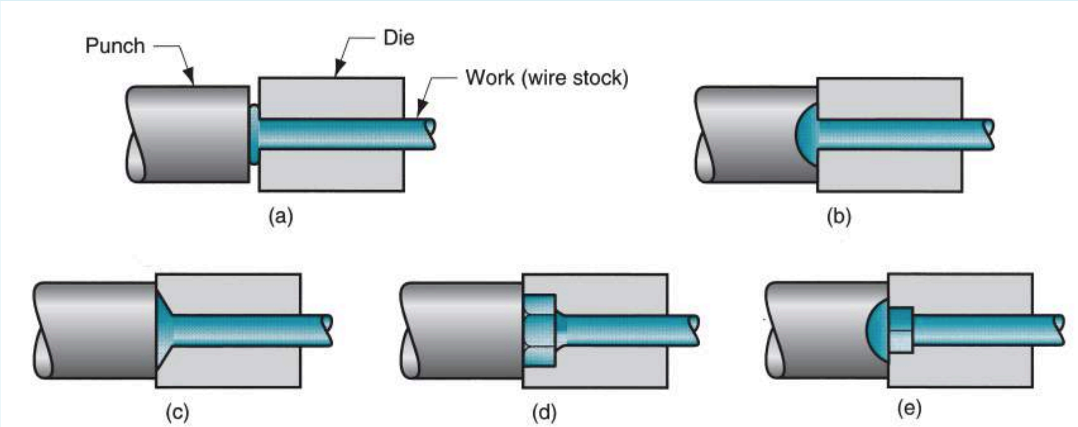
FIGURE 13.16 Drop forging hammer, fed by conveyor and heating units at the right of the scene. Photo courtesy of Ajax-Ceco. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)


v, F
Punch
Workpiece
Die (stationary)




3
4
2
1


3
4



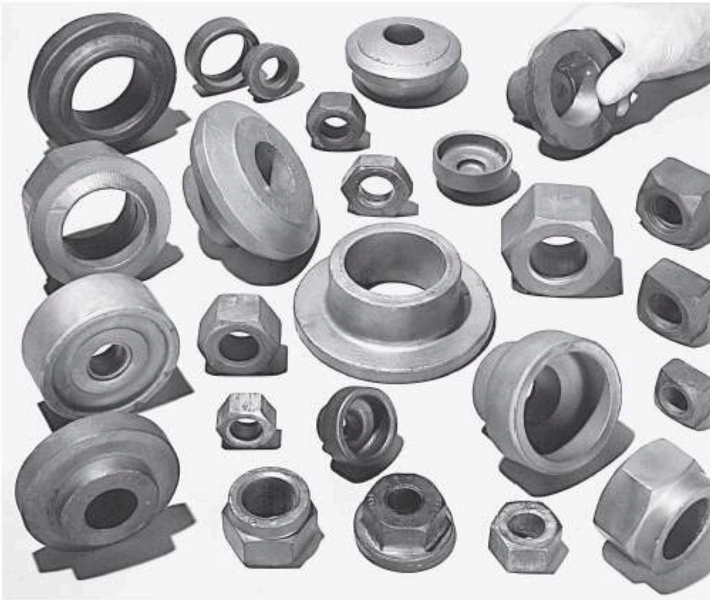
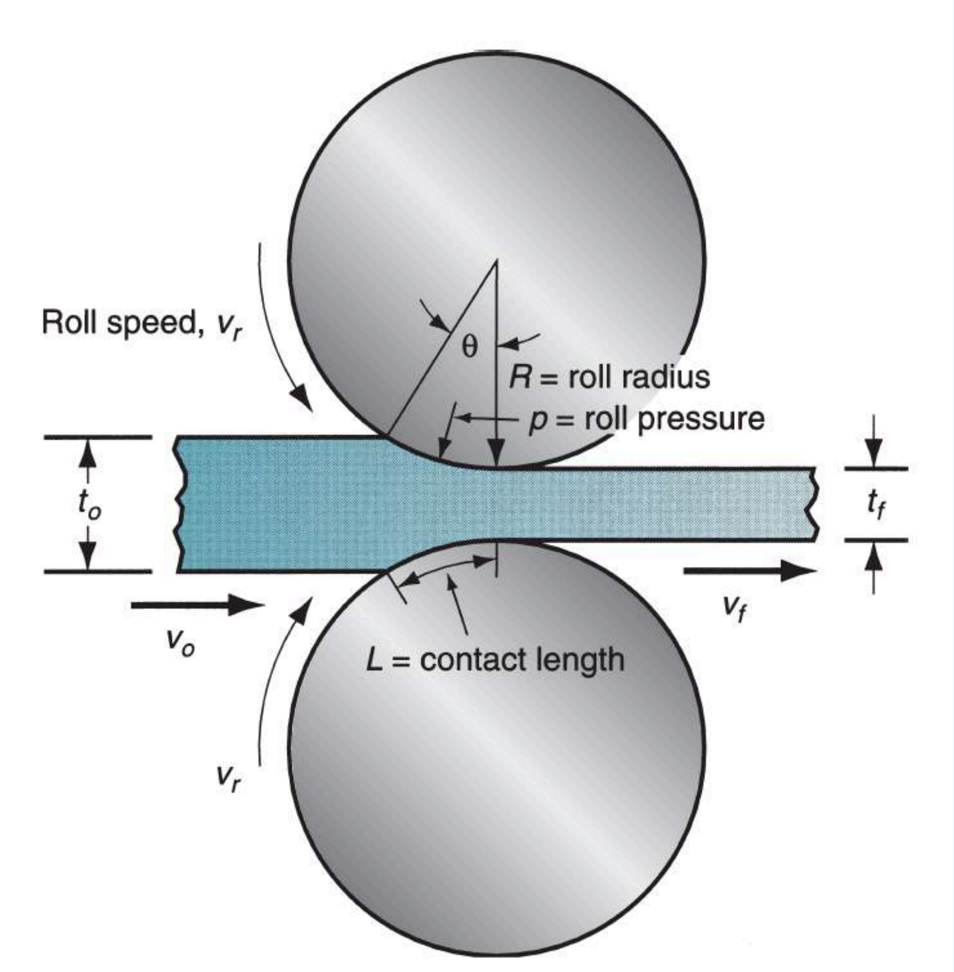


FIGURE 16-15 A forged and machined automobile engine crankshaft. Forged steel crankshafts provide superior performance, compared to those of ductile cast iron. *(© Sergiy Goruppa/iStockphoto)*

Rolling



Reduction:

$$\epsilon = \ln \frac{t_o}{t_f}$$

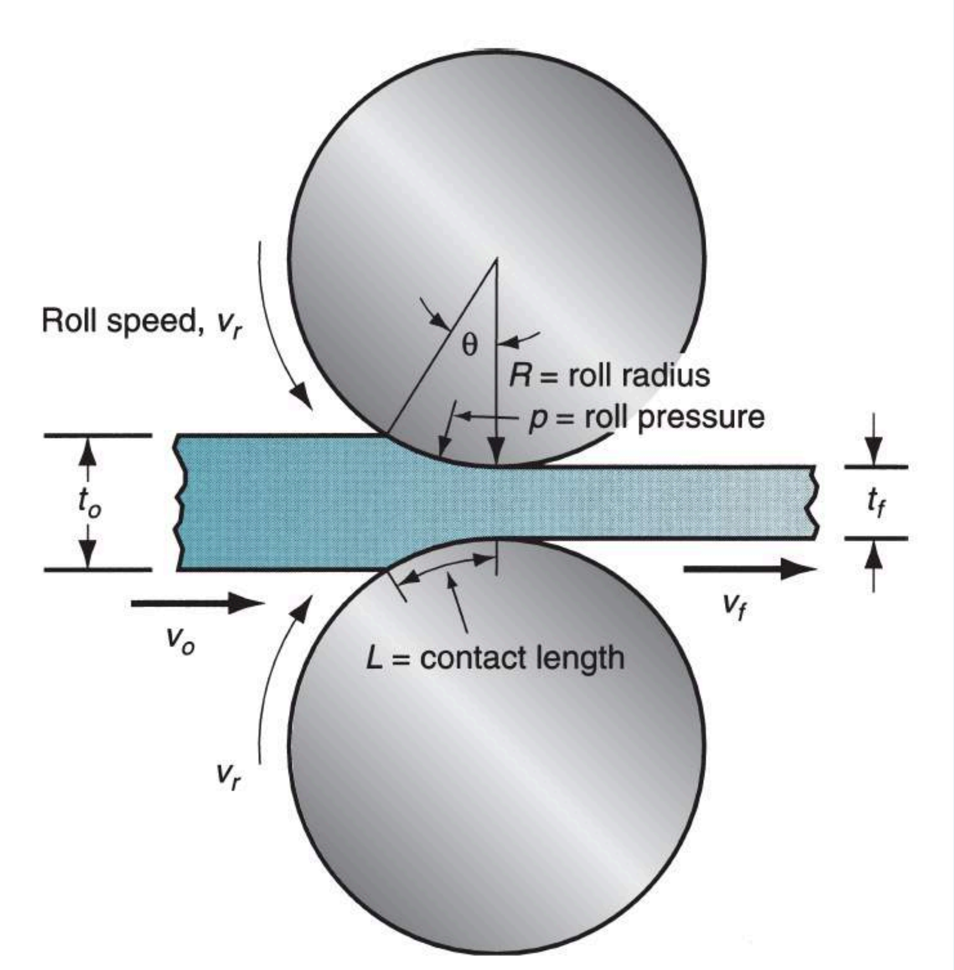
$$r = \frac{d}{t_o}$$

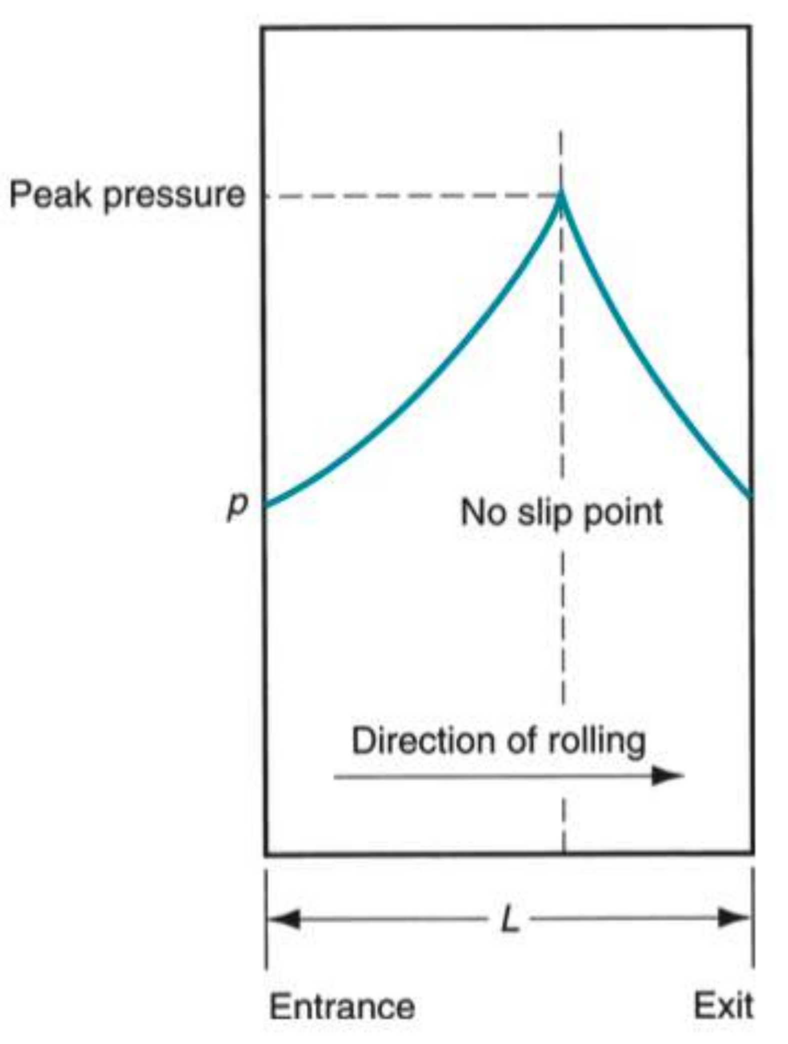
Draft: $d = t_o - t_f$

$$d_{max} = \mu^2 R$$

$$t_o w_o L_o = t_f w_f L_f$$

Pressure along the contact length in flat rolling



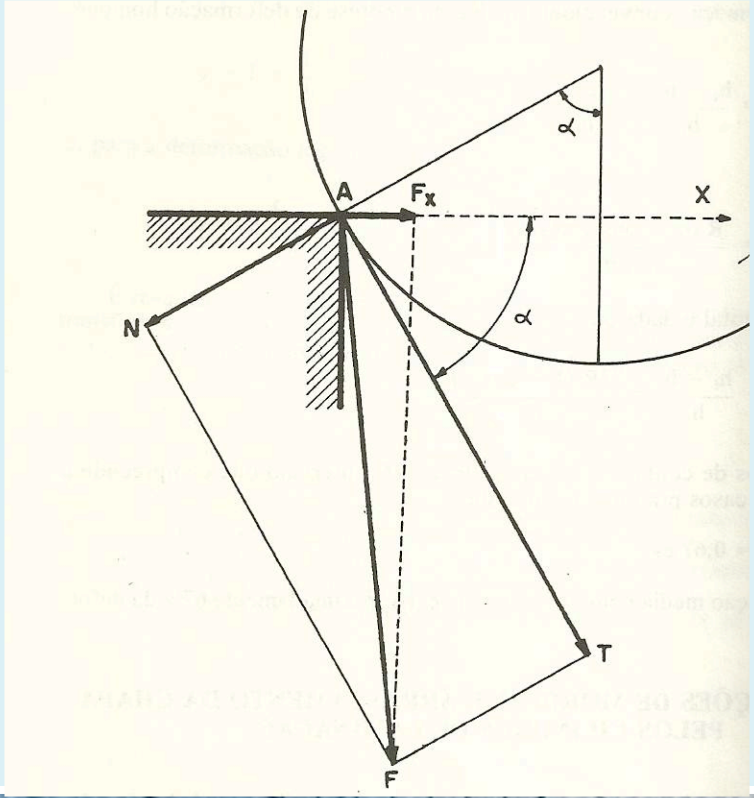


$$F = \overline{Y}_f w L$$

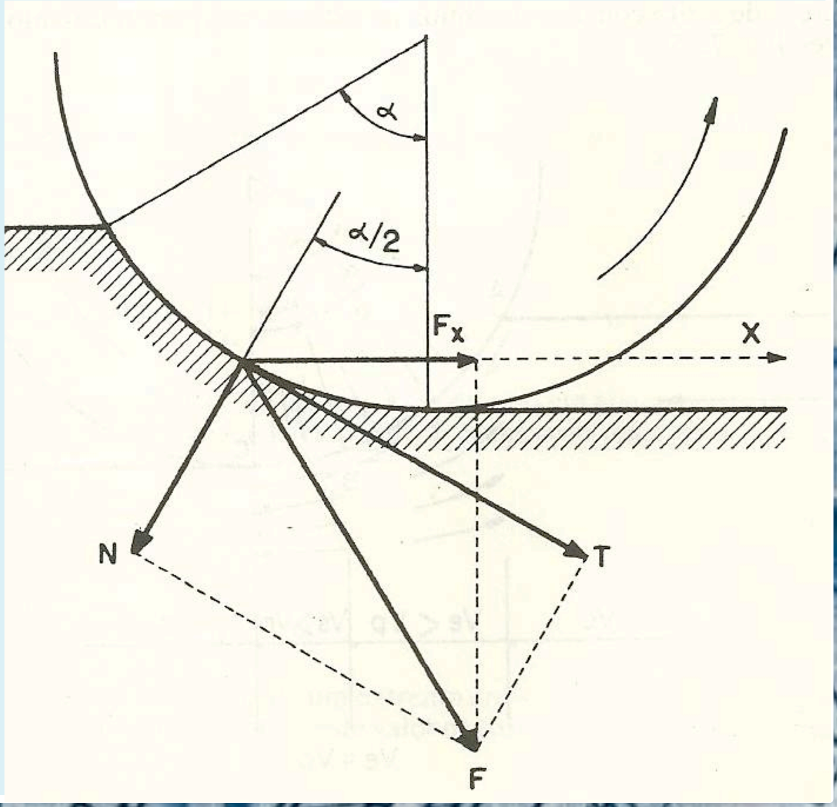
$$L = \sqrt{R(t_o - t_f)}$$

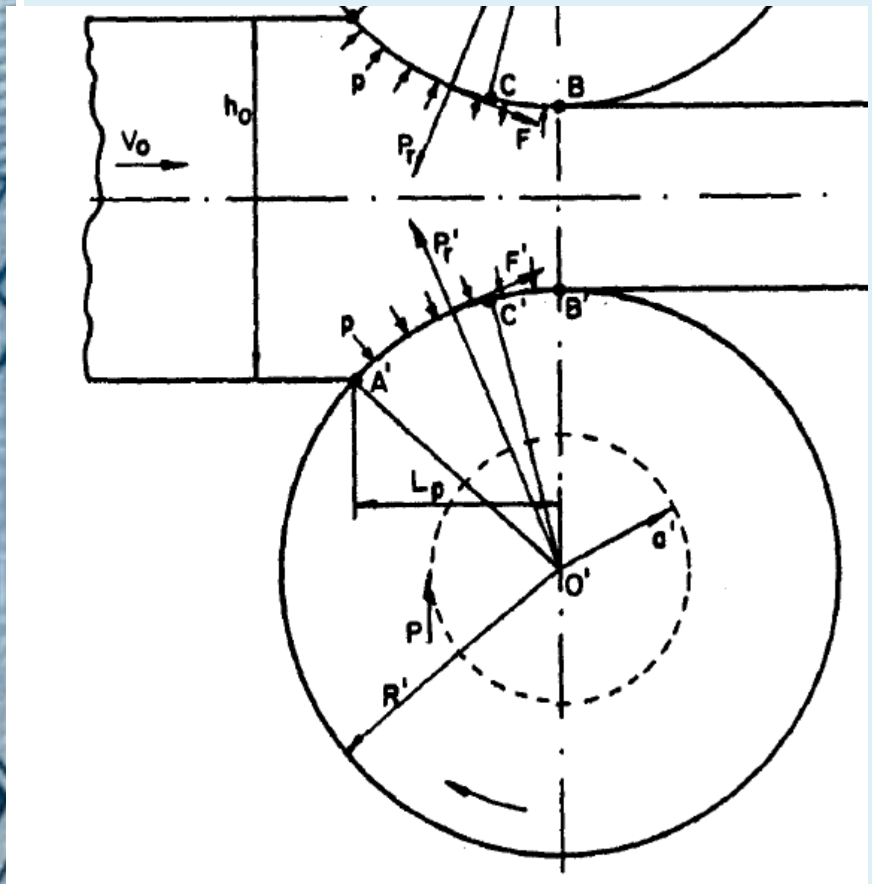
Rolling – Condiction to Pull the workpiece

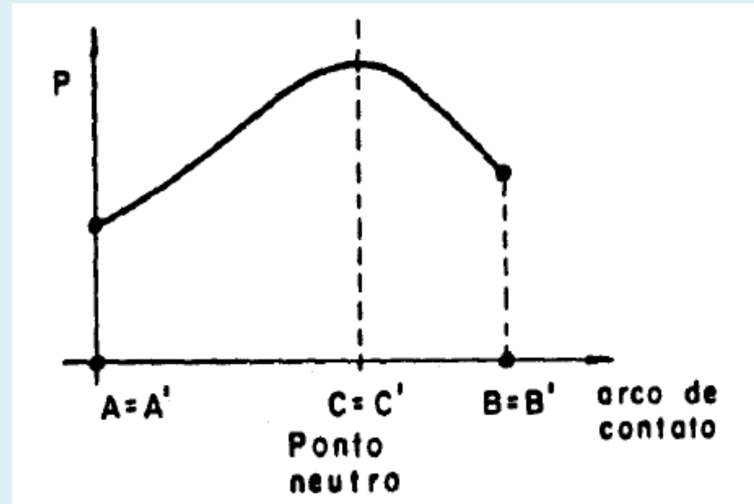
Beginning

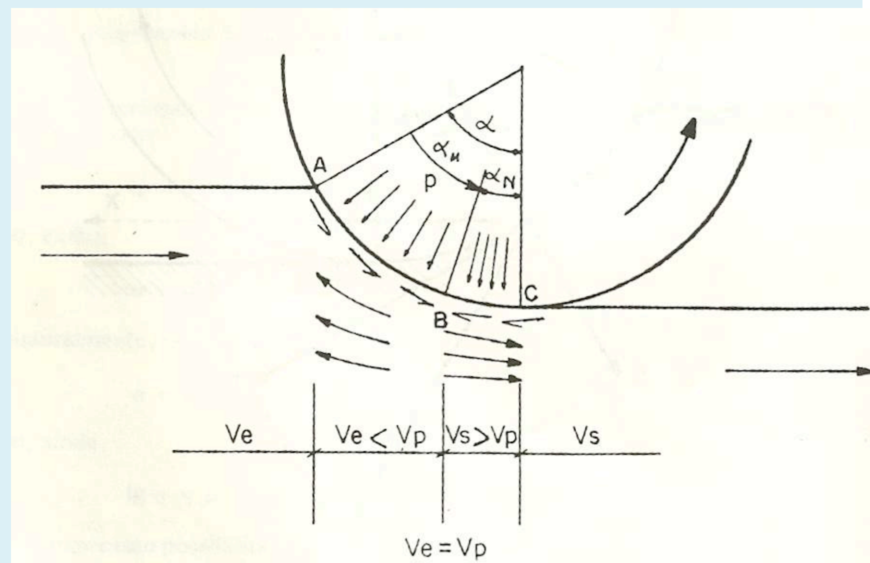


During rolling process




p
C
B
h_0
V_0
P_r
F
P_r'
F'
C'
B'
p
A'
L_p
a'
O'
P
R'


P
A = A'
C = C'
B = B'
arco de contato
Ponto neutro


α
α_N
A
p
α_N
C
B
Ve
Ve < Vp
Vs > Vp
Vs
Ve = Vp

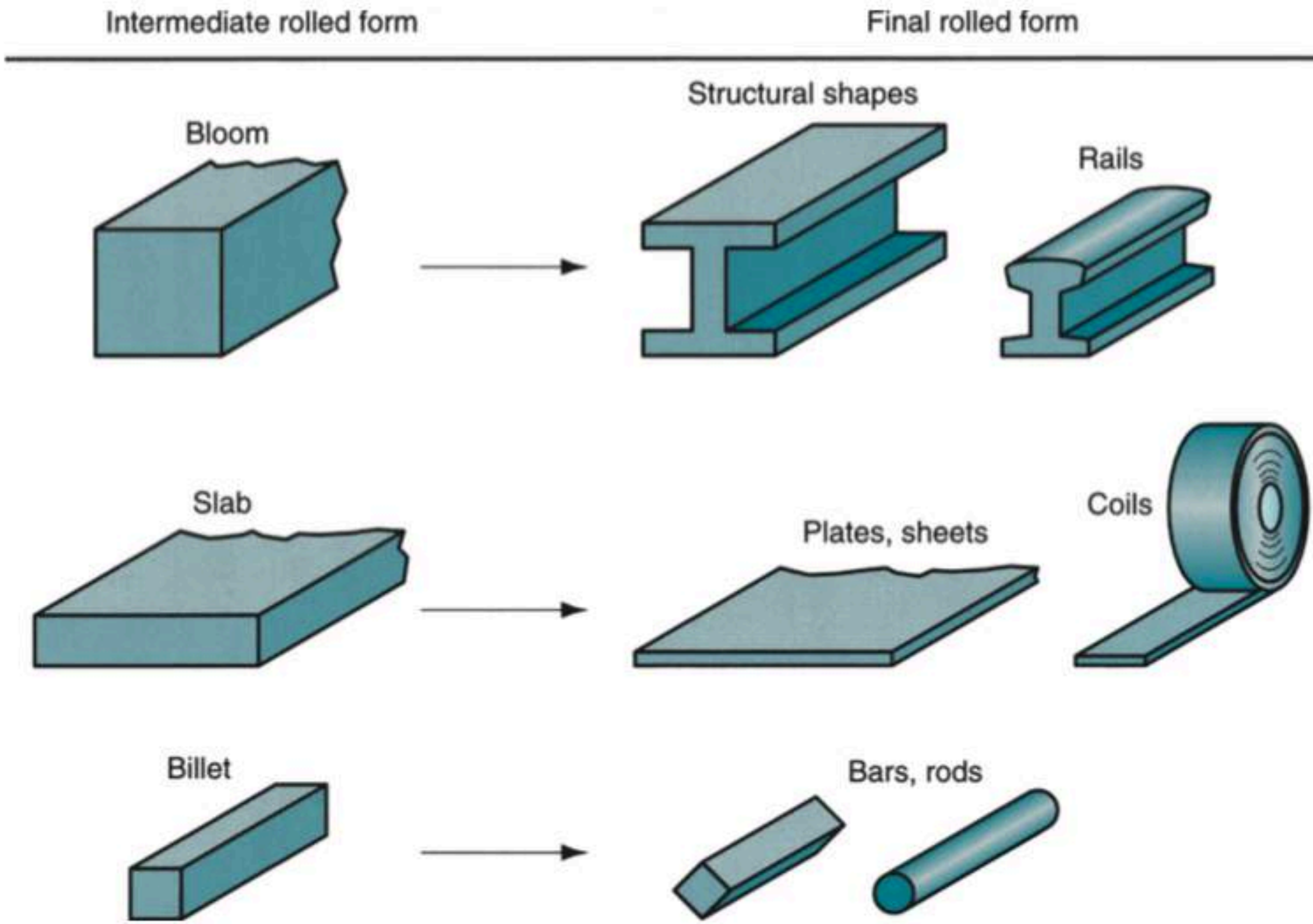
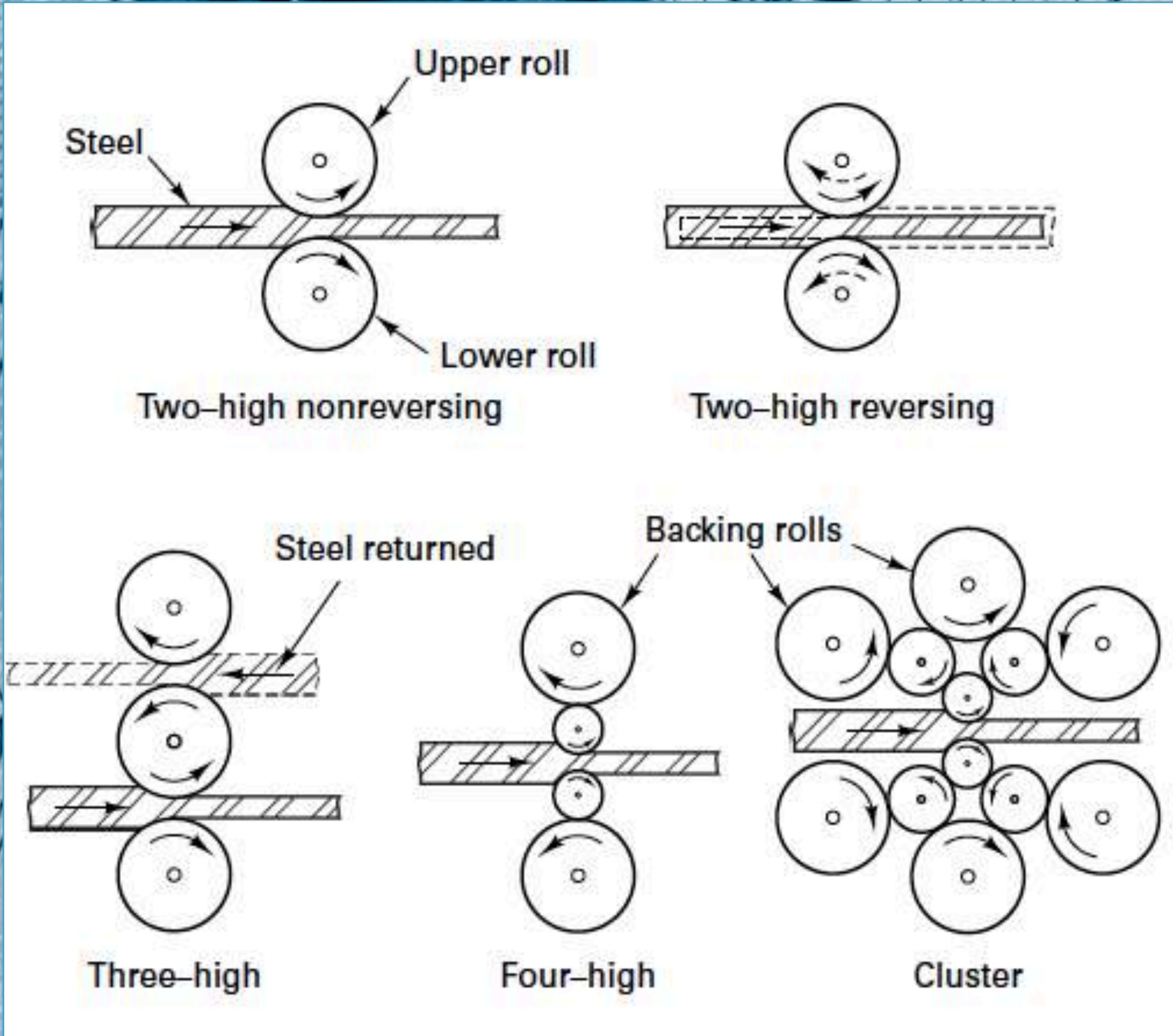
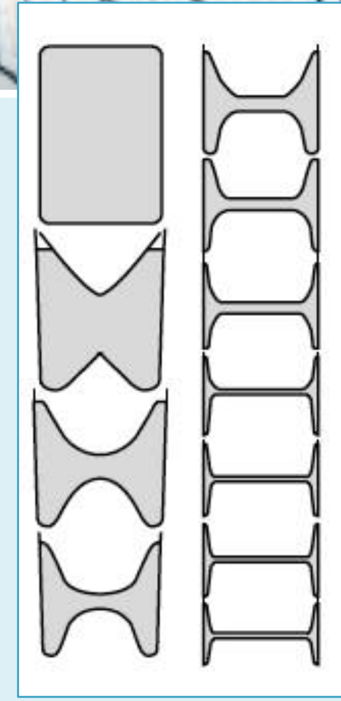
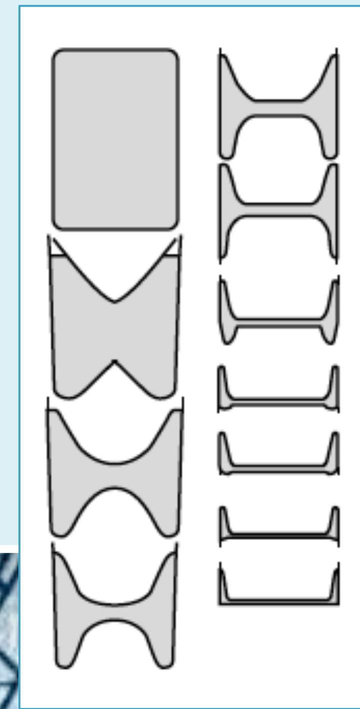


FIGURE 13.2 Some of the steel products made in a rolling mill. (Credit: *Fundamentals of Modern Manufacturing,* 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)


Upper roll
Steel
Lower roll
Two–high nonreversing
Two–high reversing
Steel returned
Backing rolls
Three–high
Four–high
Cluster



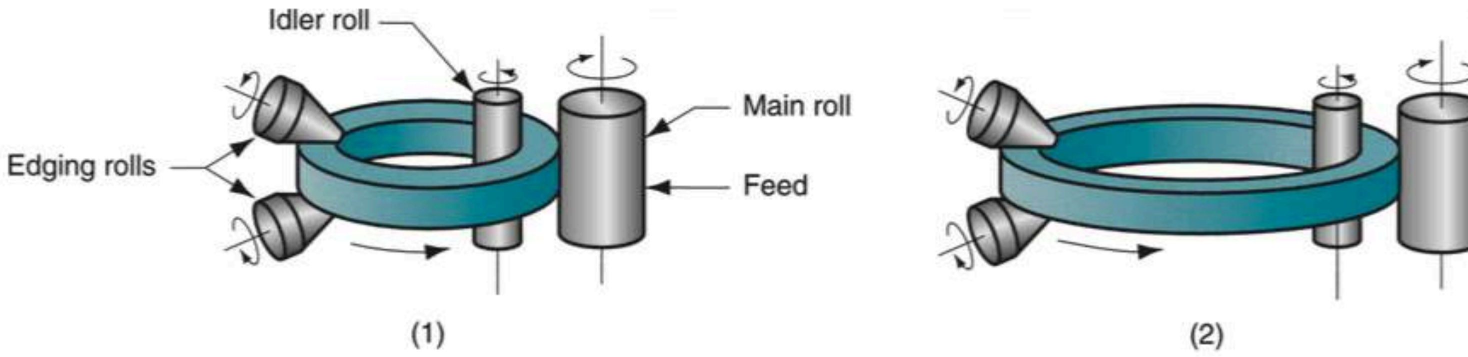


FIGURE 13.7 Ring rolling used to reduce the wall thickness and increase the diameter of a ring: (1) start and (2) completion of process. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

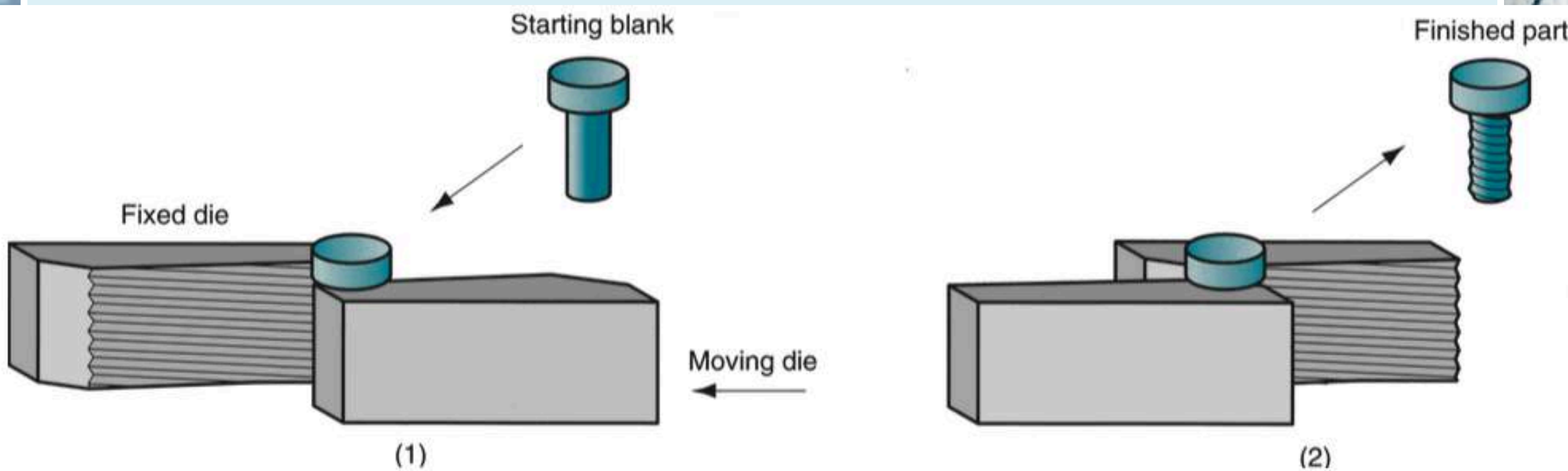
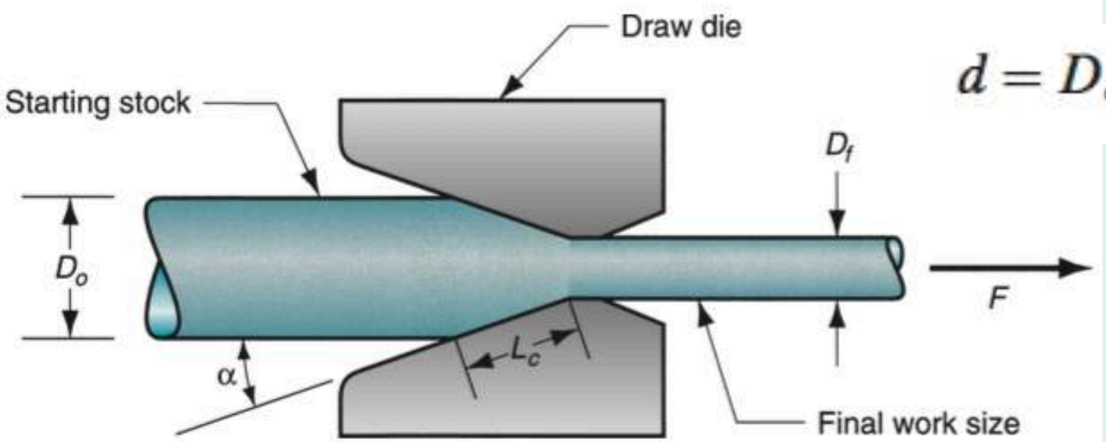


FIGURE 13.6 Thread rolling with flat dies: (1) start of cycle and (2) end of cycle. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

WIRE AND BAR DRAWING

FIGURE 13.34 Drawing of bar, rod, or wire. (Credit: *Fundamentals of Modern Manufacturing,* 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)



$$d = D_o - D_f$$

$$r = \frac{A_o - A_f}{A_o}$$

$$\epsilon = \ln \frac{A_o}{A_f} = \ln \frac{1}{1-r}$$

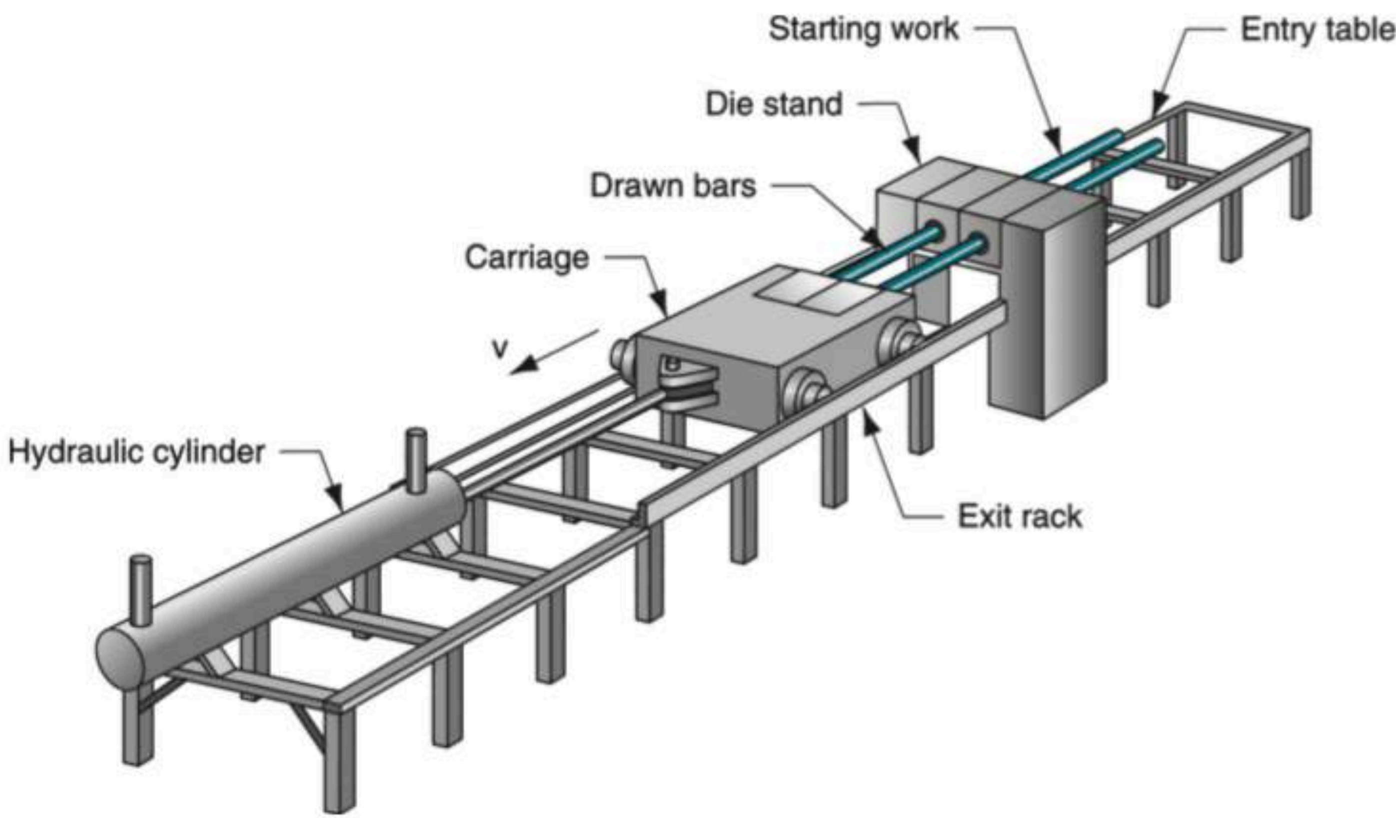
$$\sigma = \overline{Y}_f \epsilon = \overline{Y}_f \ln \frac{A_o}{A_f}$$

$$\overline{Y}_f = \frac{K\epsilon^n}{1+n}$$

$$\sigma_d = \overline{Y}_f \left(1 + \frac{\mu}{\tan\alpha}\right) \phi \ln \frac{A_o}{A_f}$$

$$F = A_f \sigma_d = A_f \overline{Y}_f \left(1 + \frac{\mu}{\tan\alpha}\right) \phi \ln \frac{A_o}{A_f}$$

FIGURE 13.35 Hydraulically operated draw bench for drawing metal bars. (Credit: *Fundamentals of Modern Manufacturing,* 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)



Maximum Reduction per Pass in wire drawing

"Why not take the entire reduction in a single pass through one die, as in extrusion? The answer can be explained as follows. From the preceding equations, it is clear that as the reduction increases, draw stress increases. If the reduction is large enough, draw stress will exceed the yield strength of the exiting metal."

Assuming a perfectly plastic metal (n = 0), no friction, and no redundant work. In this ideal case, the maximum possible draw stress is equal to the yield strength of the work material.

$$\sigma_d = \overline{Y}_f \ln \frac{A_o}{A_f} = Y \ln \frac{A_o}{A_f} = Y \ln \frac{1}{1-r} = Y$$

$$\frac{A_o}{A_f} = e = 2.7183$$

$$\boxed{r_{\max} = \frac{e-1}{e} = 0.632}$$

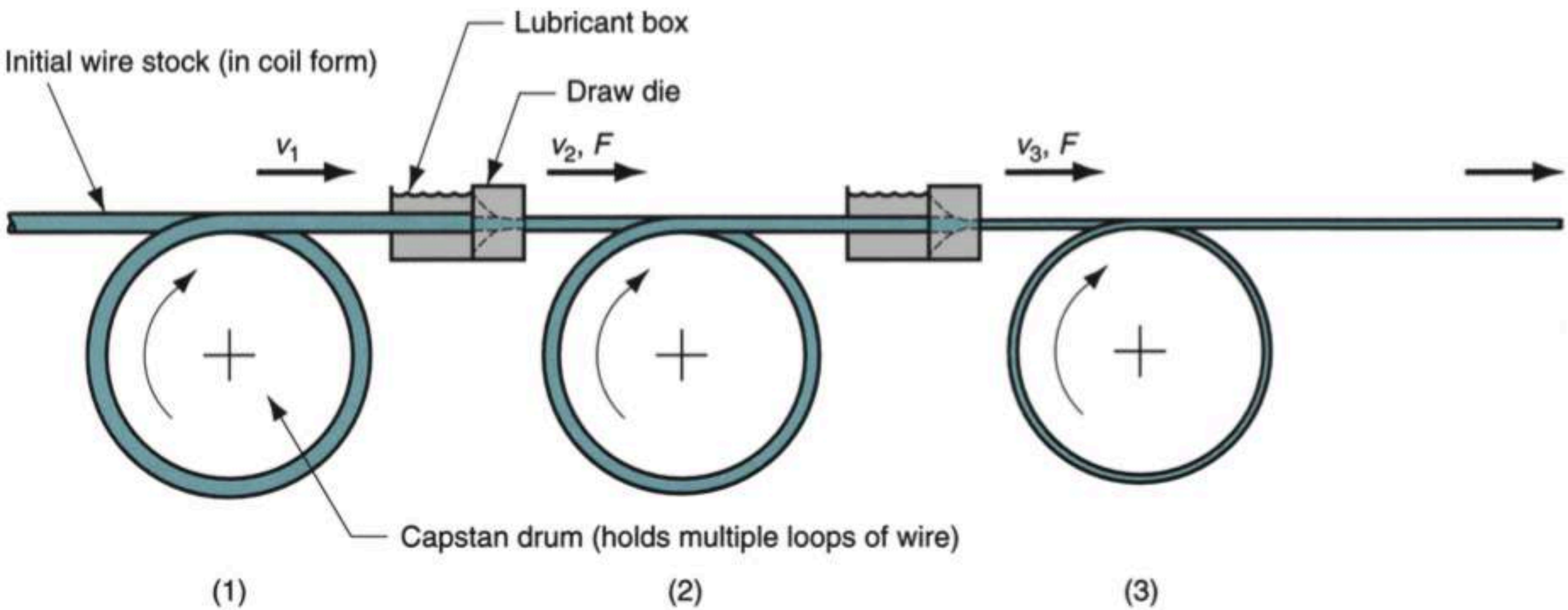
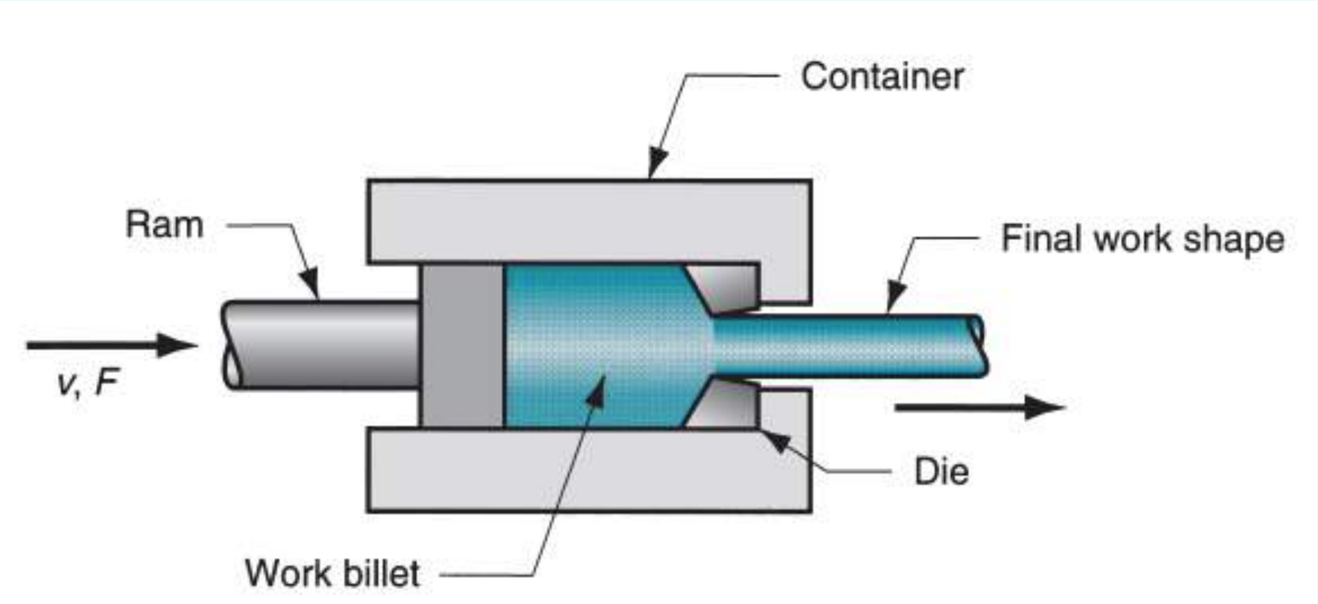
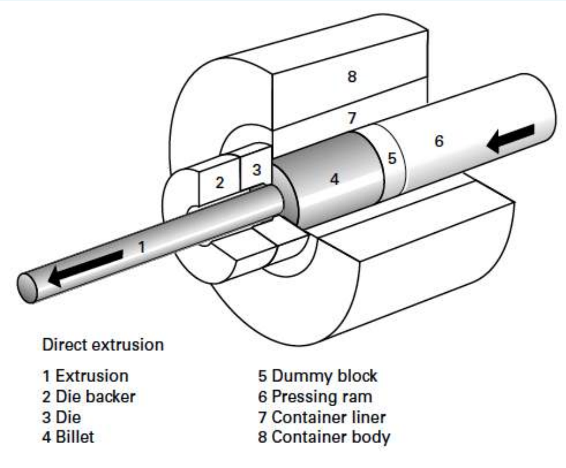


FIGURE 13.36 Continuous drawing of wire. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

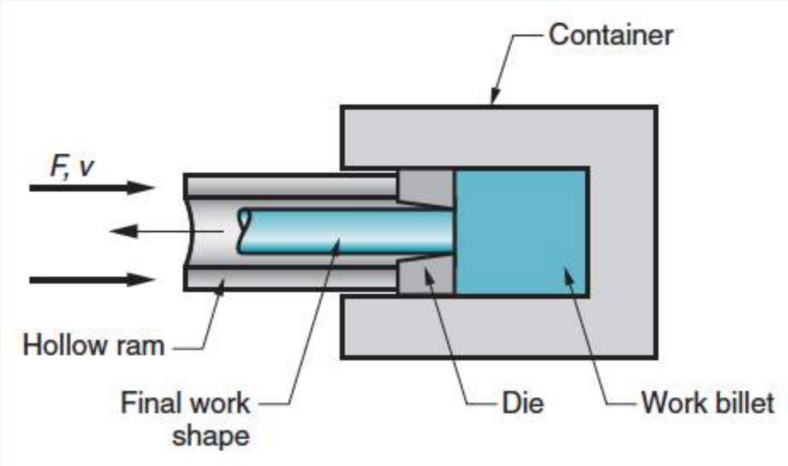
Extrusion



Container
Ram
Final work shape
v, F
Die
Work billet

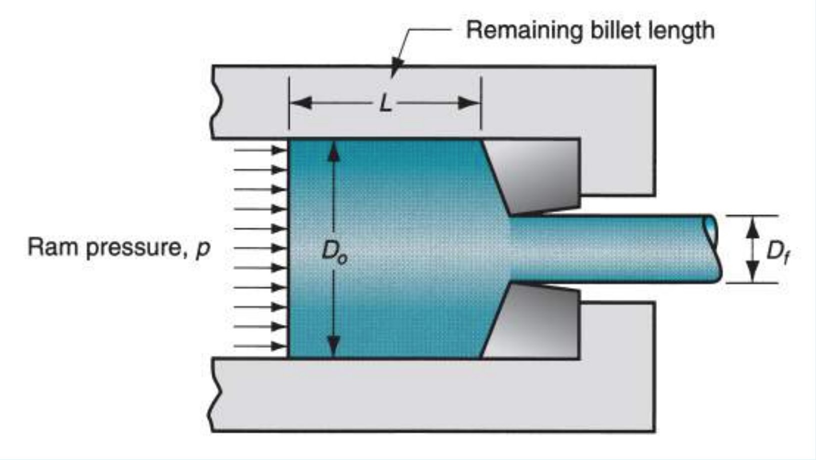


8
7
6
5
4
3
2
1
Direct extrusion
1 Extrusion
2 Die backer
3 Die
4 Billet
5 Dummy block
6 Pressing ram
7 Container liner
8 Container body



Container
F, v
Hollow ram
Final work shape
Die
Work billet

Extrusion Forces



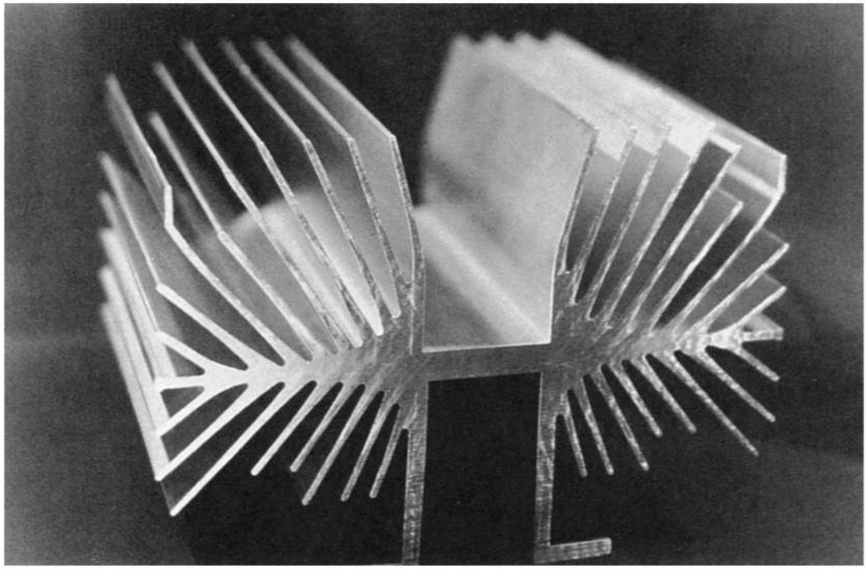


FIGURE 13.30 A complex extruded cross section for a heat sink. Photo courtesy of Aluminum Company of America. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

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

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

$$p = \overline{Y}_f \ln r_x$$

$$\overline{Y}_f = \frac{K\epsilon^n}{1+n}$$

$$p = K_x \overline{Y}_f \left(\epsilon_x + \frac{2L}{D_o} \right)$$

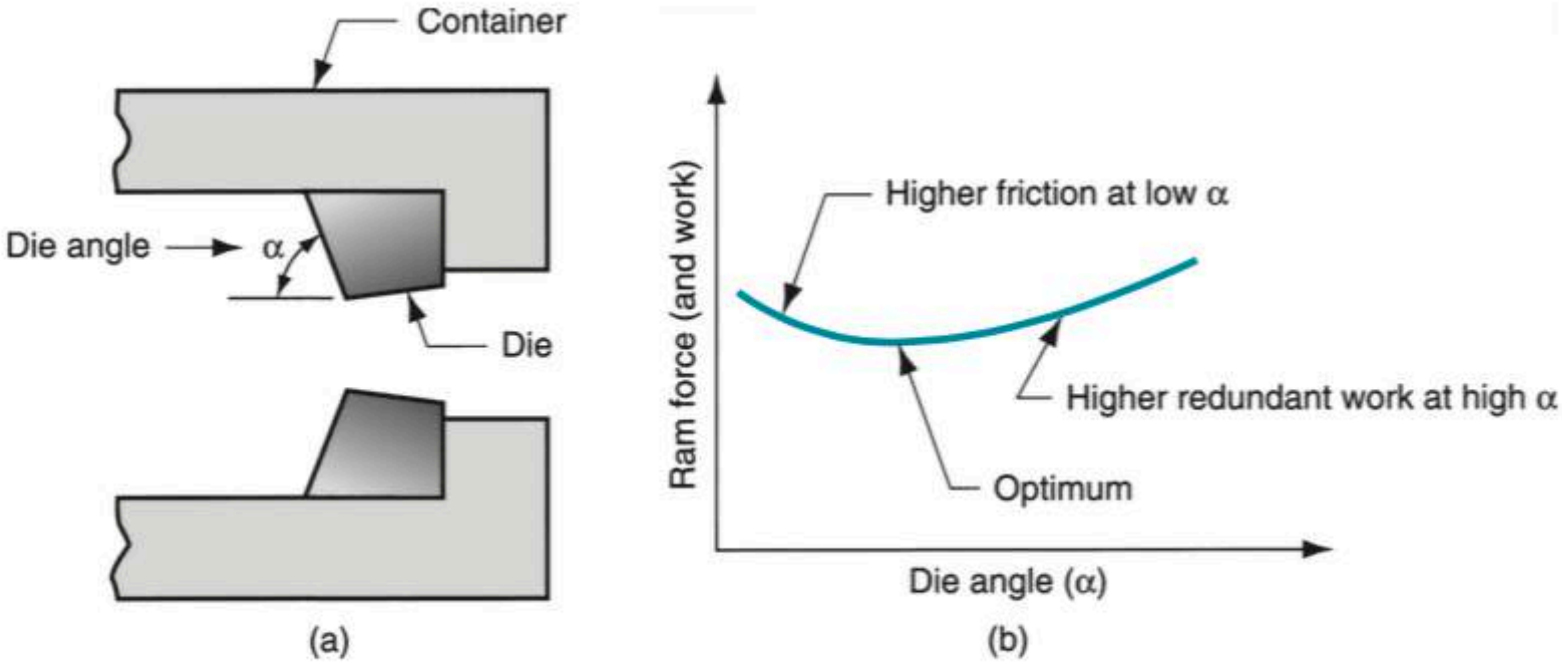
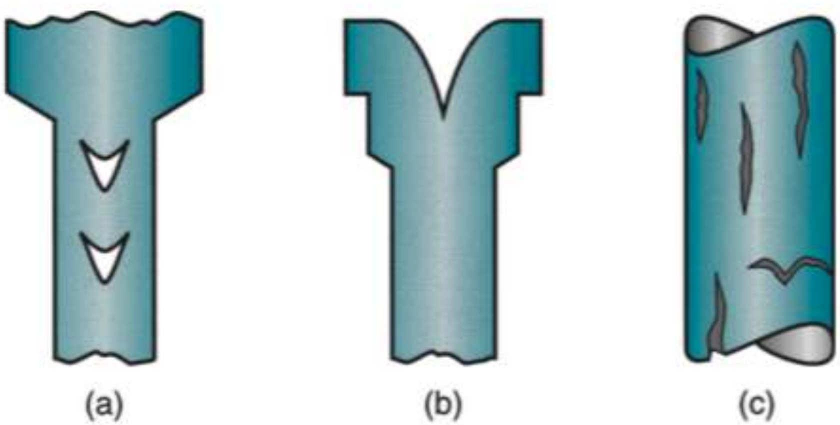


FIGURE 13.29 (a) Definition of die angle in direct extrusion; (b) effect of die angle on ram force. (Credit: *Fundamentals of Modern Manufacturing*, 4^{th} Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

FIGURE 13.33 Some common defects in extrusion: (a) centerburst, (b) piping, and (c) surface cracking. (Credit: *Fundamentals of Modern Manufacturing*, 4^{th} Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)



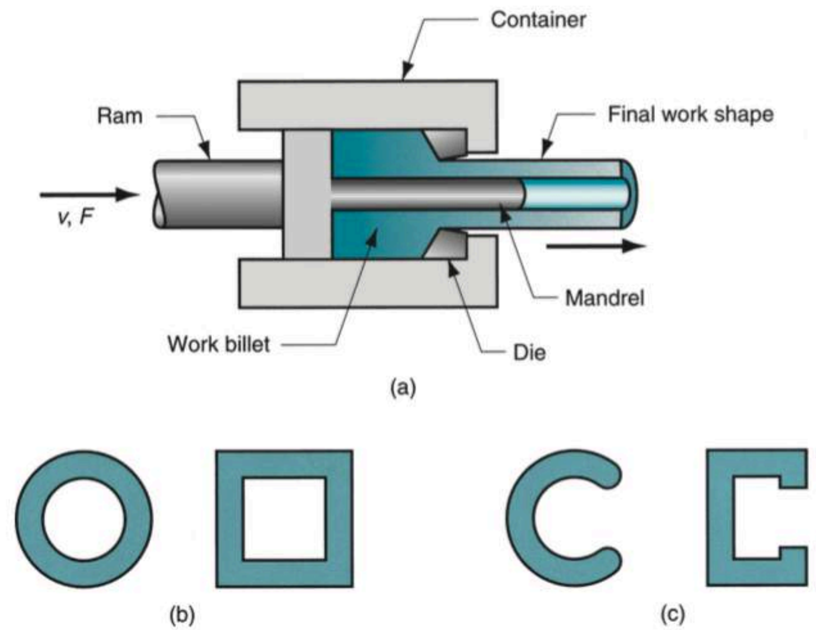


FIGURE 13.25
(a) Direct extrusion to produce a hollow or semi-hollow cross section; (b) hollow and (c) semi-hollow cross sections. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

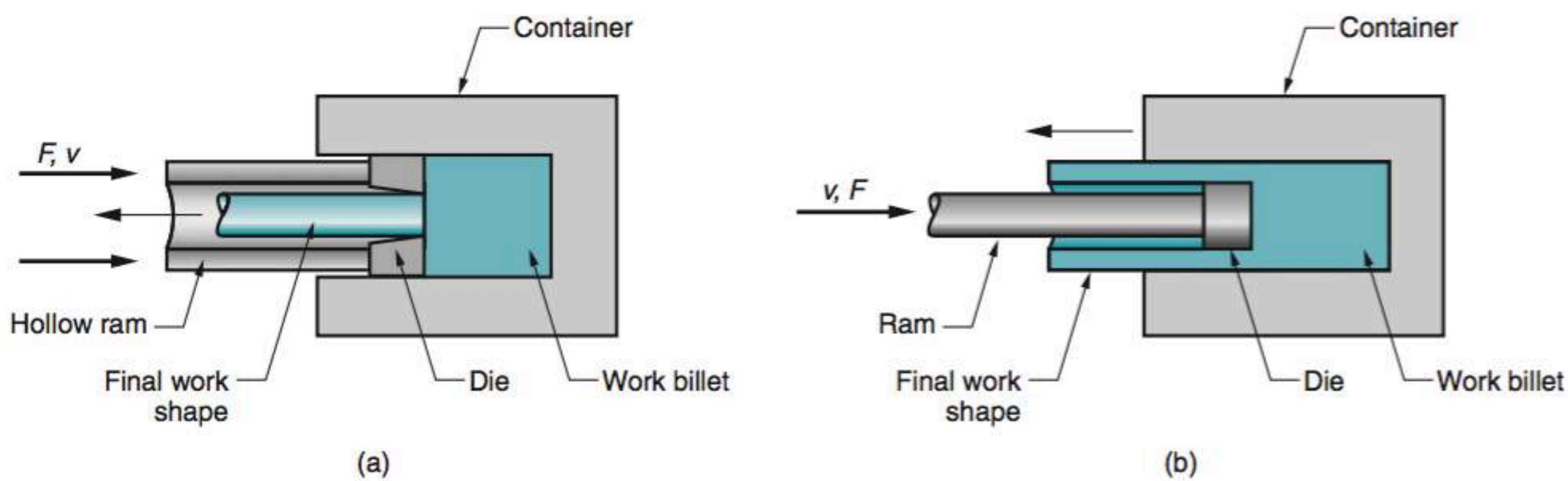
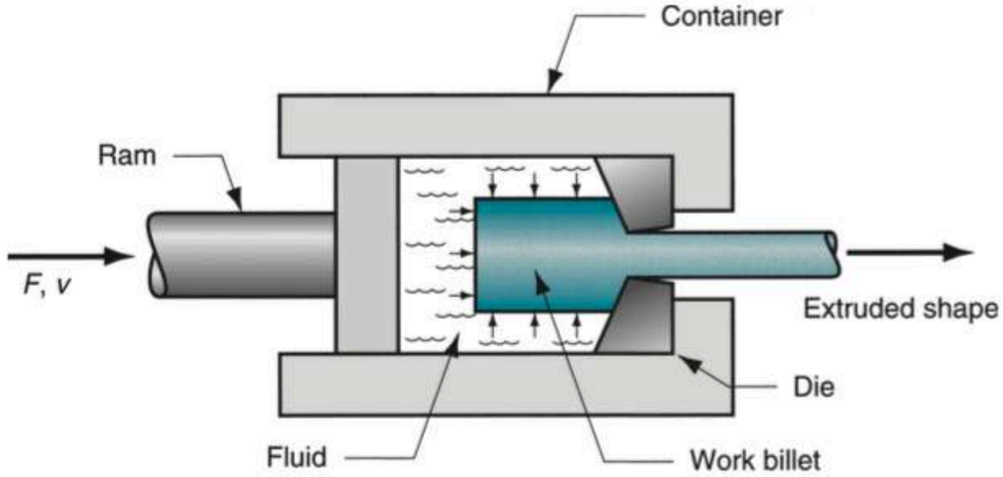


FIGURE 13.26 Indirect extrusion to produce (a) a solid cross section and (b) a hollow cross section. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

FIGURE 13.32 Hydrostatic extrusion. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)



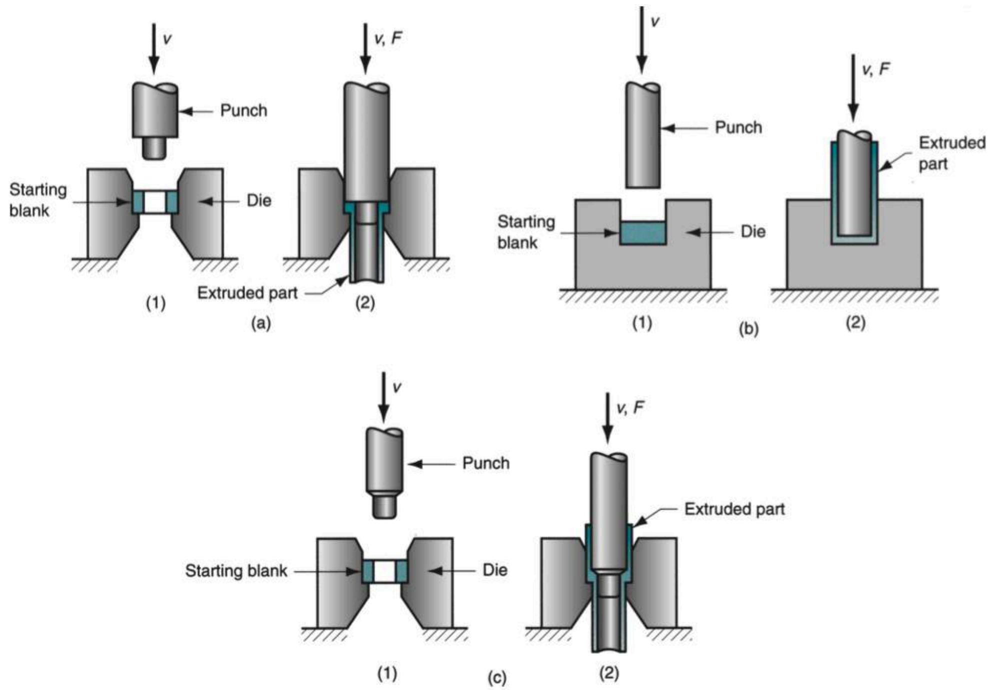


FIGURE 13.31 Several examples of impact extrusion: (a) forward, (b) backward, and (c) combination of forward and backward. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

SHEET METALWORKING (next class)

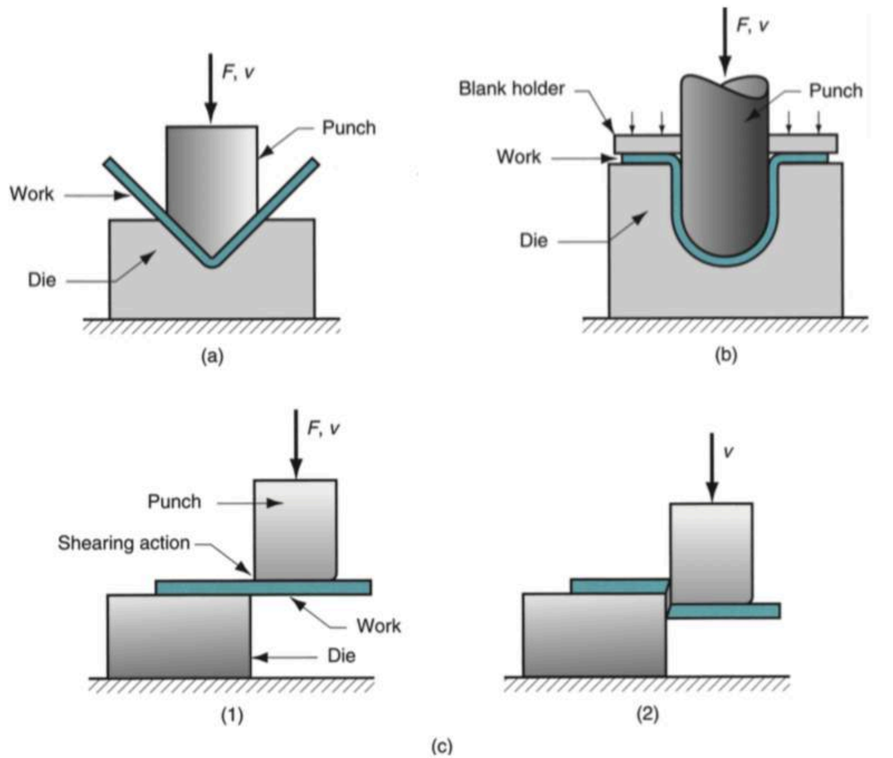


FIGURE 12.2 Basic sheet metalworking operations: (a) bending, (b) drawing, and (c) shearing: (1) as punch first contacts sheet, and (2) after cutting. Force and relative motion in these operations are indicated by *F* and *v*. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

Home Work #6 – Forming

- Answer questions from class #2 applied to Extrusion.
- Local Suppliers of Extruded Aluminum parts in your home country
- Due to 21st September