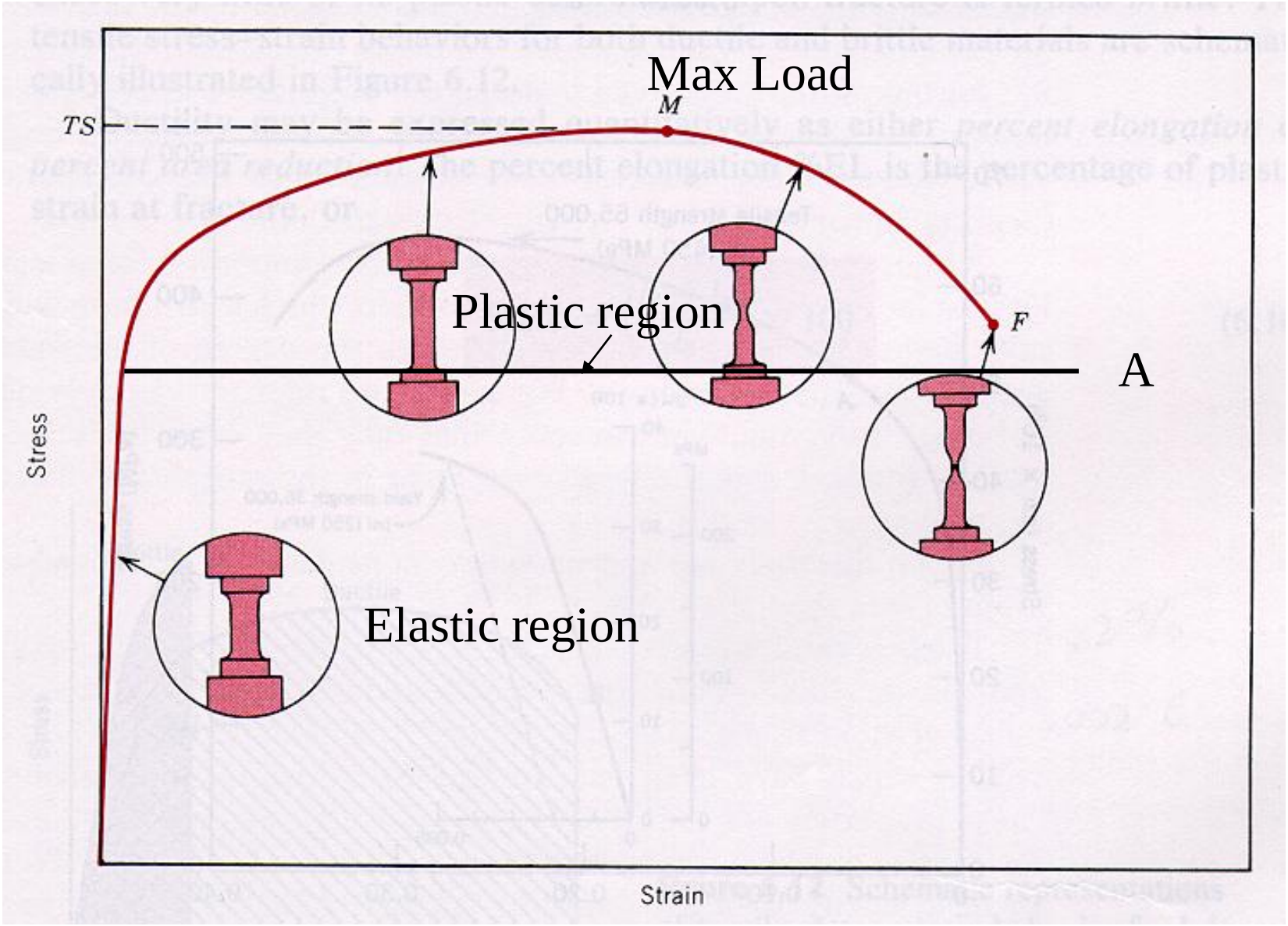
Metal Forming

Outline

- Fundamentals of Metal Forming
- Bulk deformation
- Sheet metalworking

Plastic Deformation

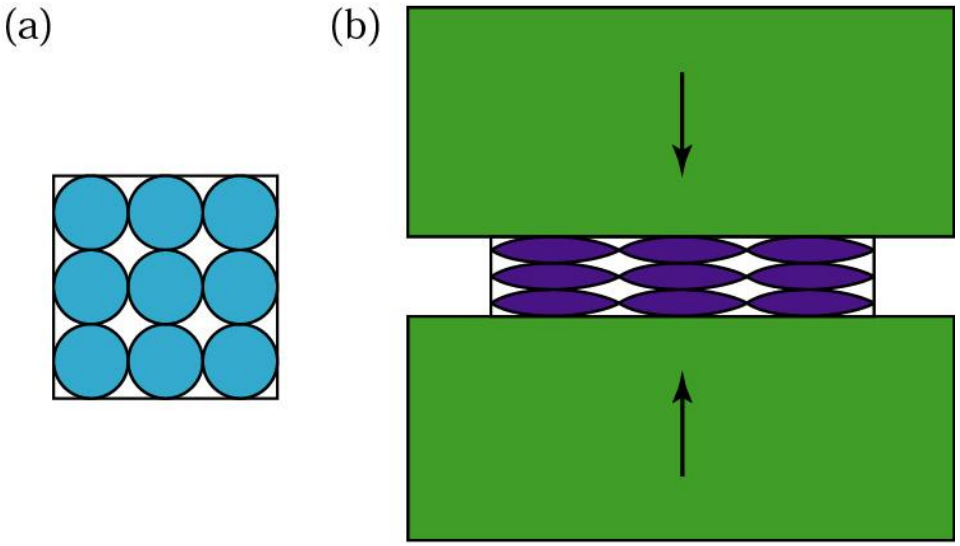


Temperature in metal forming
Hot & Cold Working

See Movies

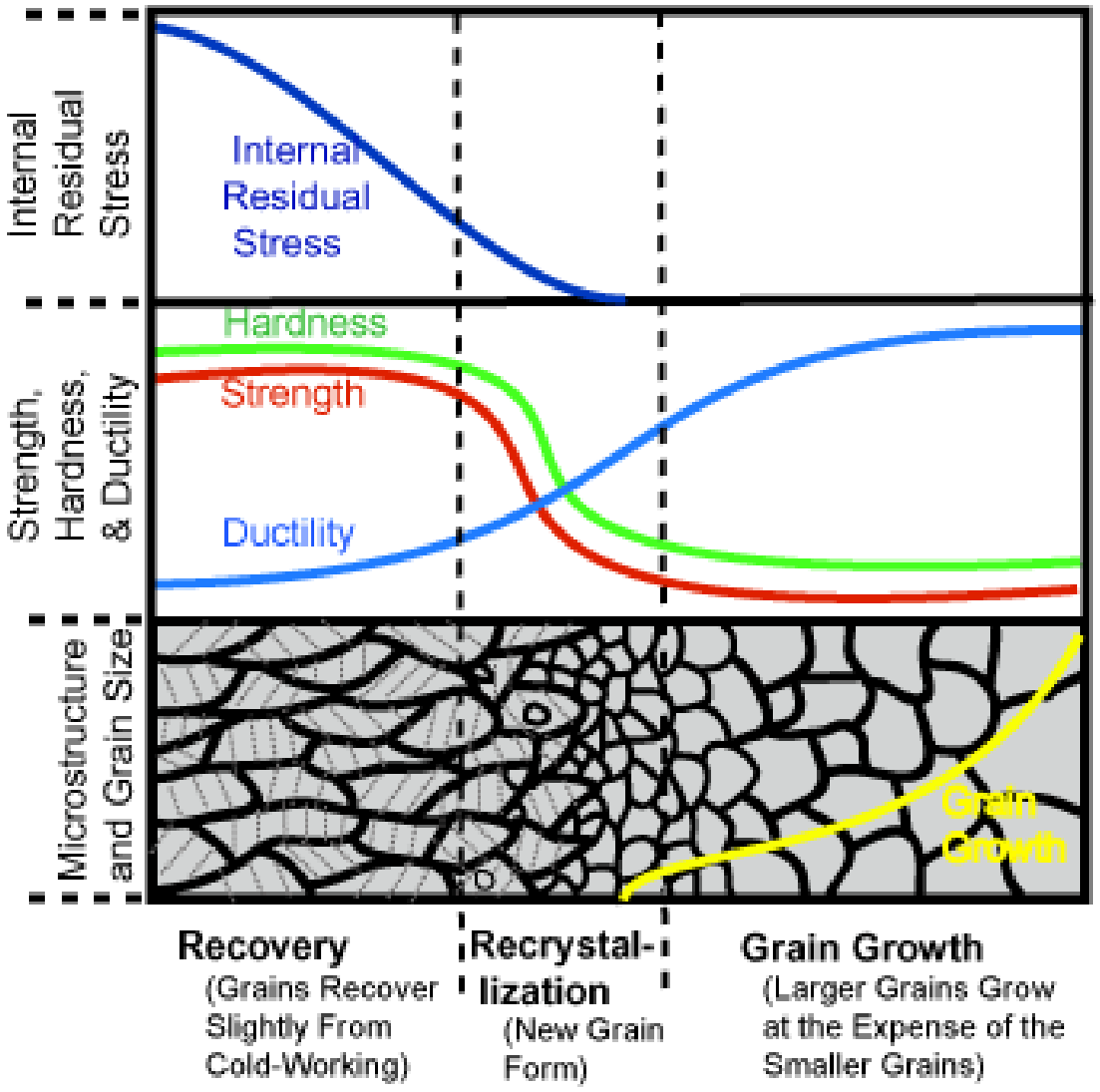
- Answer.
- Better accuracy
- Better Surface finishing
- Strain hardening increase strength
- Costs

Preferred Orientation



Plastic deformation of idealized (equiaxed) grains in a specimen subjected to compression (such as occurs in the rolling or forging of metals): (a) before deformation; and (b) after deformation. Note hte alignment of grain boundaries along a horizontal direction; this effect is known as preferred orientation.

Recrystallization

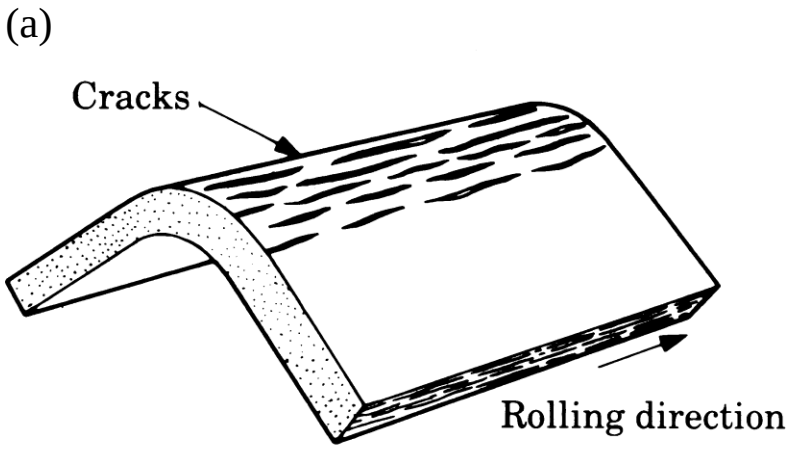


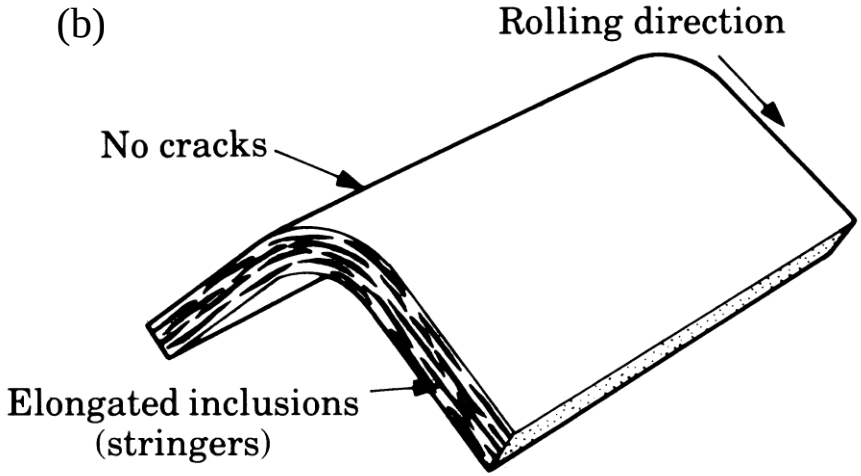
Cold Working

- Metal forming performed at room temp or slightly above

Advantage	**Disadvantage**
Better accuracy	Higher forces are required
Better Surface finishing	Care the surface
Strain hardening increase strength	Ductility is limited.
Costs	

Cracks





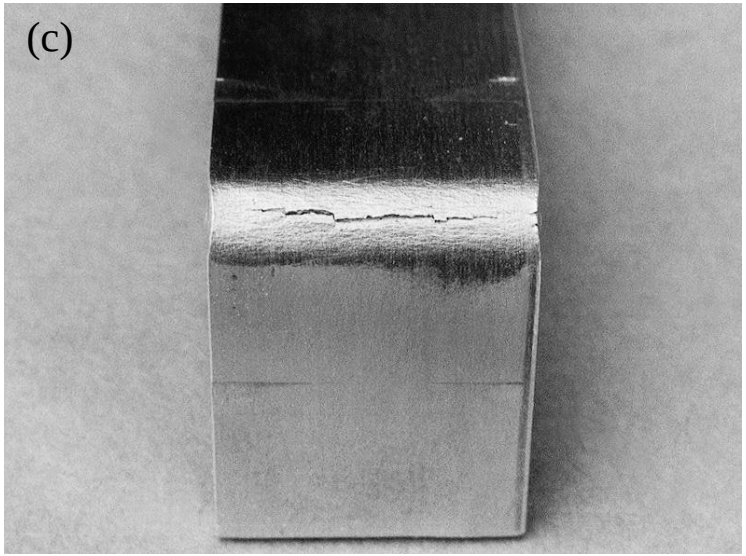


Figure (a) and (b) The effect of elongated inclusions (stringers) on cracking, as a function of the direction of bending with respect to the original rolling direction of the sheet. (c) Cracks on the outer surface of an aluminum strip bent to an angle of 90o. Note the narrowing of the tope surface due to the Poisson effect.

Hot working

- T above Recrystallization Temp.
- 0. $5T_m$ < T < $0.75T_m$)

Advantage

- The shape can be significantly altered
- Lower forces are required
- Fracture can be reduced
- Strength properties are generally isotropic
- No strengthing of the part occurs from work hardening

Disadvantage

Lower dimensional accuracy, higher energy, poorer surface finish
Shorter tool life

Warm Working

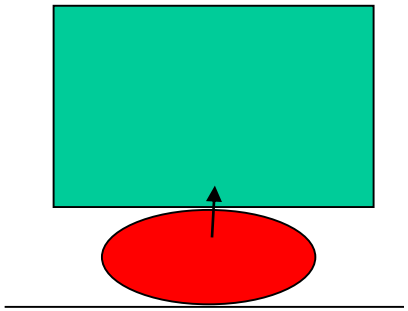
- $0.3T_m < T < 0.5T_m$

Advantage

- Lower forces are required
- More intricate work geometries possible
- The need for annealing may be reduced

Isothermal

- For high speed steel, titanium alloy, good hot hardness



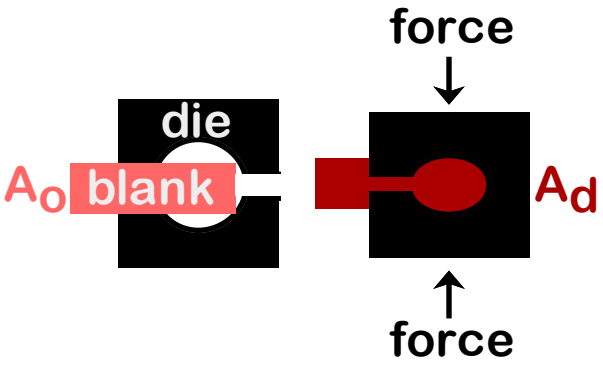
Quick heat transfer

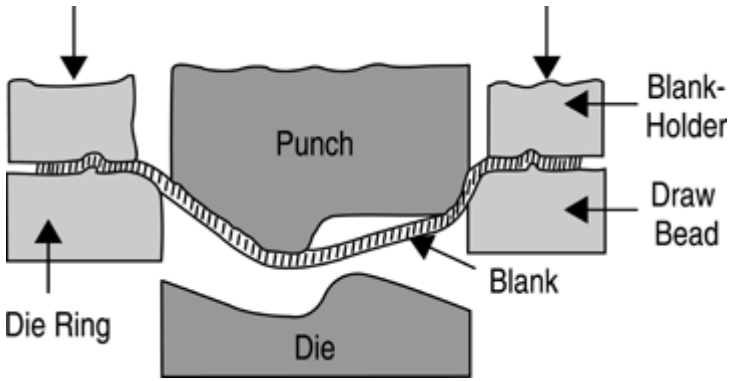
- Raising strength leading to high residual stress

Cracking

Metal forming process

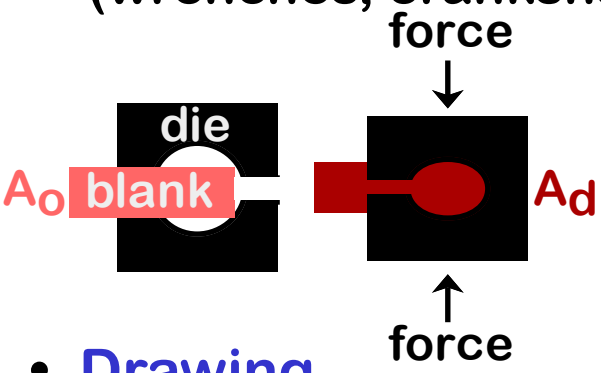
- 1. Bulk deformation processes
- 2. Sheet metal working processes





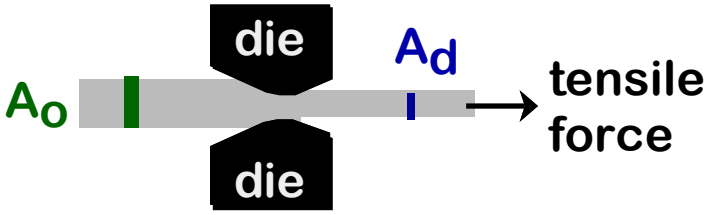
Bulk Deforming Processes

- **Forging**
  (wrenches, crankshafts)

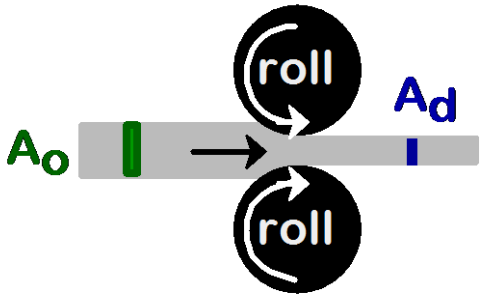


often at elev. T

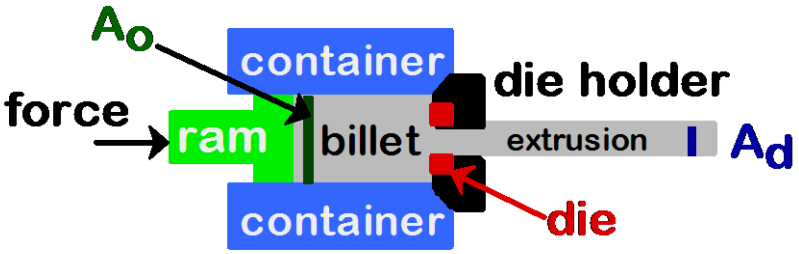
- **Drawing**
  (rods, wire, tubing)



- **Rolling**
  (I-beams, rails)

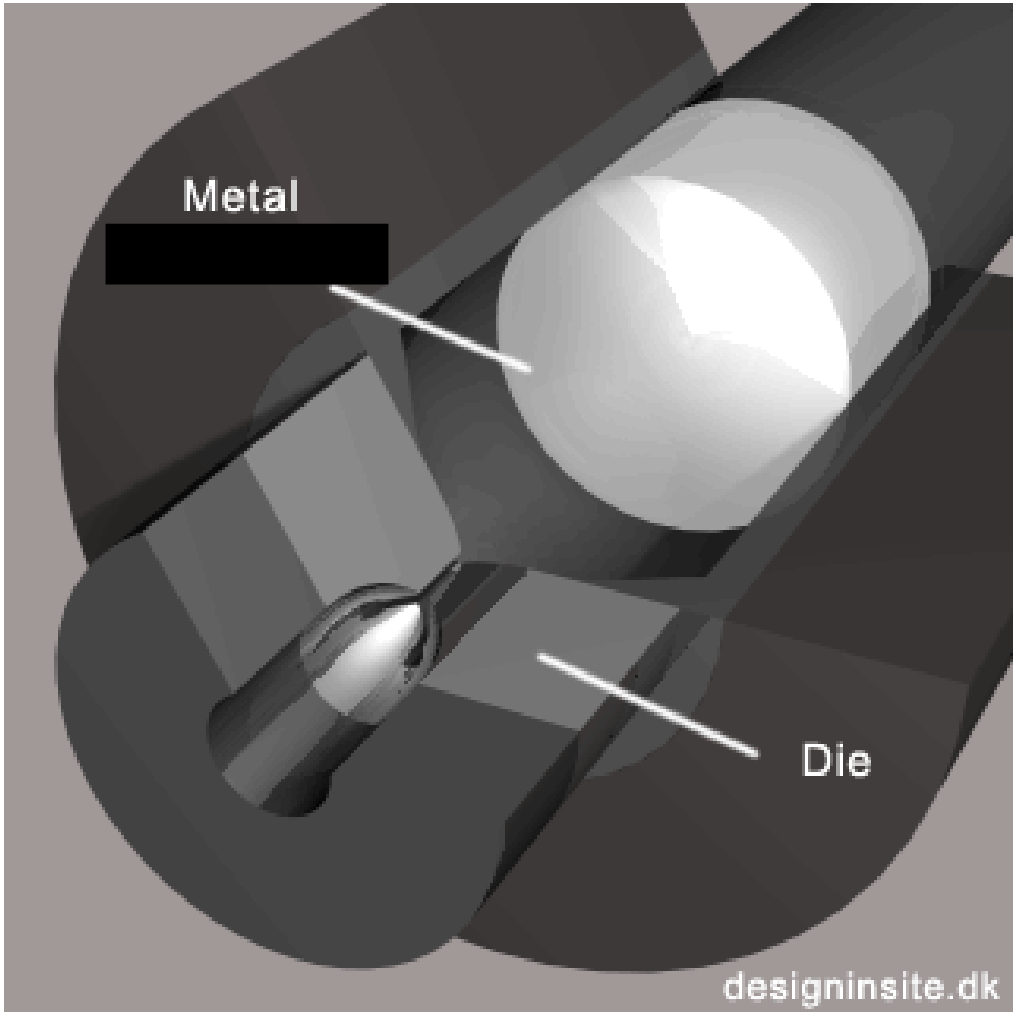


- **Extrusion**
  (rods, tubing)



Extrusion

Metal forced/squeezed out through a hole (die)



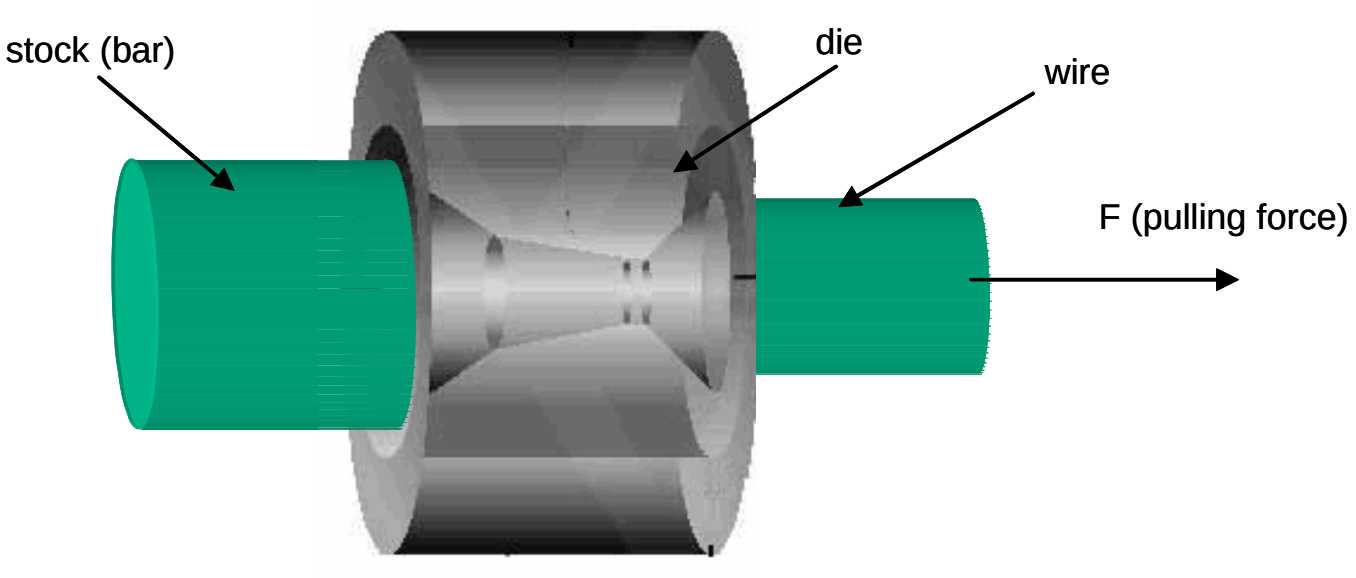
Typical use: ductile metals (Cu, Steel, Al, Mg), Plastics, Rubbers

Common products:

Al frames of white-boards, doors, windows, …

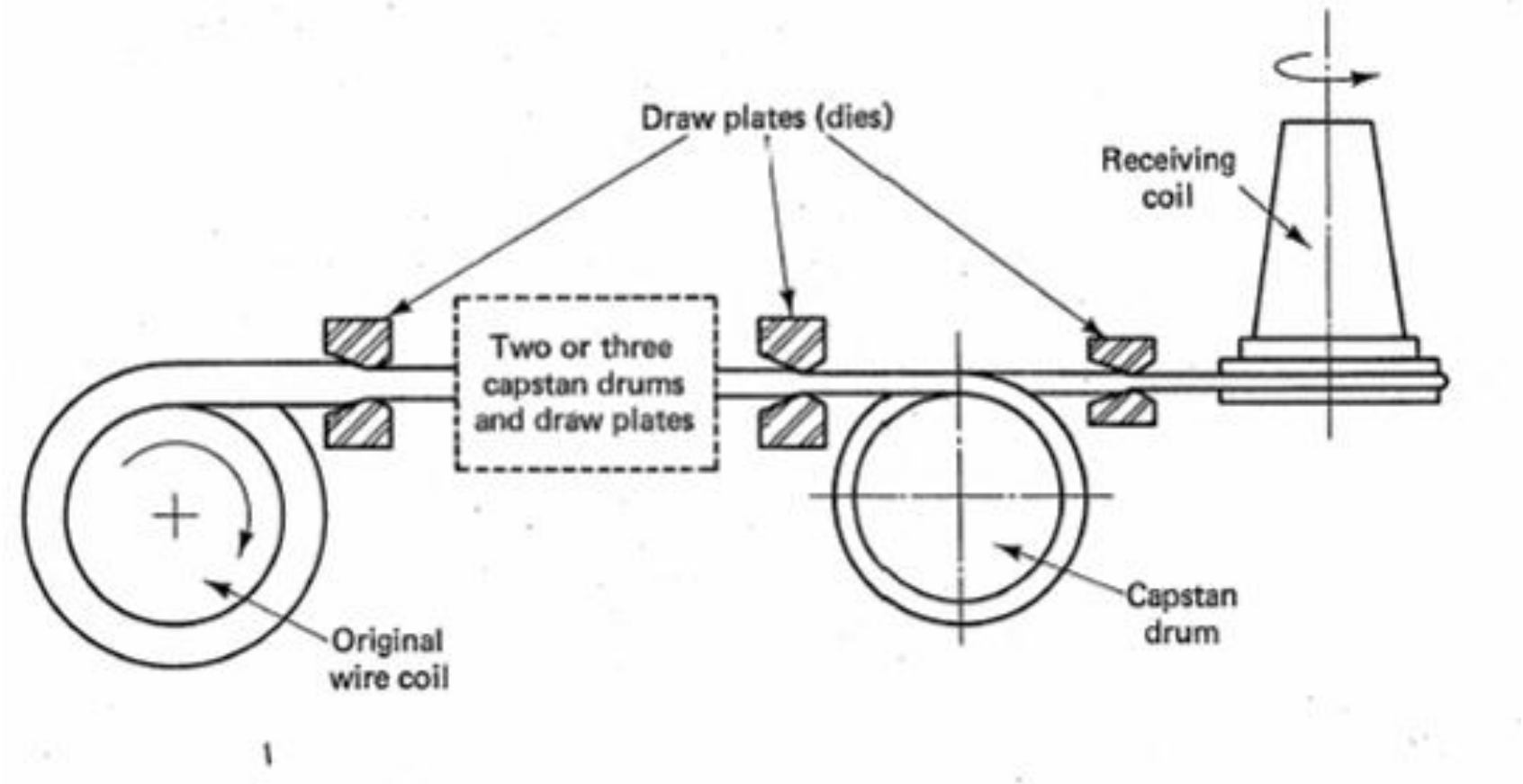
Drawing

Similar to extrusion, except: ***pulling force*** is applied



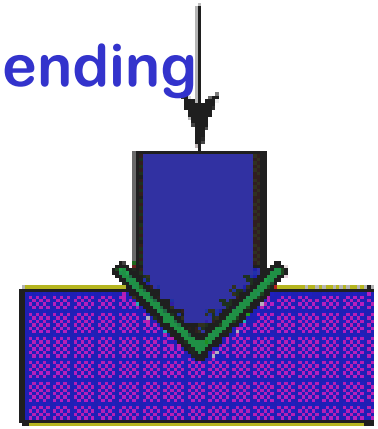
Commonly used to make wires from round bars

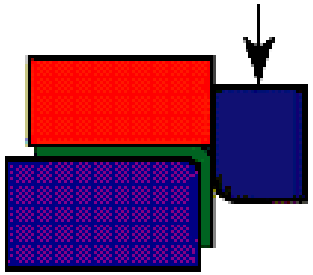
Continuous Drawing



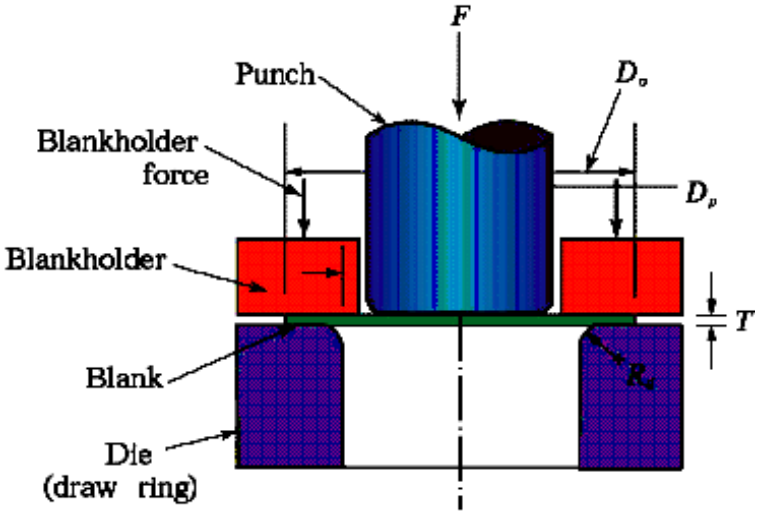
Sheet Metalworking

- **Bending**





- **Deep drawing**



- **Shearing**

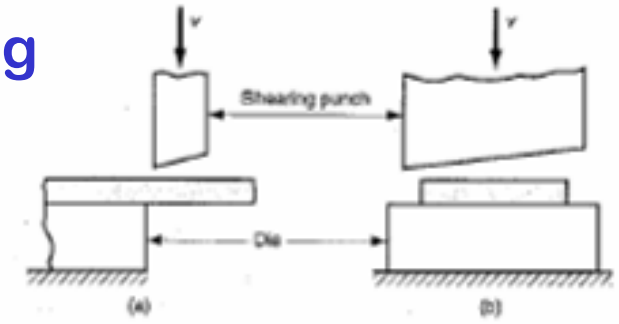
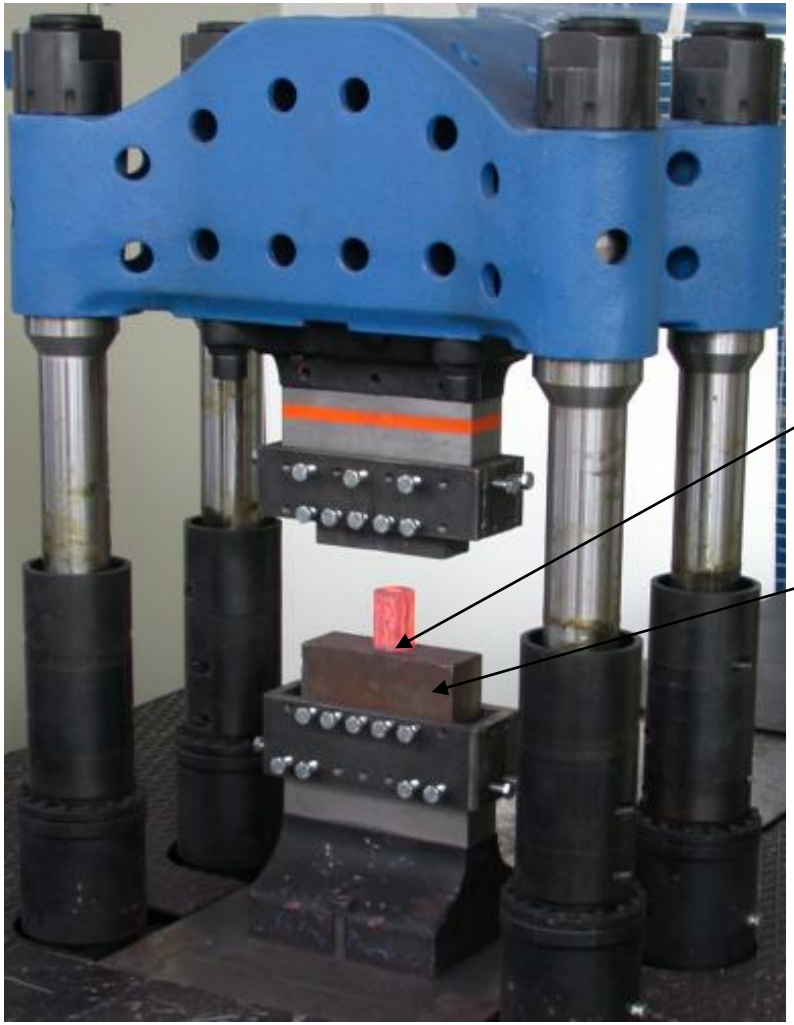


FIGURE 22.3 Shearing operation: (a) side view of the shearing operation; (b) front view of power shears equipped with inclined upper cutting blade. Symbol v indicates motion.

Forging

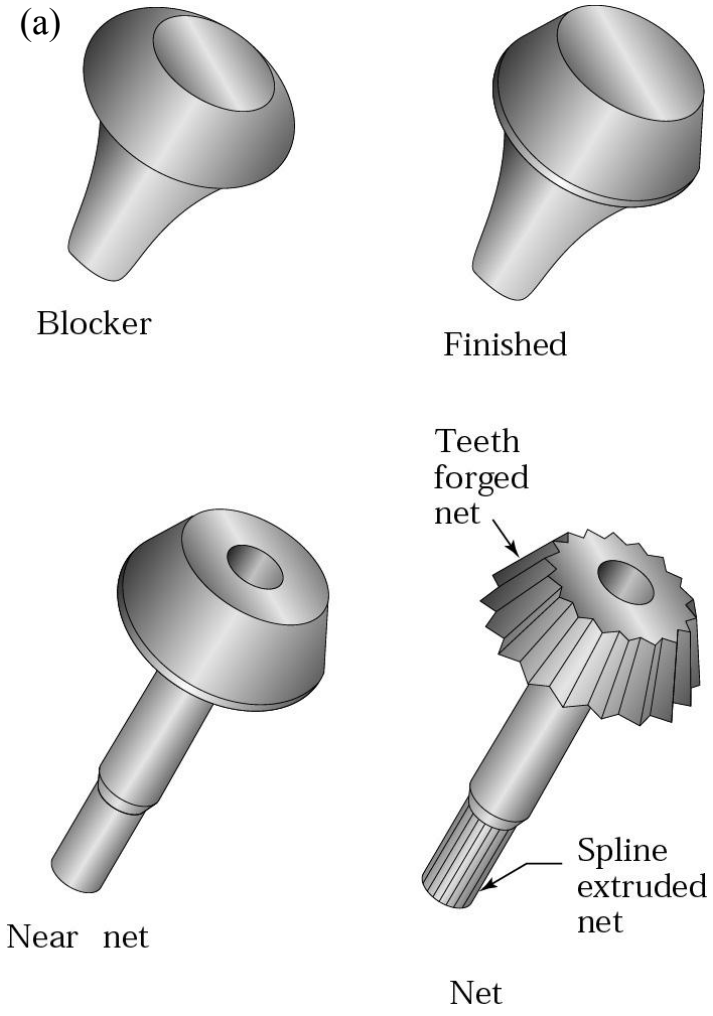
[Heated] metal is beaten with a heavy hammer to give it the required shape



Hot forging,

open-die

Forging



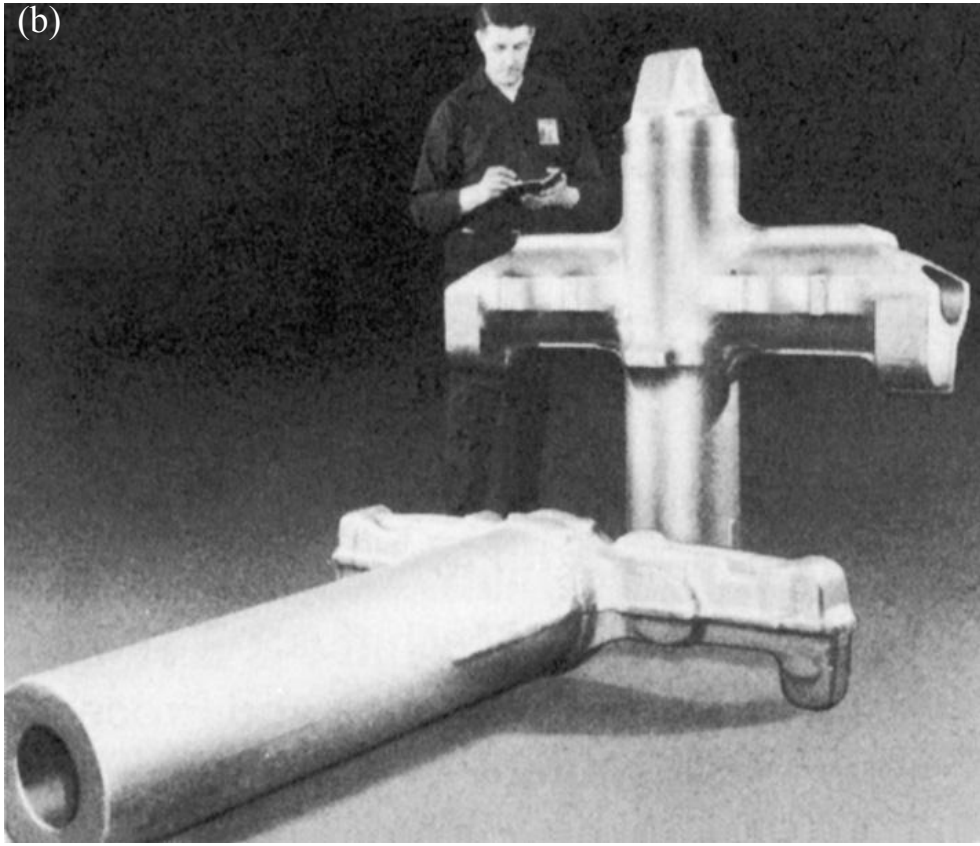
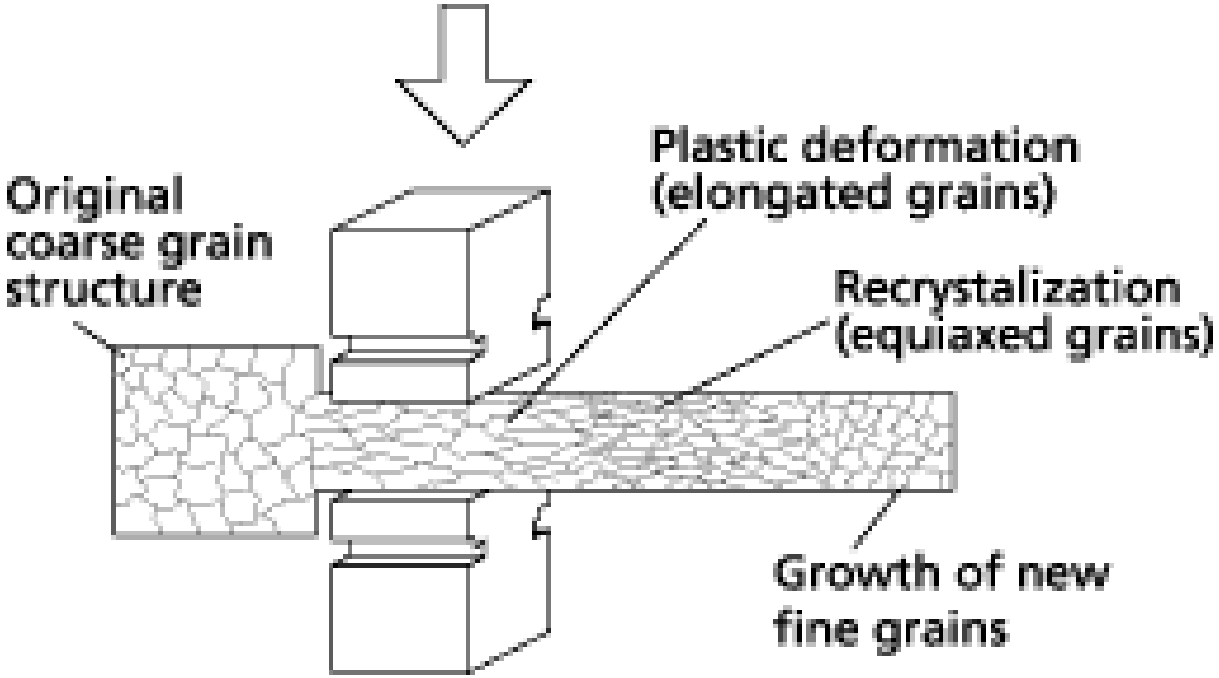


Figure 14.1 (a) Schematic illustration of the steps involved in forging a bevel gear with a shaft. *Source*: Forging Industry Association. (b) Landing-gear components for the C5A and C5B transport aircraft, made by forging. *Source*: Wyman-Gordon Company.

Quality of forged parts

Surface finish/Dimensional control:
Better than casting (typically)

Stronger/tougher than cast/machined parts of same material



[source:www.scotforge.com]

Grain Flow Pattern of Pierced Round Billet

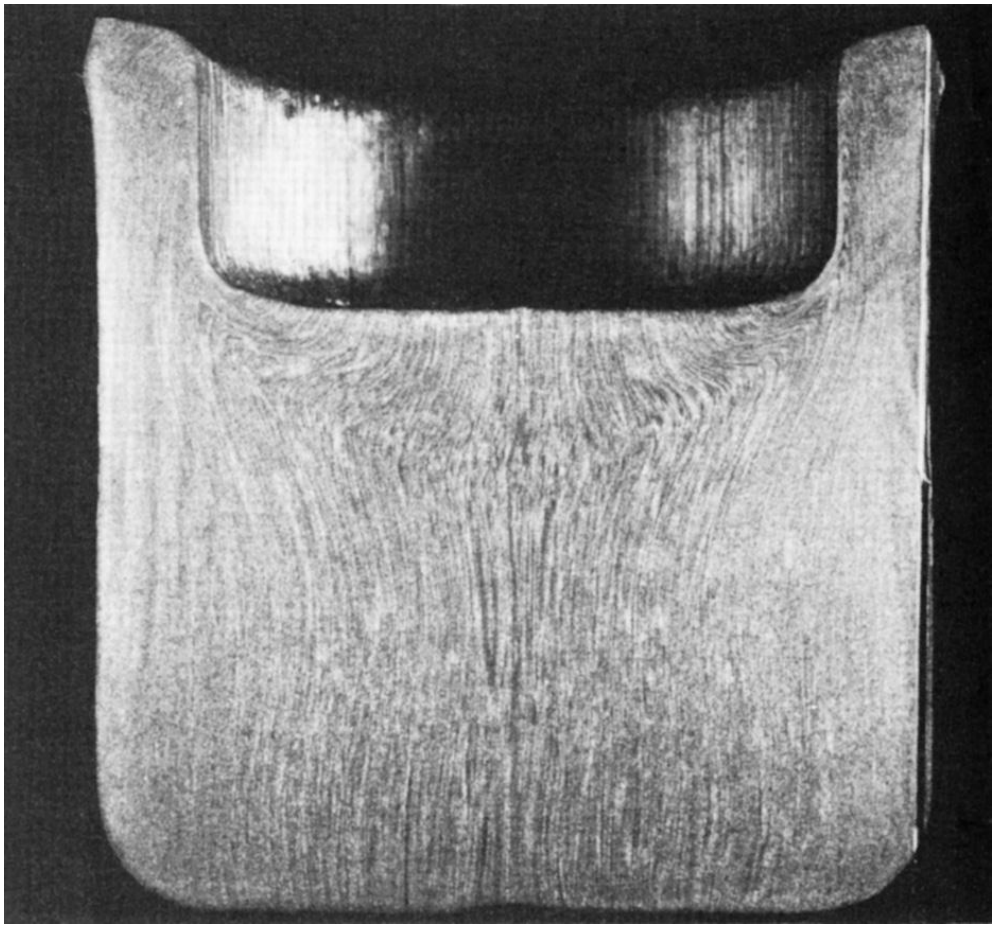


Figure 14.12 A pierced round billet, showing grain flow pattern. *Source*: Courtesy of Ladish Co., Inc.

Grain Flow Comparison

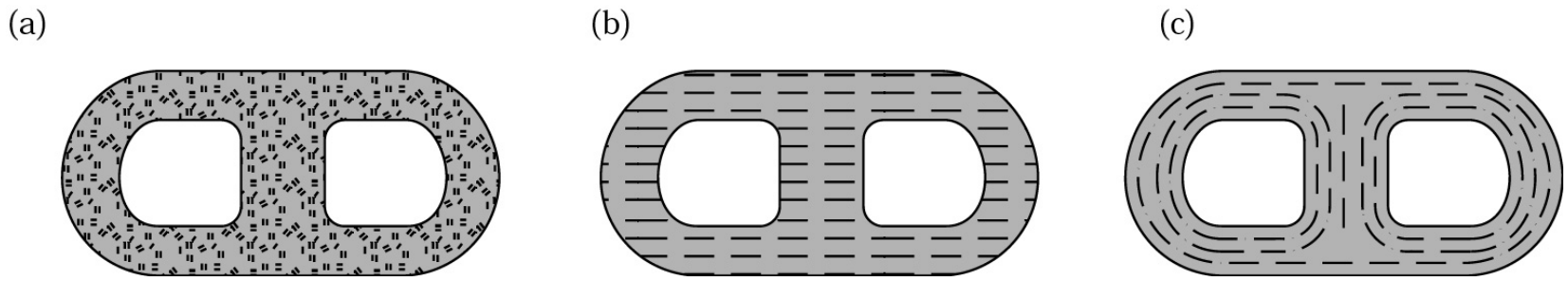


Figure 14.3 A part made by three different processes, showing grain flow. (a) casting, (b) machining, (c) forging. *Source*: Forging Industry Association.

Upsetting

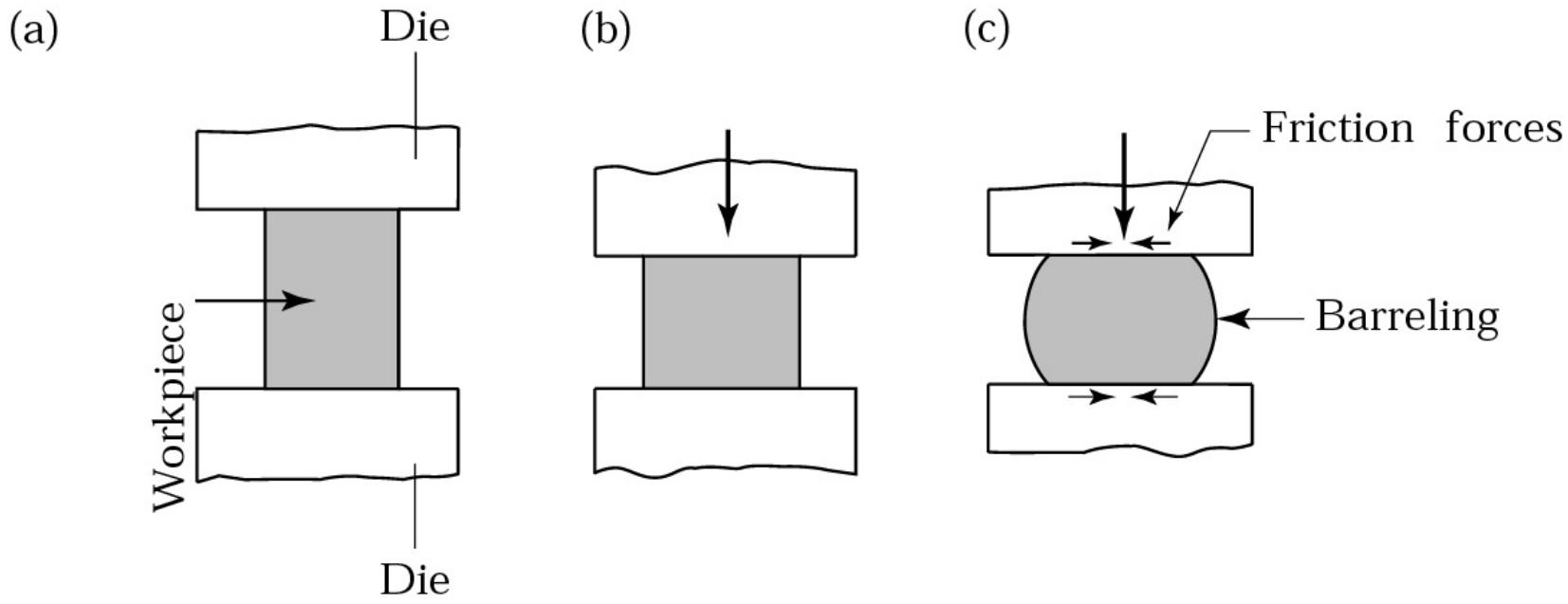


Figure (a) Solid cylindrical billet upset between two flat dies. (b) Uniform deformation of the billet without friction. (c) Deformation with friction. Note barreling of the billet caused by friction forces at the billet-die interfaces.

Impression-Die Forging

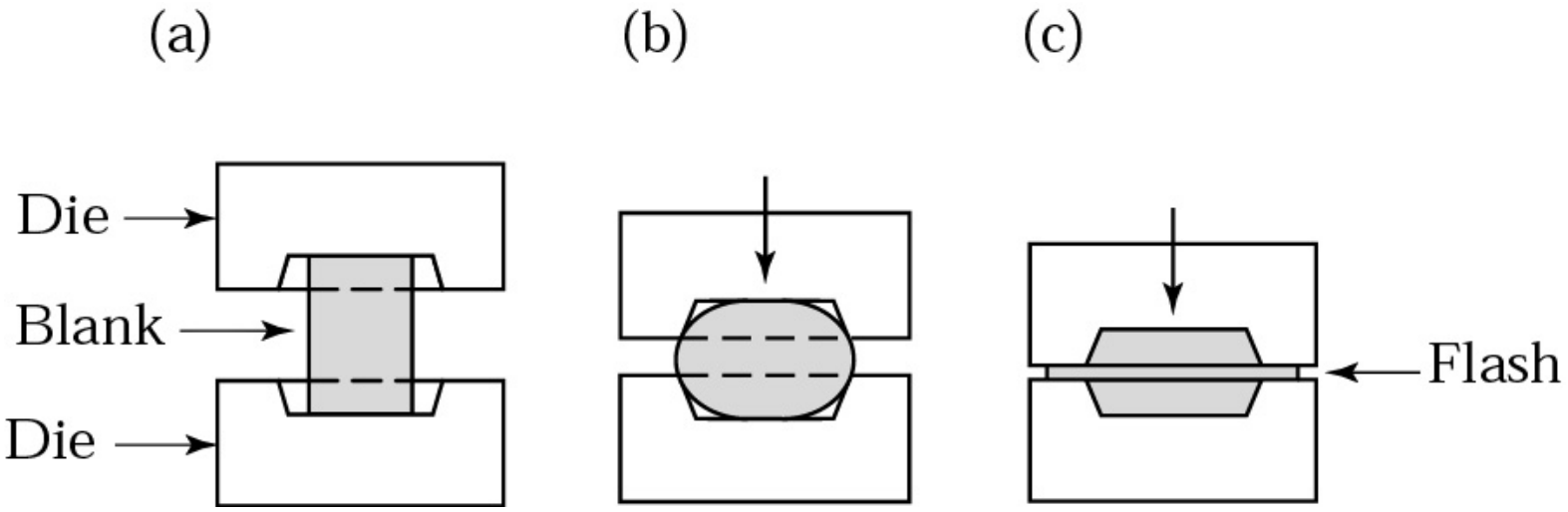
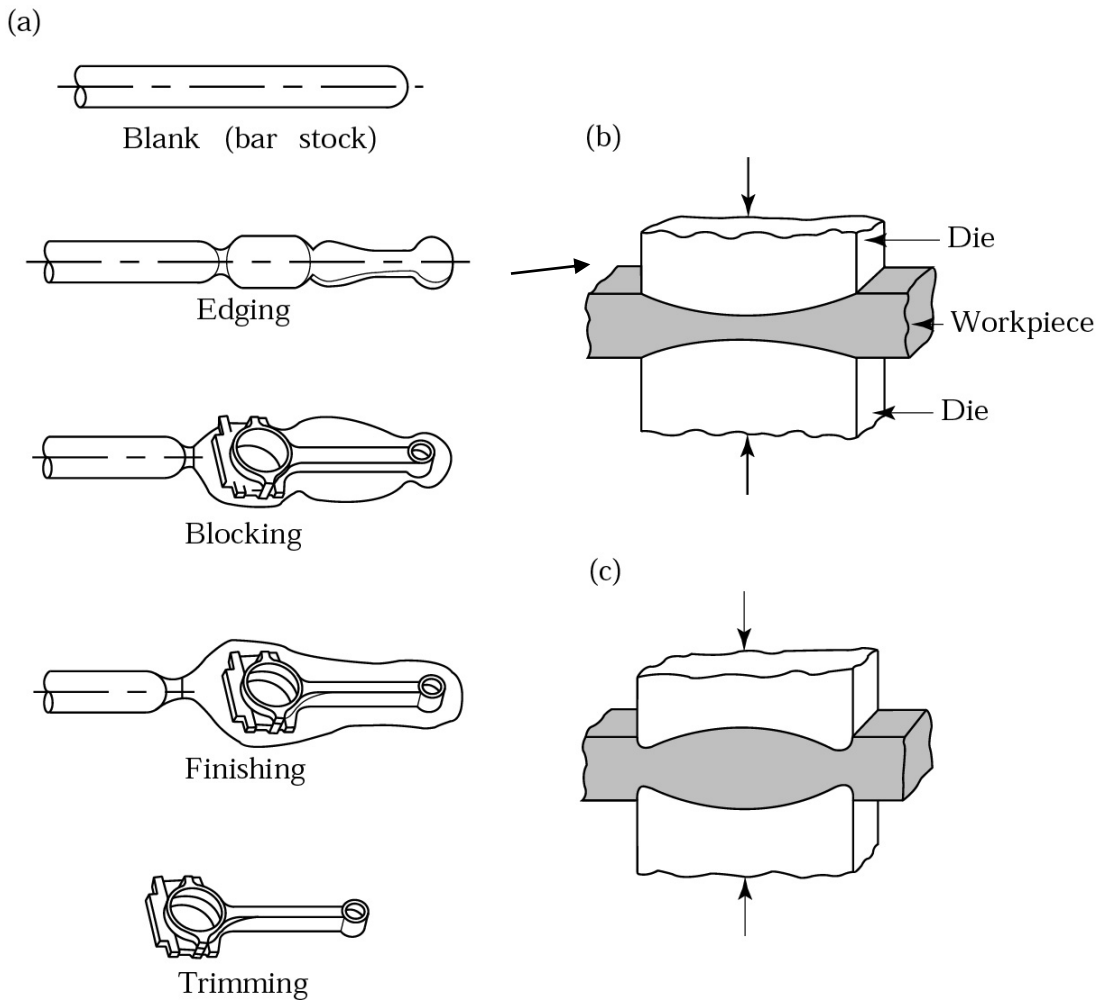


Figure 14.6 Stages in impression-die forging of a solid round billet. Note the formation of flash, which is excess metal that is subsequently trimmed off (see Fig. 14.8).

Forging a Connecting Rod

Figure (a) Stages in forging a connecting rod for an internal combustion engine. Note the amount of flash required to ensure proper filling of the die cavities. (b) Fullering, and (c) edging operations to distribute the material when preshaping the blank for forging.



Trimming Flash from a Forged Part

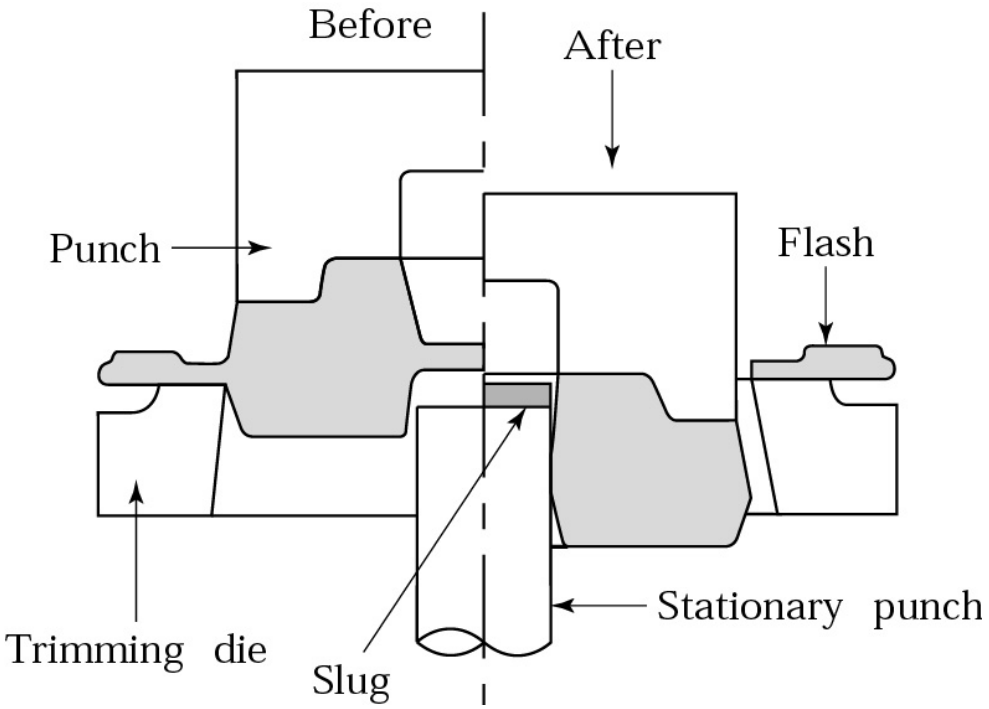


Figure. Trimming flash from a forged part. Note that the thin material at the center is removed by punching.

Flashless forging

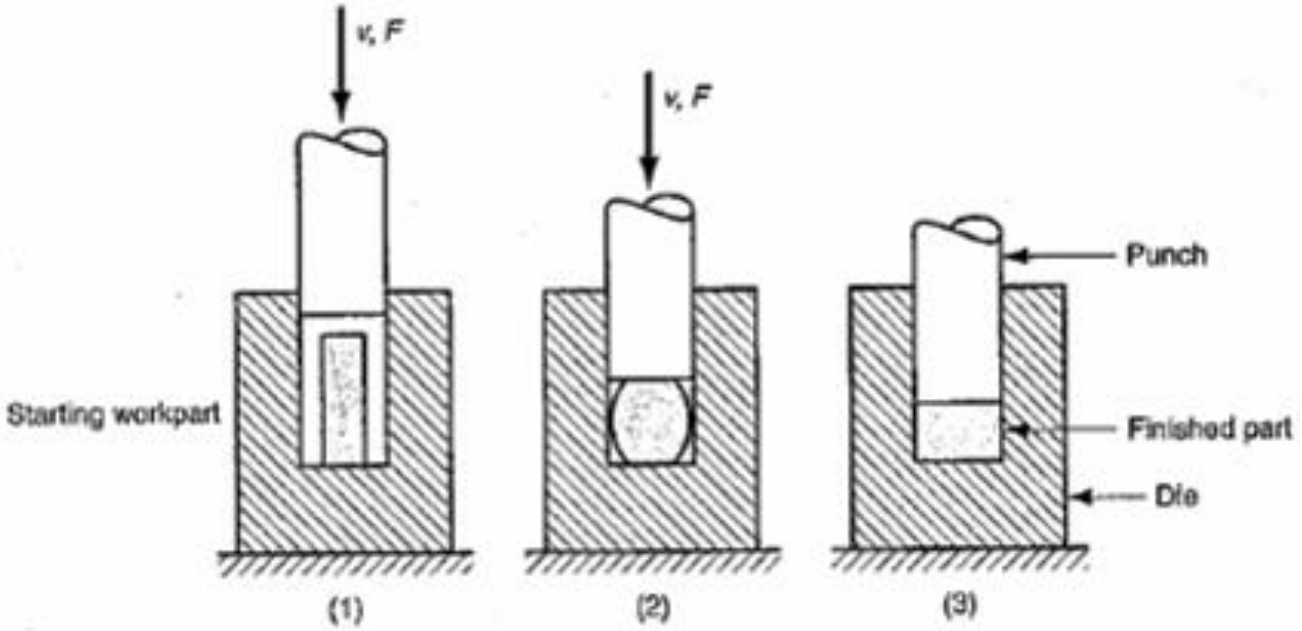
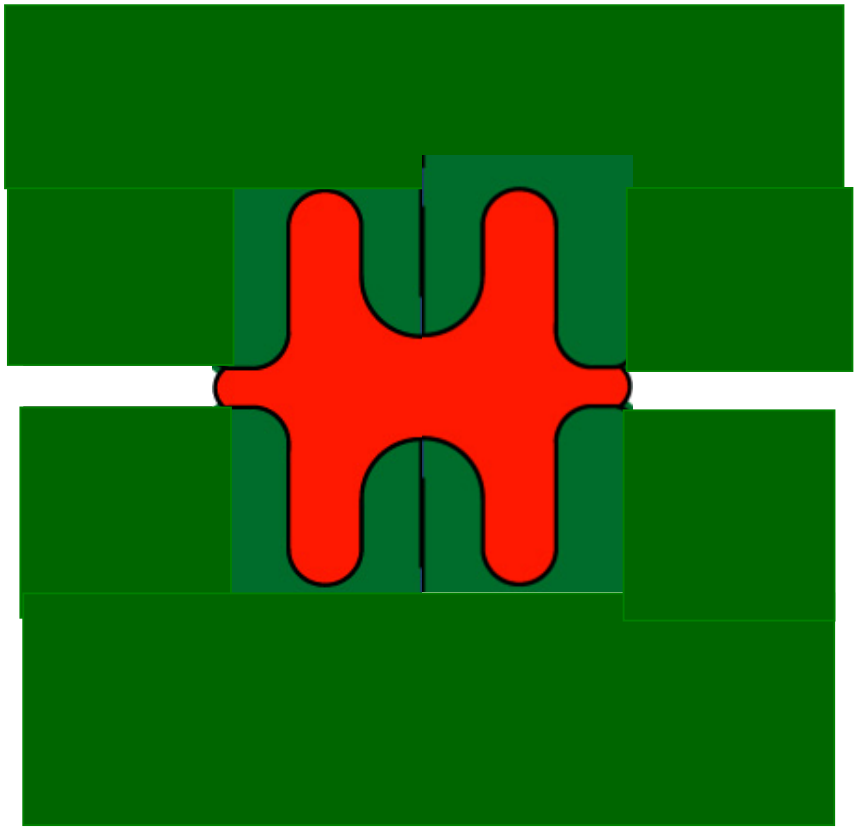
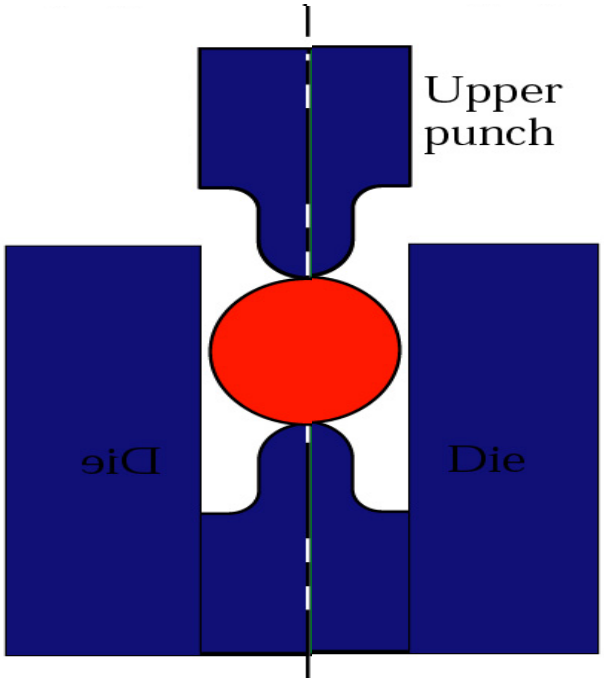


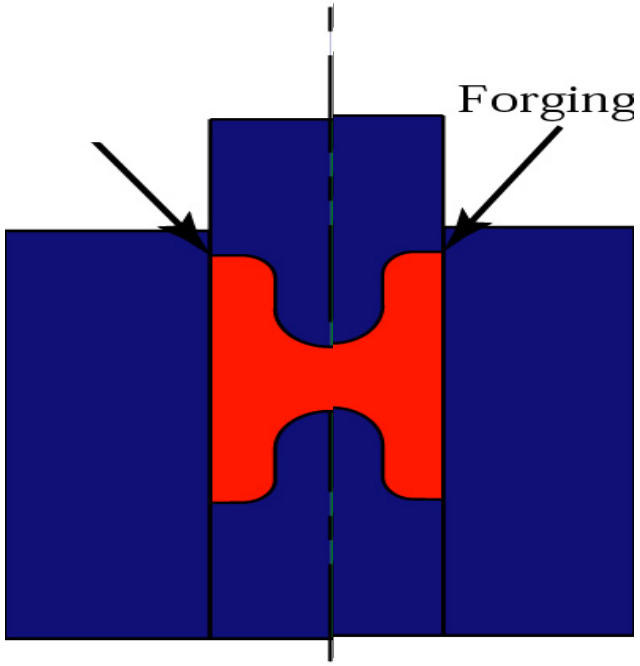
FIGURE 21.18 Flashless forging: (1) just before initial contact with workpiece, (2) partial compression, and (3) final punch and die closure. Symbols v and F indicate motion (v = velocity) and applied force, respectively.

Normal



Flashless Forging





of stroke

Comparison of Forging With and Without Flash

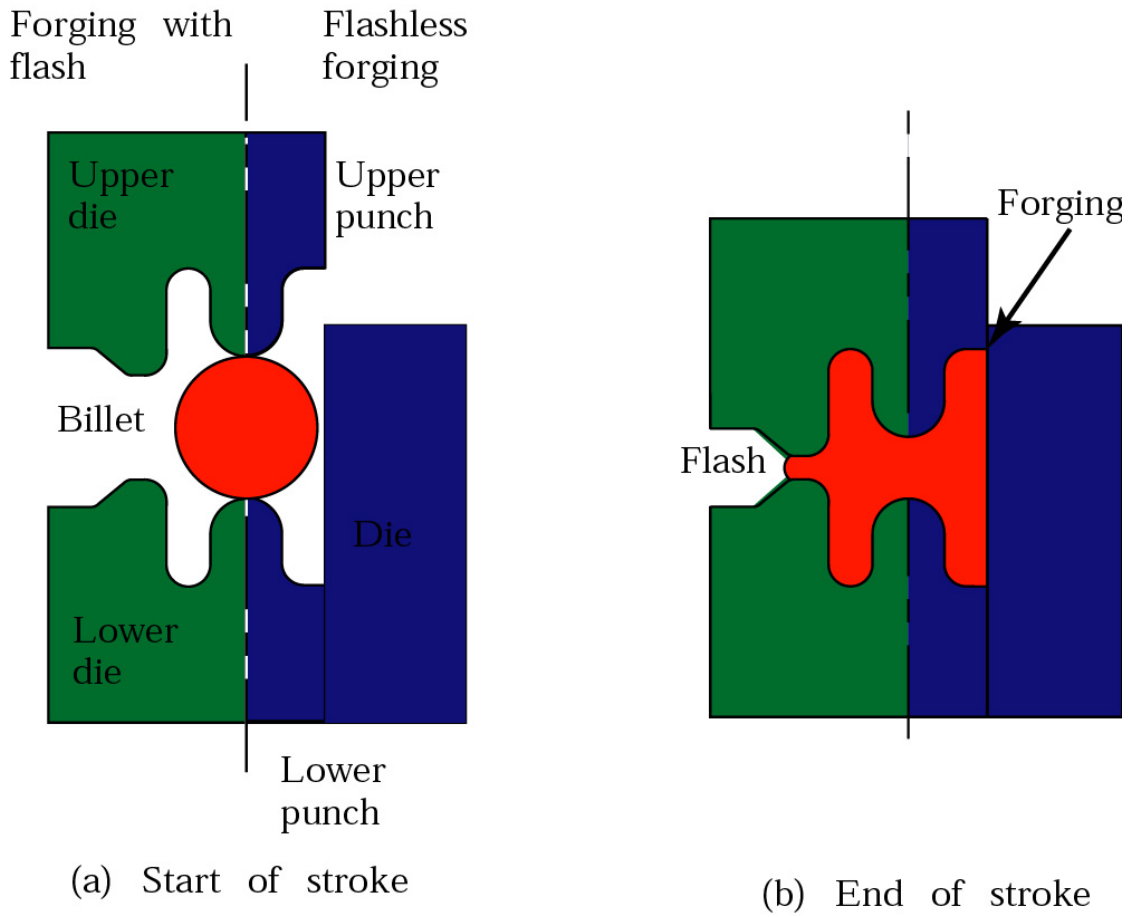


Figure 14.9 Comparison of closed-die forging to precision or flashless forging of a cylindrical billet. *Source*: H. Takemasu, V. Vazquez, B. Painter, and T. Altan.

Unit Cost in Forging

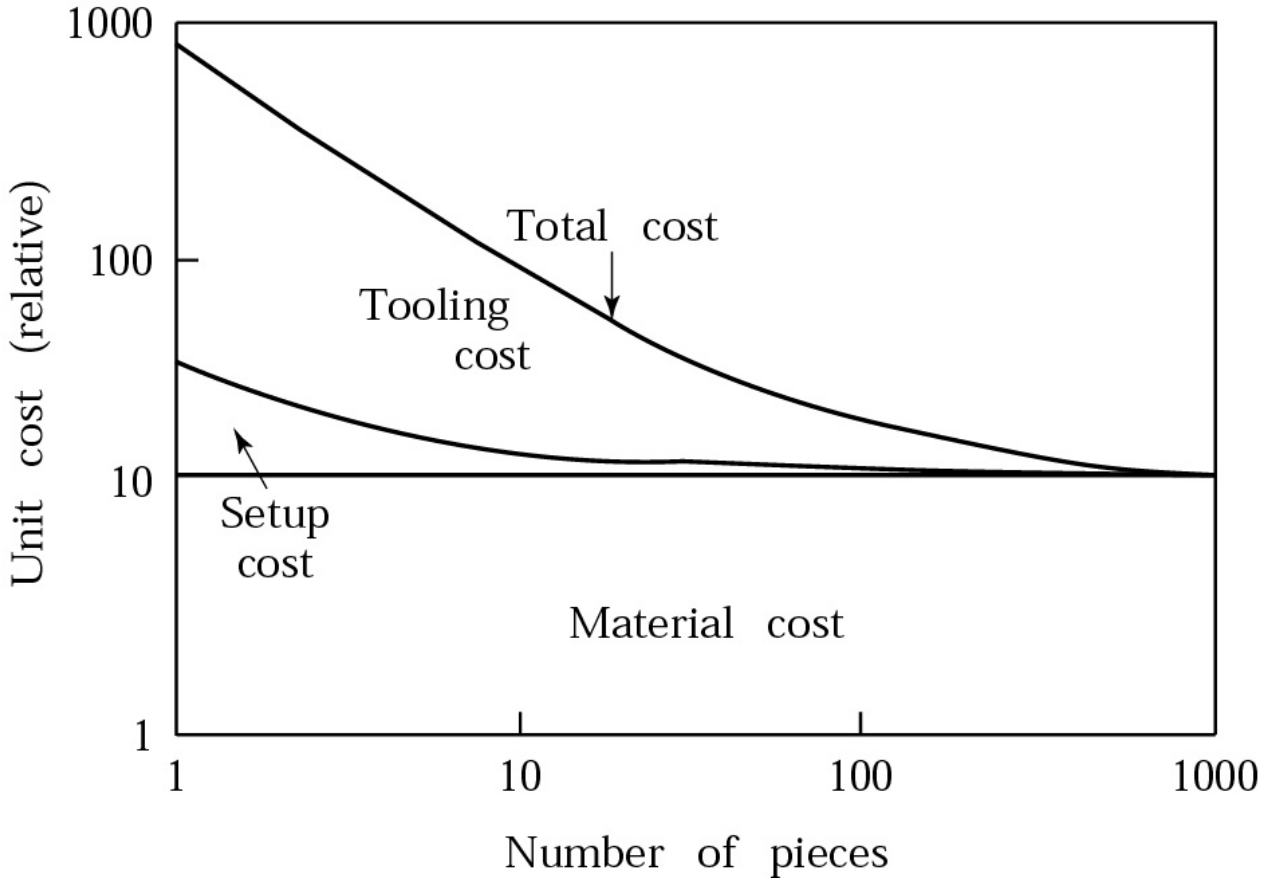
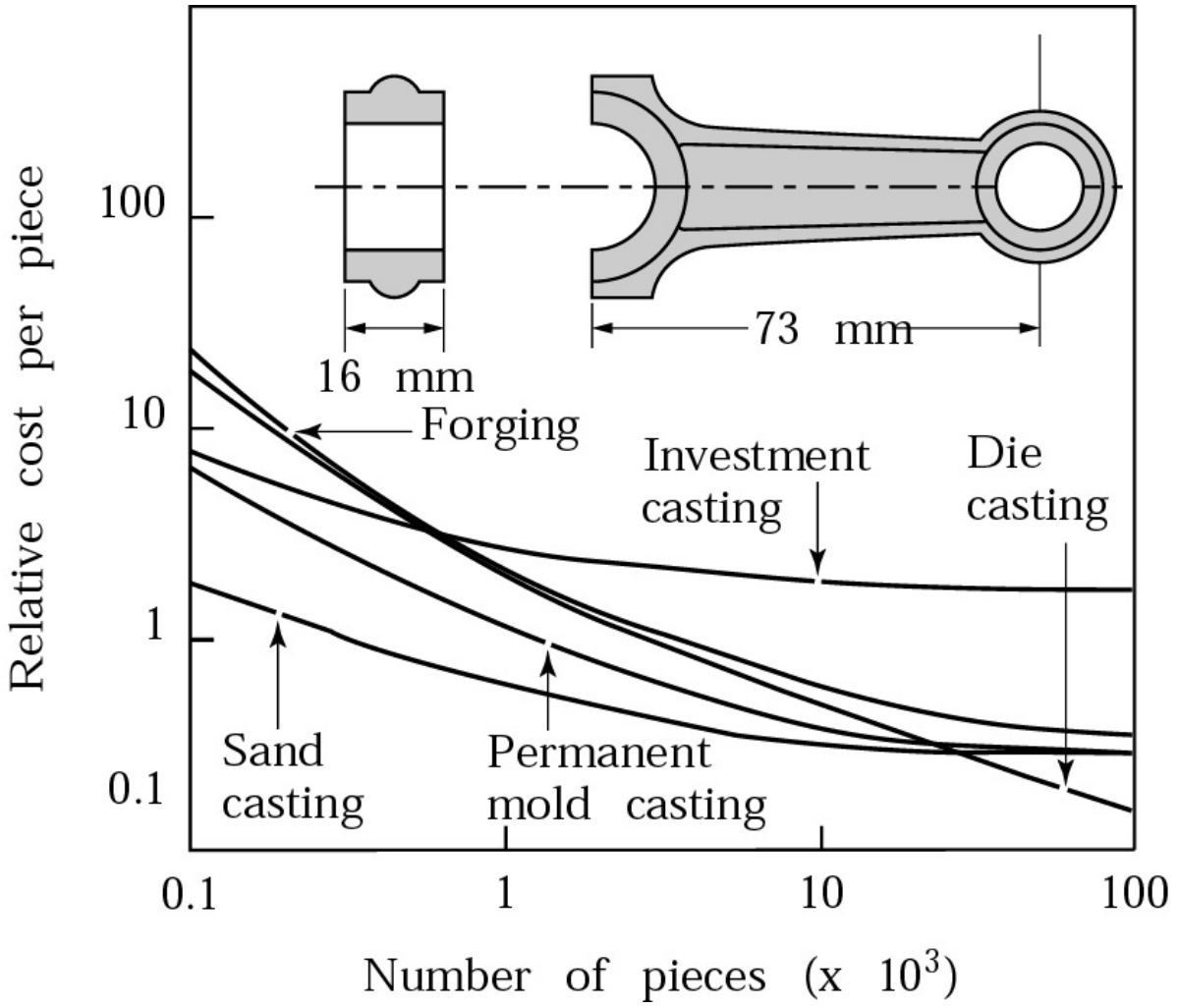


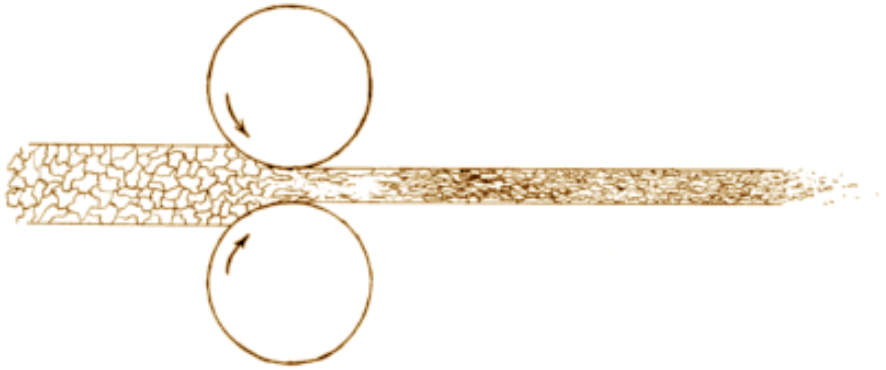
Figure Typical unit cost (cost per piece) in forging; note how the setup and the tooling costs per piece decrease as the number of pieces forged increases, if all pieces use the same die.

Relative Unit Costs of a Small Connecting Rod

Figure .
Relative unit costs of a small connecting rod made by various forging and casting processes. Note that, for large quantities, forging is more economical. Sand casting is the more economical process for fewer than about 20,000 pieces.



Rolling

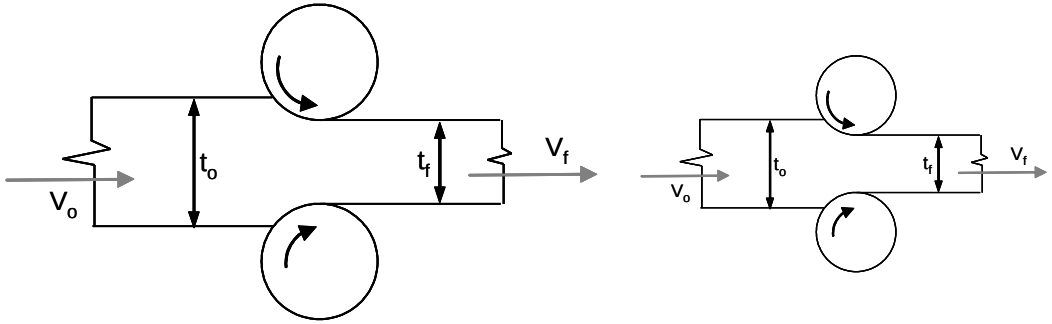


ROLLING PROCESS

Important Applications:

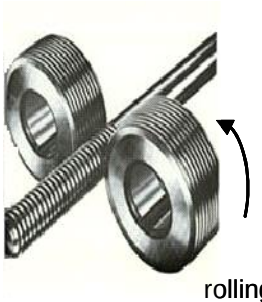
Steel Plants,
Raw stock production (sheets, tubes, Rods, etc.)
Screw manufacture

Rolling Basics



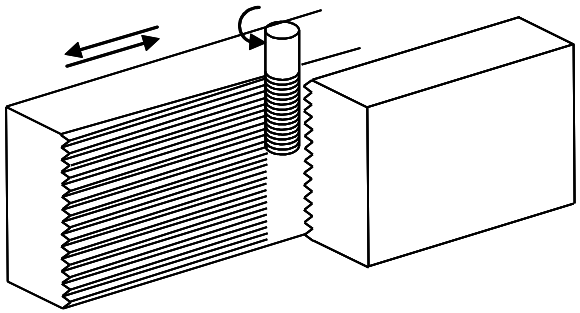
Screw manufacture:

stationary die



rolling die

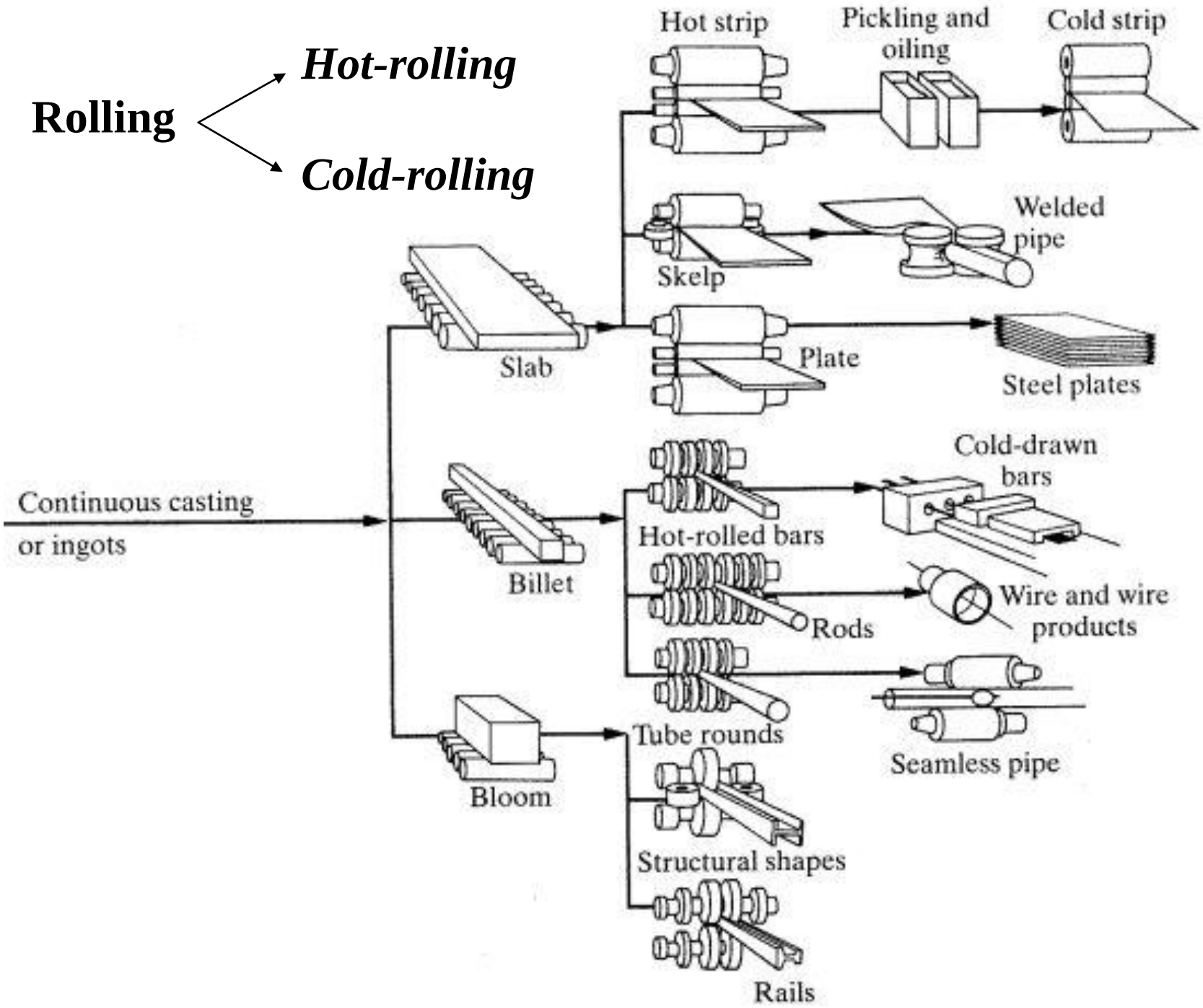
thread rolling machine



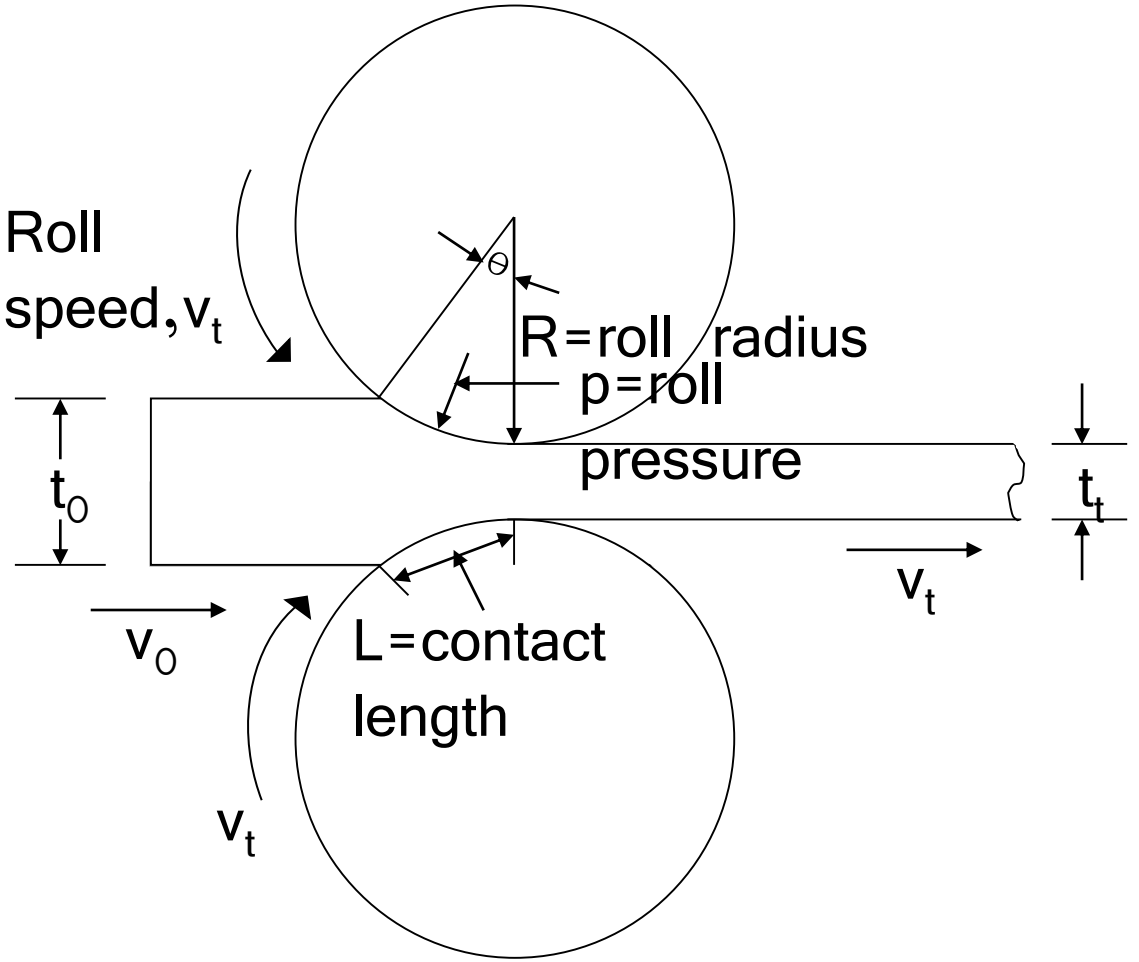
Reciprocating flat thread-rolling dies

Rolling → ***Hot-rolling***

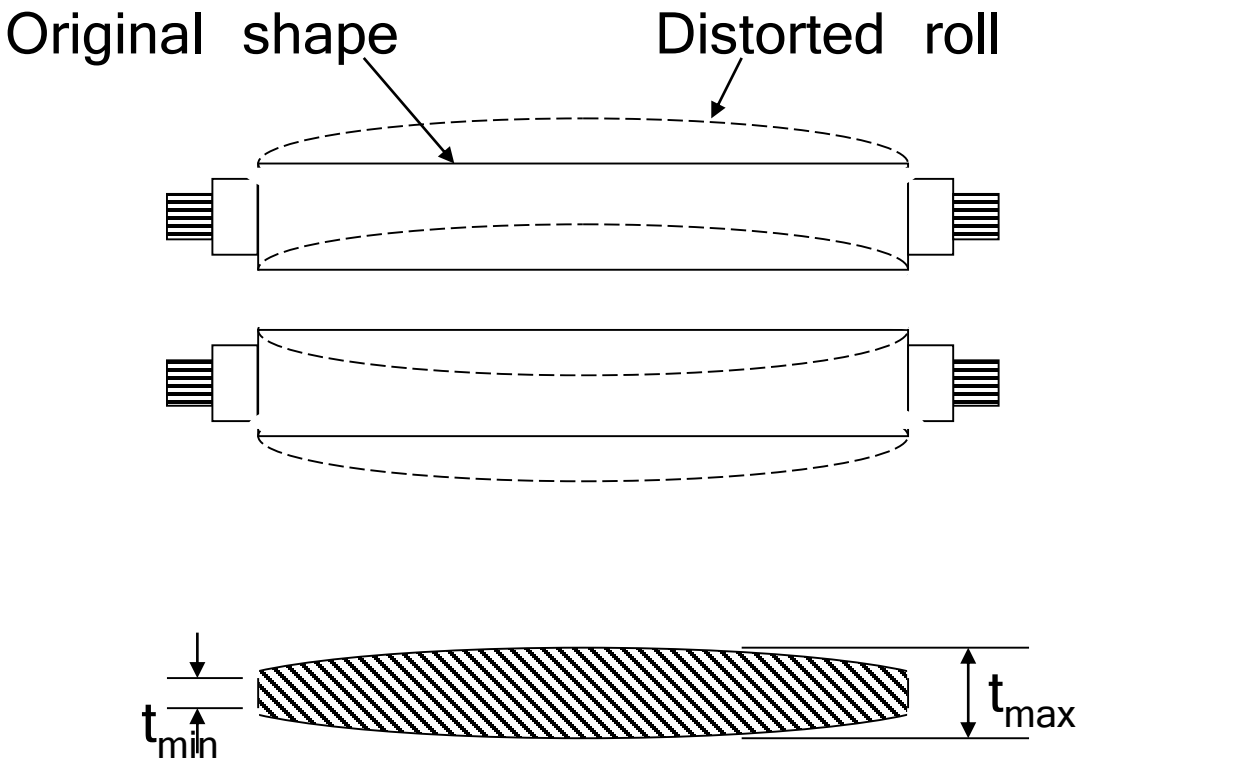
Rolling → ***Cold-rolling***



Rolling Theory

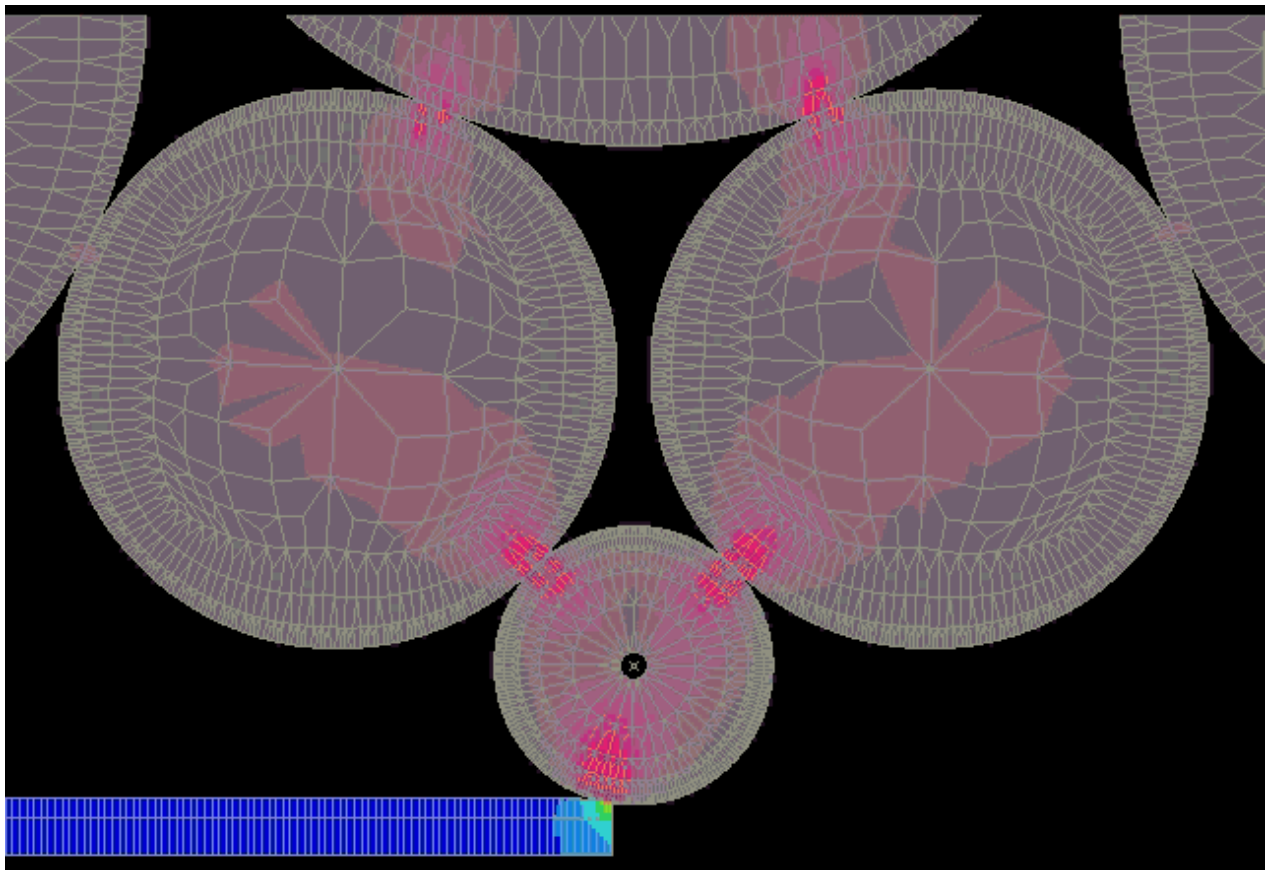


Distorted roll

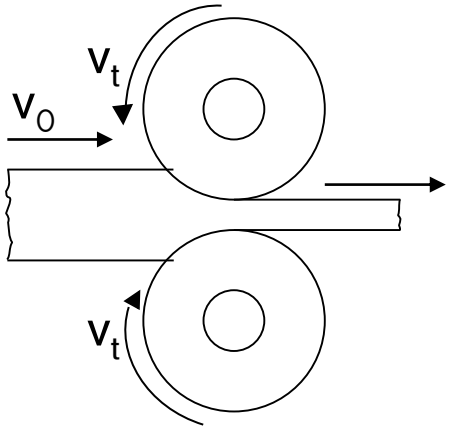


Cross section of the sheet

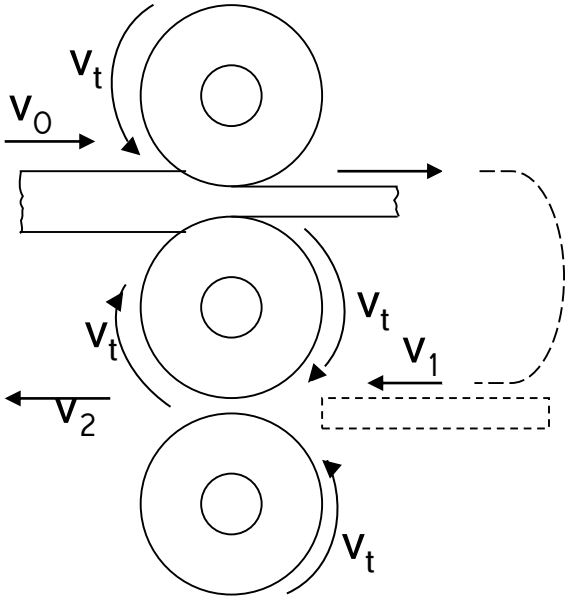
Rolling force



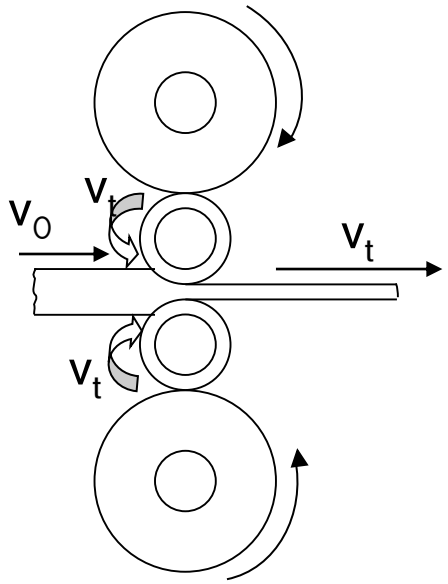
Various Configurations



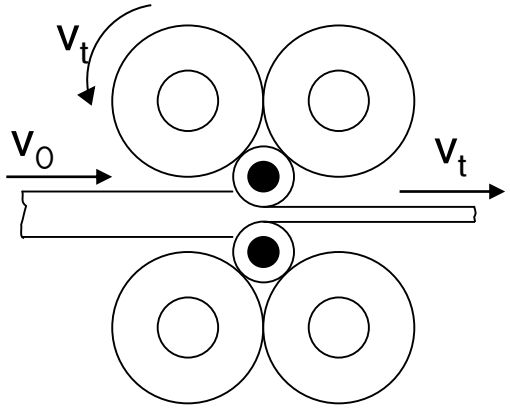
Two high



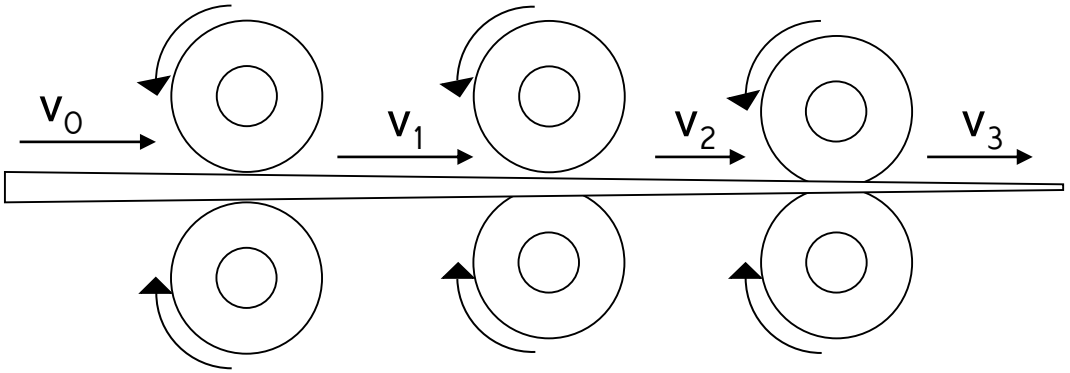
Three high



Four high



Cluster Mill



Tandem rolling mill

Cluster Mill

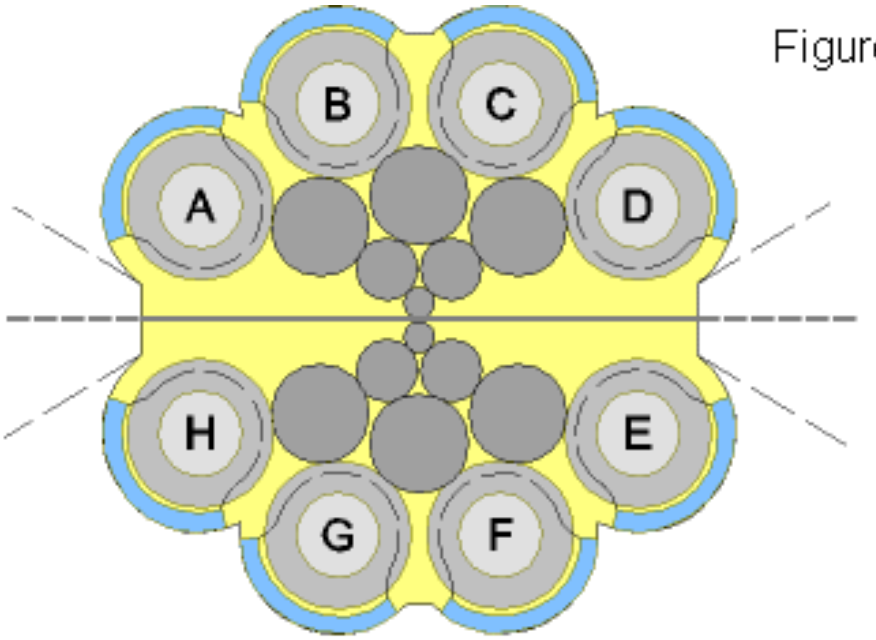


Figure 1

Shapes Produced by rolling

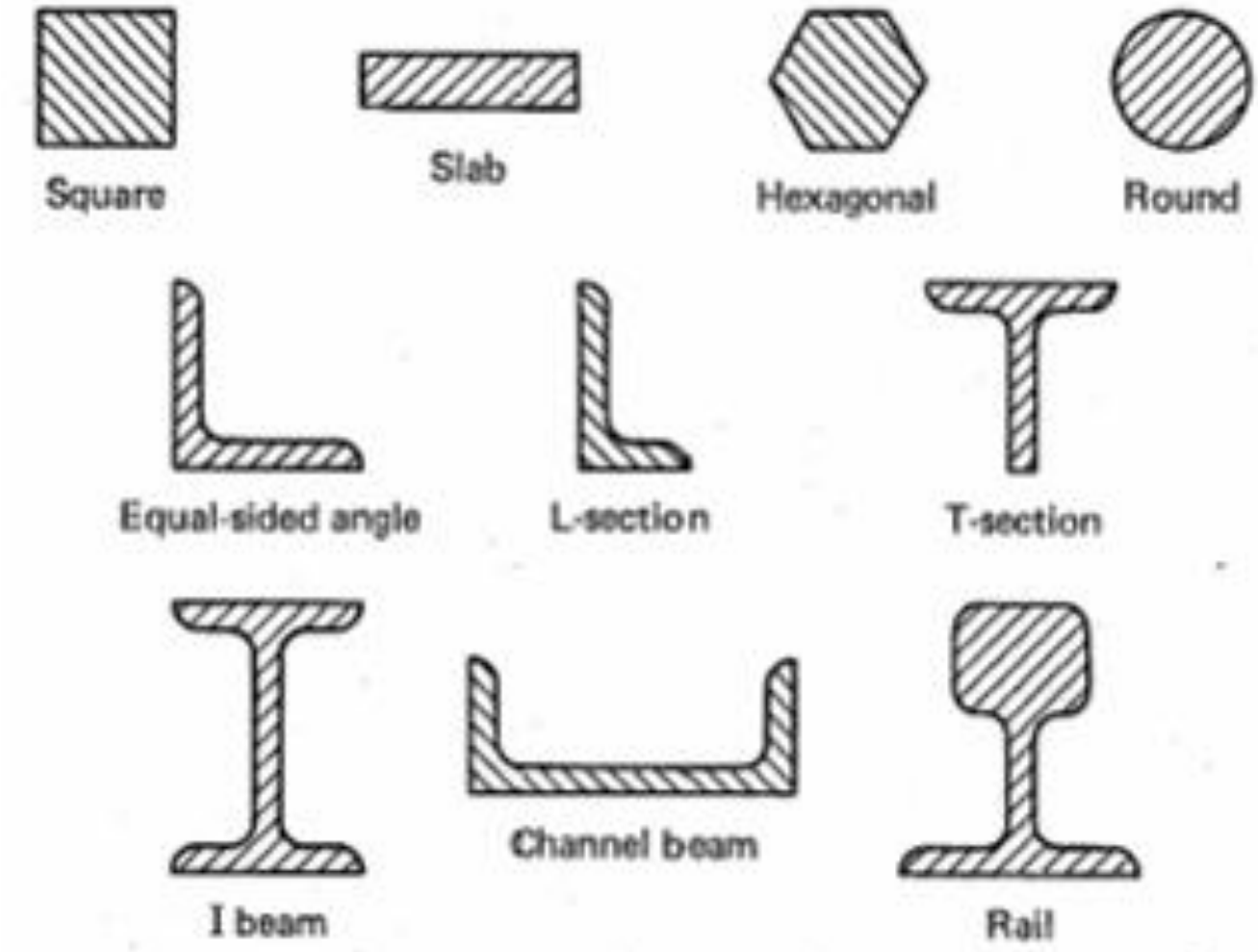
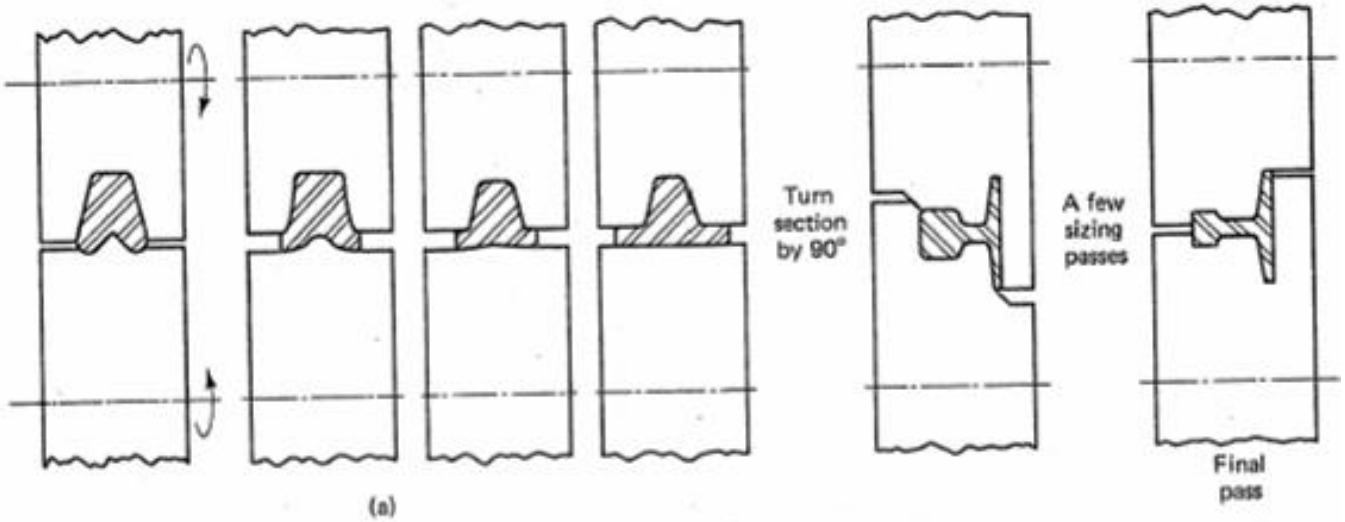
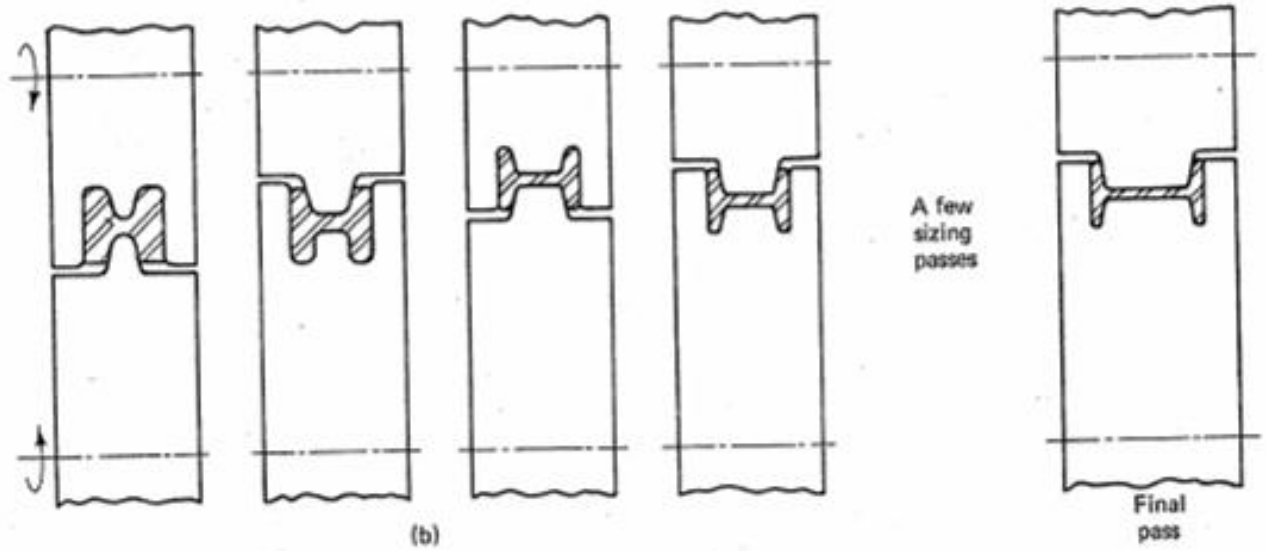


FIGURE 5.10

Roll passes: (a) for producing rails; (b) for producing an I beam





Roll-Forging

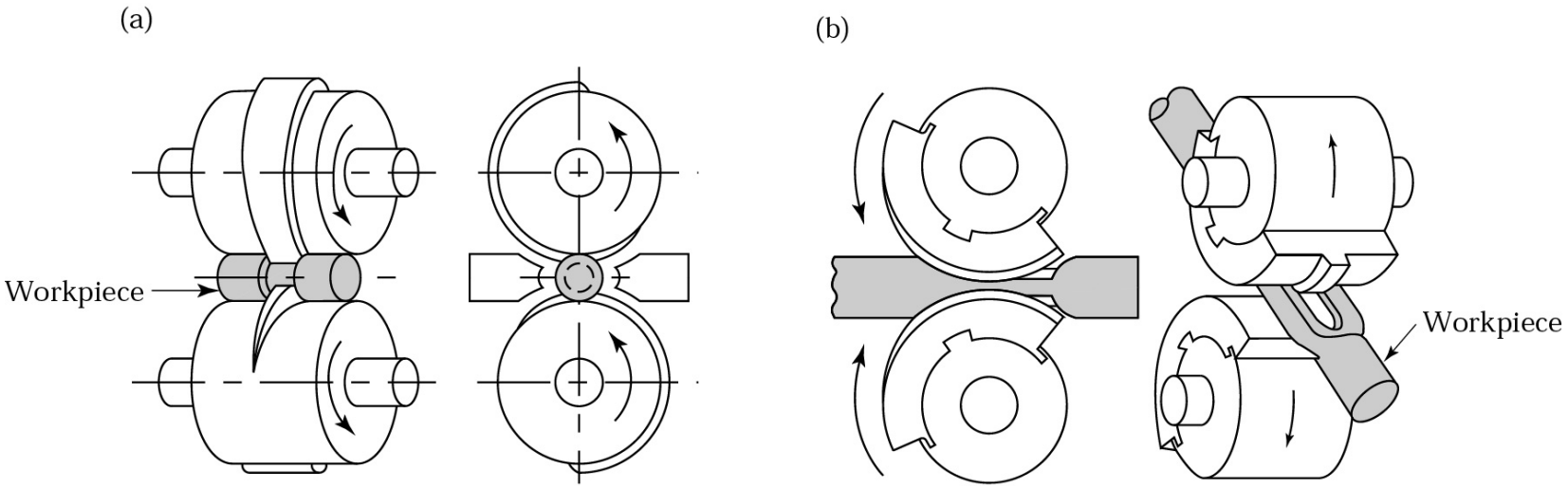
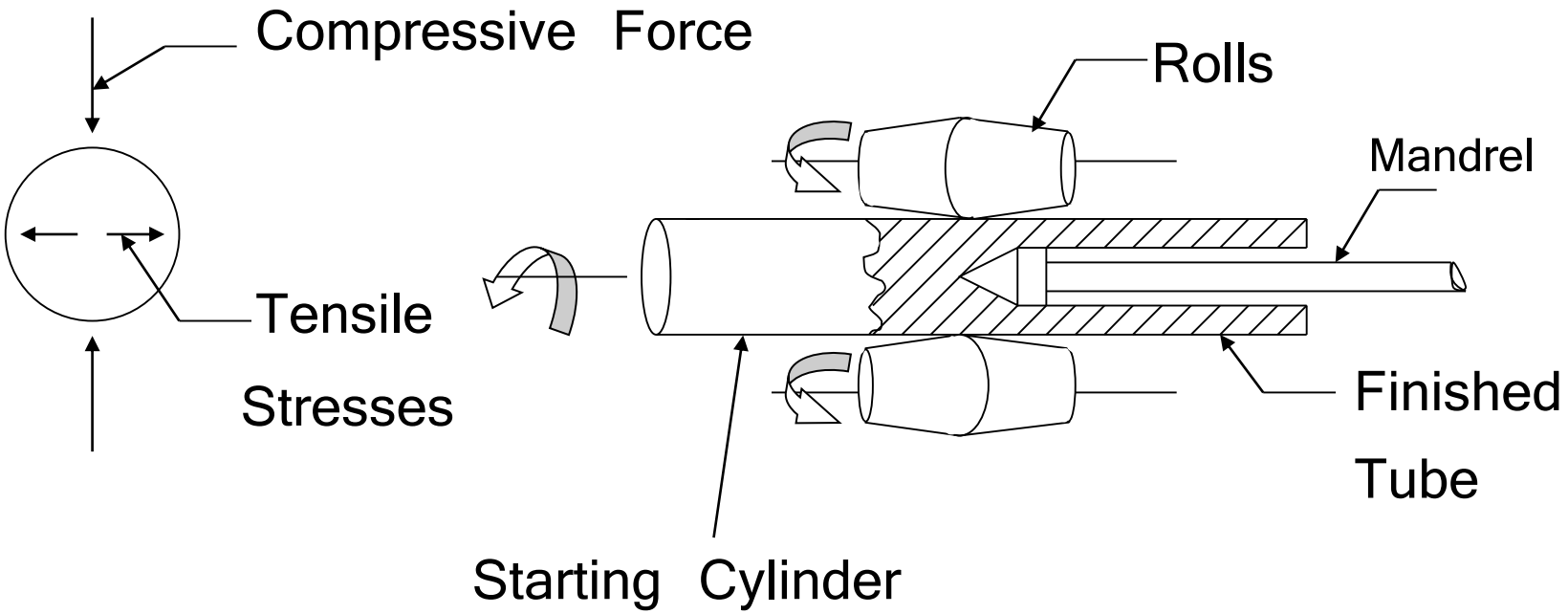


Figure 14.13 Two examples of the roll-forging operation, also known as *cross-rolling*. Tapered leaf springs and knives can be made by this process. *Source*: (a) J. Holub; (b) reprinted with permission of General Motors Corporation.

Roll piercing



Friction and lubrication

- Friction is undesirable;
  - Metal flow in the work is retarded
  - The forces to perform are increased
  - Rapid wear of tooling

Lubrication

- Mineral oils
- Graphite
- Glass
- Graphite in water or mineral oil is a common for hot forging

Sheet Metal Processes

Raw material: sheets of metal, rectangular, large

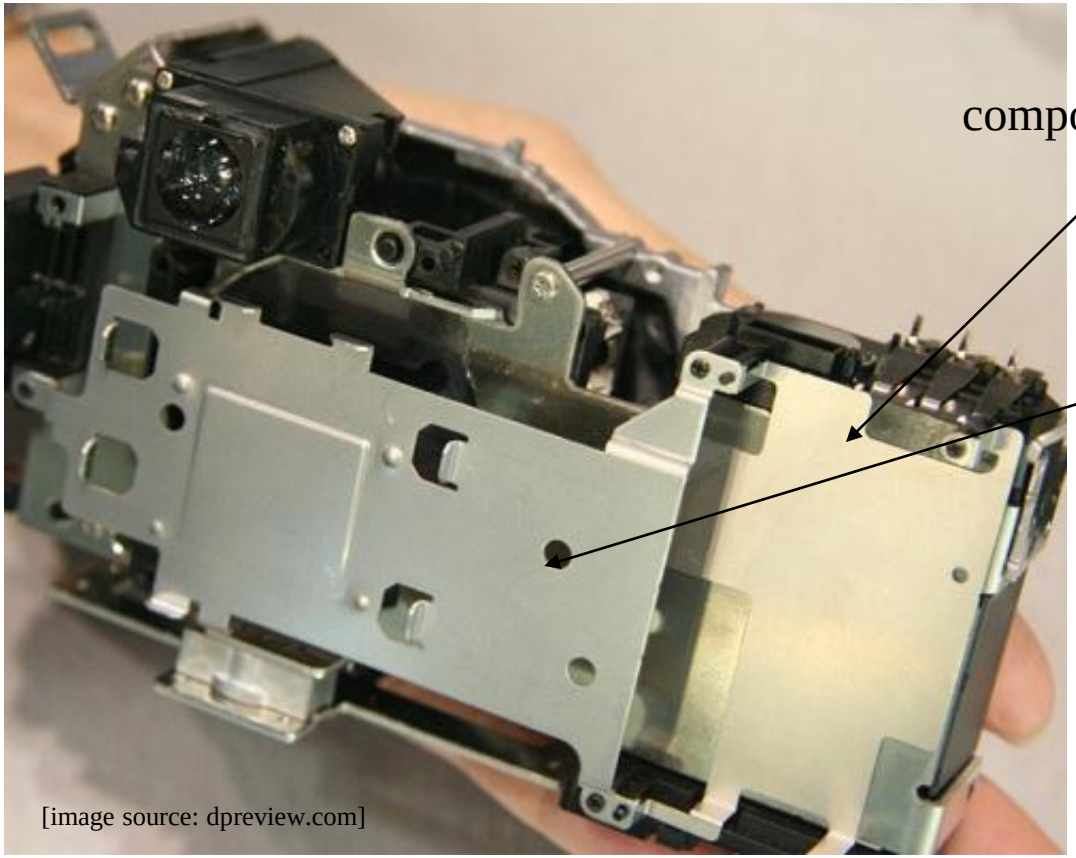
Raw material Processing: Rolling (anisotropic properties)

Processes:

- Shearing
- Punching
- Bending
- Deep drawing

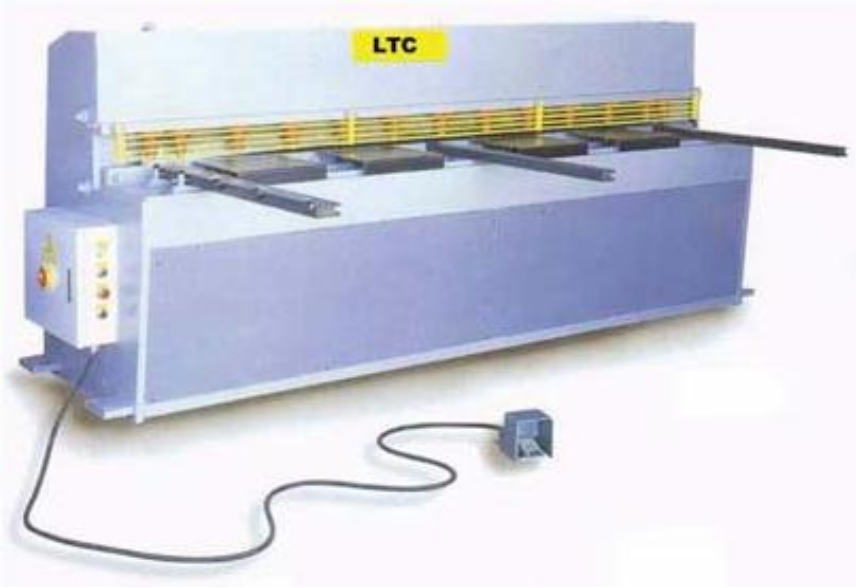
Bending

Body of Olympus E-300 camera



Shearing

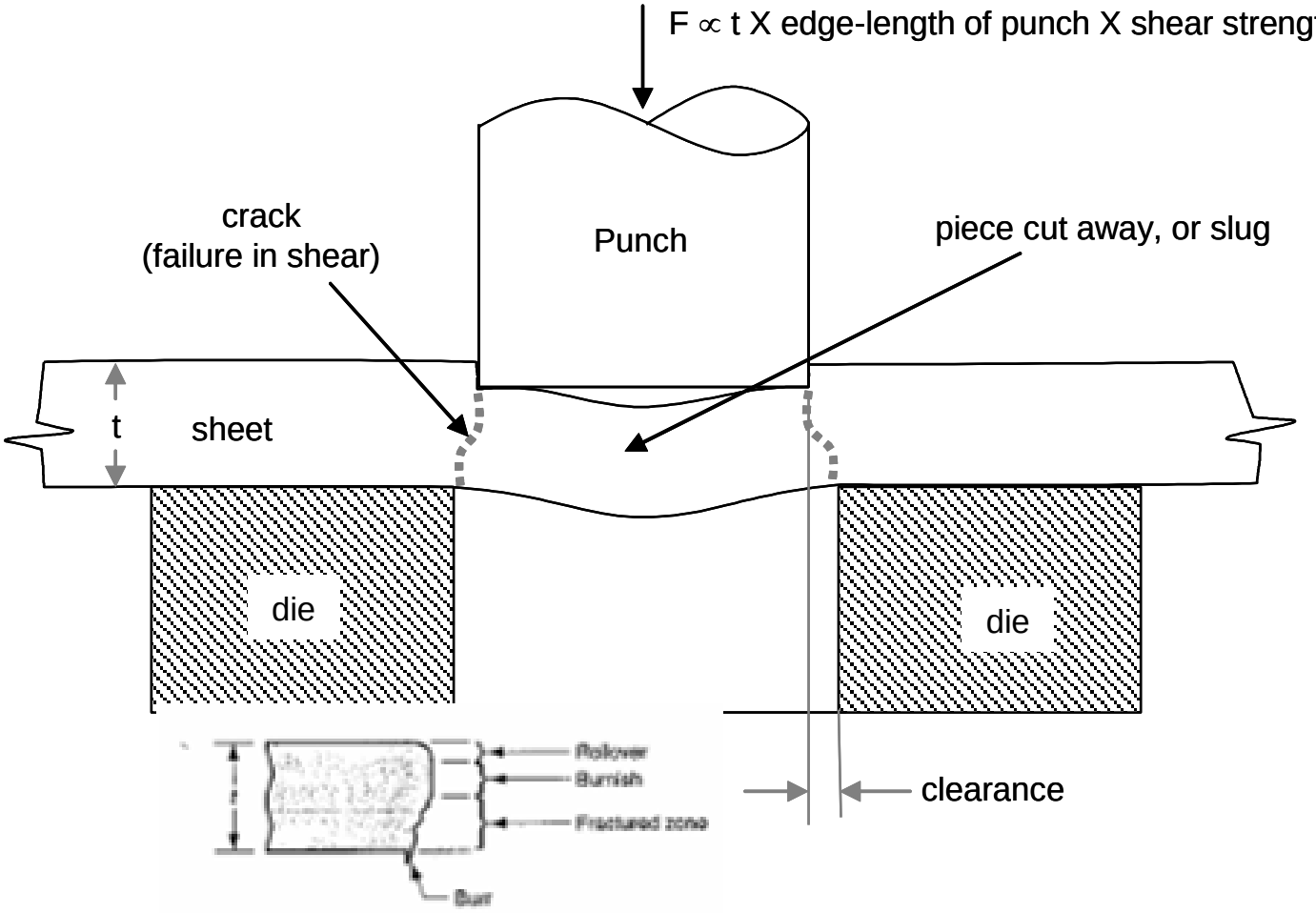
A large scissors action, cutting the sheet along a straight line



Main use: to cut large sheet into smaller sizes for making parts.

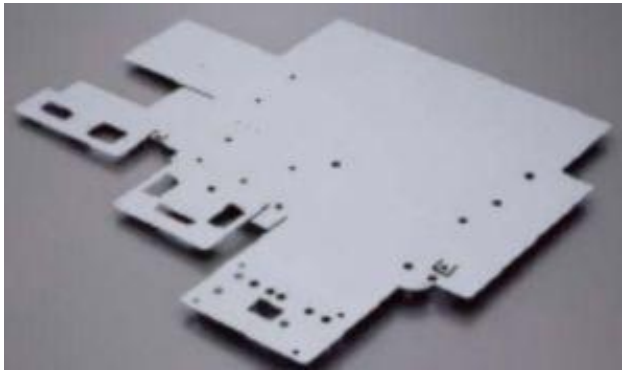
Punching

Cutting tool is a round/rectangular punch,
that goes through a hole, or die of same shape



Punching

Main uses: cutting holes in sheets; cutting sheet to required shape

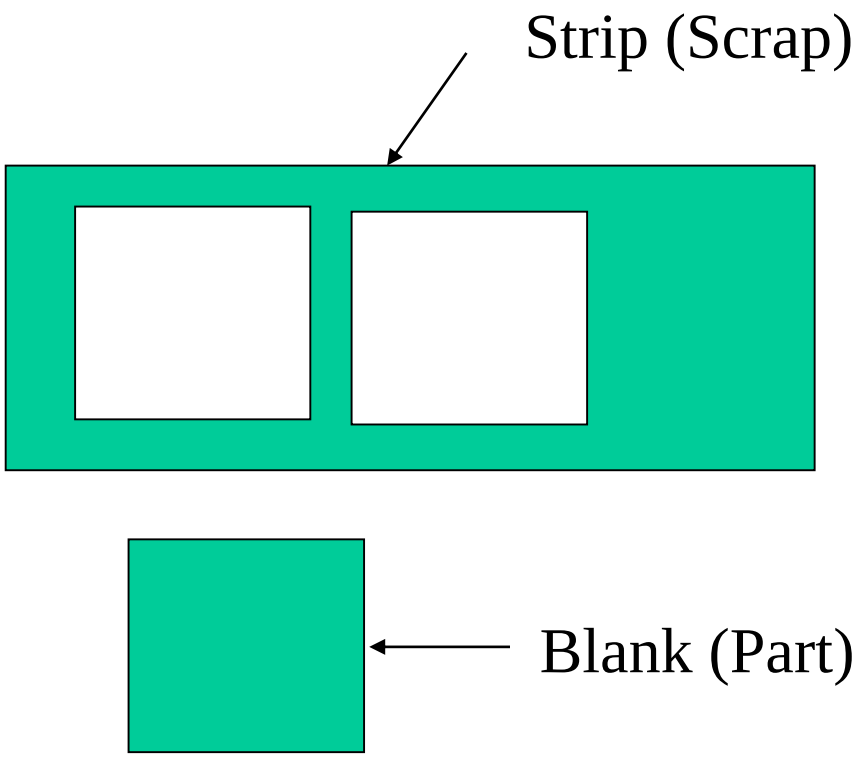


typical punched part

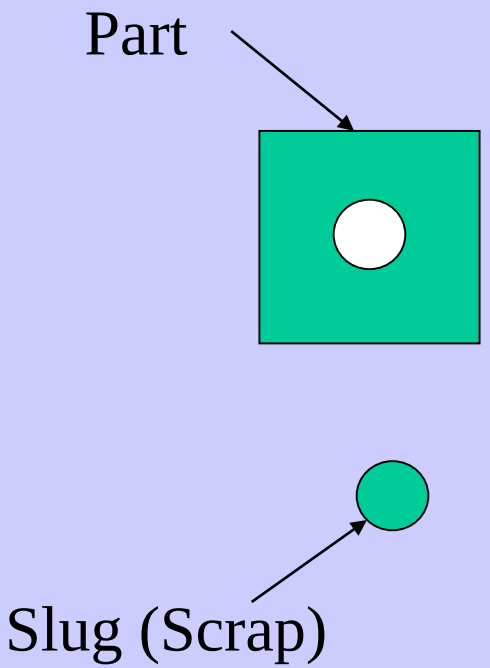
nesting of parts

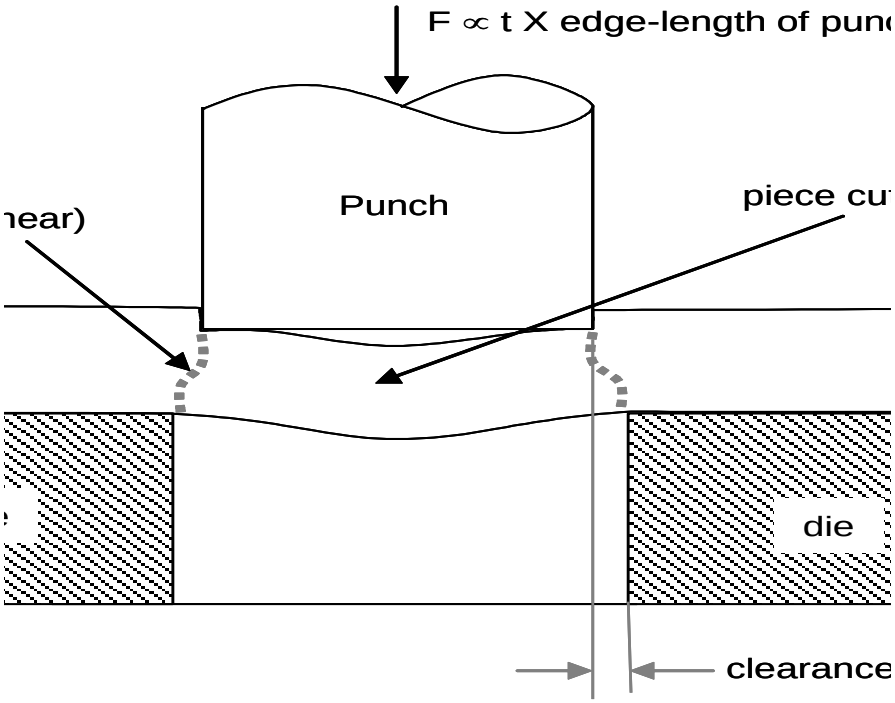
Exercise: how to determine optimal nesting?

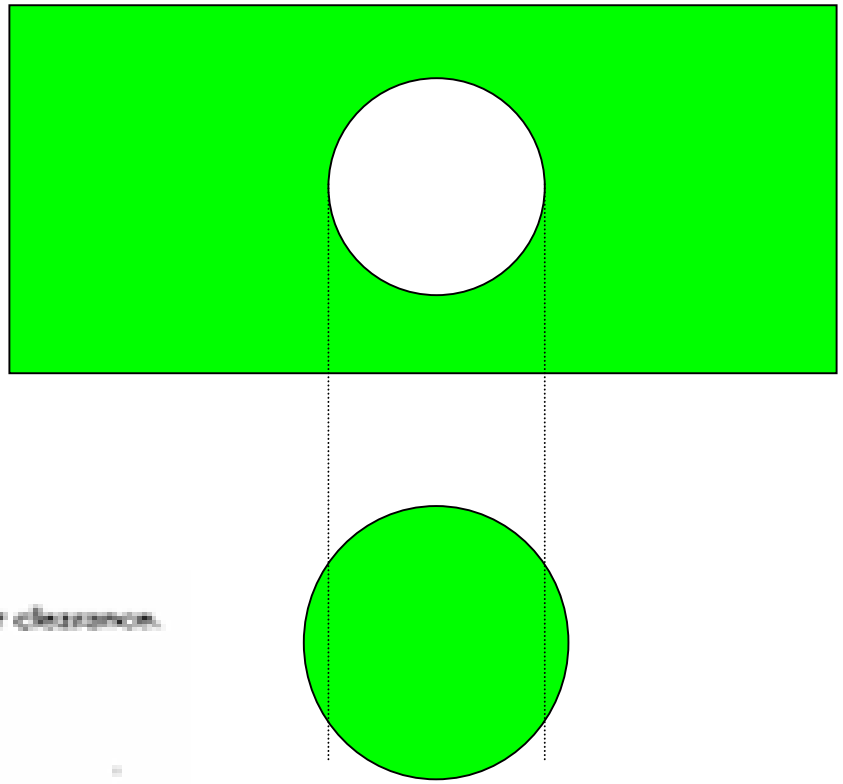
Blanking



Piecing







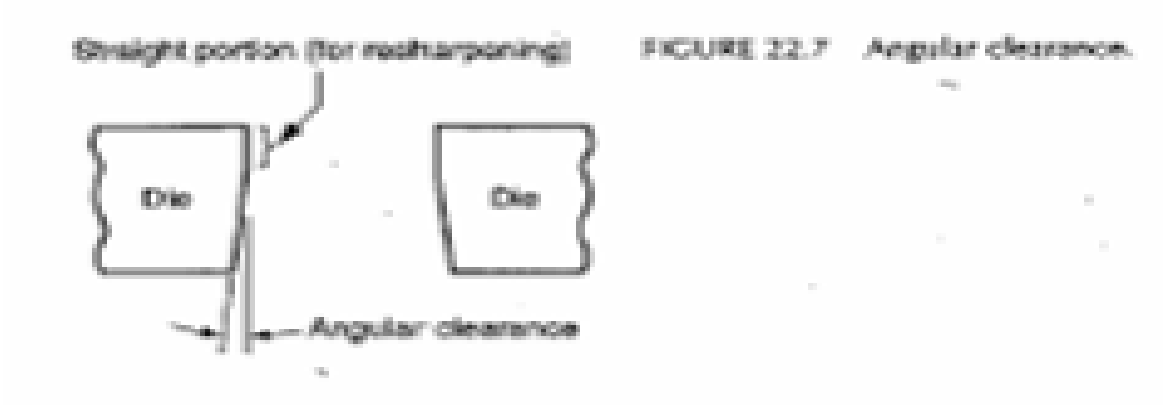
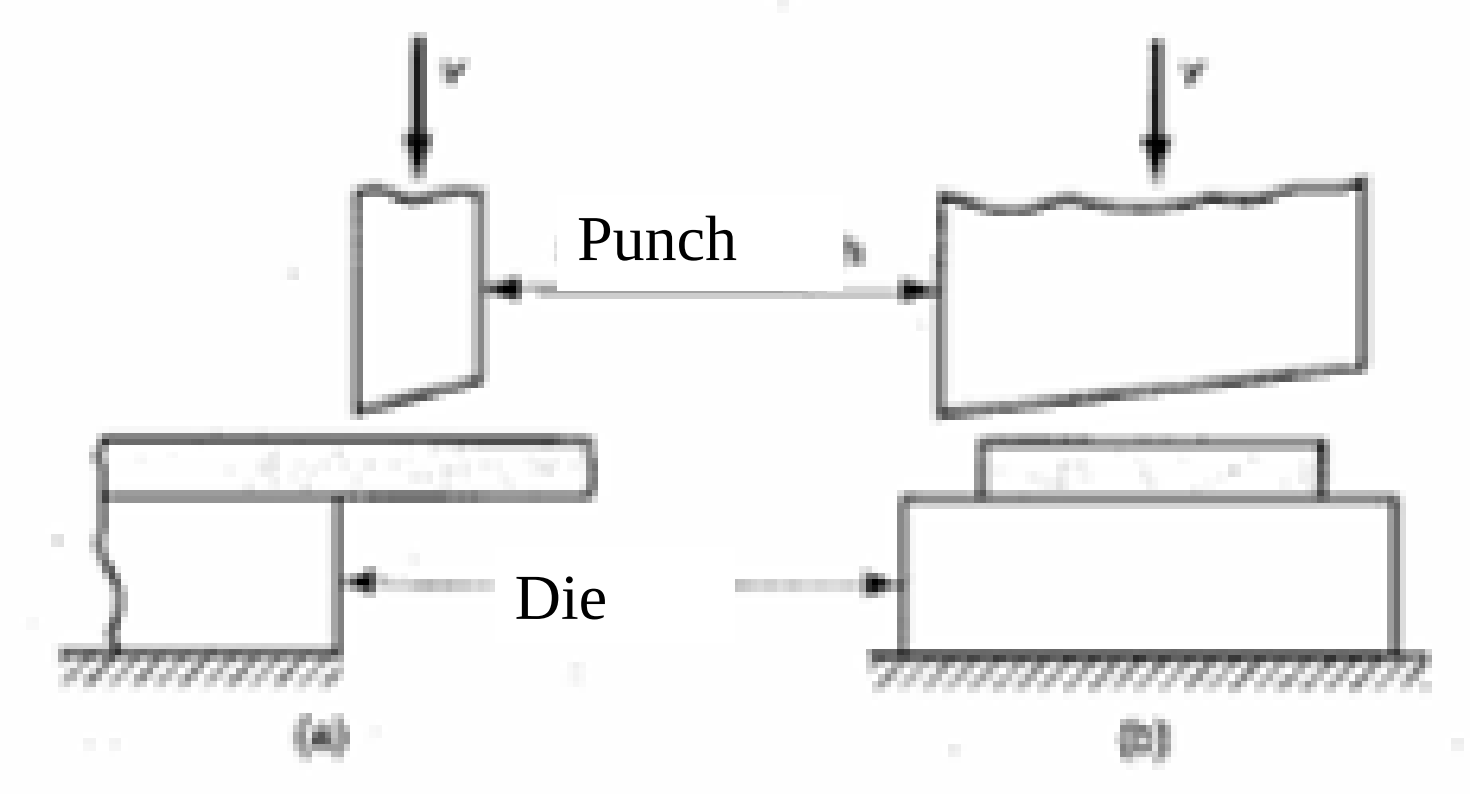


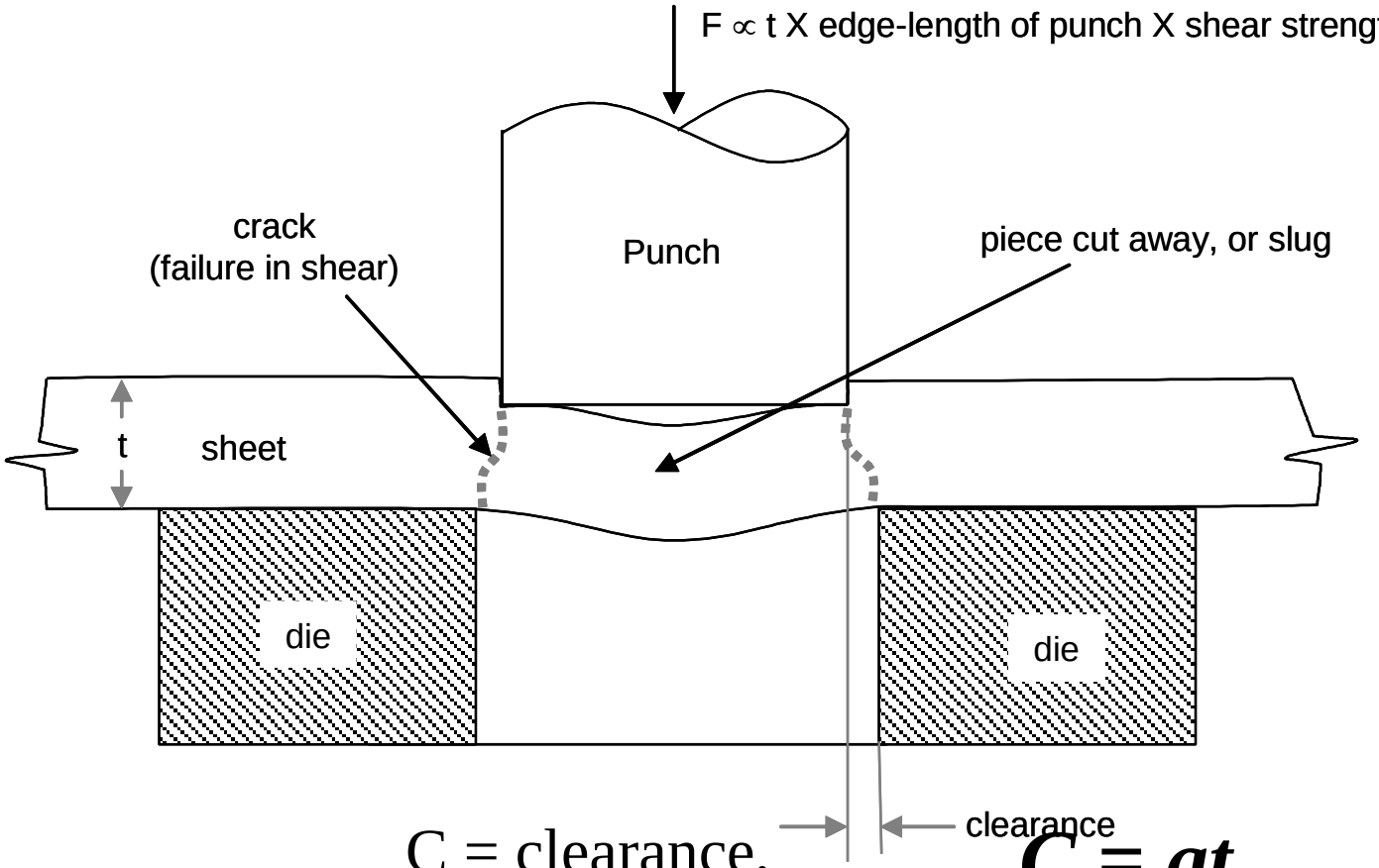
FIGURE 22.7 Angular clearance.

Shearing Operation



Side View

Front View



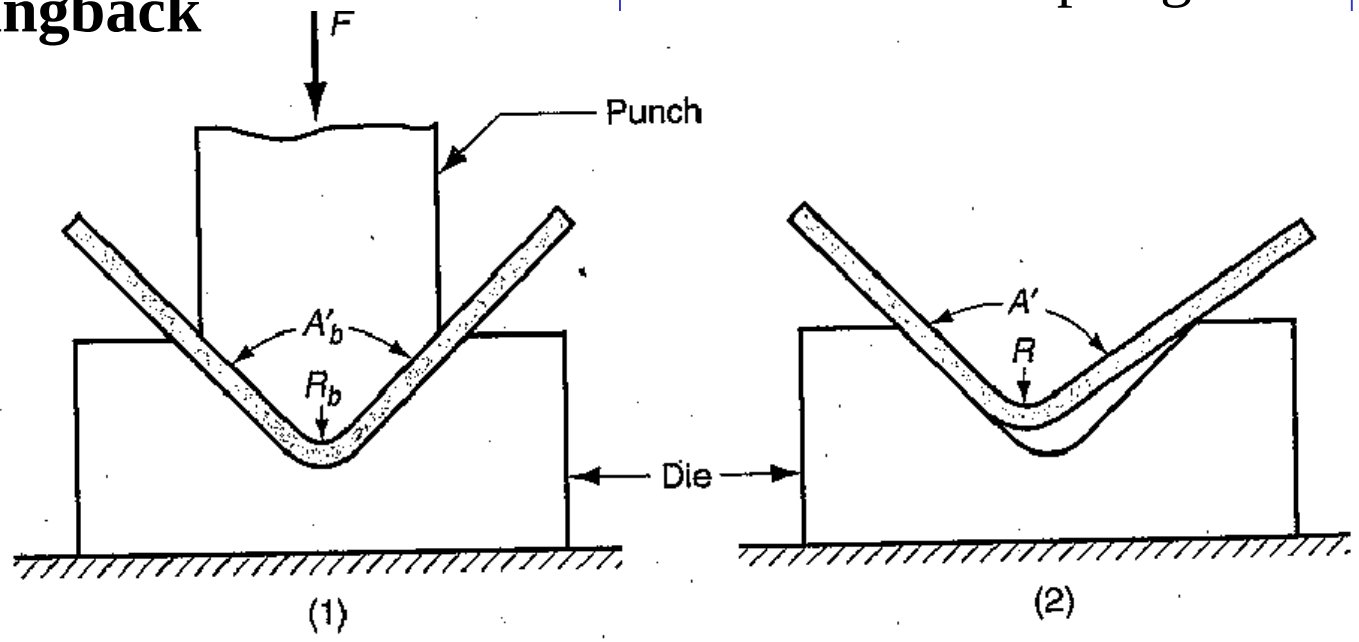
C = clearance, $C = at$

a = allowance

t = Thickness (plate)

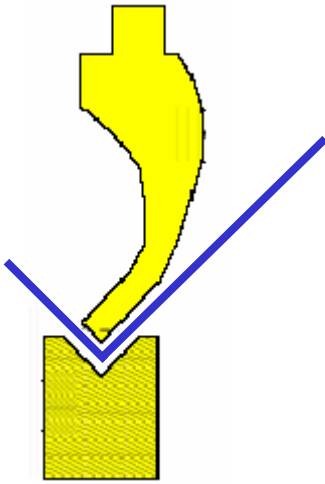
Bending: springback

How to handle springback:

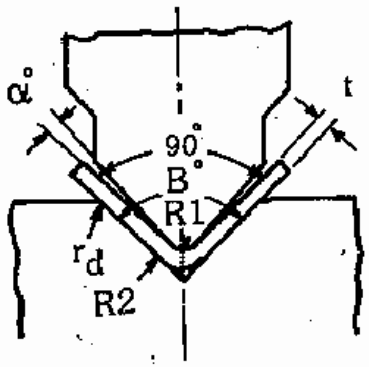


(a) Compensation: the metal is bent by a larger angle

(b) Coining the bend:
at end of bend cycle, tool exerts large force, dwells



coining: press down hard, wait, release



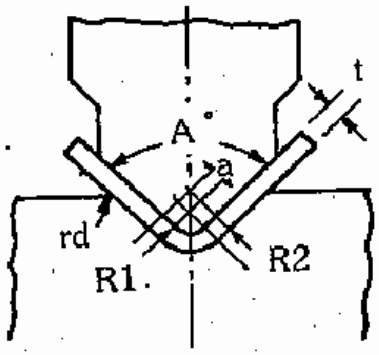
(a) ลดมุมของ punch

$B = 90^\circ$

$\alpha = 2 - 5^\circ$

$R_2 = R_1 + t$

$r_d = (2 - 4)t$



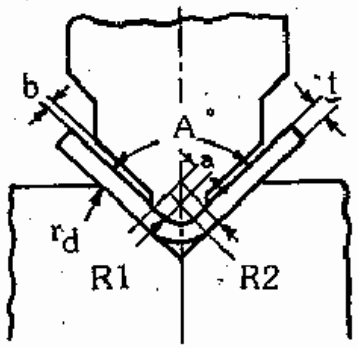
(b) ให้ die มีส่วนโค้งรับชิ้นงาน

$A = 90^\circ$

$R_2 = R_1 + t + a$

$a = (2 - 5\%)t$

$r_d = (2 - 4)t$



(c) ออกแบบ punch ให้กดเฉพาะปลาย

$A = 90^\circ$

$R_2 = R_1 + t + a$

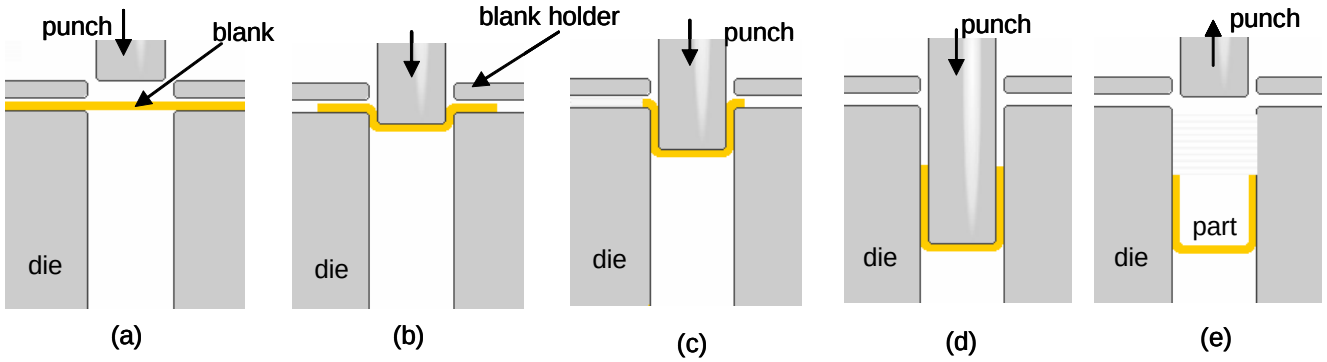
$a = (5 - 10\%)t$

$b = (5 - 8\%)t$

$r_d = (2 - 4)\ t$

Deep Drawing

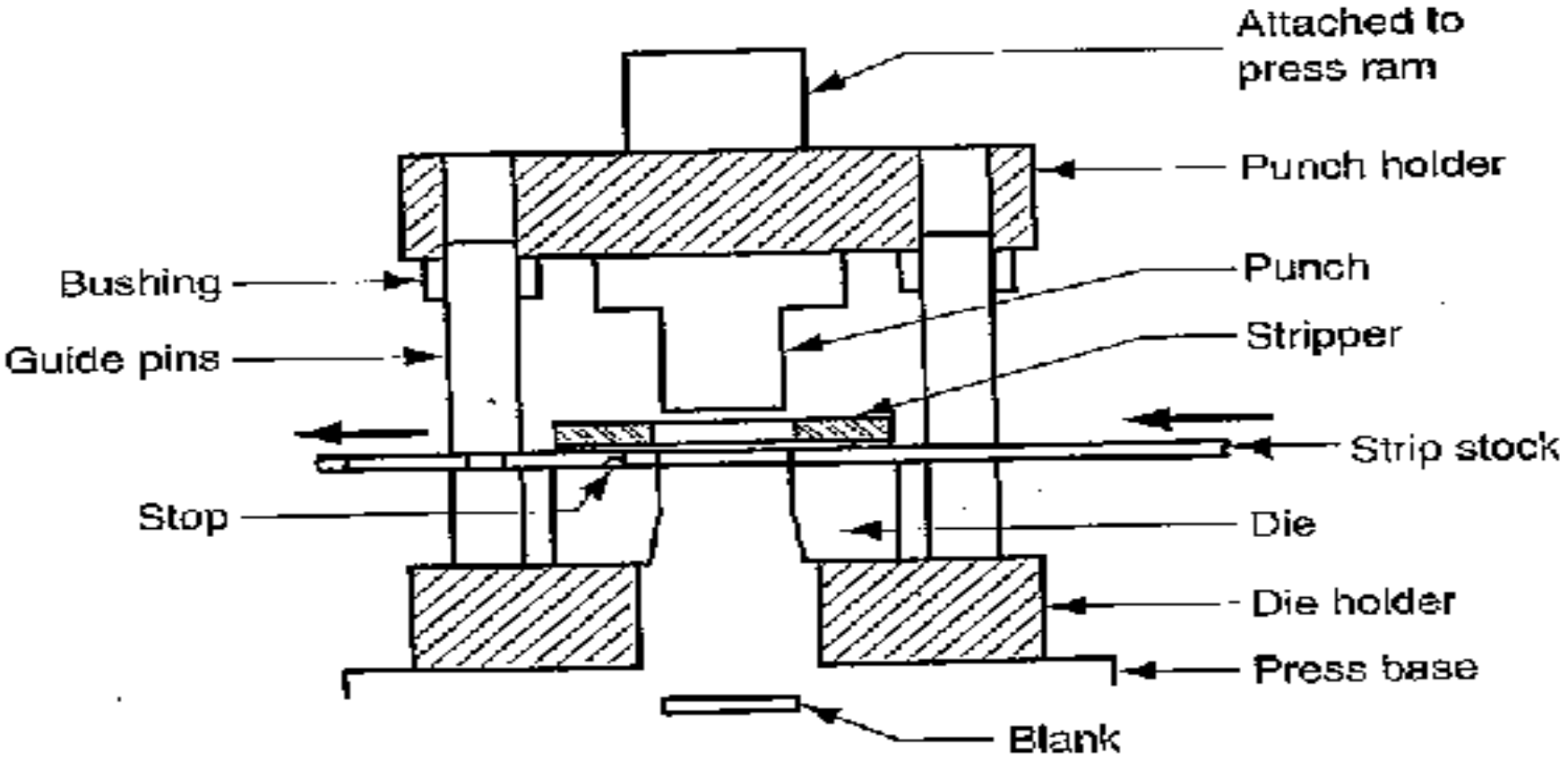
Tooling: similar to punching operation,
Mechanics: similar to bending operation



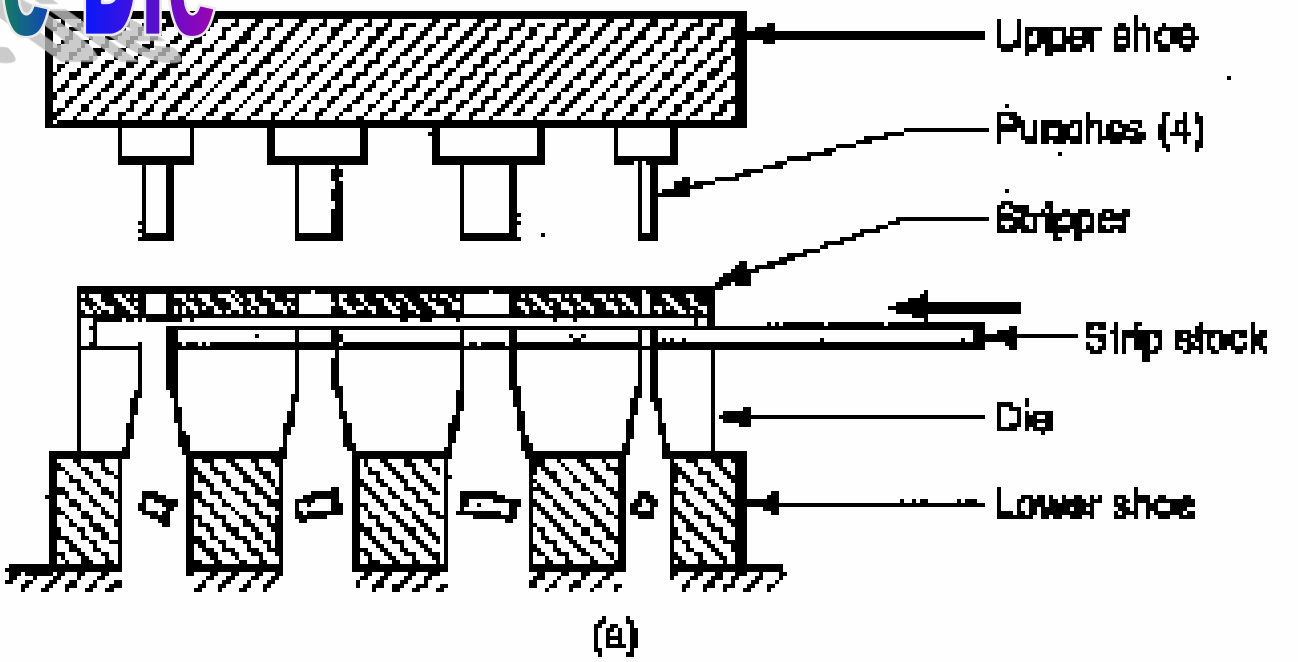
Examples of deep drawn parts

Common applications: cooking pots, containers, …

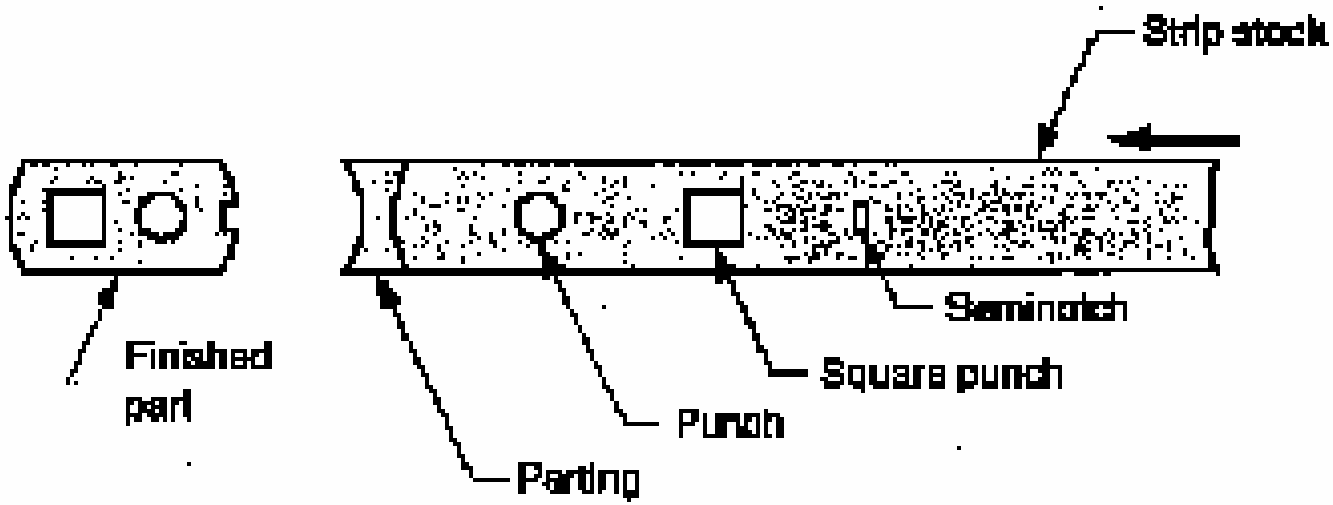
Punch Die


Attached to press ram
Punch holder
Bushing
Punch
Guide pins
Stripper
Strip stock
Stop
Die
Die holder
Press base
Blank

Progressive Die

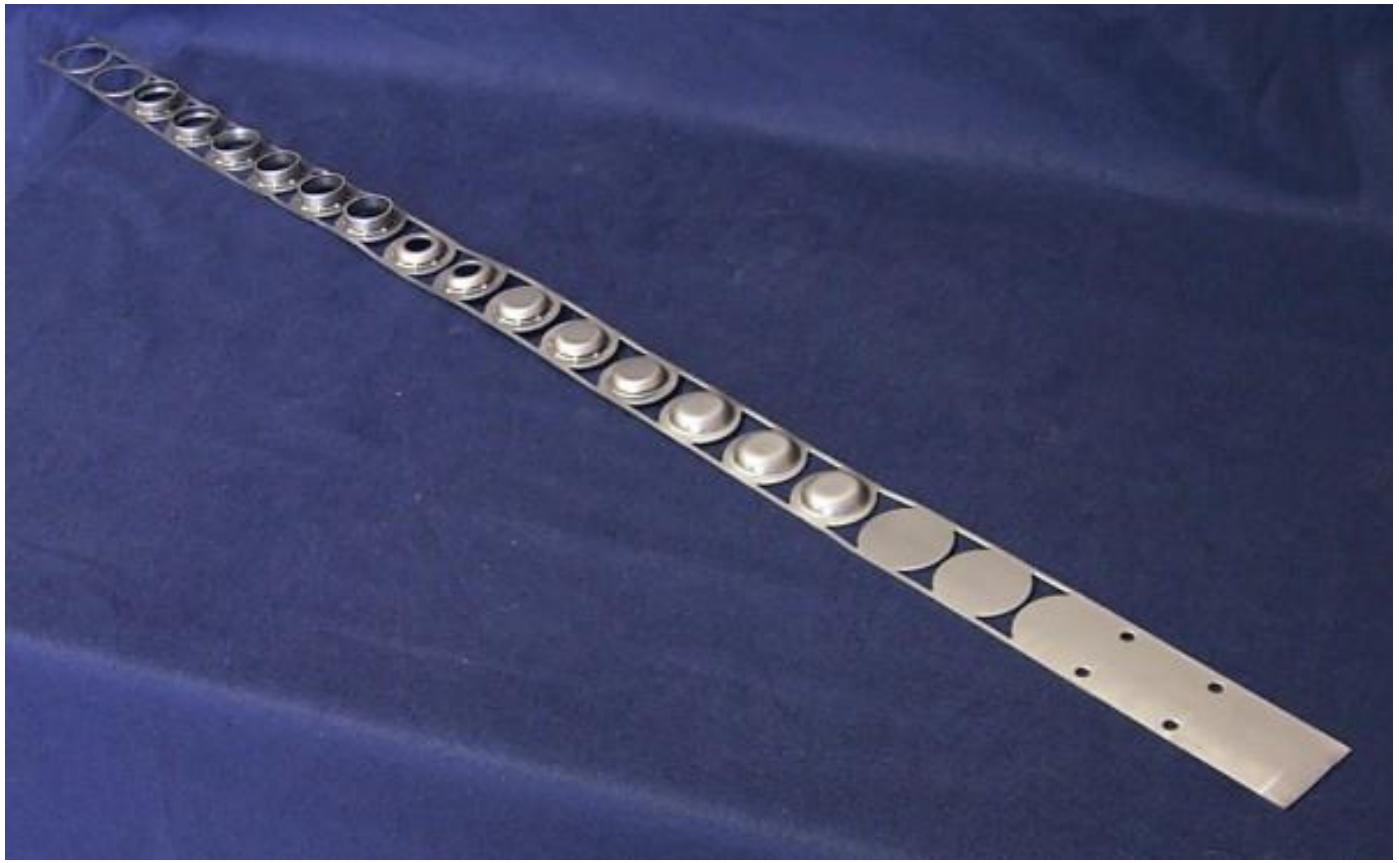


(a)

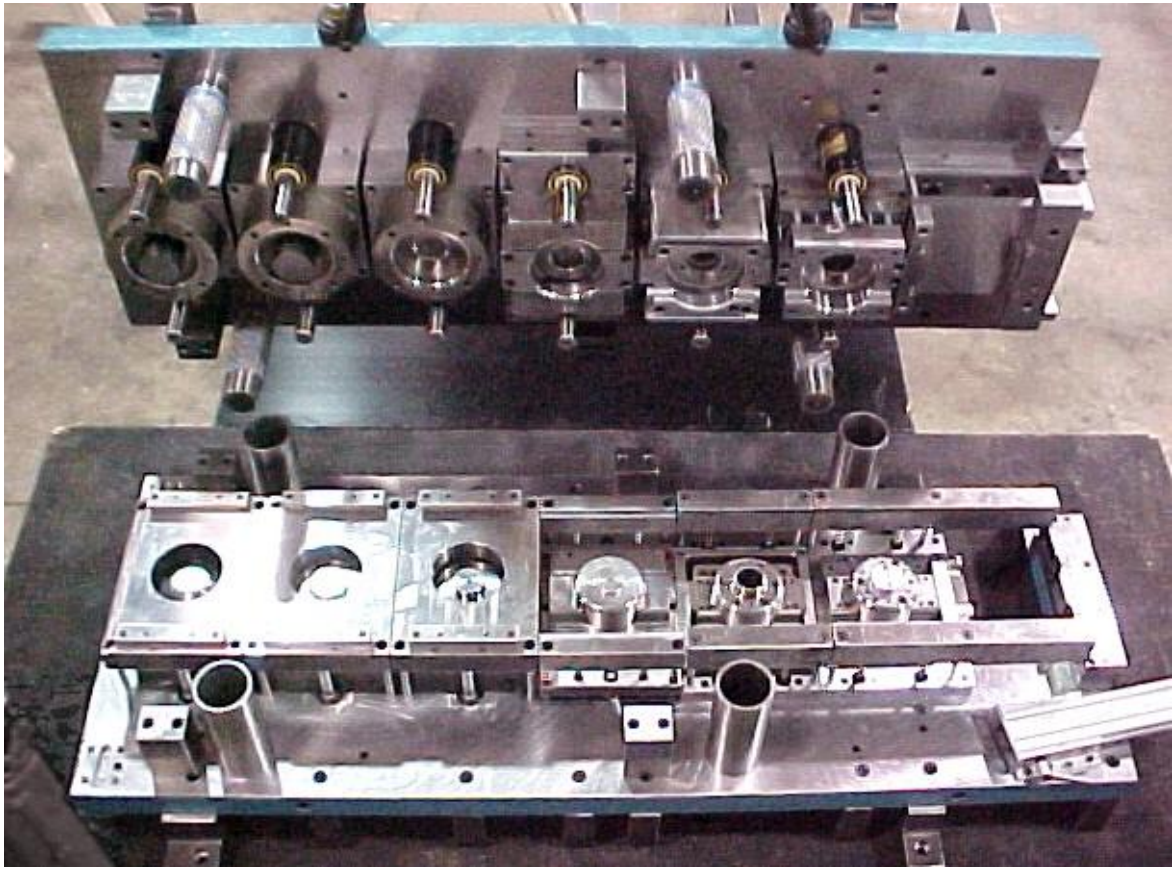


(b)

Progressive Strip



Progressive Die



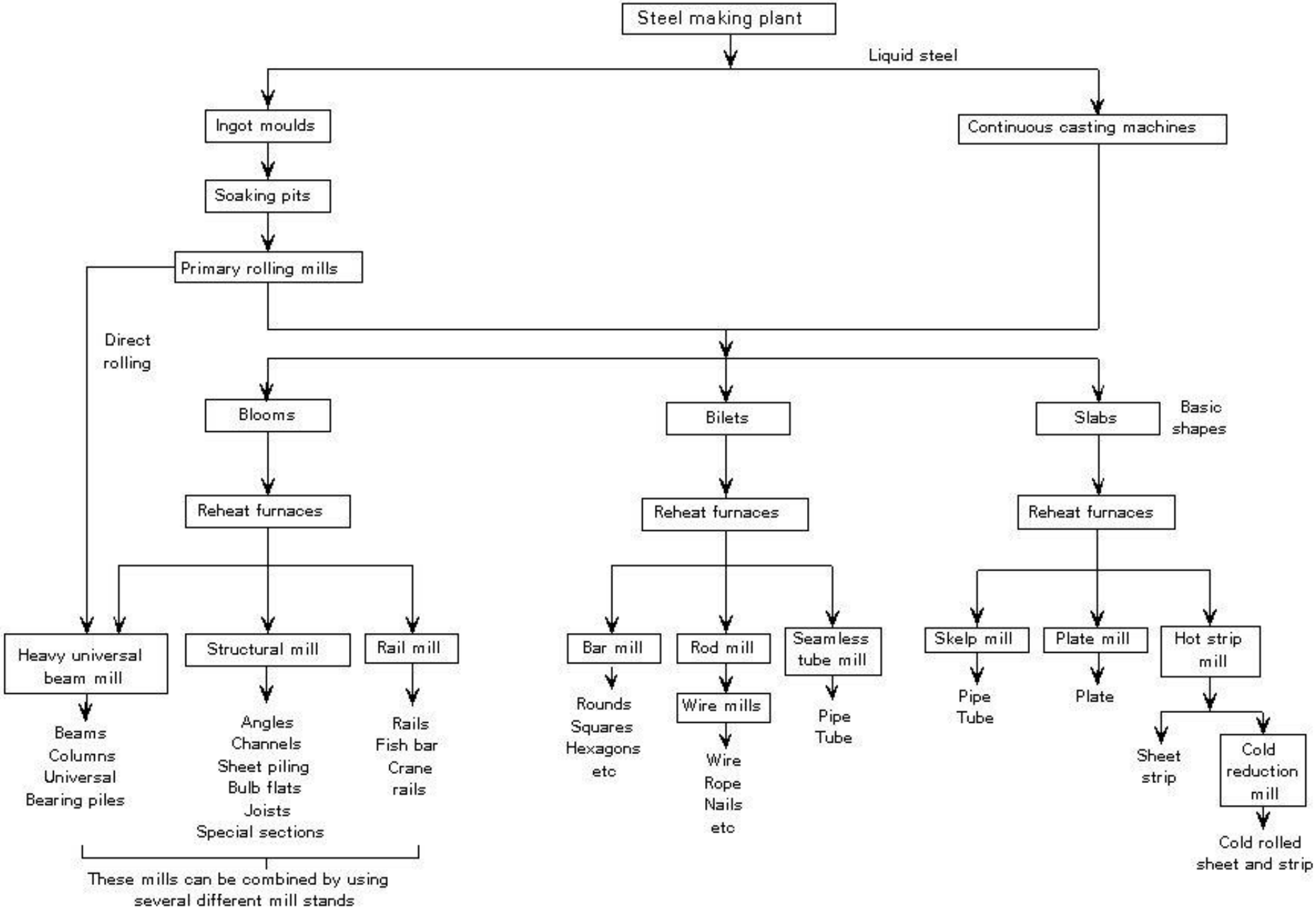


Figure 9 Principal product routes