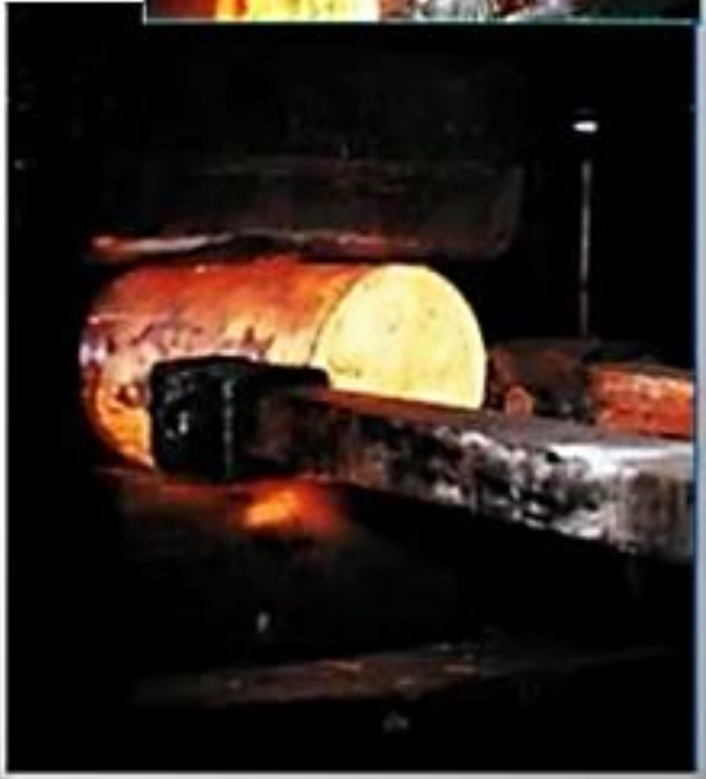
MODULE 3

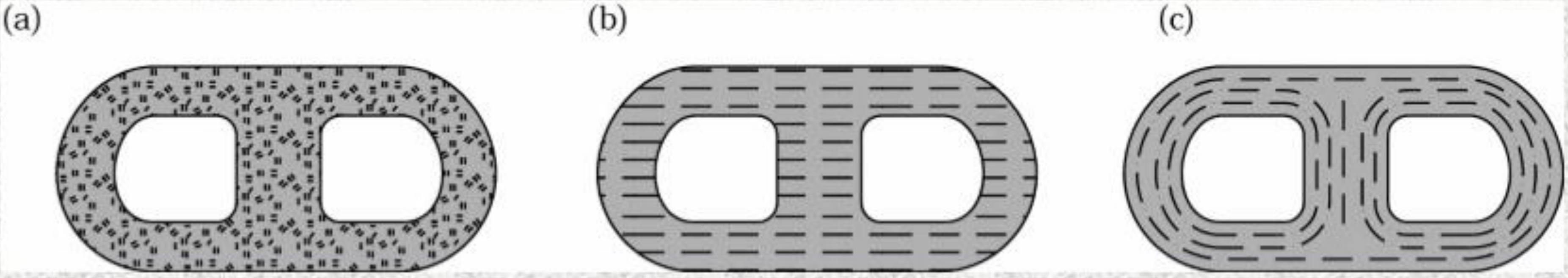
FORGING

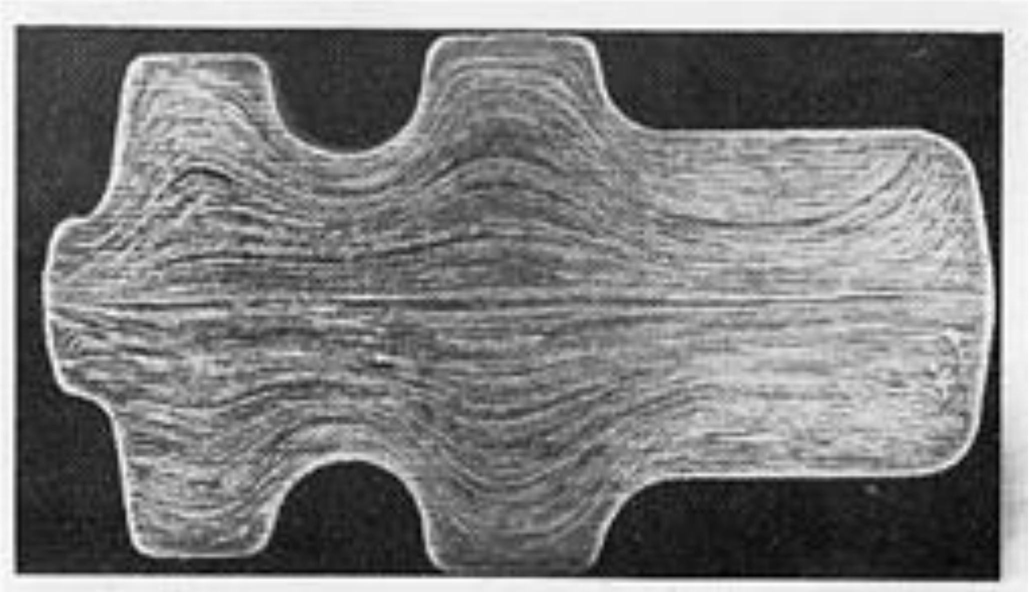
- Forging is the working of metal into a useful shape by hammering or pressing.
- The oldest of the metalworking arts (primitive blacksmith).
- Replacement of machinery occurred during early the Industrial revolution.
- Forging machines are now capable of making parts ranging in size of a bolt to a turbine rotor.
- Most forging operations are carried out hot, although certain metals may be cold-forged.



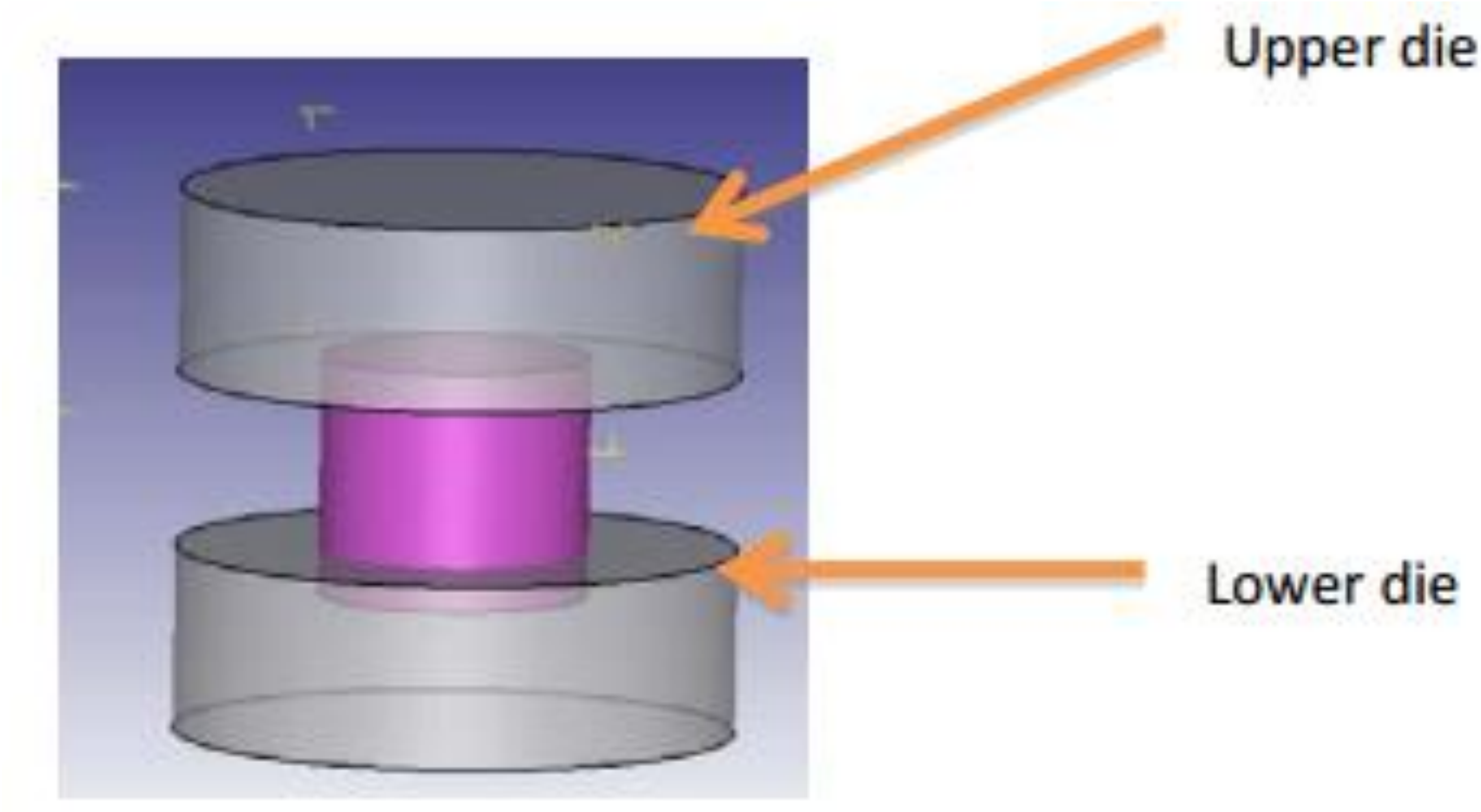
Grain Flow Comparison

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





UPSET FORGING



Upsetting

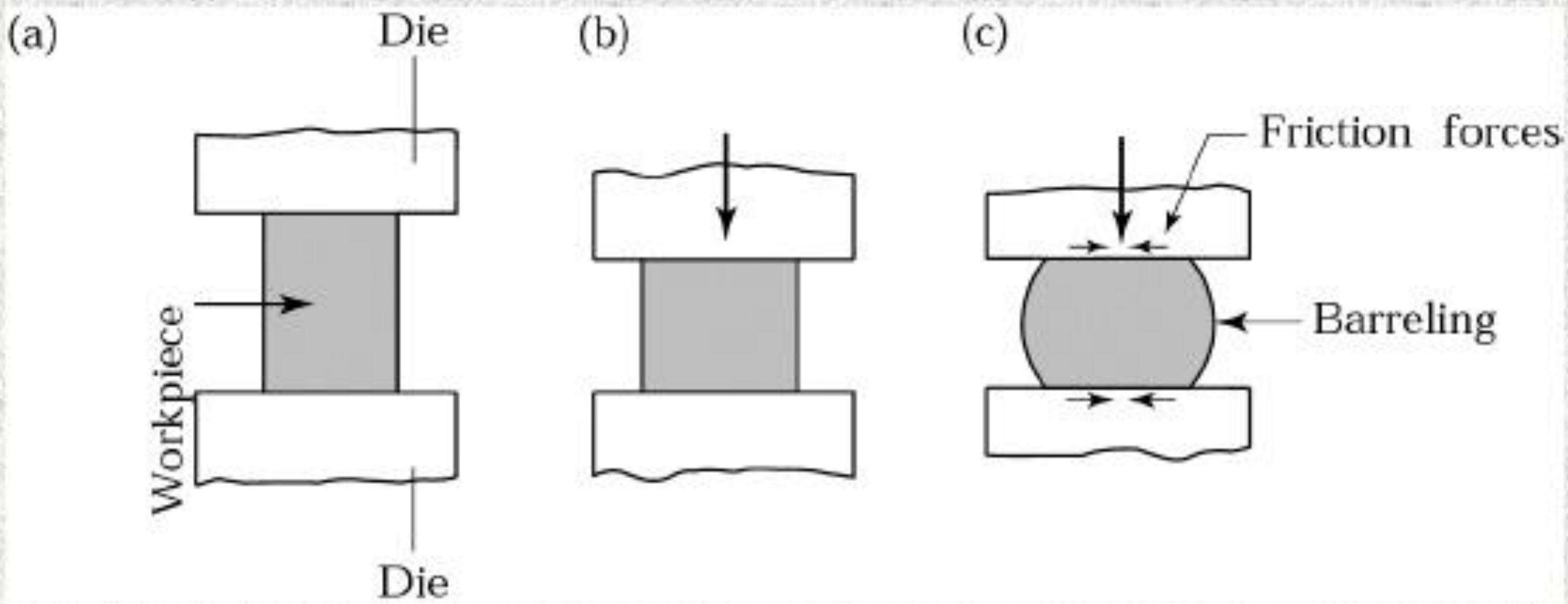
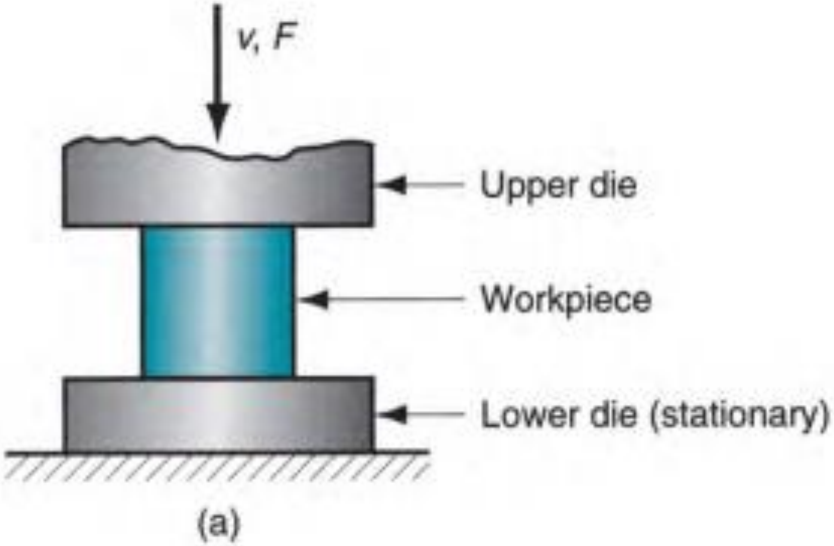
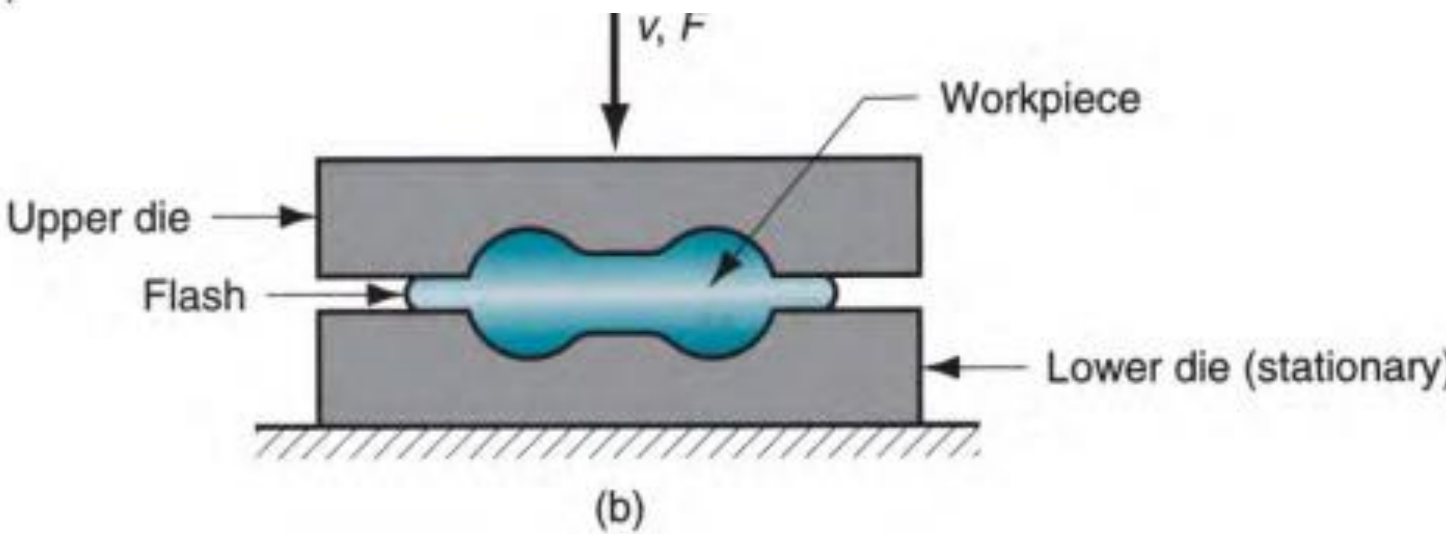


Figure 14.4 (a) Solid cylindrical billet upset between two flat dies. (b) Uniform deformation of the billet without friction. (c) Deformation with friction. Note barreling of the billet caused by friction forces at the billet-die interfaces.

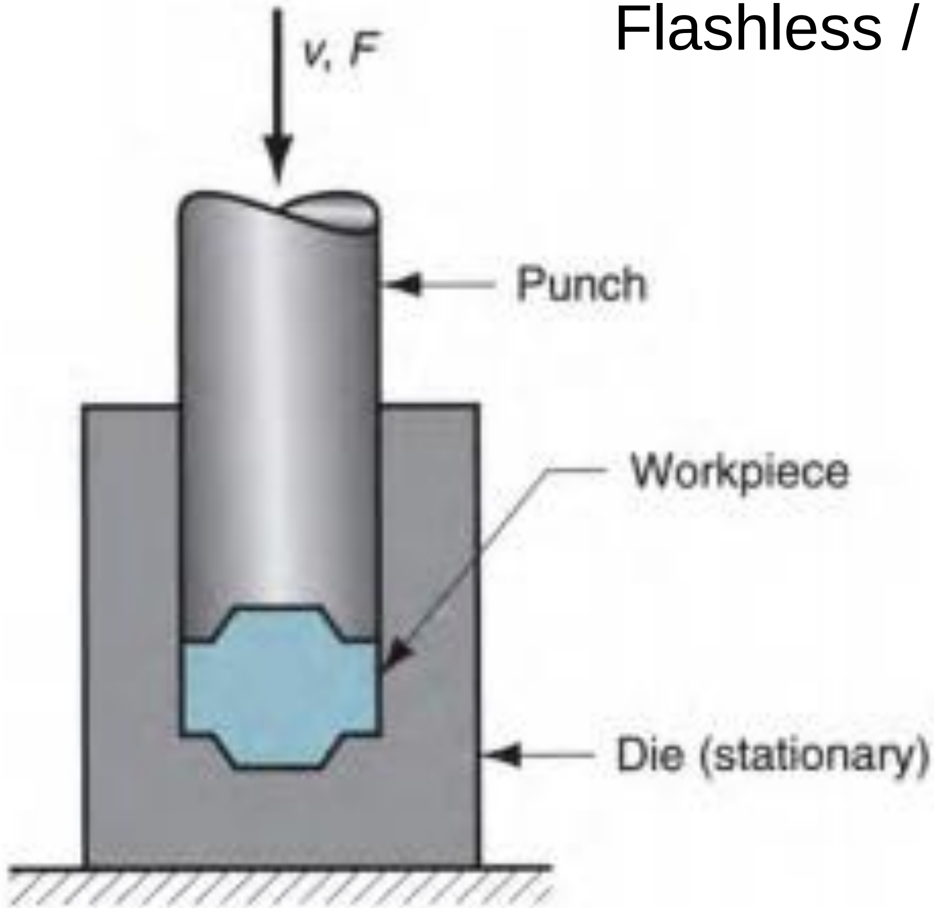
Open Die forging





Impression/Closed Die forging

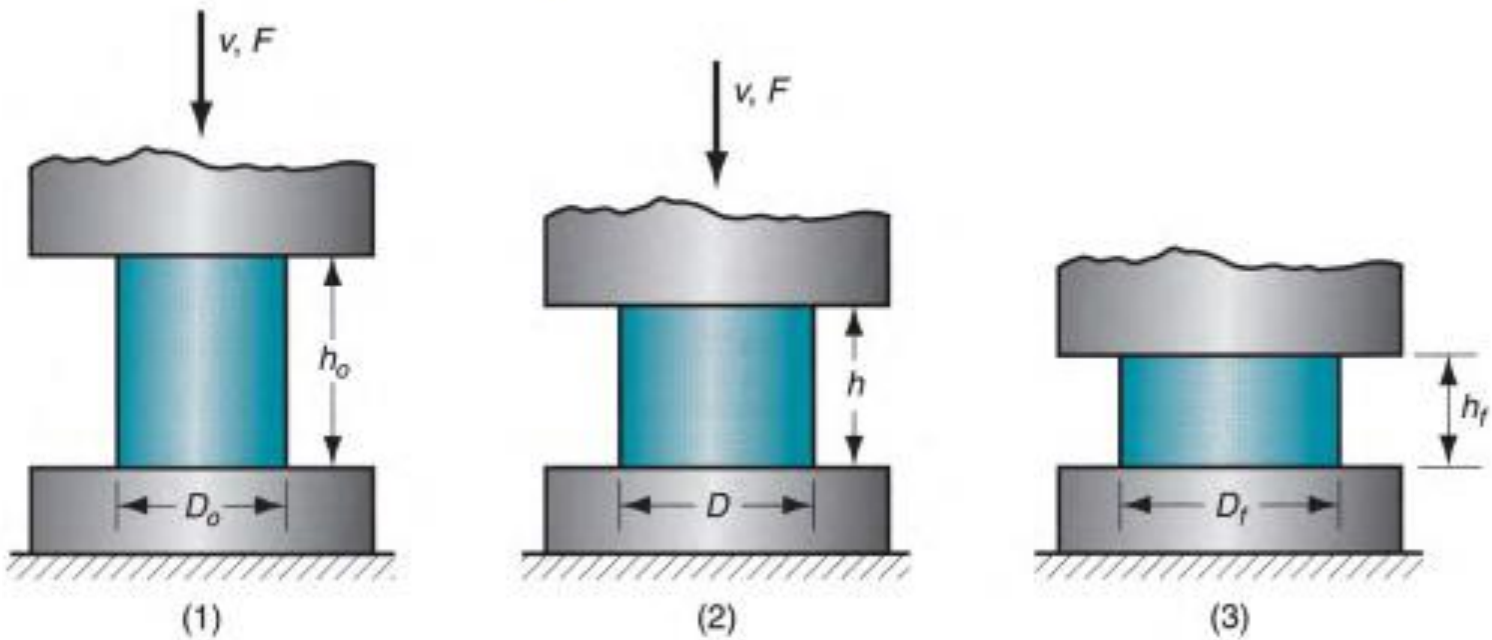
Flashless / Precision forging



(c)

Open-Die Forging with No Friction

- (1) Start of process with workpiece at its original length and diameter, (2) partial compression, and (3) final size

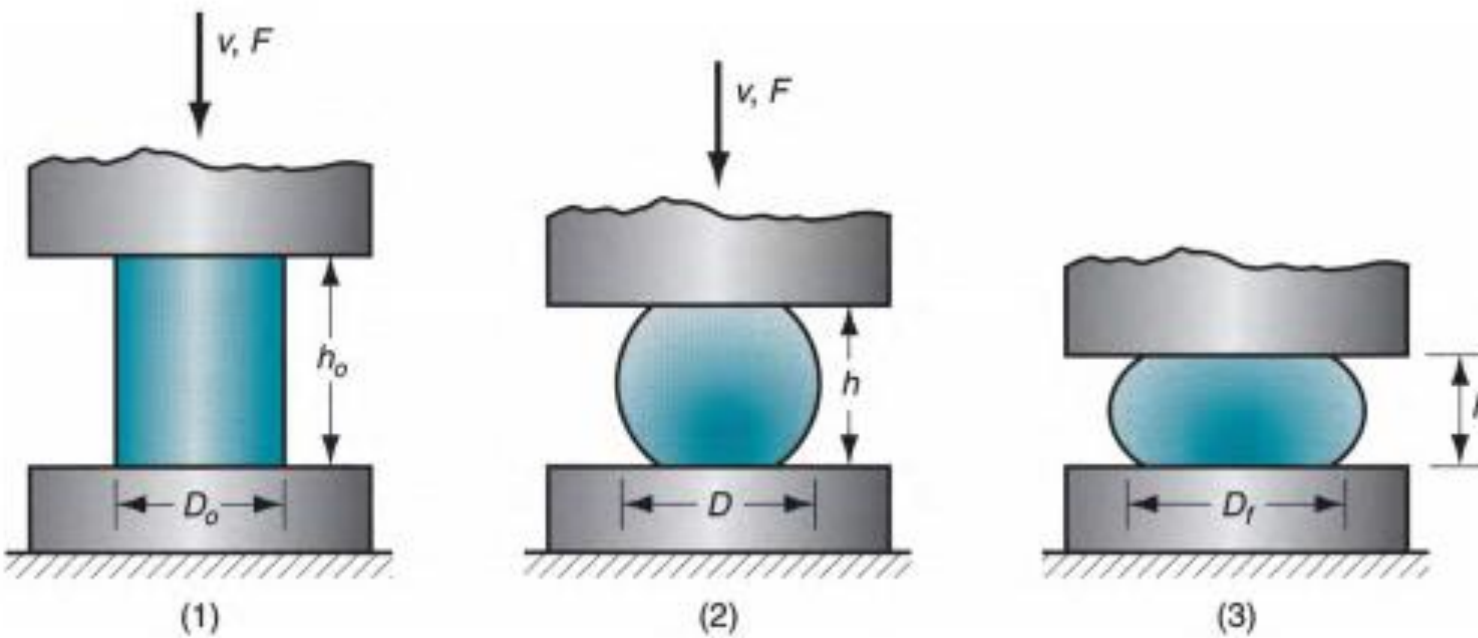


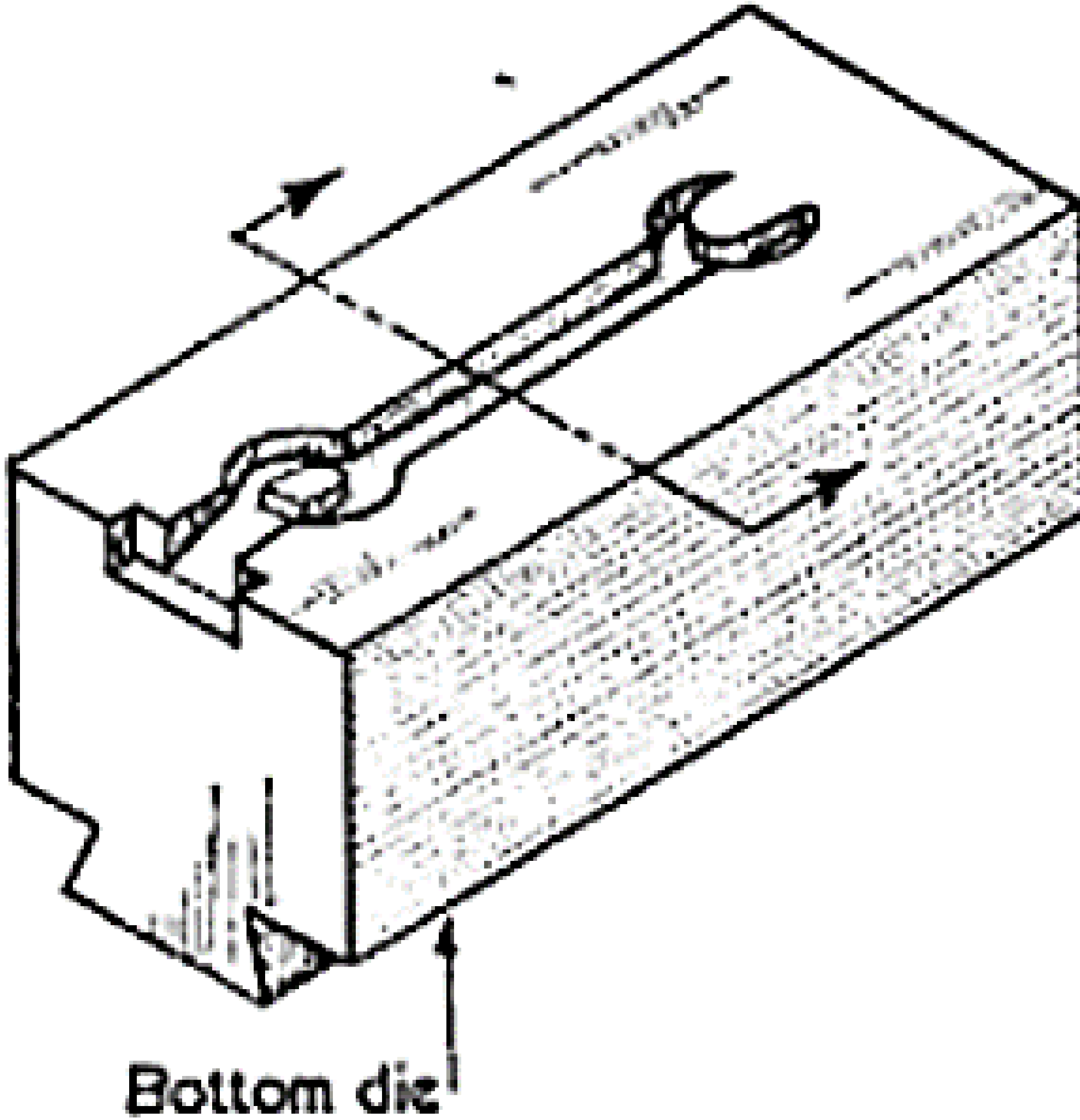
True strain:

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

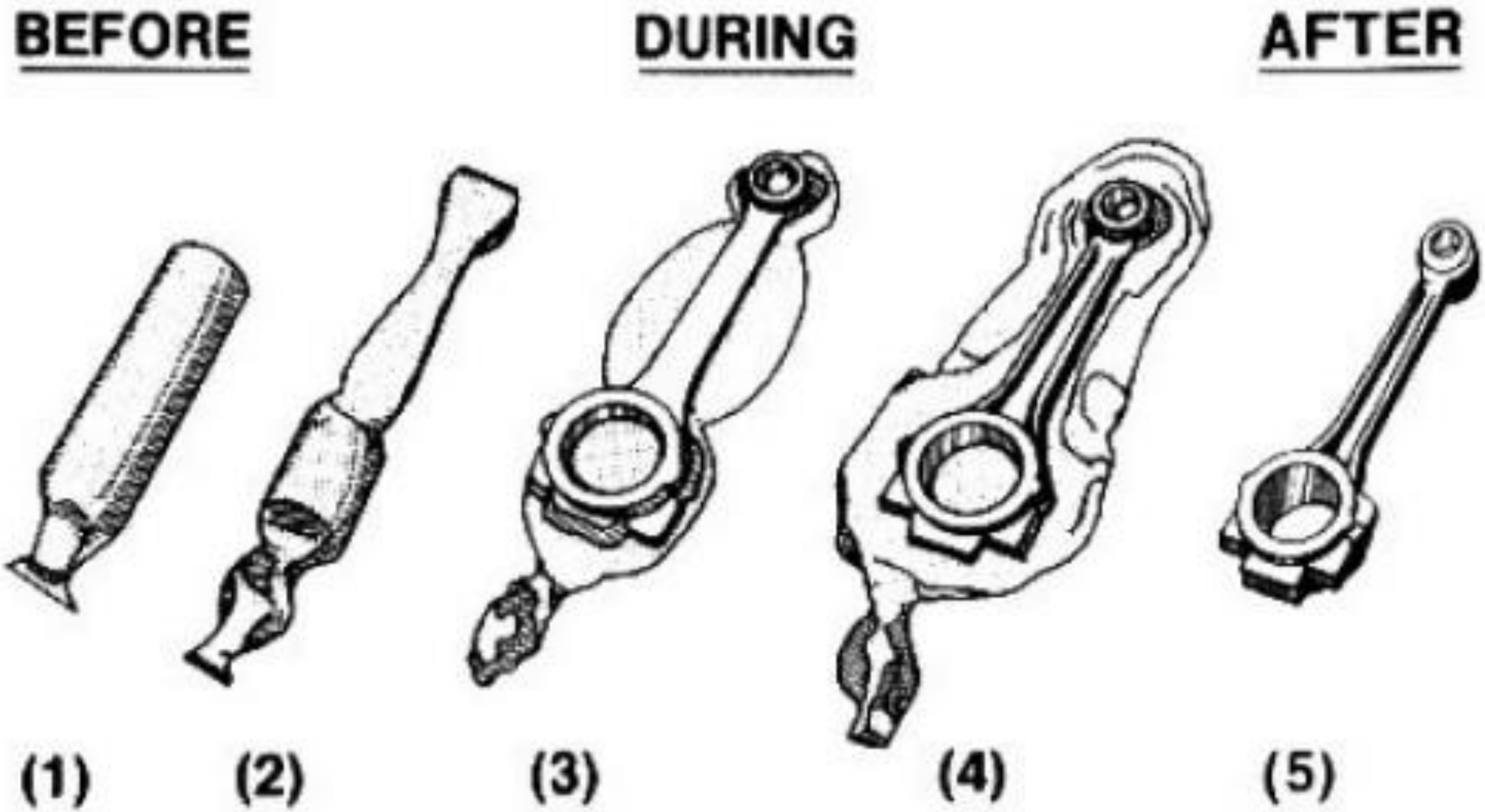
Open-Die Forging with Friction

Actual deformation of a cylindrical workpart in open-die forging, showing pronounced *barreling*: (1) start of process, (2) partial deformation, and (3) final shape

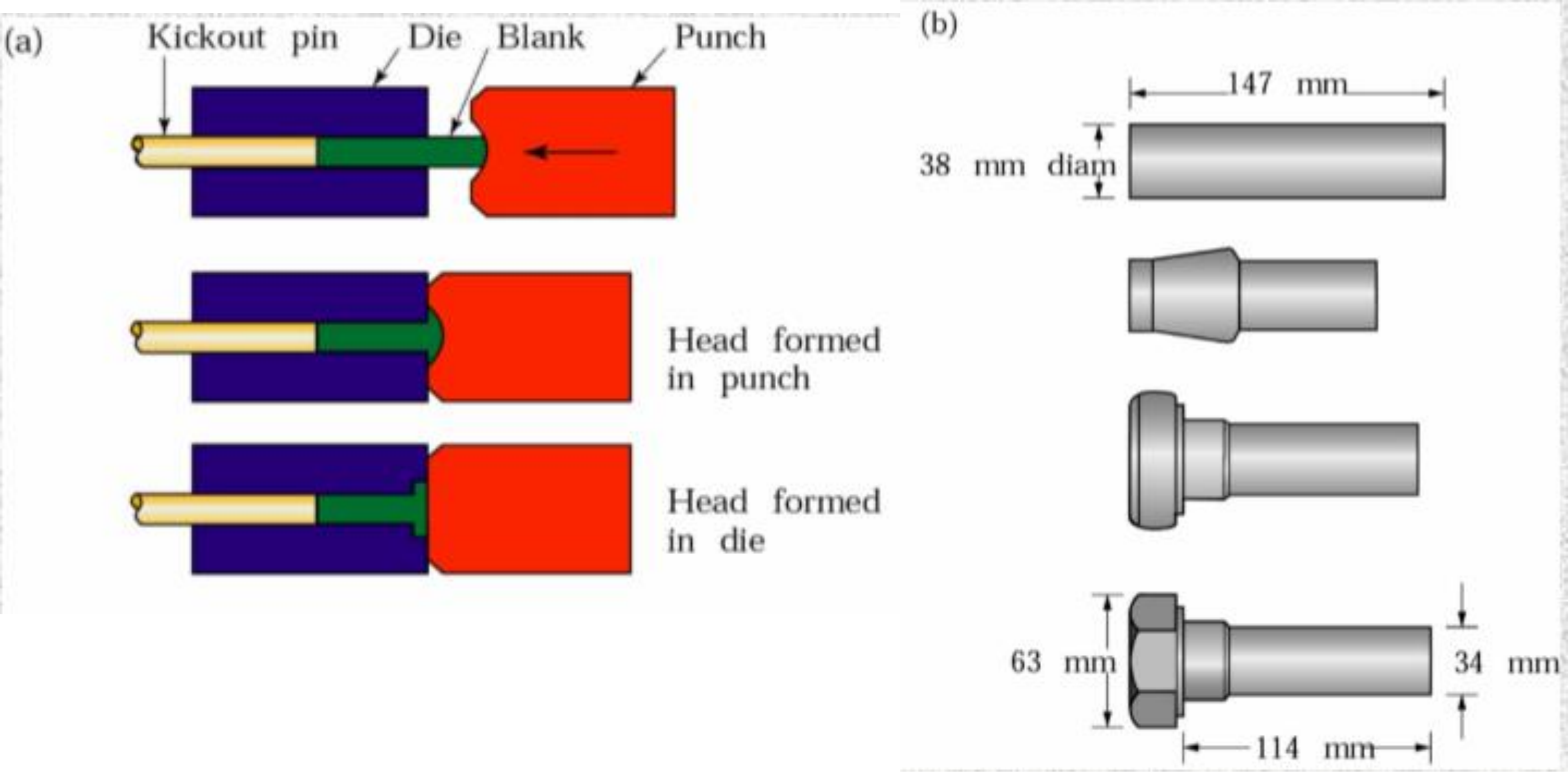



Bottom die

Forging a connecting rod

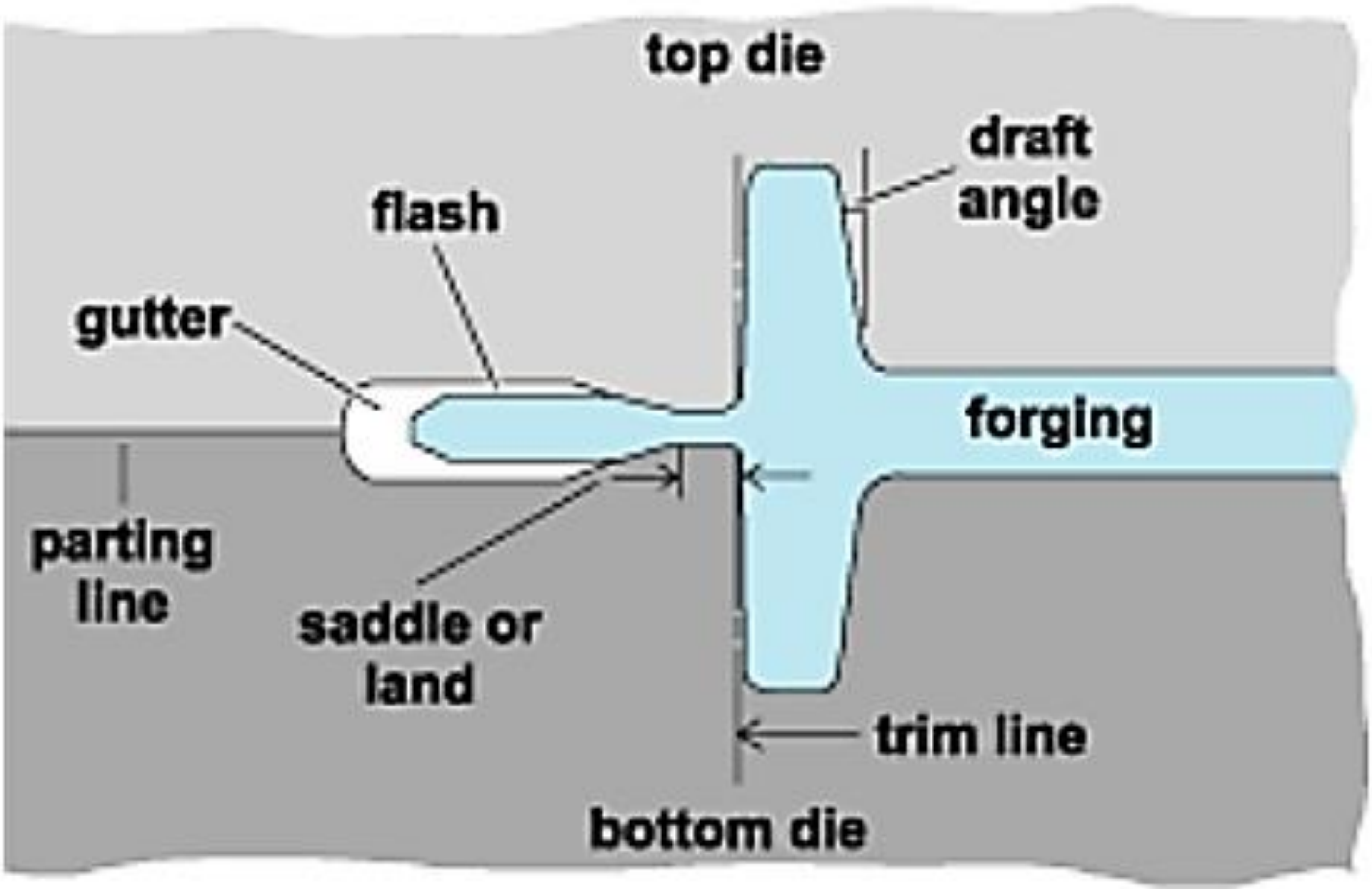


Heading/Upset Forging

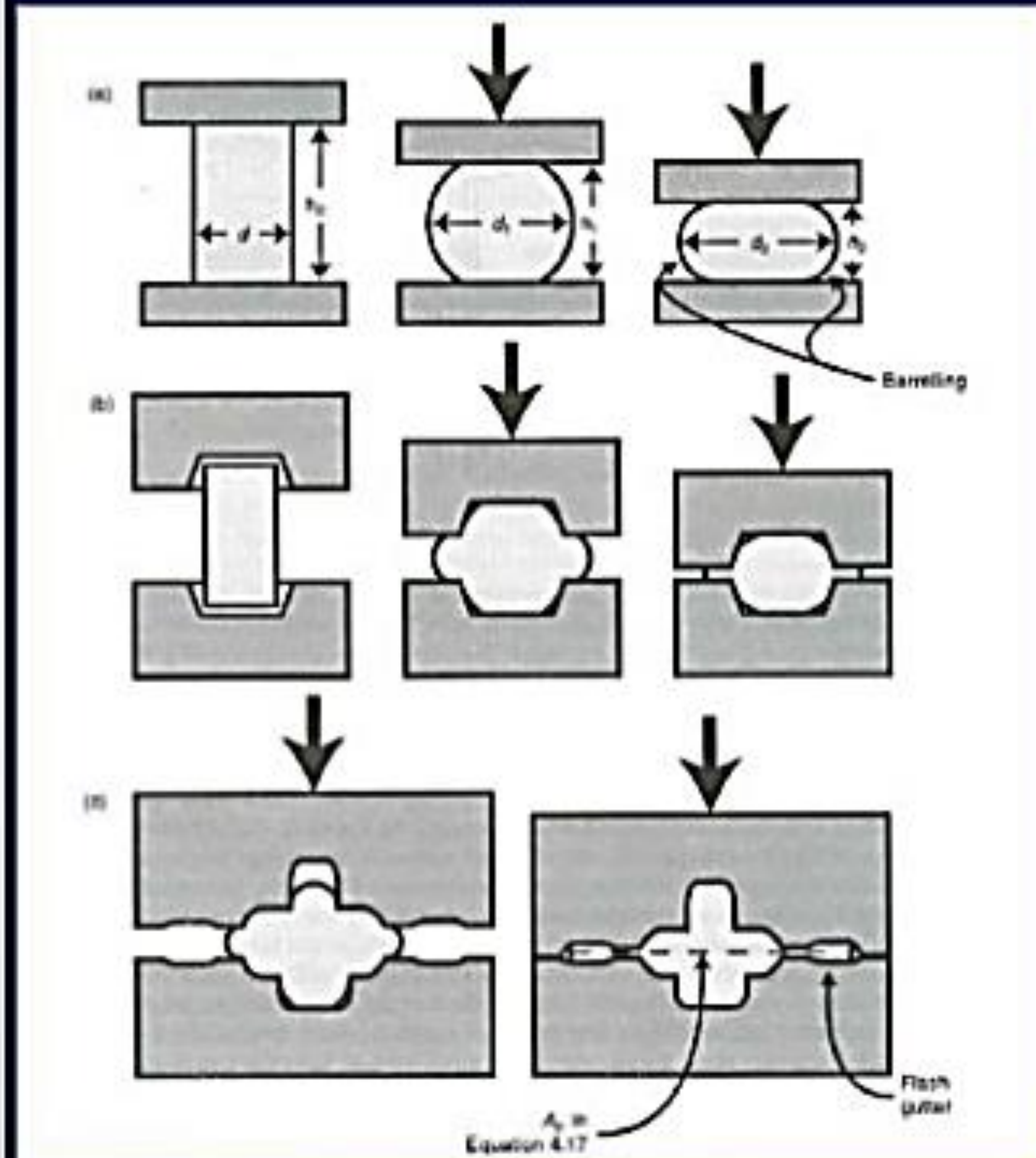


(a) Heading operation, to form heads on fasteners such as nails and rivets. (b) Sequence of operations to produce a bolt head by heading.

STANDARD TERMINOLOGY



Closed and open die forging processes



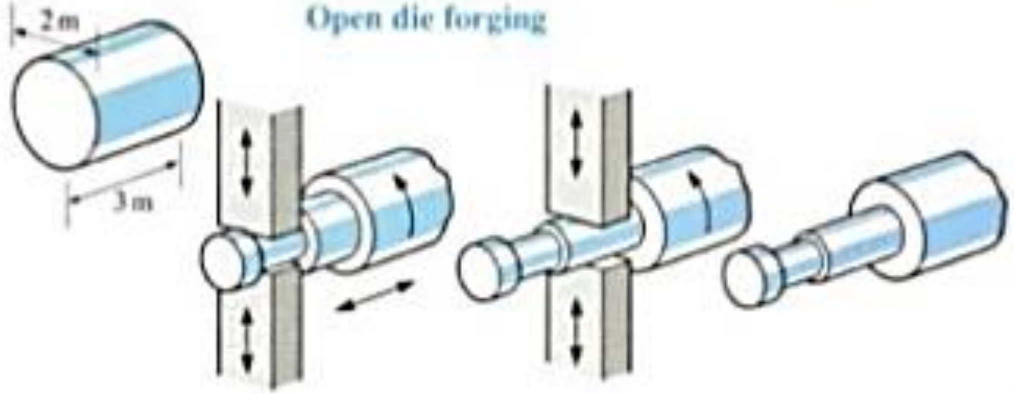
Open-die forging

Closed-die forging

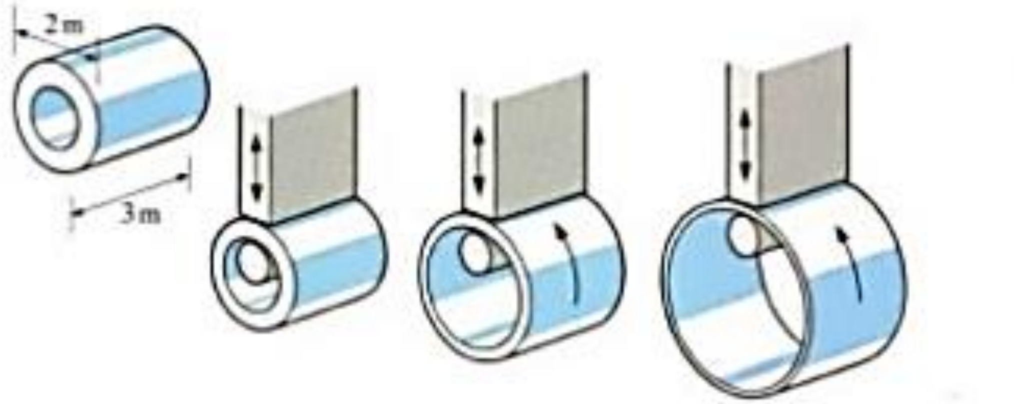
Impression-die forging

Open-die forging

- Open-die forging is carried out between flat dies or dies of very simple shape.
- The process is used for mostly large objects or when the number of parts produced is small.
- Open-die forging is often used to perform the work-piece for closed-die forging.



Forging large turbine shaft



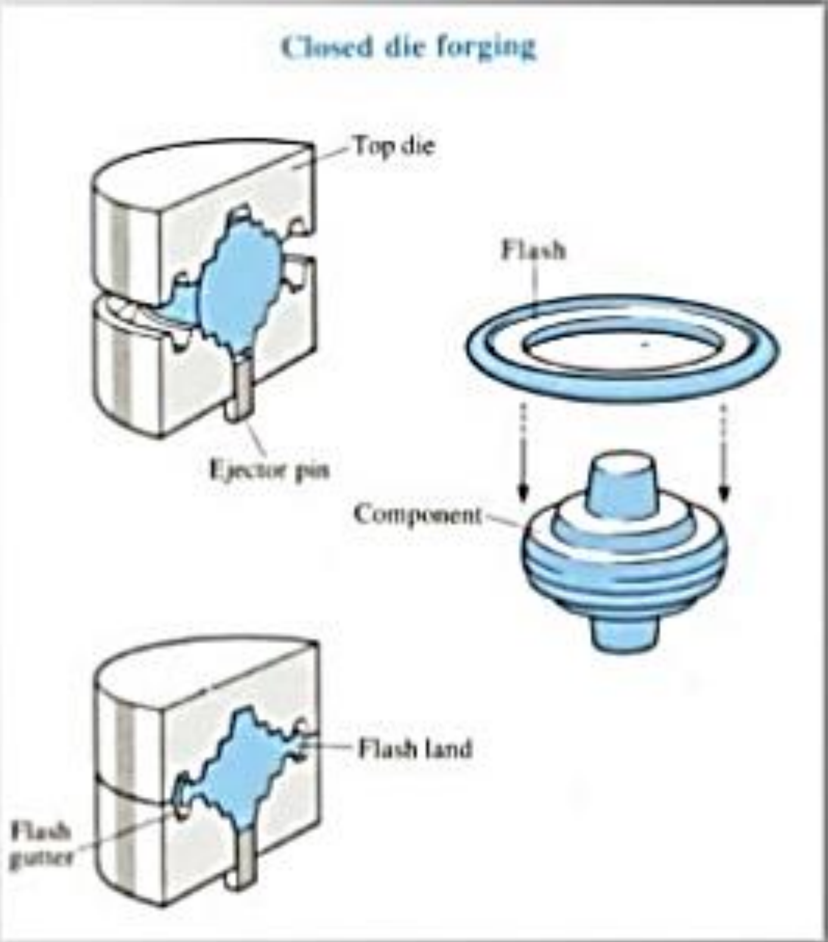
Forging pressure vessel cylinder

Closed-die forging (or impression-die forging)

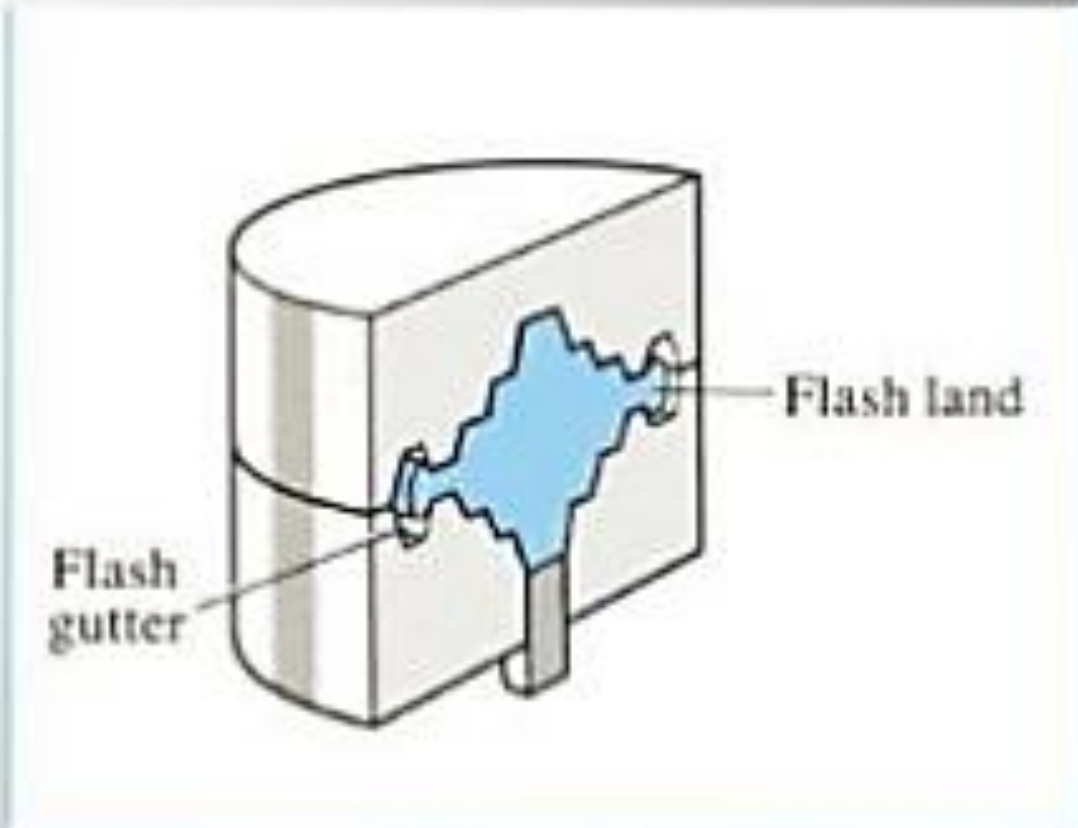
- The work-piece is deformed between two die halves which carry the impressions of the desired final shape.
- The work-piece is deformed under high pressure in a closed cavity.

Normally used for smaller components

- The process provide precision forging with close dimensional tolerance.
- Closed dies are expensive.

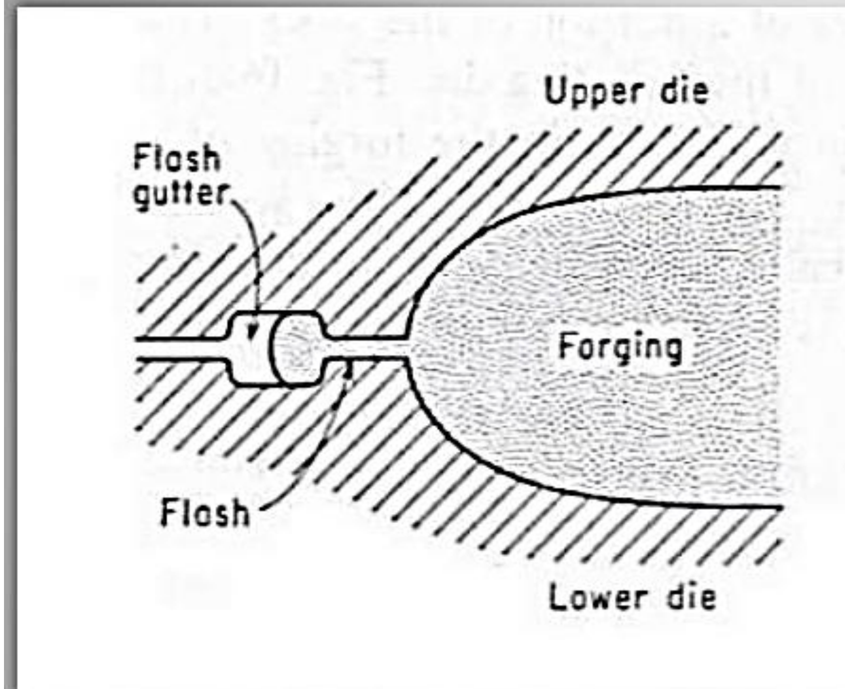


Closed-die forging operation



Flash is the excess metal, which squirts out of the cavity as a thick ribbon of metal.

Functions of flash



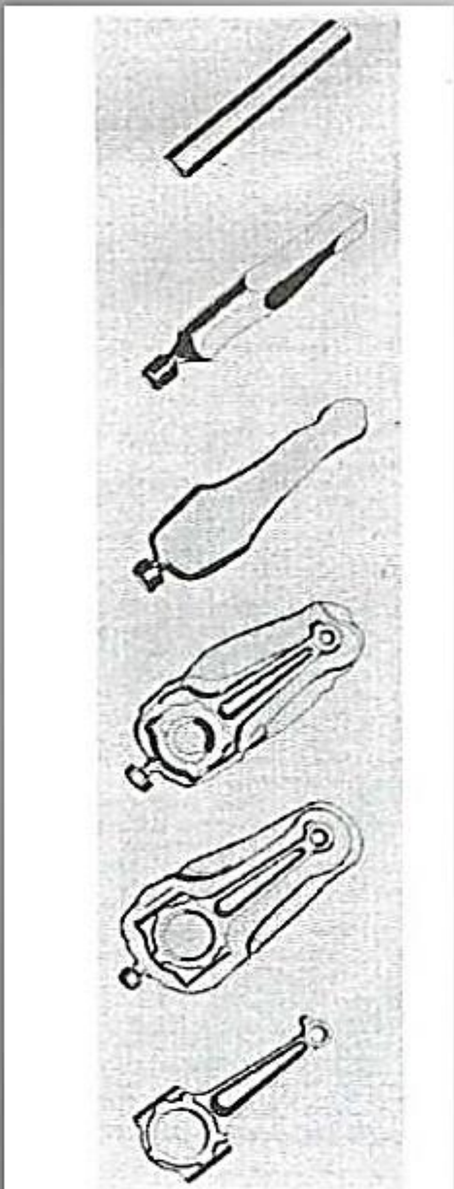
The flash serves two purposes:

➢Acts as a 'safety value' for excess metal.

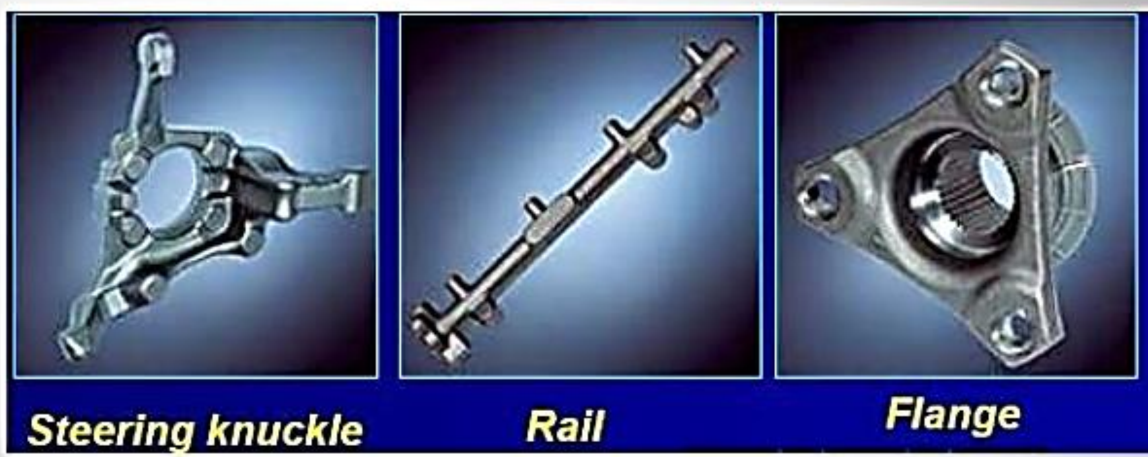
➢Builds up high pressure to ensure that the metal fills all recesses of the die cavity.

Remark: It is necessary to achieve complete filling of the forging cavity without generating excessive pressures against the die that may cause it to fracture.

Example: Die set and forging steps for the manufacturing of an automobile engine connecting rod



❖Performing of a round piece in an open die arrangement.
❖Rough shape is formed using a block die.
❖The finishing die is used to bring the part to final tolerances and surface finish.
❖Removal of flash (excess metal).



FORGING – OPERATIONS AND CLASSIFICATIONS

Forging is a metal working process in which useful shape is obtained in solid state by hammering or pressing metal.

1. Upsetting

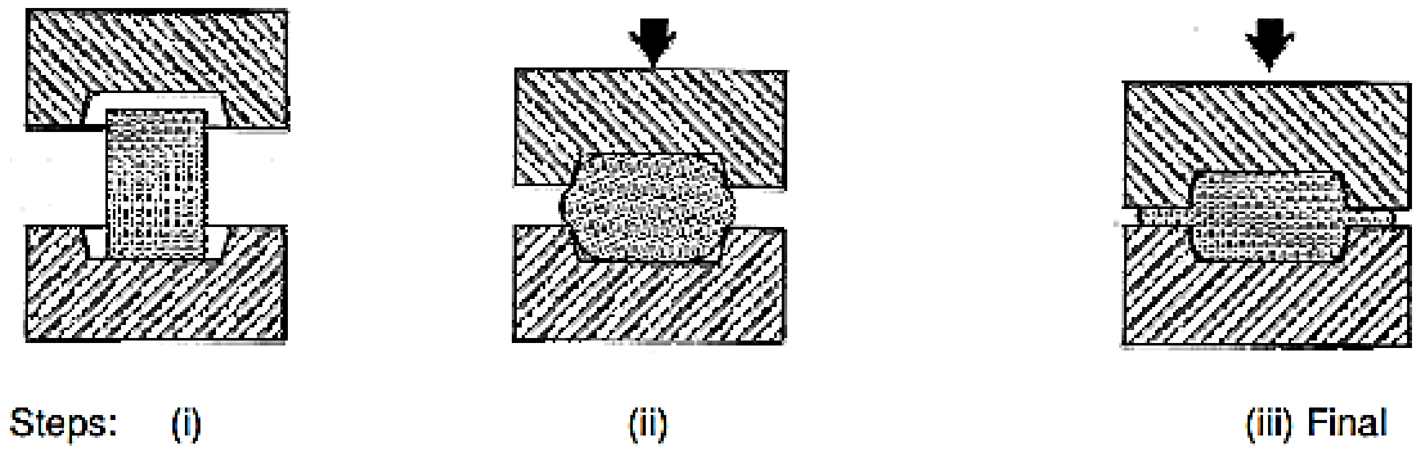
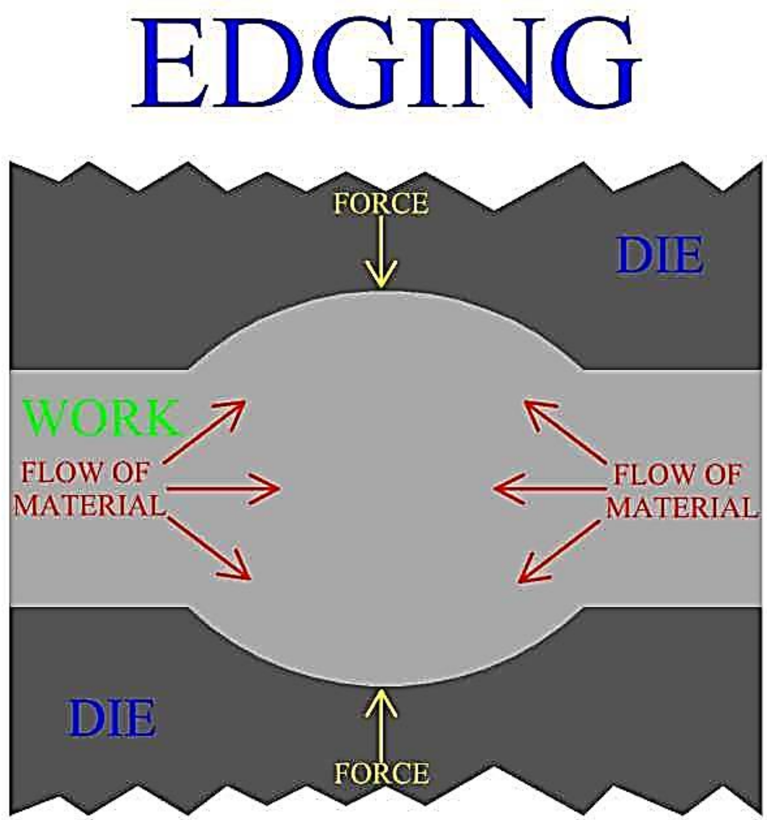


Fig1. Upsetting

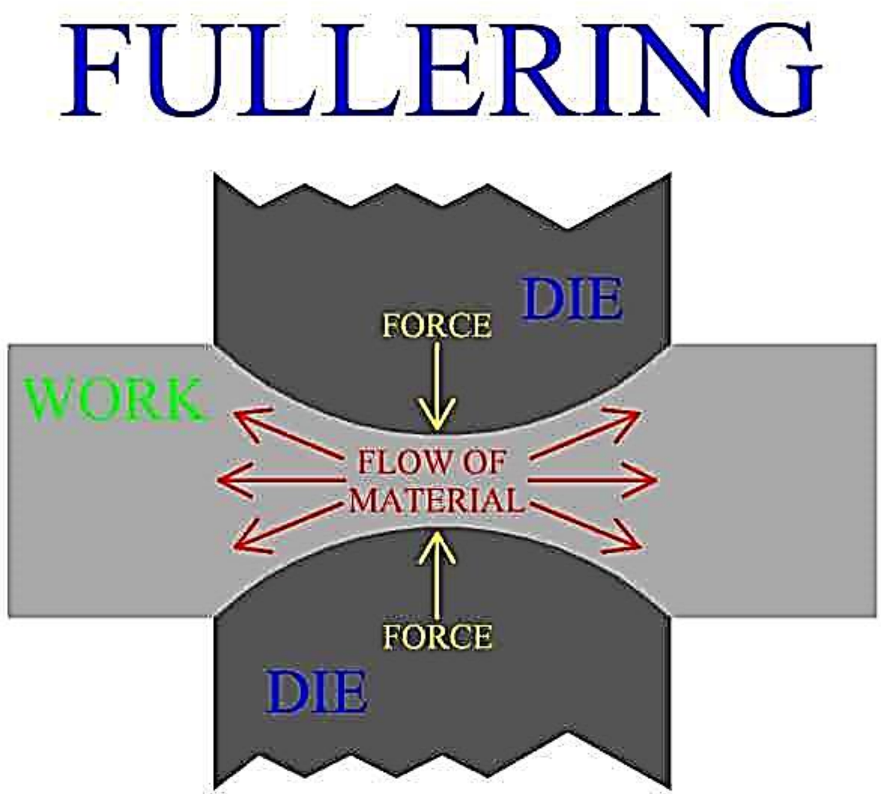
2. Edging

Ends of the bar are shaped to requirement using edging dies.



3. Fullering

Cross sectional area of the work reduces as metal flows outward, away from centre



4. Drawing

Cross sectional area of the work is reduced with corresponding increase in length using convex dies.

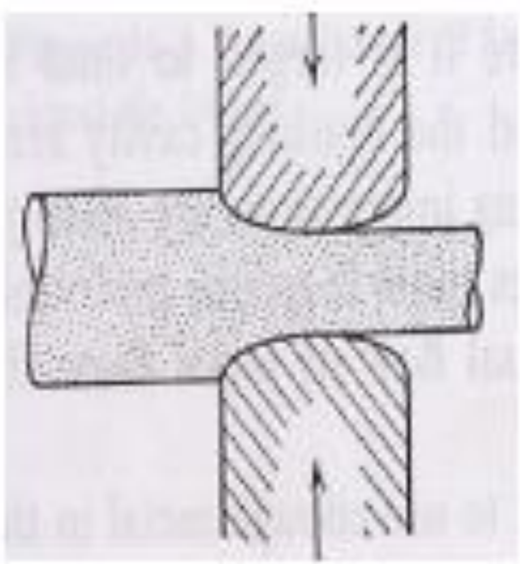


Fig 4. Drawing

5. Swaging

Cross sectional area of the bar is reduced using concave dies.

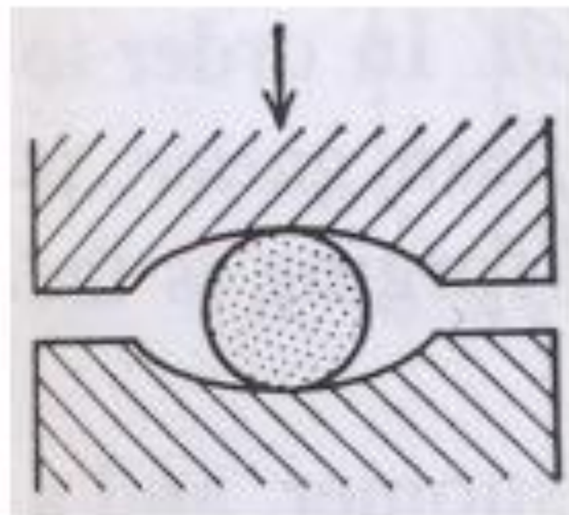
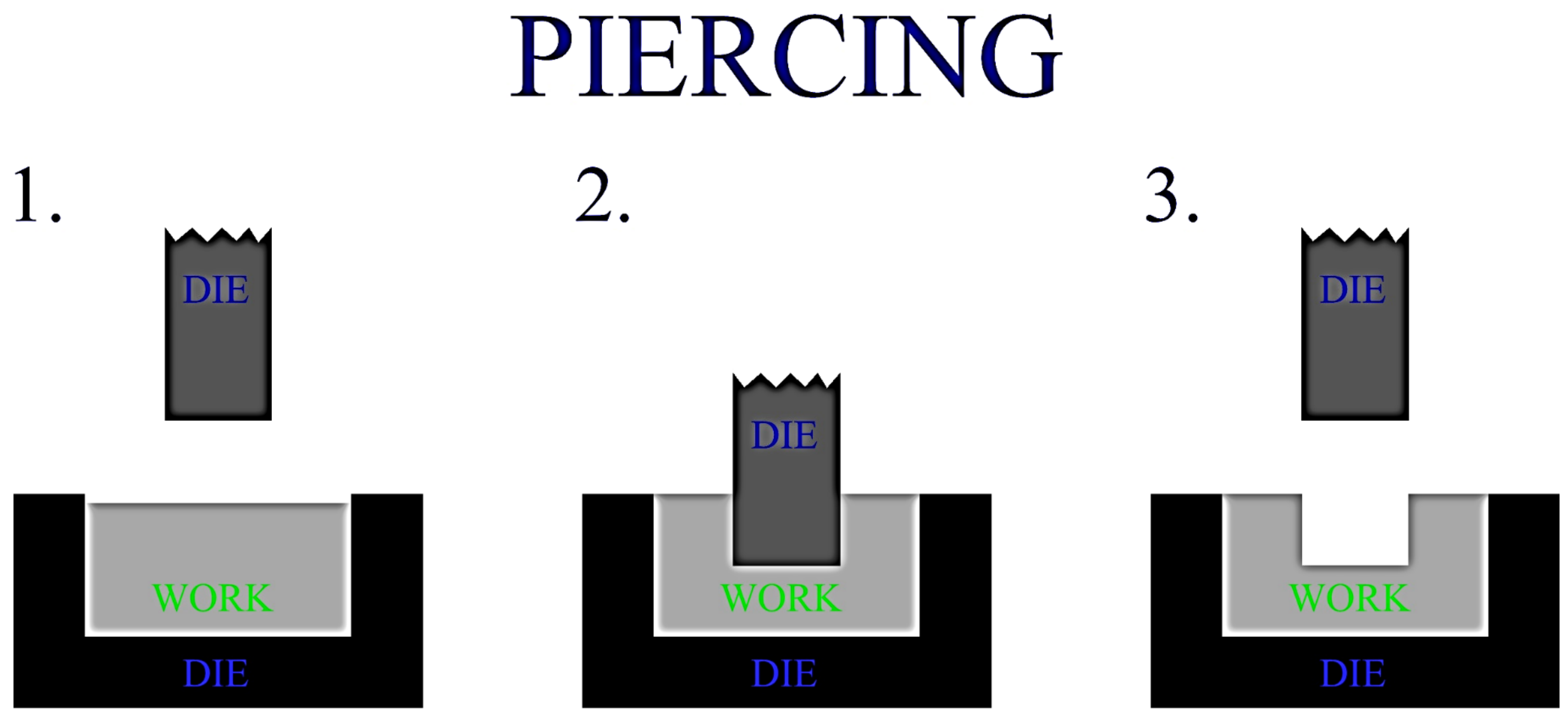


Fig 5. Swaging

6. Piercing

Metal flows around the die cavity as a moving die pierces the metal.



7. Punching

It is a cutting operation in which a required hole is produced using a punching die.

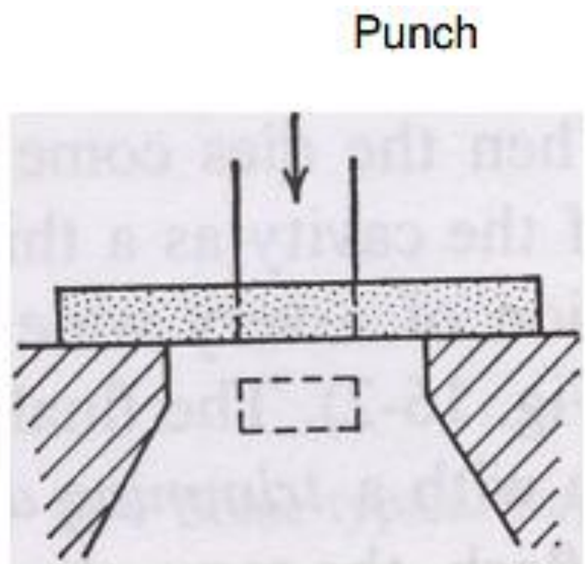
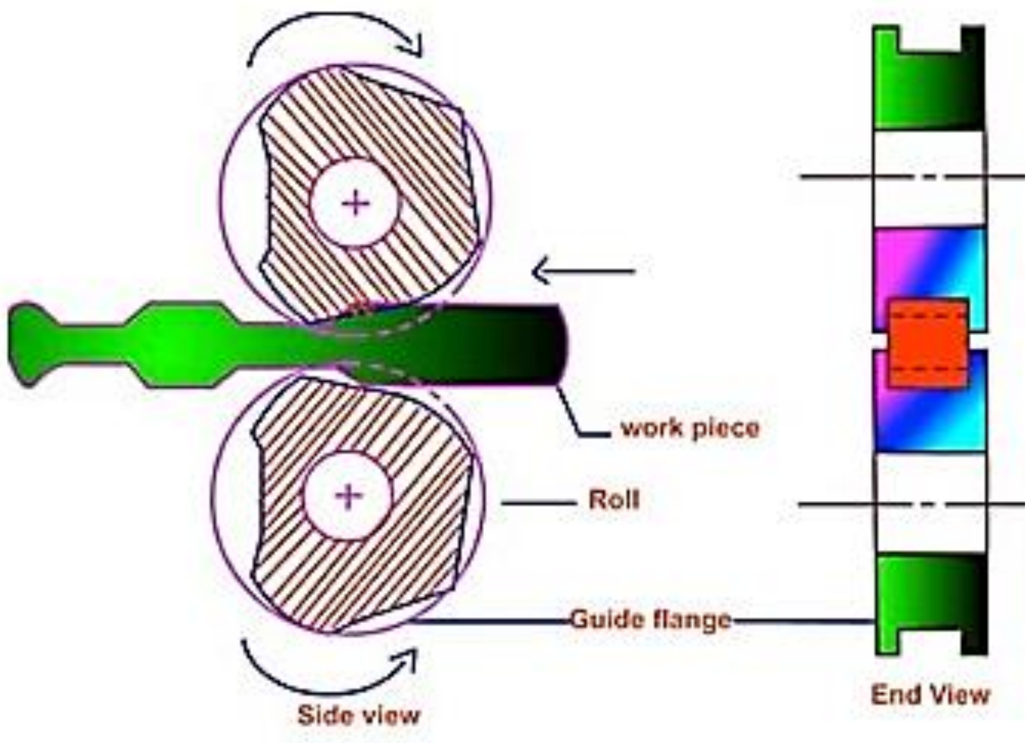


Fig 7. Punching

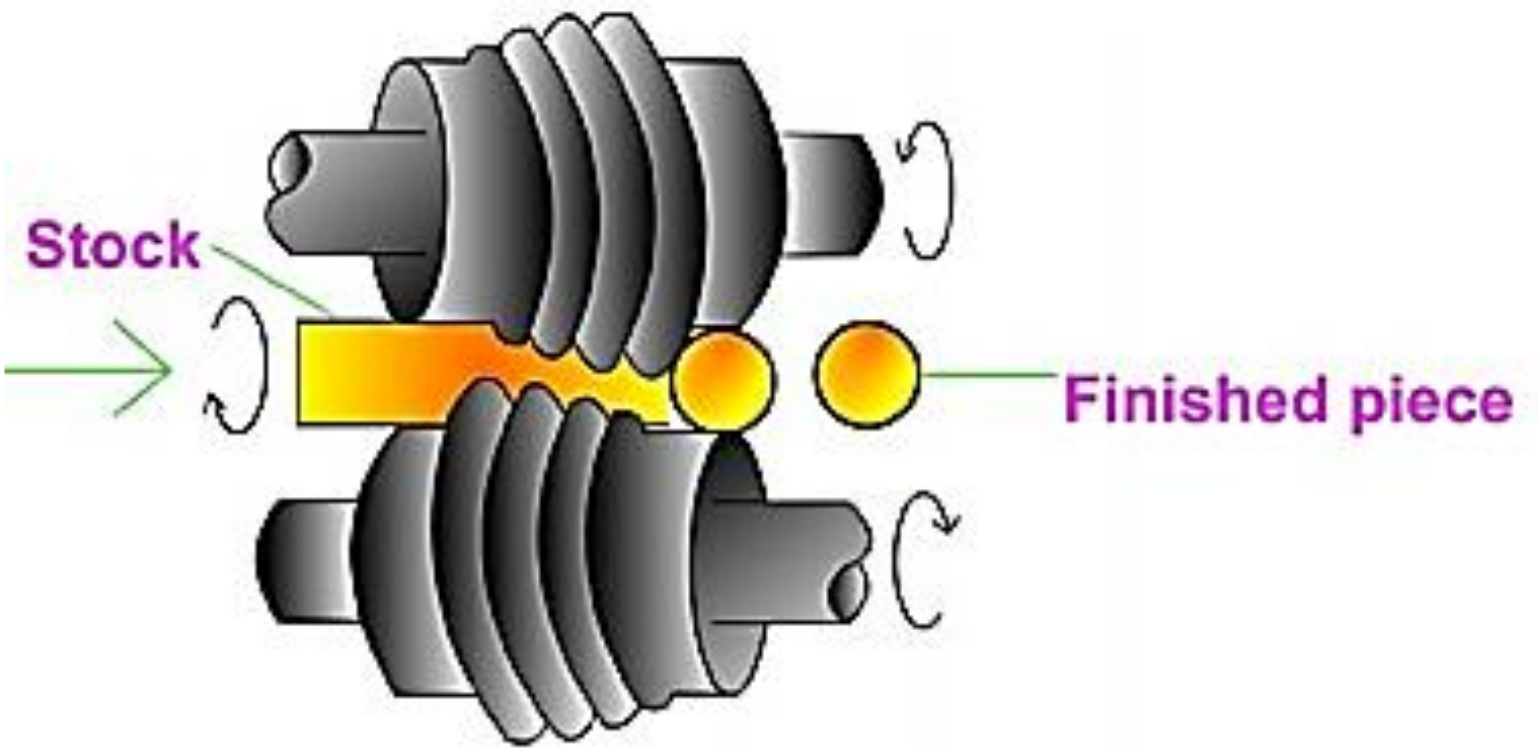
8. Bending: The metal is bent around a die/anvil.

Roll forging

- In this process, the bar stock is reduced in cross-section or undergoes change in cross-section when it is passed through a pair of grooved rolls made of die steel.
- This process serves as the initial processing step for forging of parts such as connecting rod, crank shaft etc.



A particular type of roll forging called skew rolling is used for making spherical balls for ball bearings

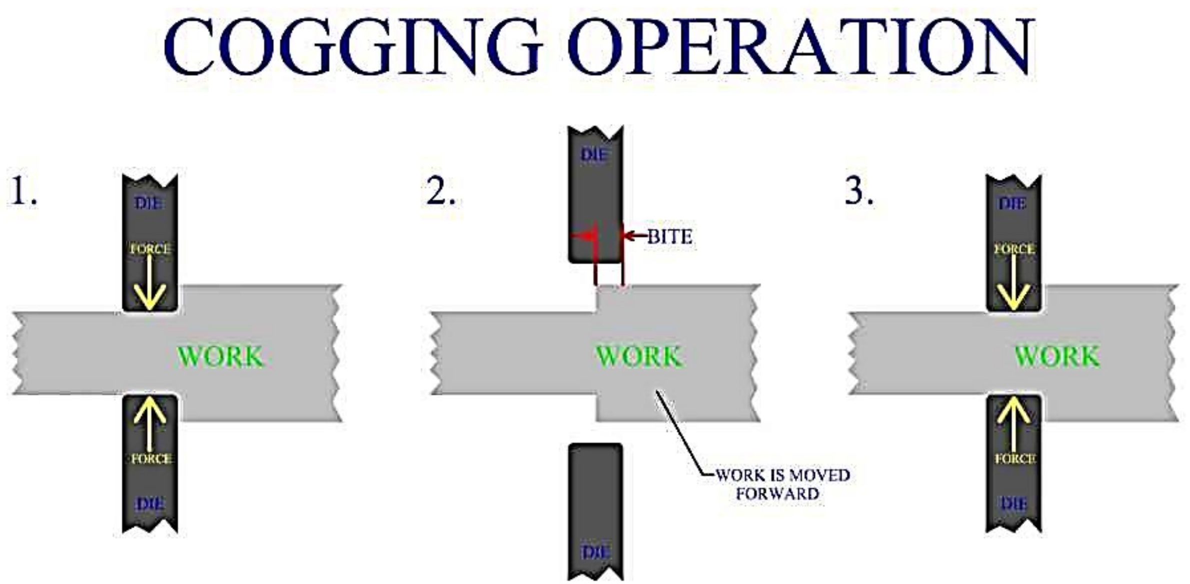


SKEW ROLLING

Cogging

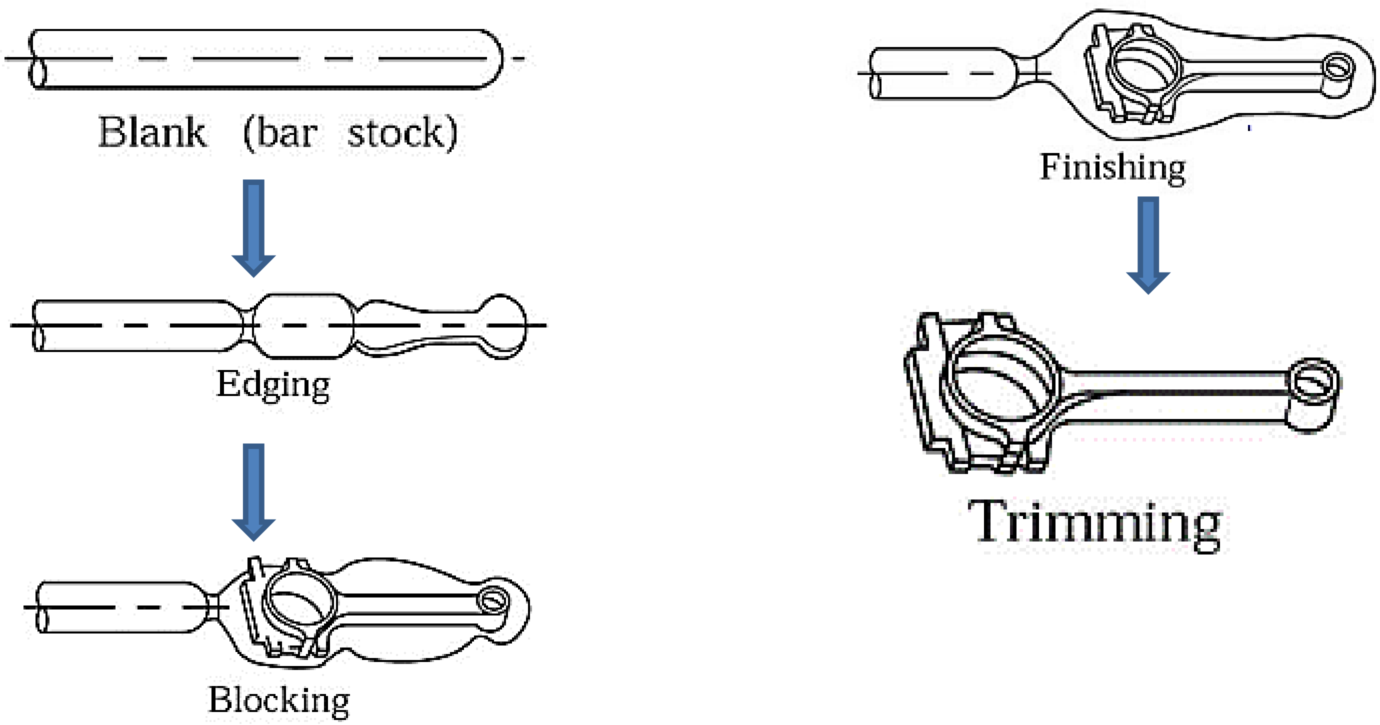
Successively reducing the thickness of a bar with open die forging

- Also called drawing out
- Reducing the thickness of a long section of a bar without excessive forces or machining



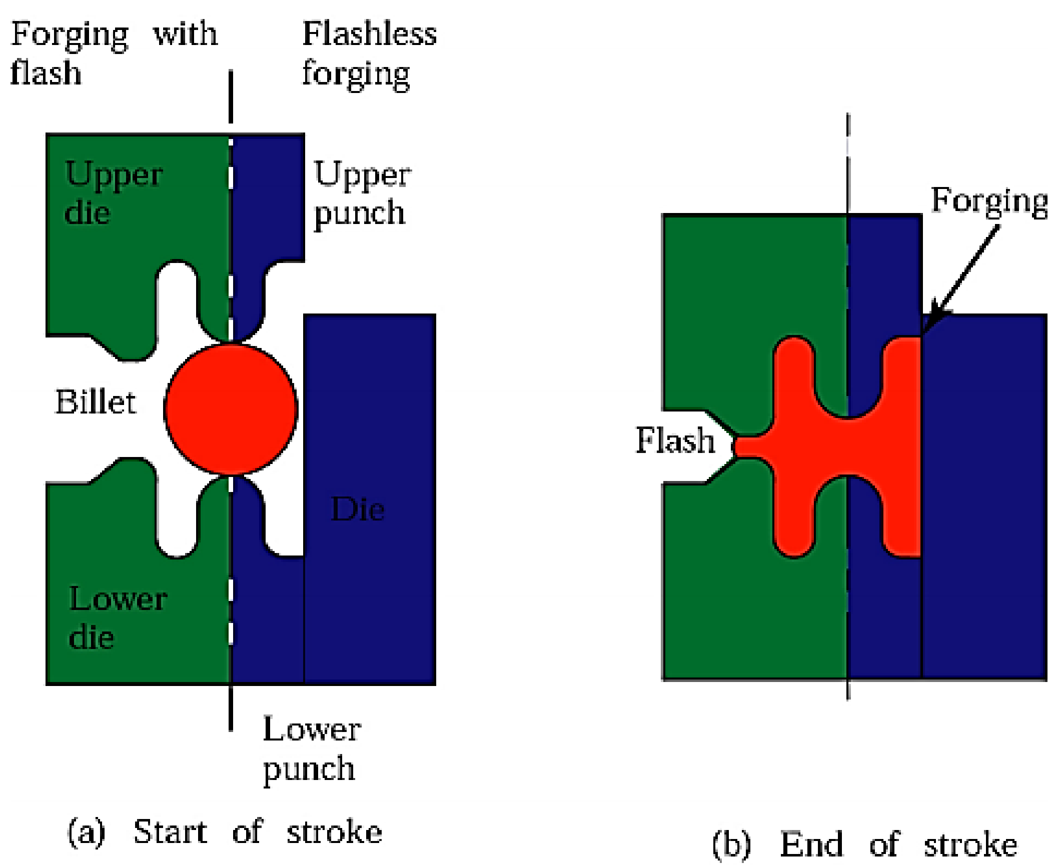
Forging between two shaped dies

- Fullering and Edging distribute material into specific regions of the blank
- Blocking creates a rough shape



Precision Forging

- True closed die or flashless forging uses precise volumes of material to completely fill the die cavity

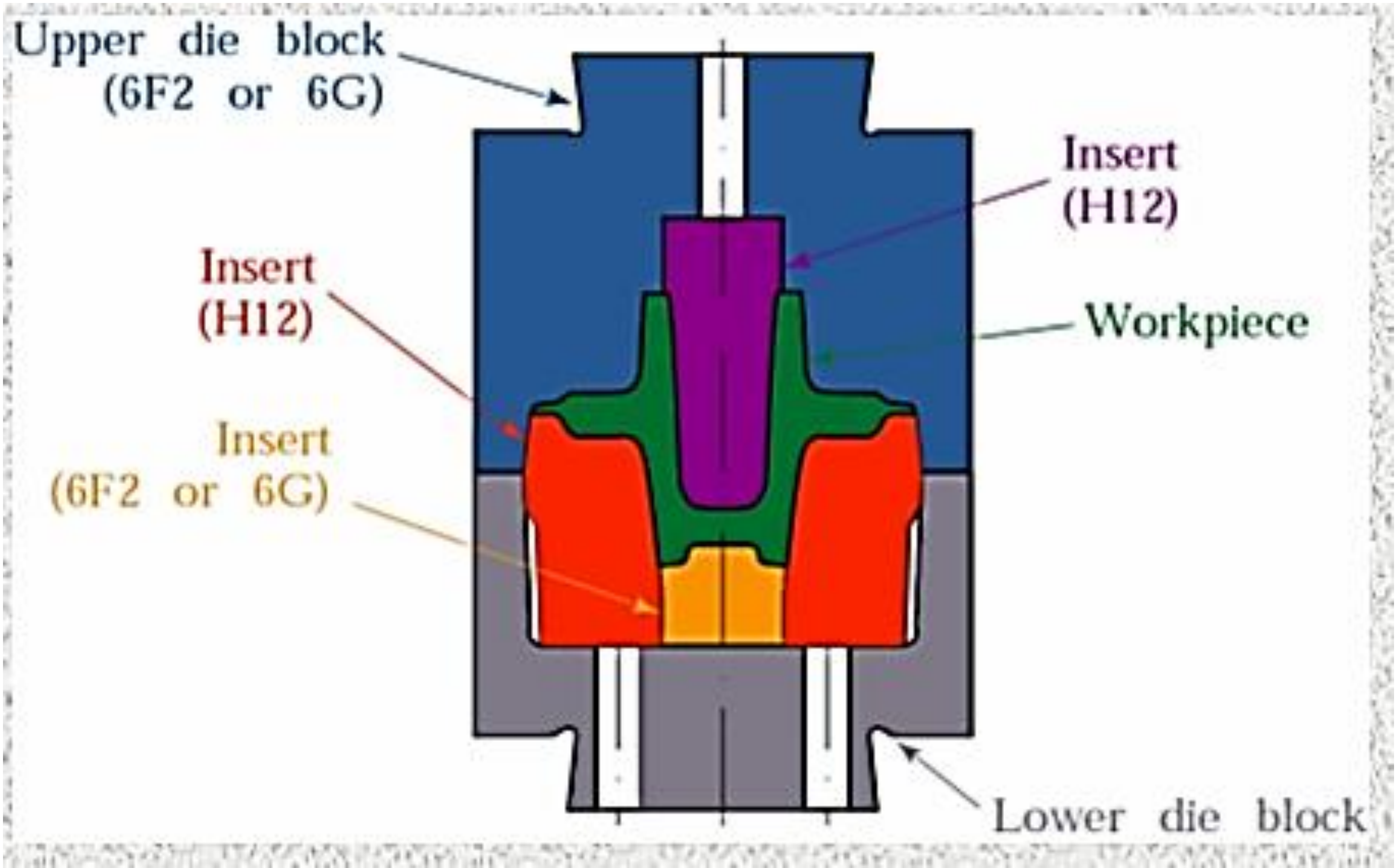


- Undersize blanks will not fill the cavity, oversize blanks will cause high pressures and may damage the dies

- • Reduces the number of additional operations and wasted material

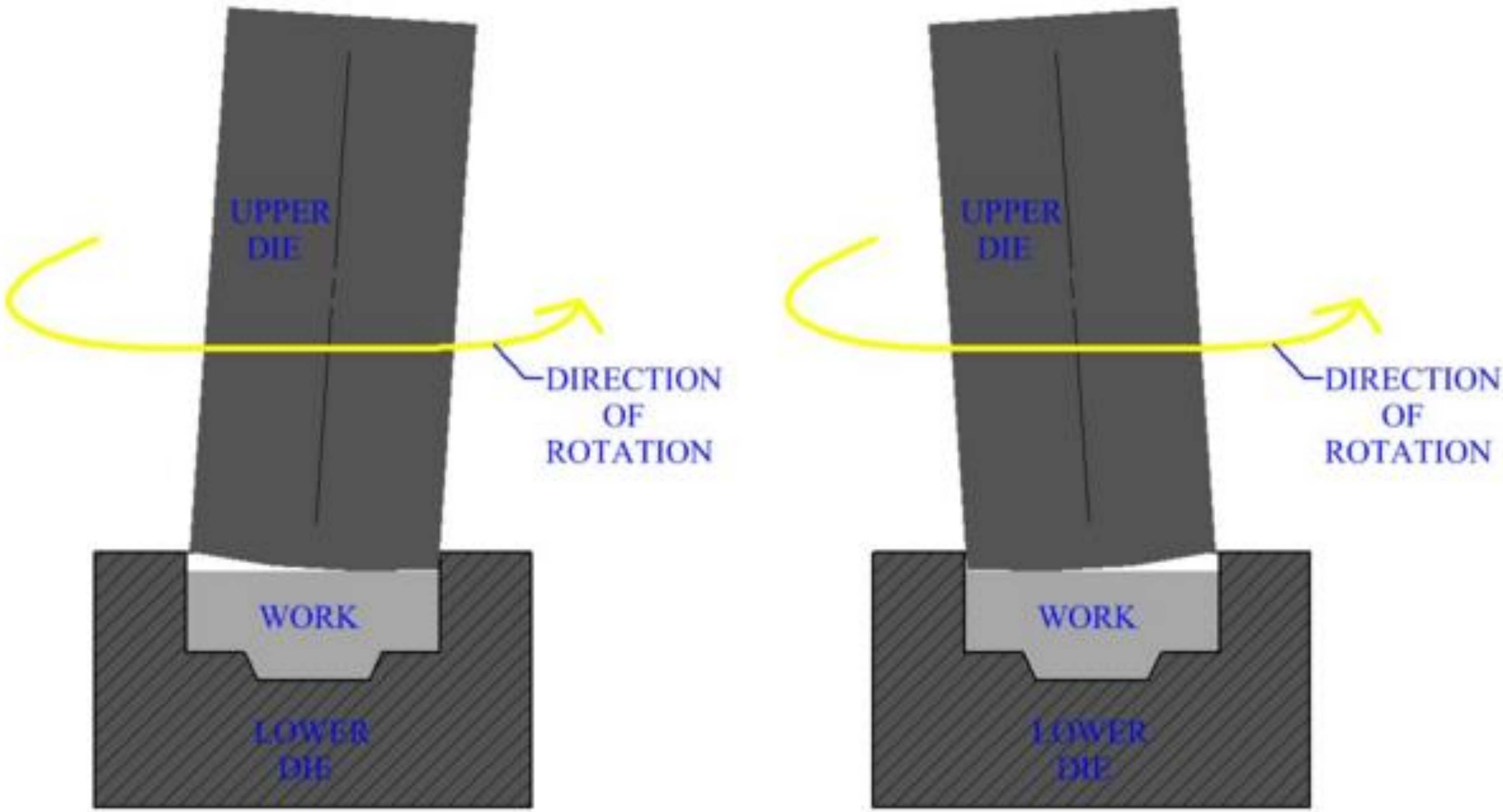
- • Near-net-shape forging (or net-shape)

DIE INSERTS

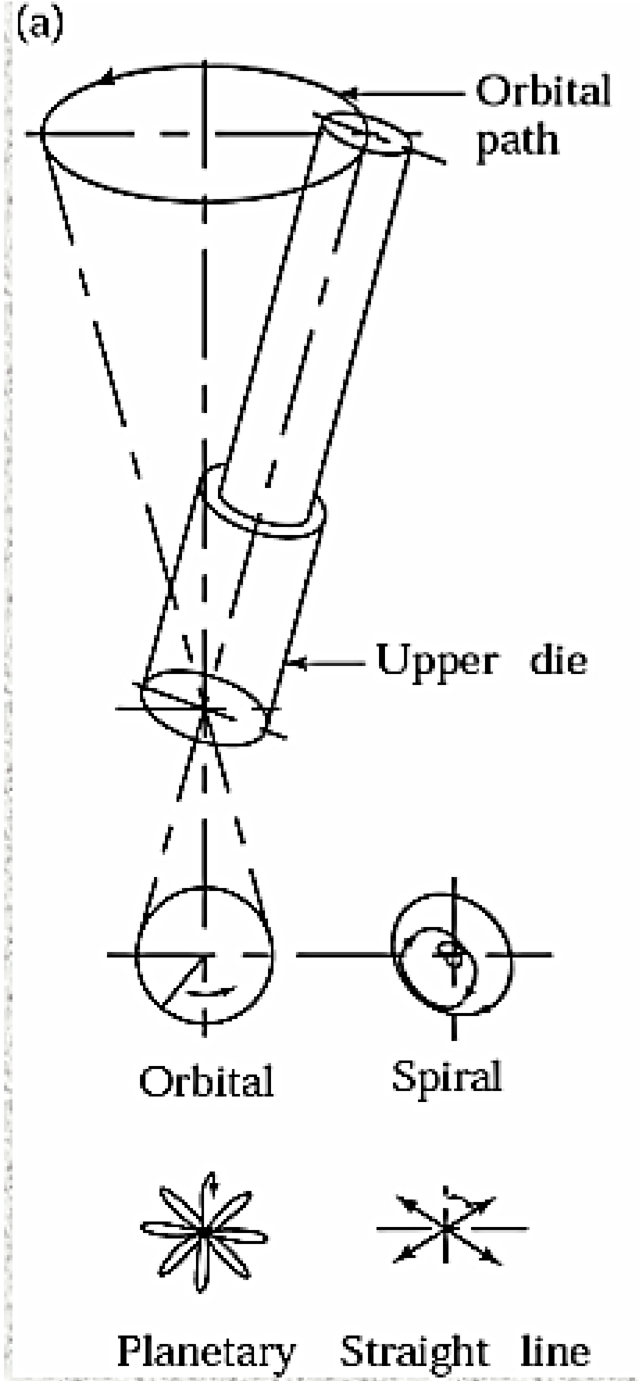


Upper die block
(6F2 or 6G)
Insert
(H12)
Insert
(H12)
Workpiece
Insert
(6F2 or 6G)
Lower die block

ORBITAL FORGING



Orbital Forging



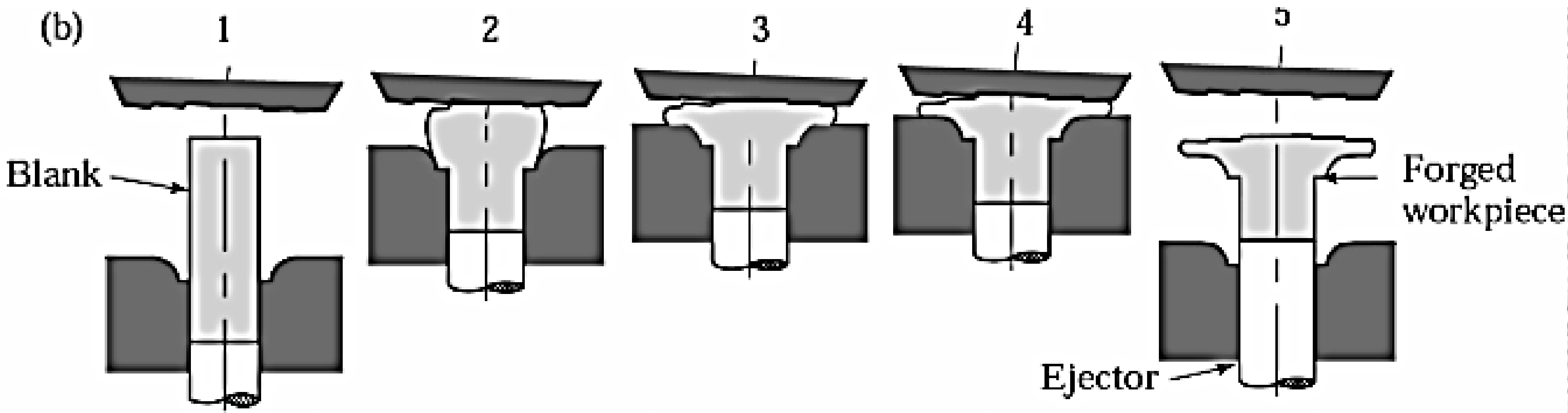
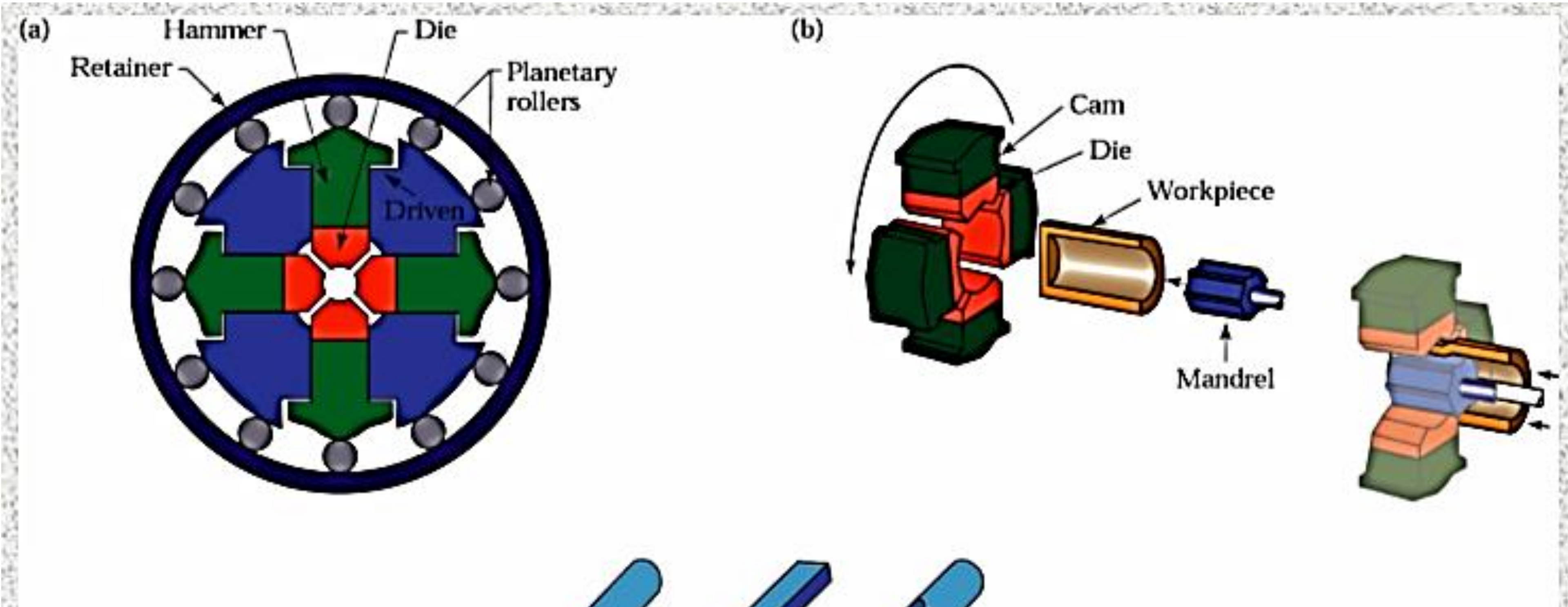
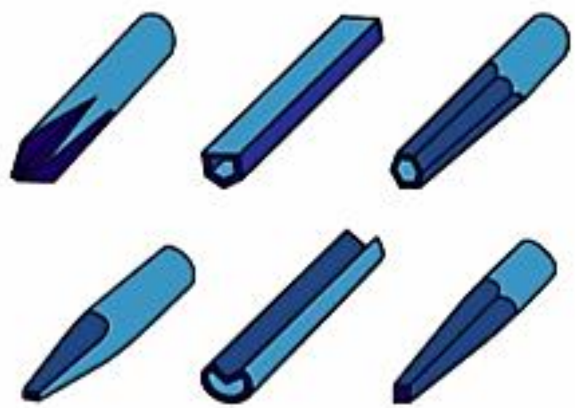


Figure 14.15 (a) Various movements of the upper die in orbital forging (also called rotary, swing, or rocking-die forging); the process is similar to the action of a mortar and pestle. (b) An example of orbital forging. Bevel gears, wheels, and rings for bearings can be made by this process.

SWAGING



(a)
Hammer
Die
Retainer
Planetary rollers
Driven
(b)
Cam
Die
Workpiece
Mandrel



Rotary swaging or radial forging and Tube swaging

- A solid rod or tube is subjected to radial impact forces by reciprocating dies (workpiece is stationary)
- Screwdriver blades made this way

Swaging of Tubes With and Without a Mandrel

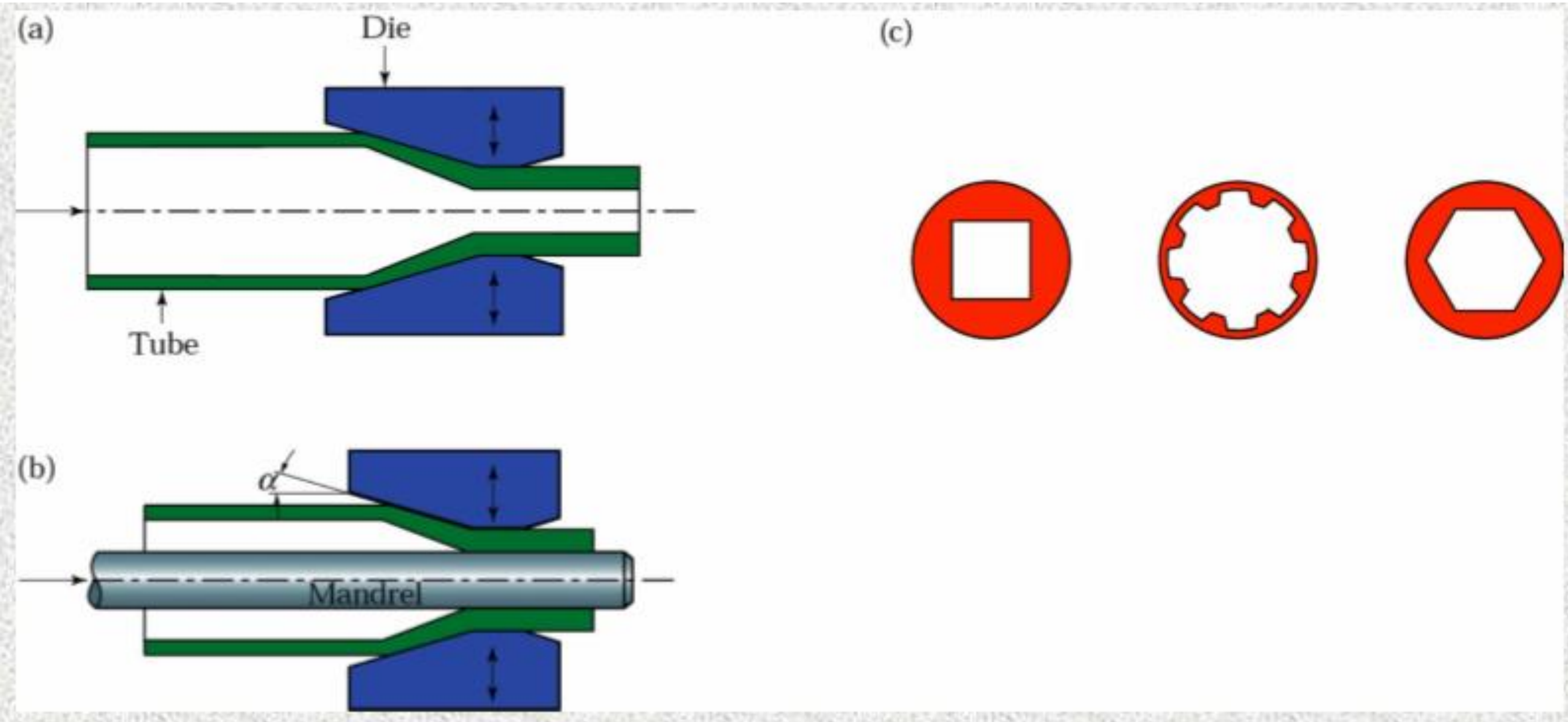
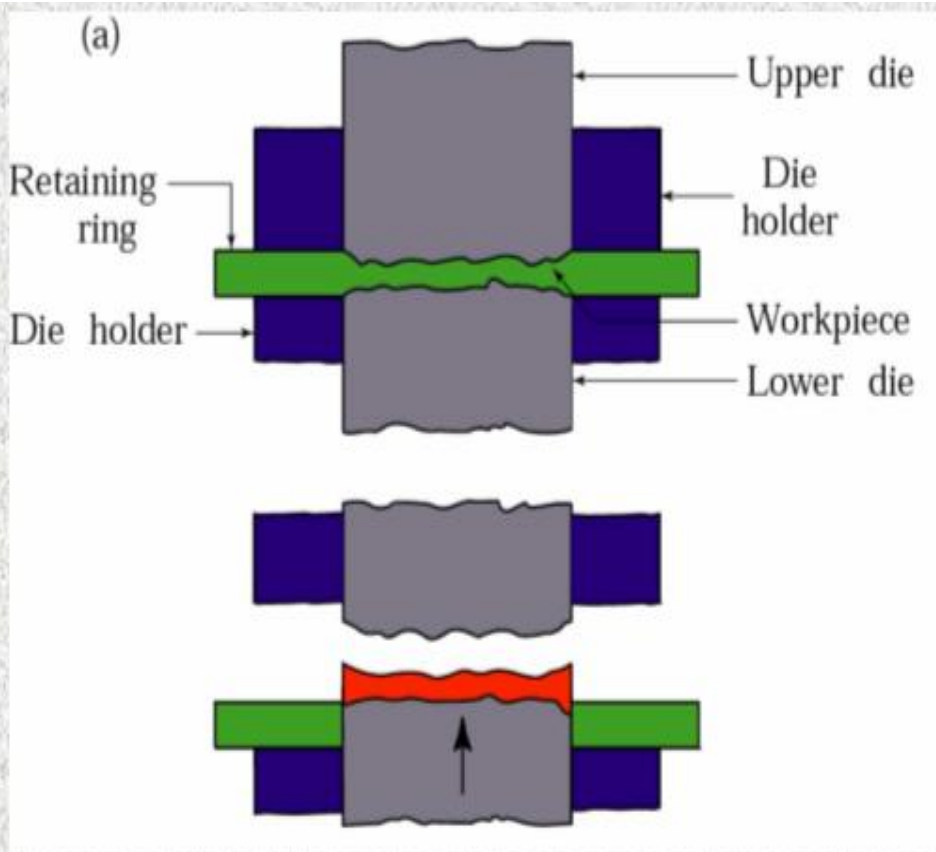


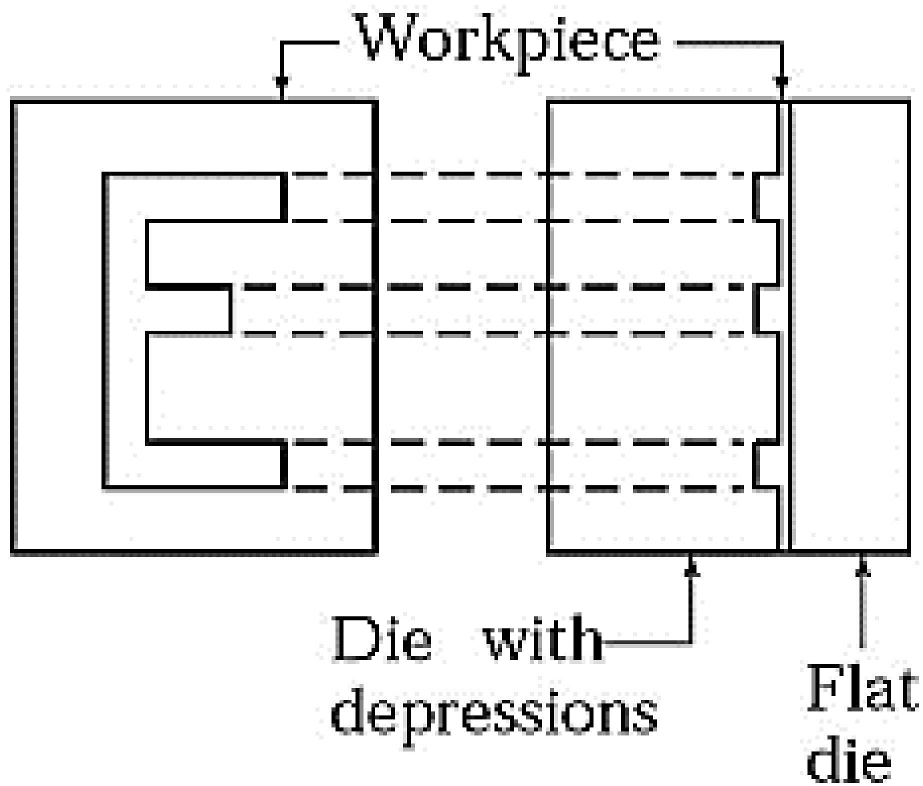
Figure 14.17 (a) Swaging of tubes without a mandrel; not the increase in wall thickness in the die gap. (b) Swaging with a mandrel; note that the final wall thickness of the tube depends on the mandrel diameter. (c) Examples of cross-sections of tubes produced by swaging on shaped mandrels. Rifling (spiral grooves) in small gun barrels can be made by this process.

COINING



- Coining is for minting coins and jewelry
- Completely closed dies and high pressures (5-6 times the strength of the material) to obtain fine details
- Lubricants cannot be used since they are incompressible

(b)



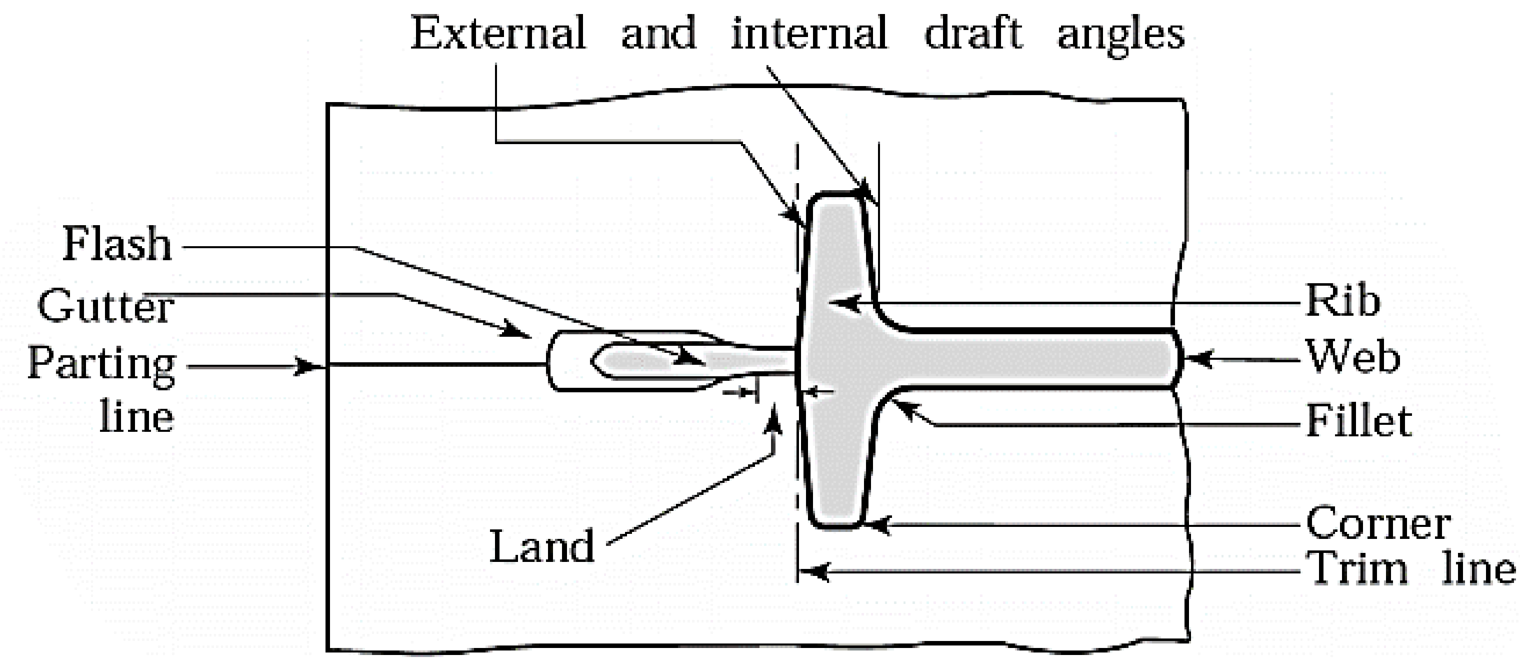
An example of a coining operation to produce an impression of the letter E

Die Design

- ✓ Must know workpiece material strength and ductility, deformation rate, temperature sensitivity, frictional characteristics
- ✓ Forgeability of materials is capability to undergo deformation without cracking
- ✓ Must evaluate shape, size, and complexity of design
- ✓ Material flows in the direction of least resistance, which is why intermediate shapes may need to be formed

- ✓ Preshaping should prevent material from easily flowing into flash, produce favorable grain flow patterns, and minimize friction and wear at the die-workpiece interface

- ✓ Computers can model and predict material flow



- Parting lines are usually at the largest cross section
- <u>Flash specifications:</u>
- Flash clearance should be 3% of maximum forging thickness
- Land that is 2-5 times flash thickness, then a larger gutter that does not restrict flash flow

- Draft angles are needed (7-10 deg internal, 3-5 external)

- Avoid small radii

- Avoid sharp corners

- Inserts can be used

- Die materials must have strength and toughness at elevated temperatures, hardenability, resistance to mechanical and thermal shock, wear resistance

- Die selection based on size, required properties, forging temperature, operation type, cost, and production quantities

- Common die materials are tool and die steels with chromium, nickel, molybdenum, and vanadium

- Dies are forged from castings, and then machined and finished as needed, often with heat treatment to increase hardness and wear resistance

- Lubricants act as thermal barriers for hot workpiece and cooler dies, improve metal flow, and are parting agents

Die Failure Causes

- Improper design
- Defective material
- Improper heat treatment and finishing operations
- Overheating and cracks caused by temperature cycling – usually preheat dies to 1500-2500 degrees Celsius
- Excessive wear – chipping or cracking from impact forces (can be repaired by welding or laser metal deposition)

- Overloading

- Misuse or improper handling – failure to remove a forged part before inserting a new blank

Types of Forging Machine

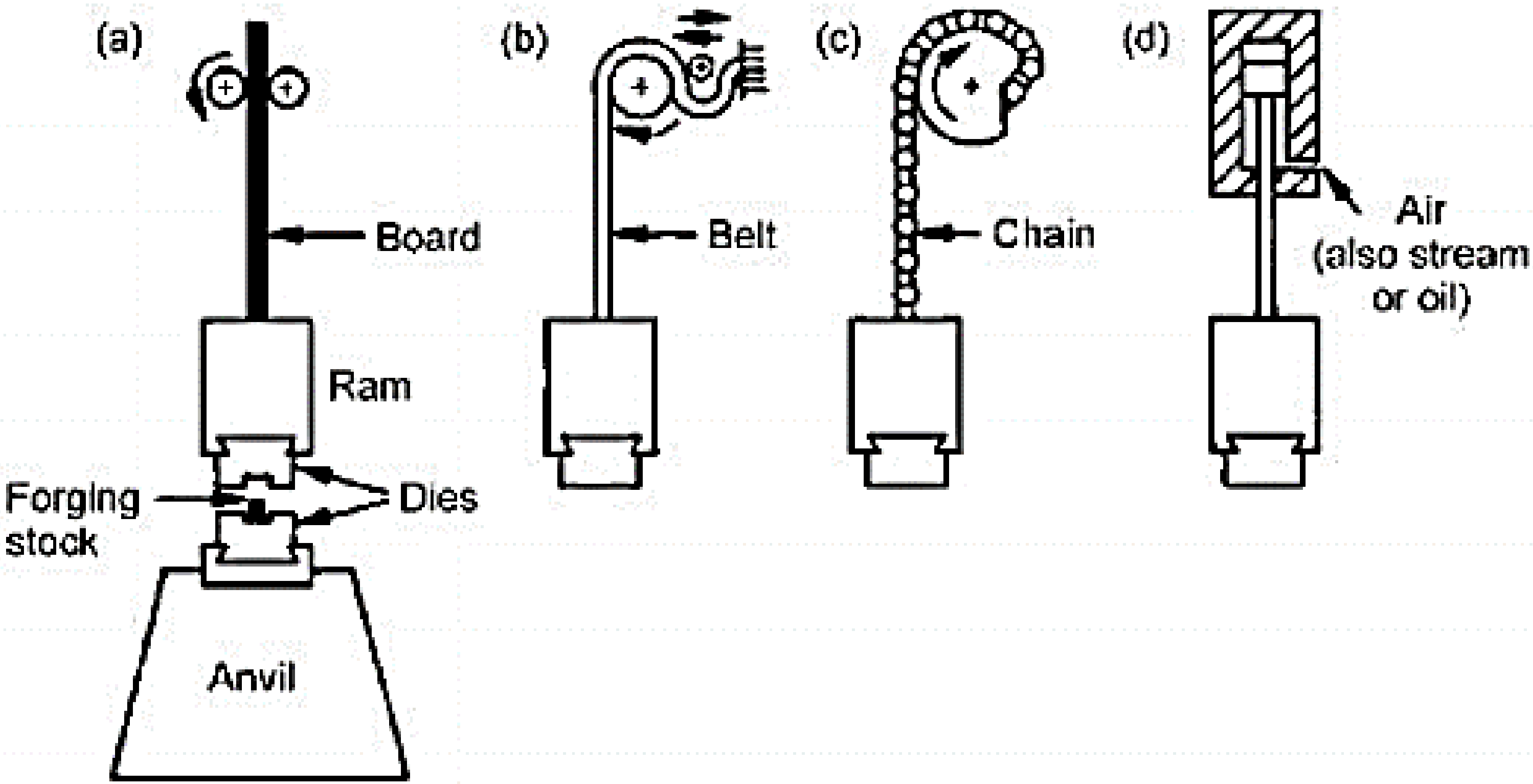
Work Restricted Machines (Energy or Load Limited) – Hammers

- Gravity drop hammers
- Power hammers
- Counterblow hammers – Friction Screw

Presses – Hydraulic Presses

- Stroke Limited (Restricted) Machines – Mechanical presses

DIFFERENT TYPES OF DROP HAMMERS



Mechanical board hammer

It is a stroke restricted machine.

- Repeatedly the board (weight) is raised by rolls and is dropped on the die.
- Rating is in terms of weight of the ram and energy delivered.

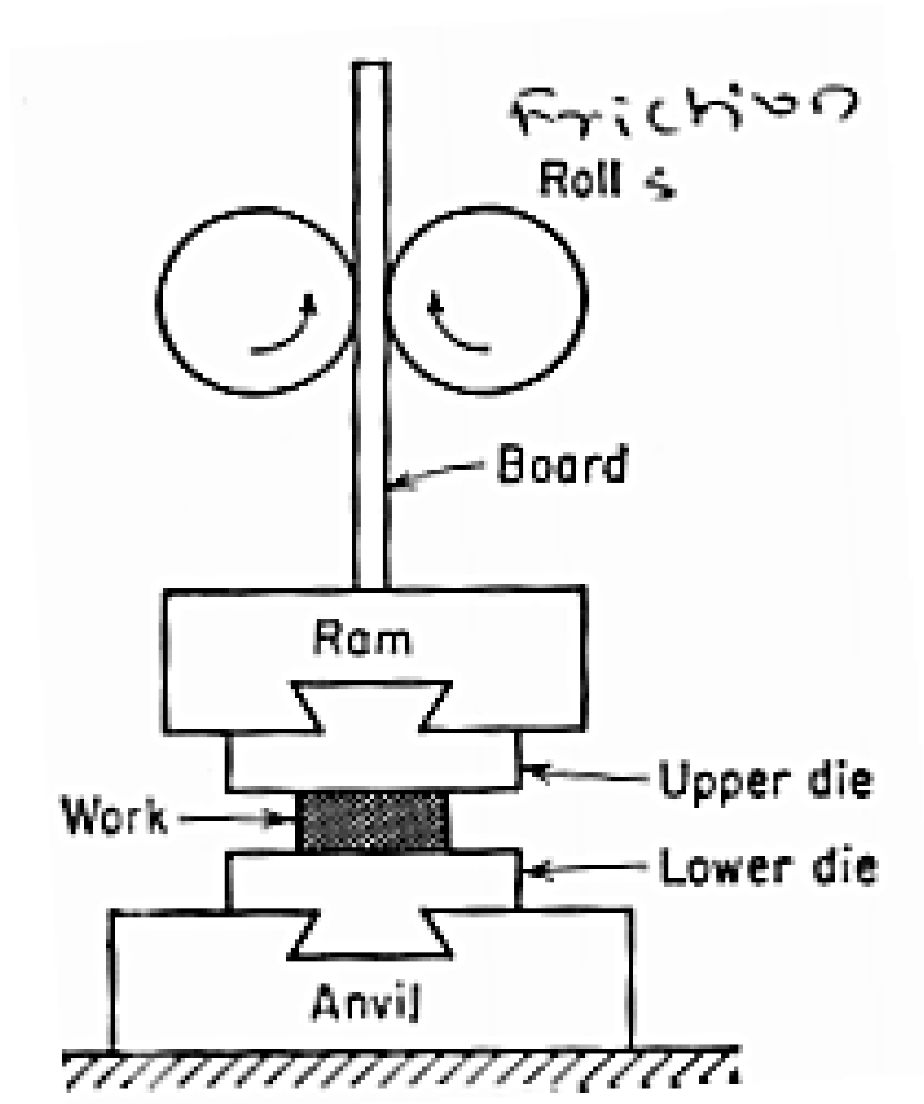


Fig. Mechanical Board Hammer

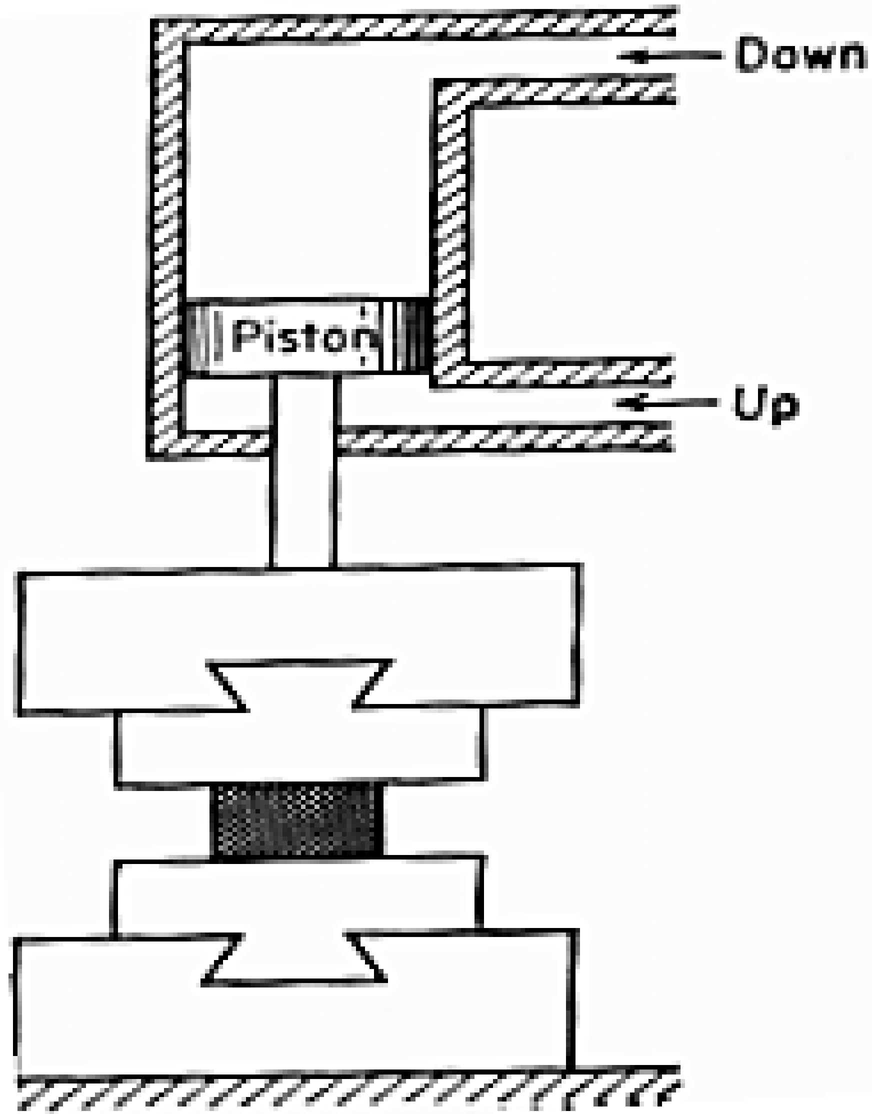


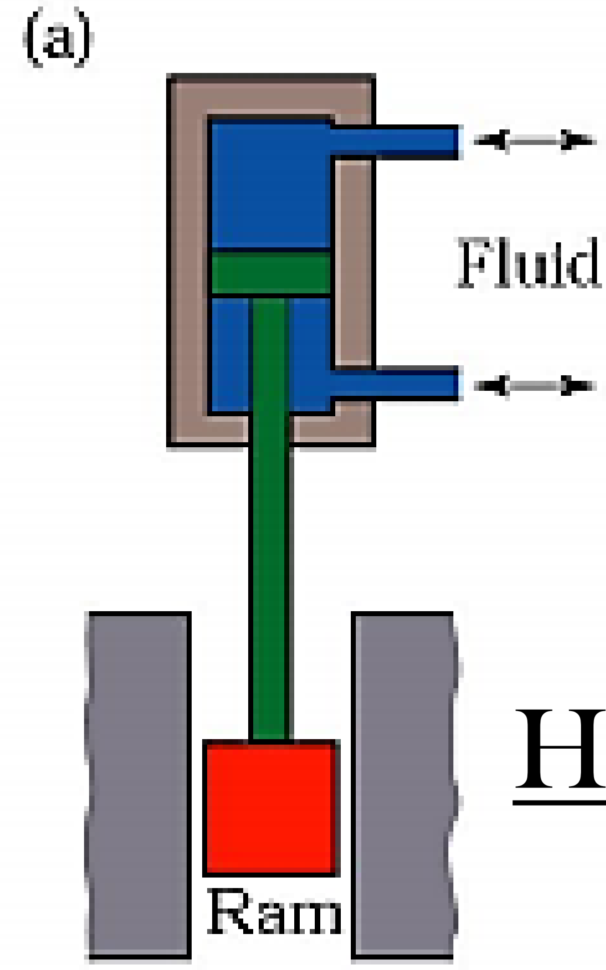
Fig. Steam Hammer

Steam Hammer (Power Hammer)

Range: 5 kN to 200 kN

- It uses steam in a piston and cylinder arrangement.
- It has greater forging capacity.
- It can produce forgings ranging from a few kgs to several tonnes.
- Preferred in closed die forging

FORGING MACHINES



Hydraulic press

Hydraulic press

It is a load restricted machine.

- It has more of squeezing action than hammering action.
- Hence dies can be smaller and have longer life than with a hammer.

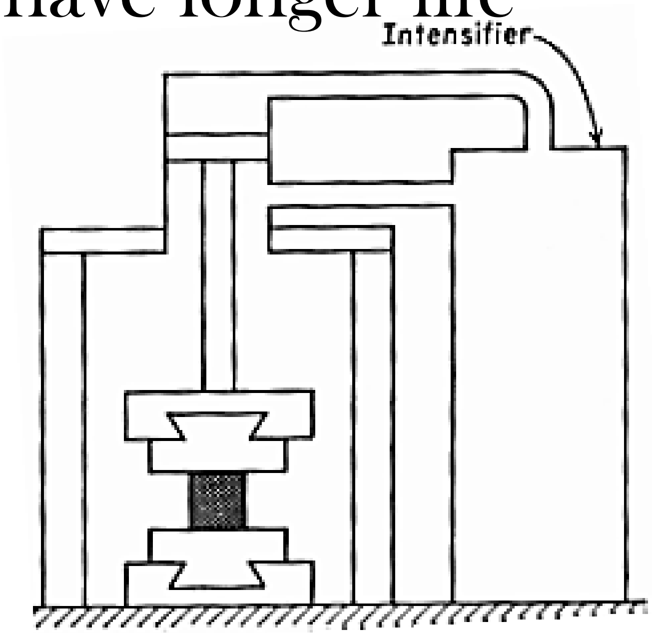
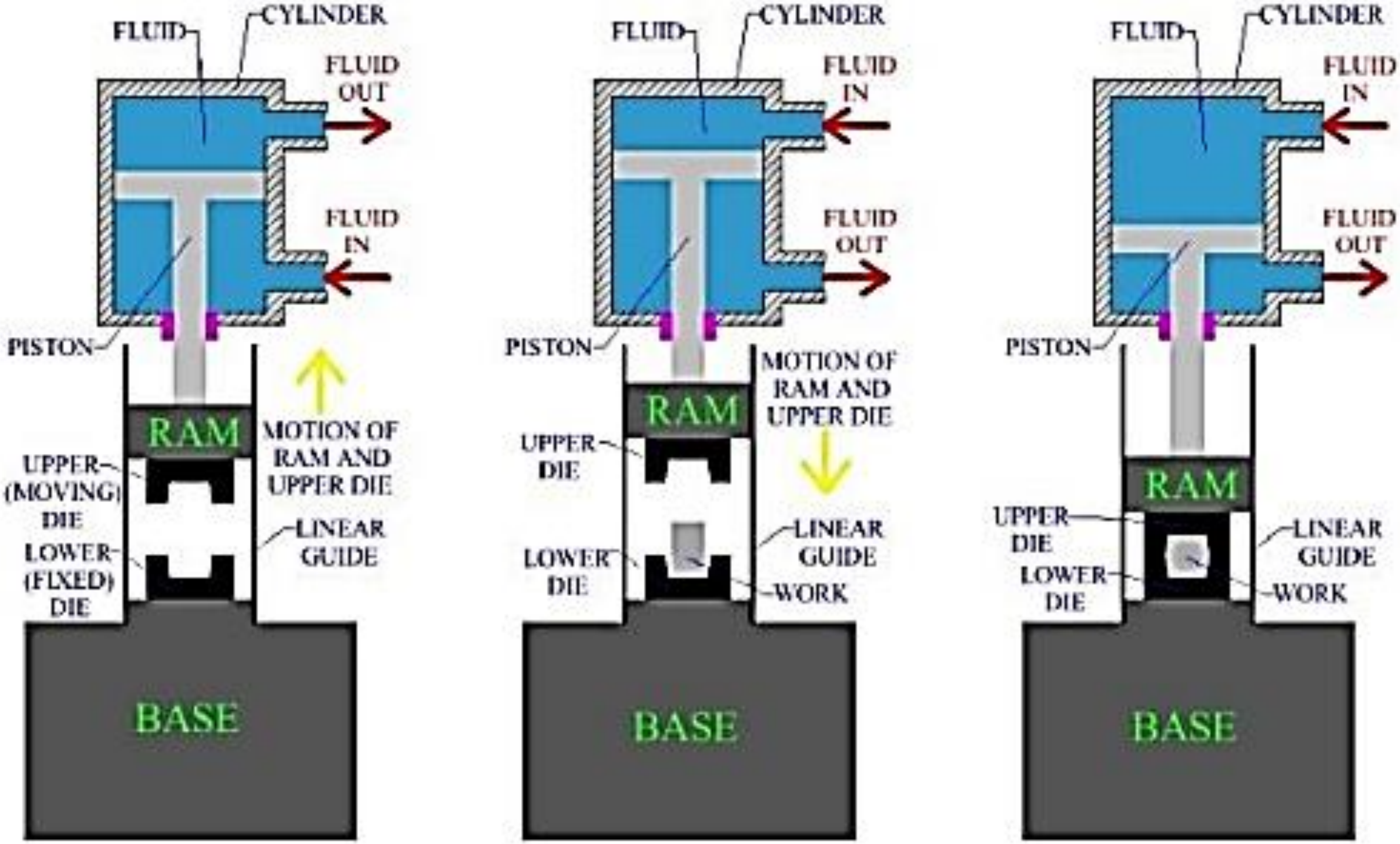
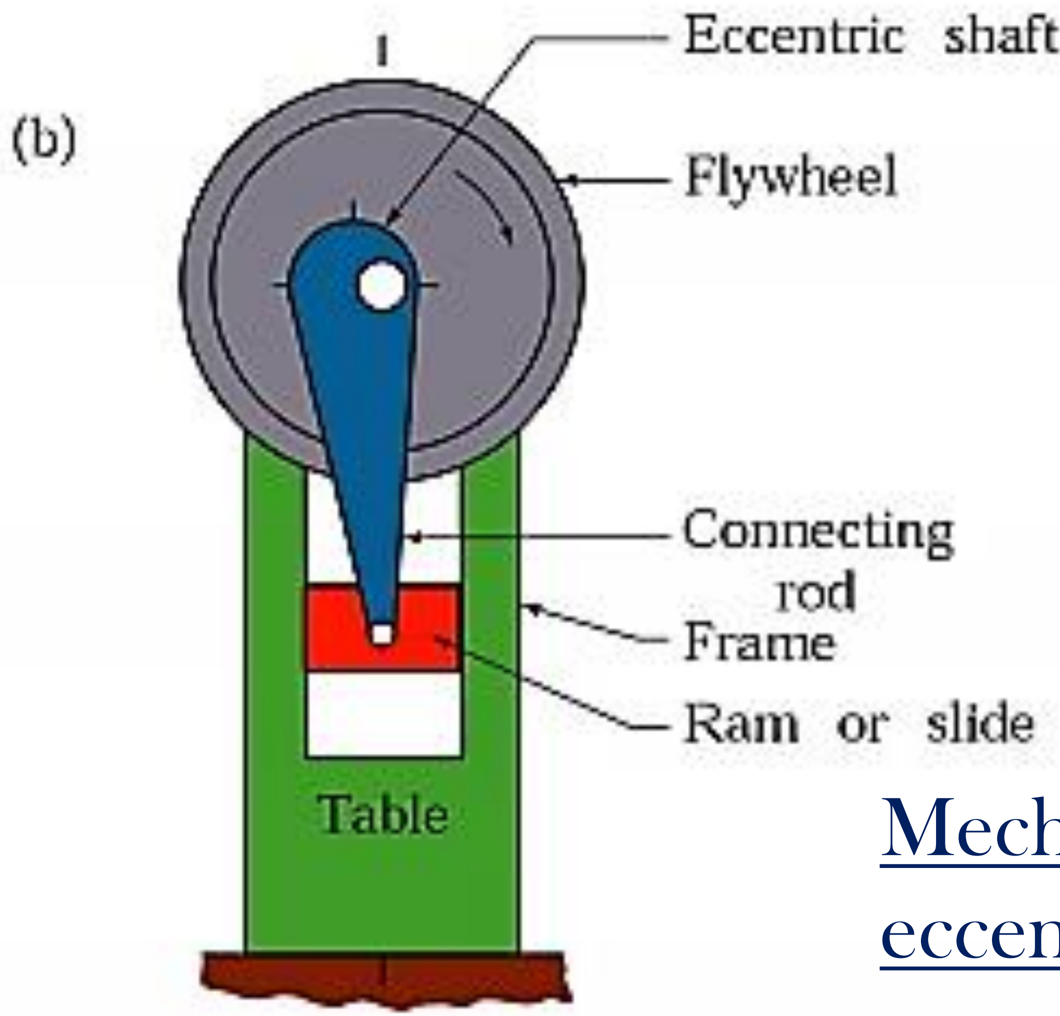


Fig. Hydraulic Press


FLUID
CYLINDER
FLUID OUT
FLUID IN
PISTON
RAM
MOTION OF RAM AND UPPER DIE
UPPER (MOVING) DIE
LOWER (FIXED) DIE
LINEAR GUIDE
BASE
FLUID
CYLINDER
FLUID IN
FLUID OUT
PISTON
RAM
MOTION OF RAM AND UPPER DIE
UPPER DIE
LOWER DIE
LINEAR GUIDE
WORK
BASE
FLUID
CYLINDER
FLUID IN
FLUID OUT
PISTON
RAM
UPPER DIE
LOWER DIE
LINEAR GUIDE
WORK
BASE

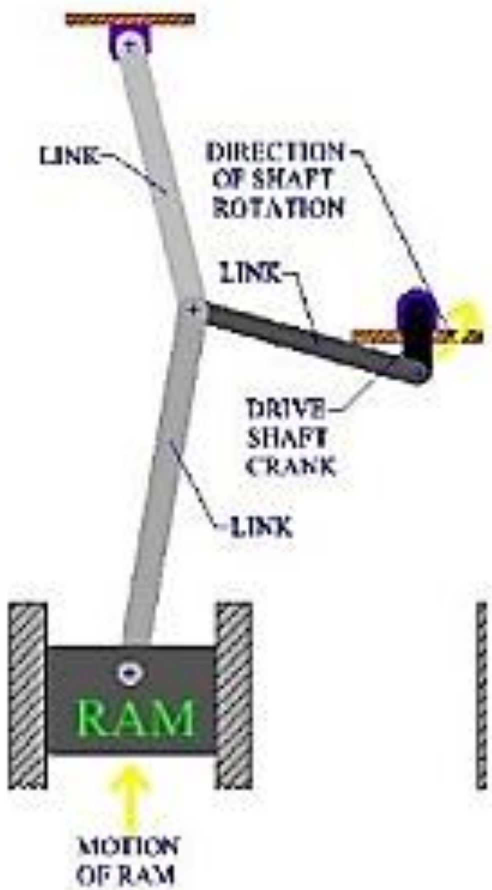
Features of Hydraulic Press

- Full press load is available during the full stroke of the ram.
- Ram velocity can be controlled and varied during the stroke.
- It is a slow speed machine and hence has longer contact time and hence higher die temperatures.
- The slow squeezing action gives close tolerance on forgings.
- Initial cost is higher compared to hammers.

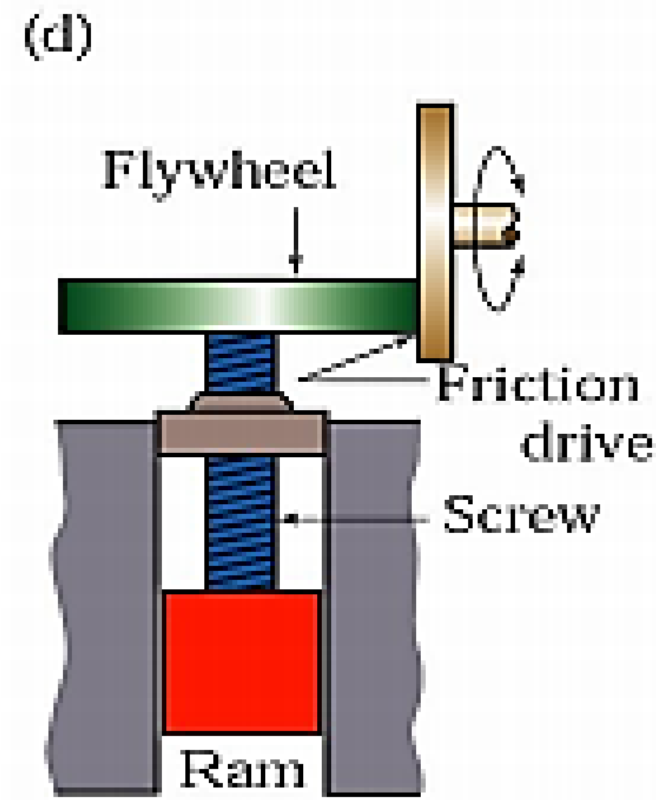


Mechanical press with an eccentric drive; the eccentric shaft can be replaced by a crankshaft to give the up - and -down motion to the ram.

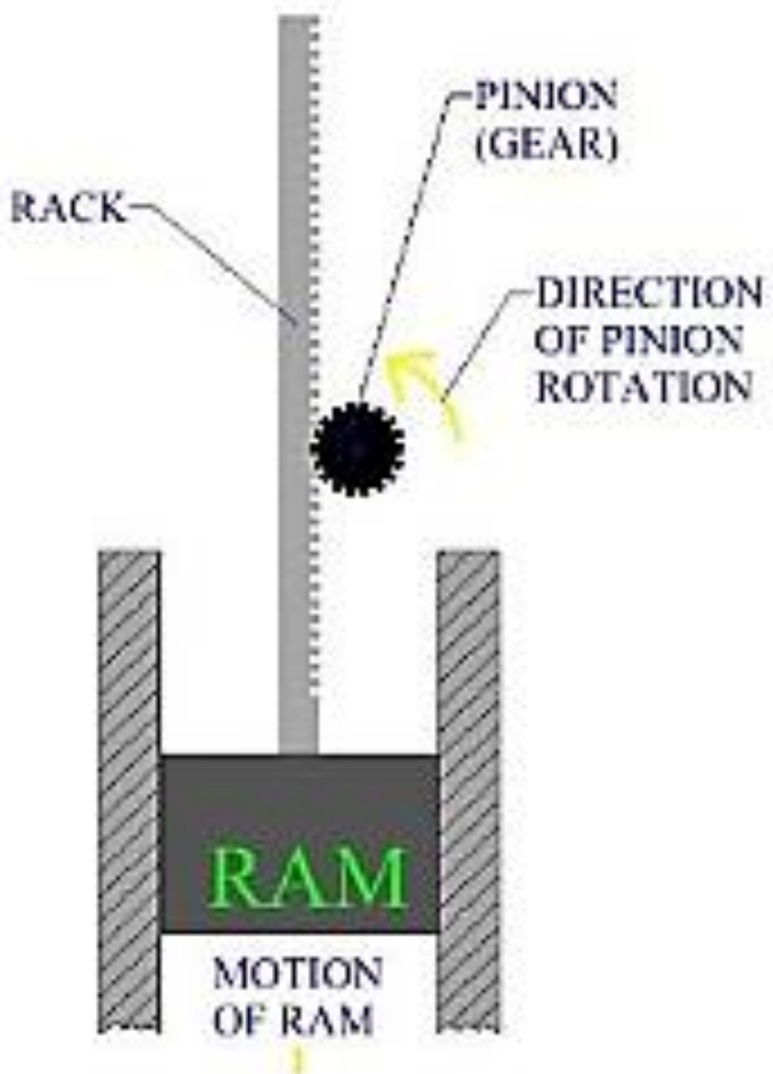
Knuckle -joint press



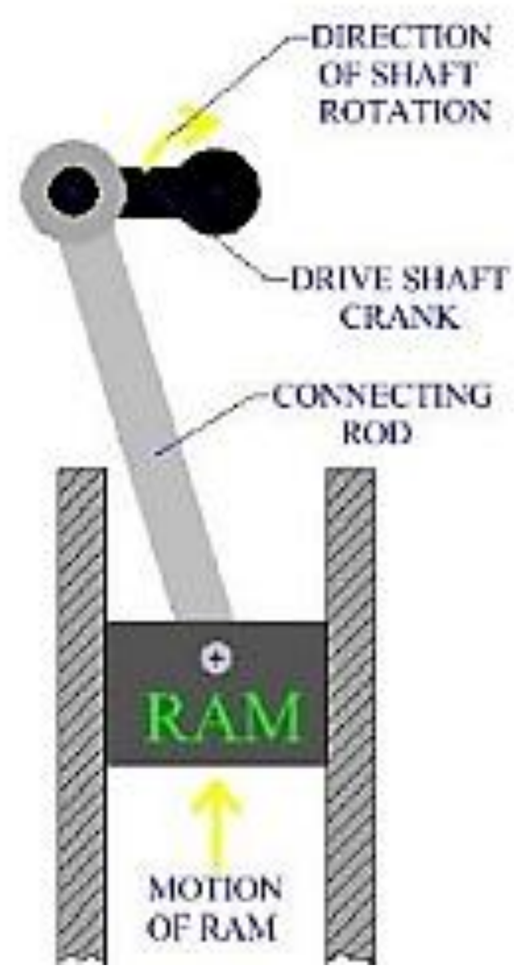
Screw press



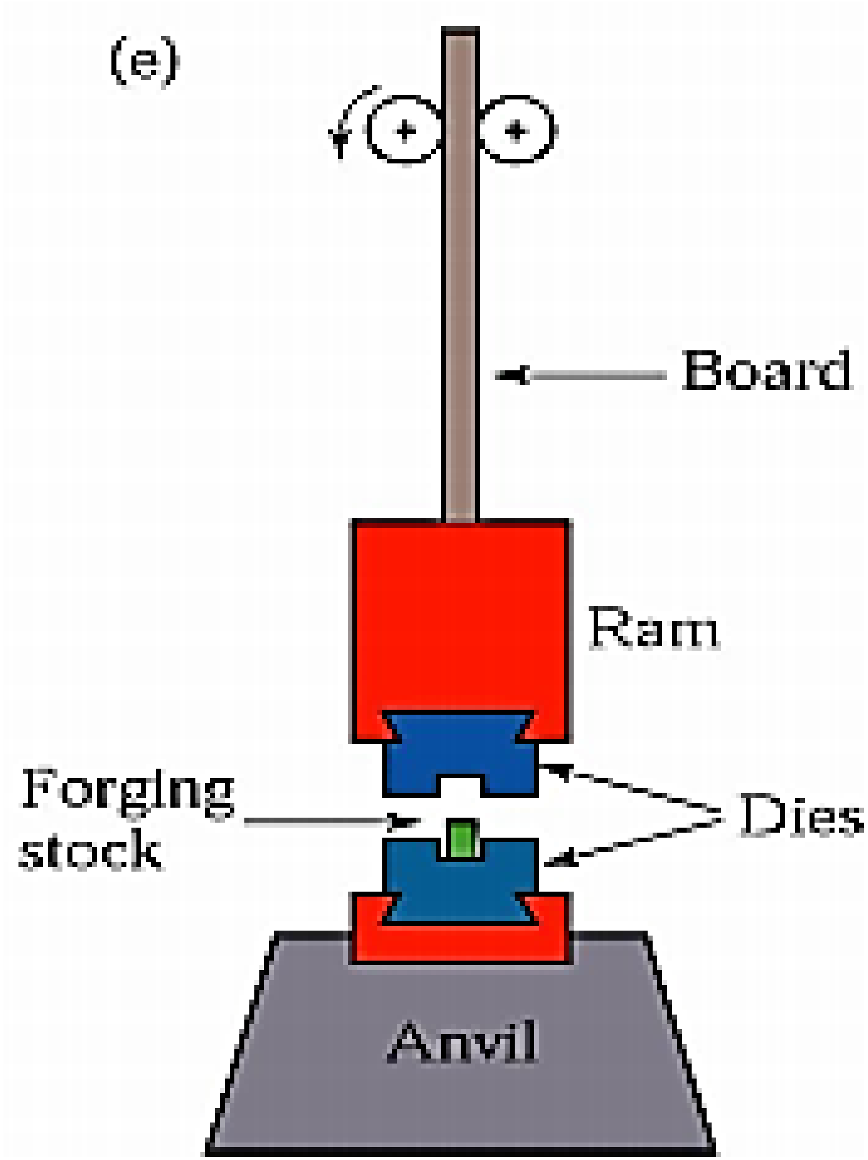
RACK AND PINION PRESS



CRANK PRESS



Gravity drop hammer



Forging Hammers

- Gravity Drop Hammers – drop forging with a free falling ram; energy based on product of ram's weight and drop height

Ram weights of 180-4500 kg (400-10000 lbs)

- Power Drop Hammers – downstroke is accelerated by steam, air, or hydraulic pressure

Ram weights of 225-22500 kg

- Counterblow Hammers – two rams that approach each other horizontally or vertically (part may be rotated between successive blows); operate at high speeds with less vibrations transmitted – very large capacity possible

- High Energy Rate Machines – ram accelerated by an inert gas at high pressure; very high speeds but problems with maintenance, die breakage, and safety

FORGING HAMMERS

Mechanical Presses

Mechanical Presses – crank or eccentric shaft driven, or knuckle-joint for very high forces; stroke limited

2.7-107 MN (300-14000 tons)

- Higher production rates than hammers
- less blows More precise than hammers
- moving die plate guided by slide ways or columns

Hydraulic Presses

Hydraulic Presses – constant speeds, load limited, longer processing times, higher initial cost than mechanical presses but require less maintenance *125 MN (14000 tons) open die, 450 MN (50000 tons) closed die*

40,000 Ton Forging Press

Friction Screw Presses

Screw Presses – flywheel driven, energy limited (if dies do not completely close, cycle repeats)

- Small production runs, high precision
- 1.4-280 MN (160-31500 tons)

Equipment	**m/s**
Hydraulic press	0.06–0.30
Mechanical press	0.06–1.5
Screw press	0.6–1.2
Gravity drop hammer	3.6–4.8
Power drop hammer	3.0–9.0
Counterblow hammer	4.5–9.0

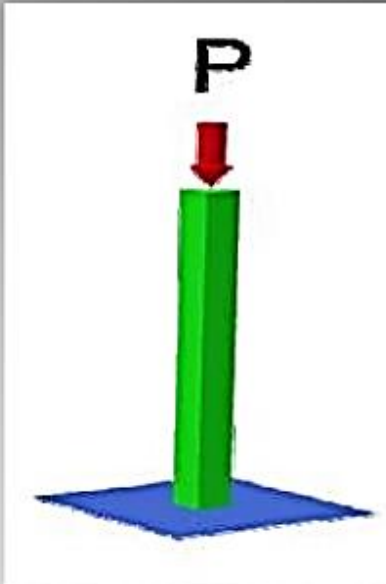
FORGING DEFECTS

The different types of defects, occurring in the forging operations are as follows:

1. Incomplete die filling.
2. Die misalignment.
3. Forging laps.
4. Incomplete forging penetration- should forge on the press.
5. Microstructural differences resulting in pronounced property variation.
6. Hot shortness, due to high sulphur concentration in steel and nickel.

7. Pitted surface, due to oxide scales occurring at high temperature stick on the dies.
8. Buckling, in upsetting forging, due to high compressive stress.
9. Surface cracking, due to temperature differential between surface and center, or excessive working of the surface at too low temperature.
10. Micro cracking, due to residual stress.

Typical forging defects



- Incomplete die filling.
- Die misalignment.
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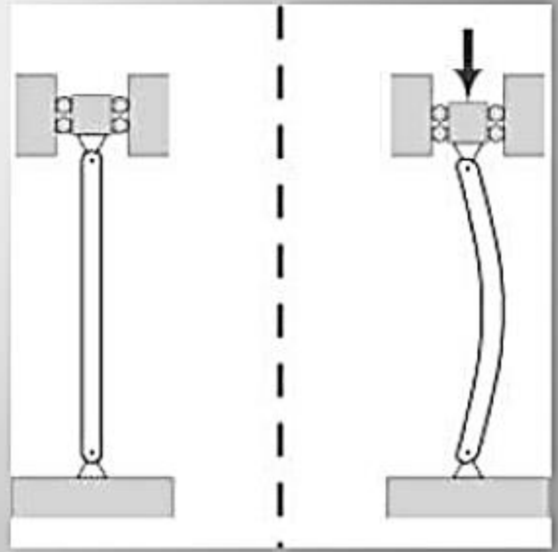
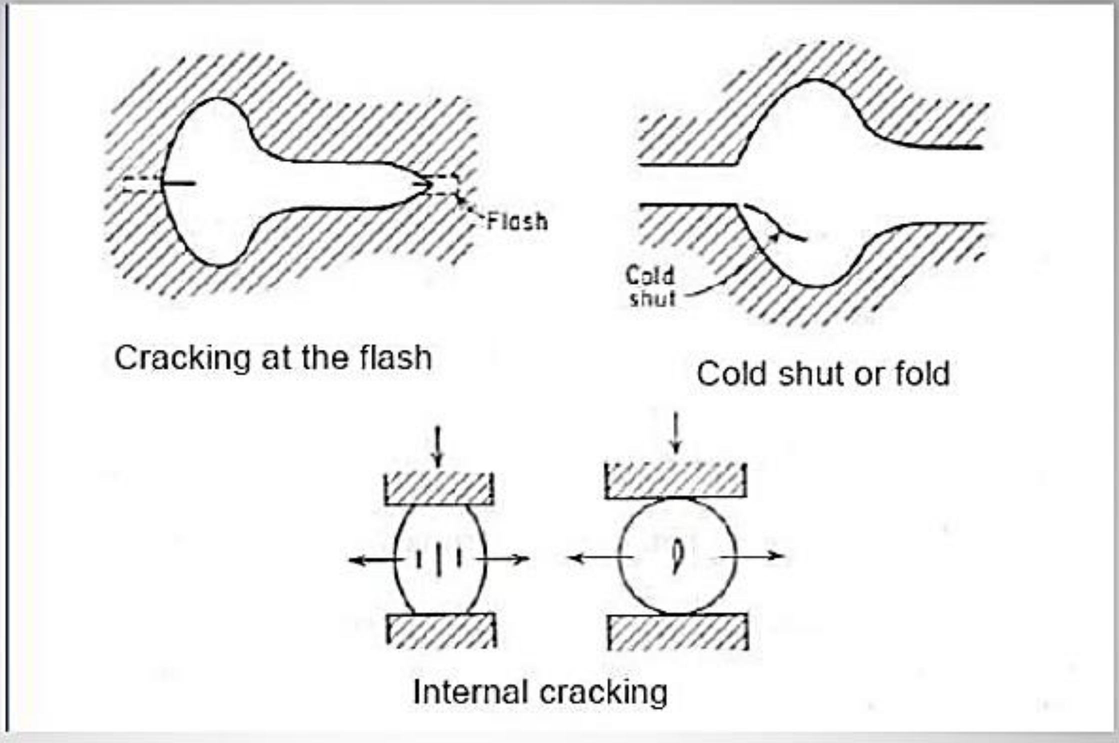
- Micro structural differences resulting in pronounced property variation.
- Hot shortness, due to high sulphur concentration in steel and nickel.

- Pitted surface, due to oxide scales occurring at high temperature stick on the dies.
- Buckling, in upsetting forging. Subject to high compressive stress.
- Surface cracking, due to temperature differential between surface and centre, or excessive working of the surface at too low temperature.
- Microcracking, due to residual stress.



Typical forging defects



• **Flash line crack**, after trimming-occurs more often in thin work-pieces. Therefore should increase the thickness of the flash.
• **Cold shut or fold** , due to flash or fin from prior forging steps is forced into the work-piece.
• **Internal cracking**, due to secondary tensile stress.

EXTRUSION

EXTRUSION

<u>HOT EXTRUSION</u>

Forward or direct extrusion

Backward or indirect extrusion

<u>COLD EXTRUSION</u>

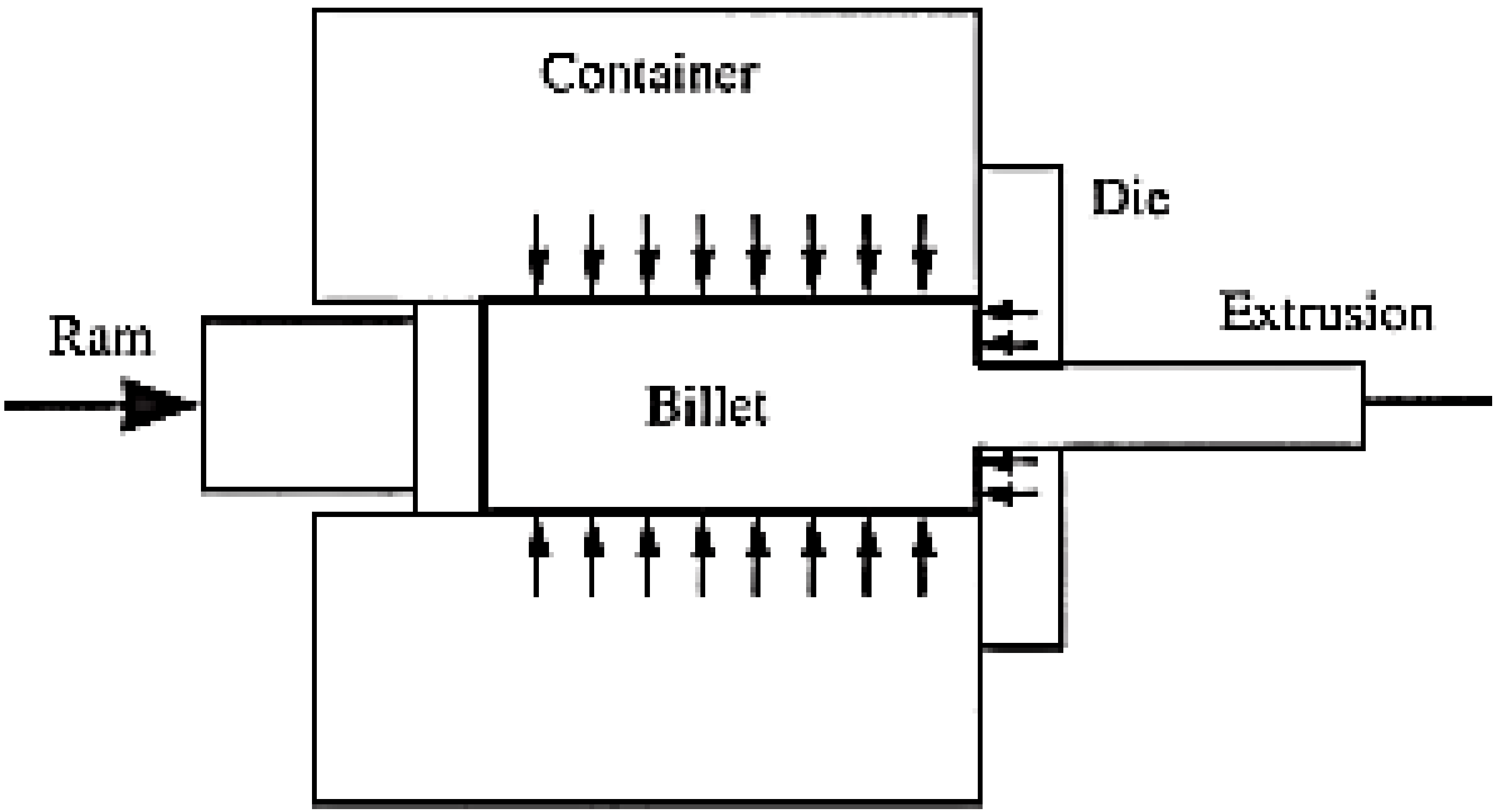
Hooker Extrusion

Hydrostatic extrusion

Impact extrusion

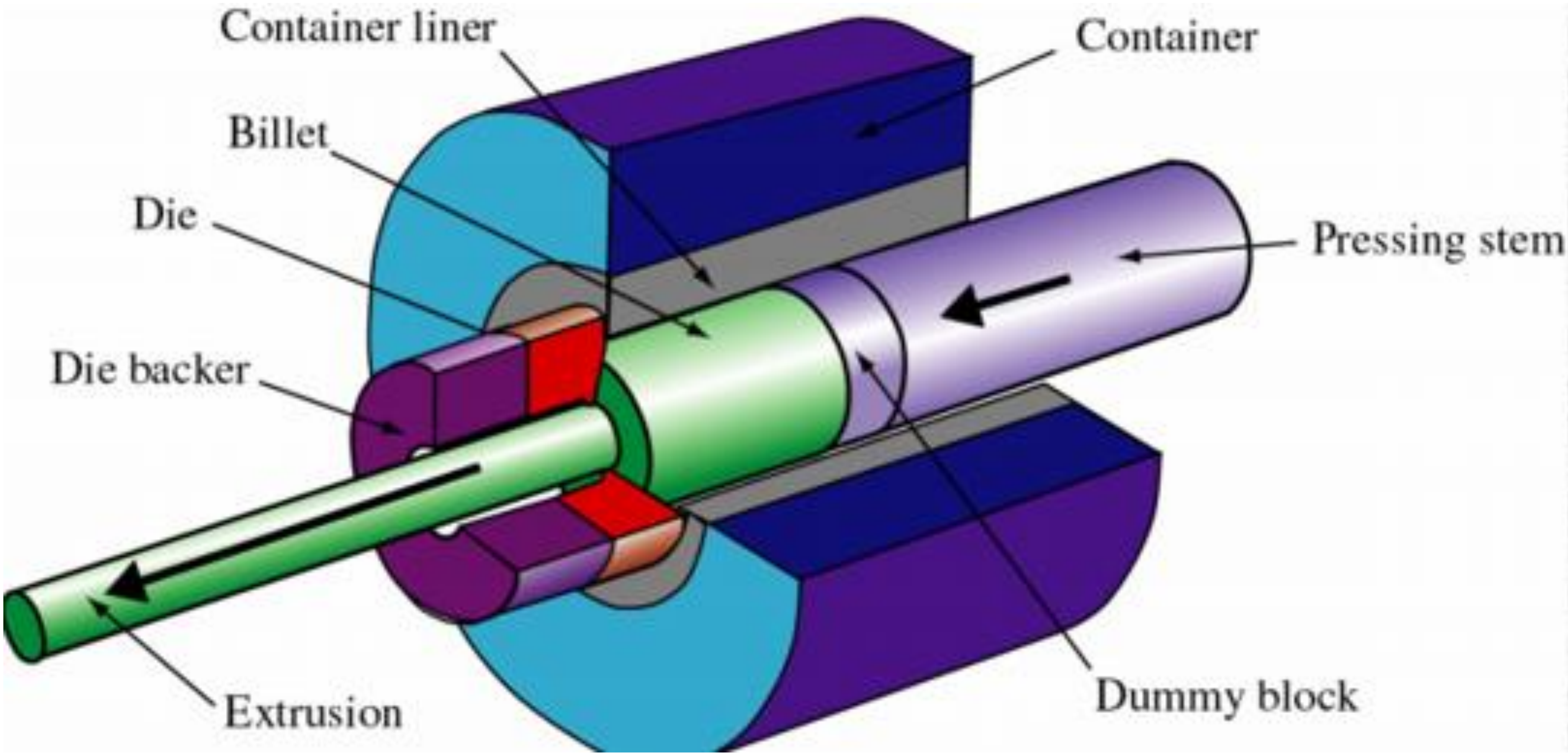
Extrusion is a plastic deformation process in which a block of metal (billet) is forced to flow by compression through the die opening of a smaller cross-sectional area than that of the original billet

Extrusion is an indirect-compression process

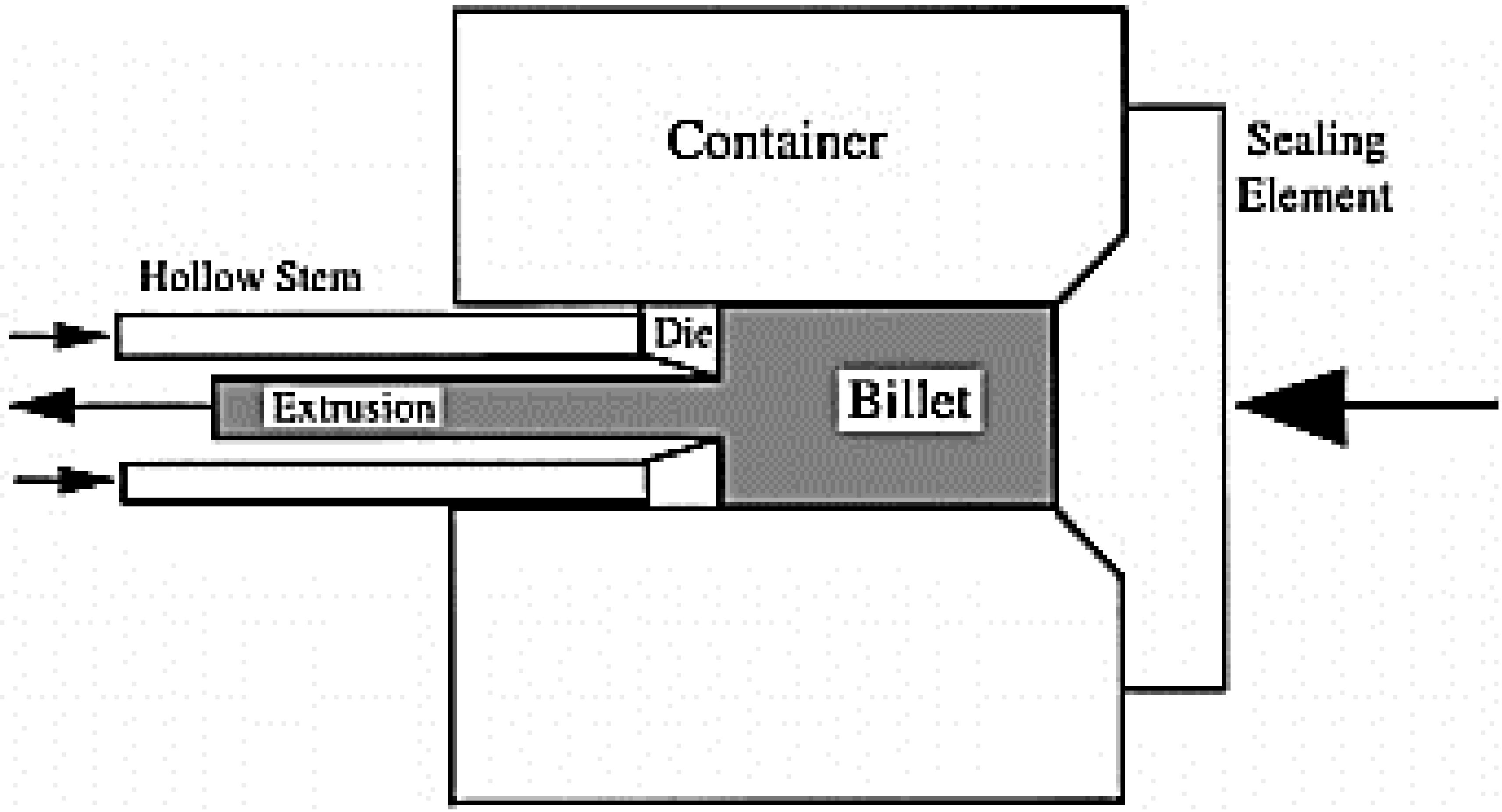


Definition and principle of DIRECT extrusion

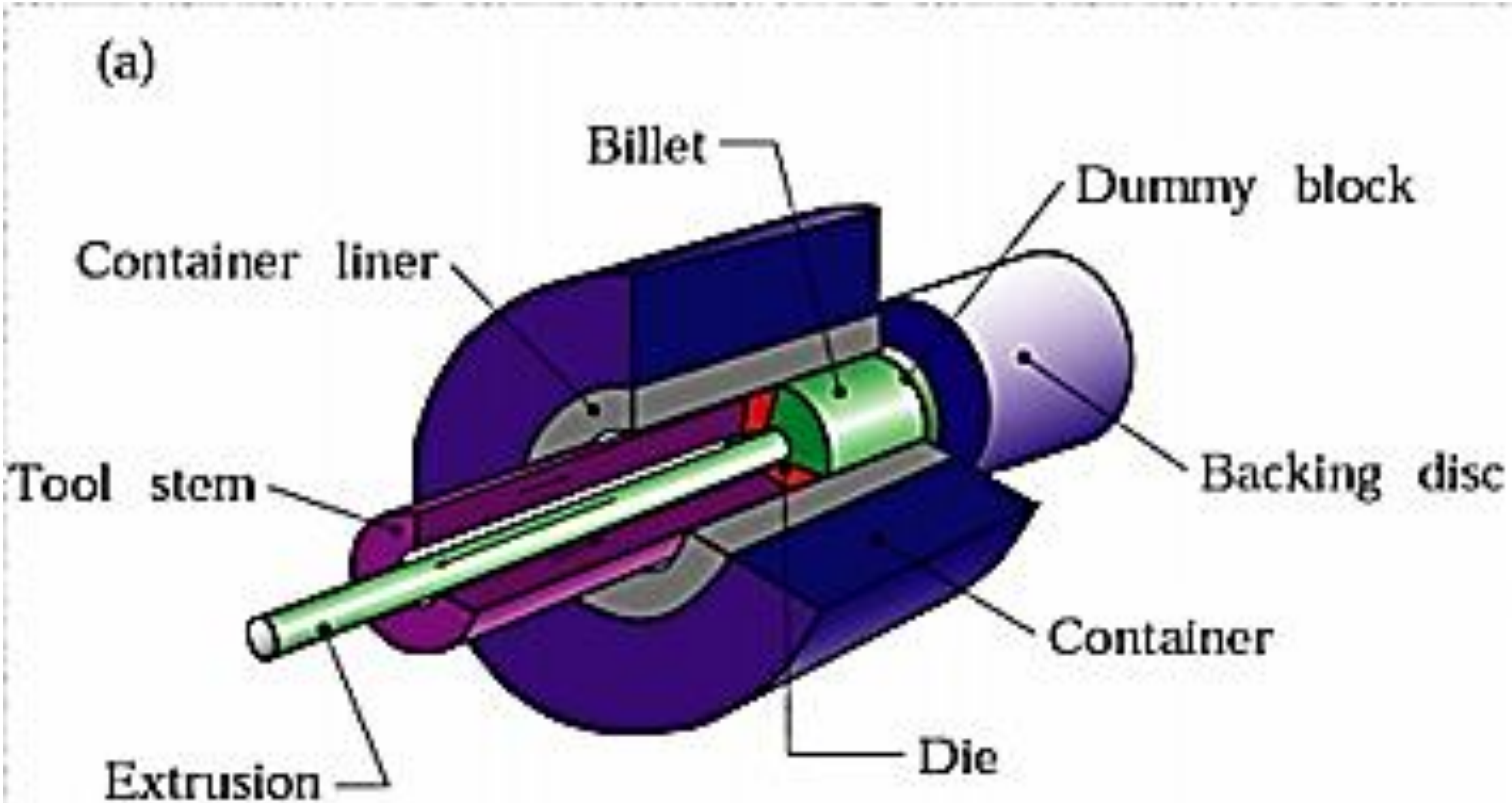
1. DIRECT EXTRUSION



2. INDIRECT EXTRUSION



INDIRECT EXTRUSION



In indirect extrusion, the die at the front end of the hollow stem moves relative to the container, but there is no relative displacement between the billet and the container.

Therefore, this process is characterized by the absence of friction between the billet surface and the container, and there is no displacement of the billet center relative to the peripheral regions.

Comparison between Forward and Backward Extrusion :

S. No.	*Forward or Direct extrusion*	*Backward or indirect or inverted extrusion*
1.	It is the *simplest,* but is limited by the fact that as the ram moves the billet must slide or shear at the interface between billet and container.	The billet proper does not move relative to container instead the *die moves.*
2.	*High friction forces* involved.	*Low friction forces ;* the friction involved is only between the die and the container and this is independent of billet length.
3.	High extruding forces required ; however, *mechanically more convenient.*	Extruding force is 25 to 30% less than in forward extrusion. However, a long hollow ram is required and this limits the loads which can be applied. Due to this and complex design of tools, this type of extrusion finds *limited application.*
4.	Scrap or process *waste* is about *18 to 20%* of the billet weight.	Scrap or process *waste* is only *5 to 6%* of billet weight.

Examples of Cold Extrusion

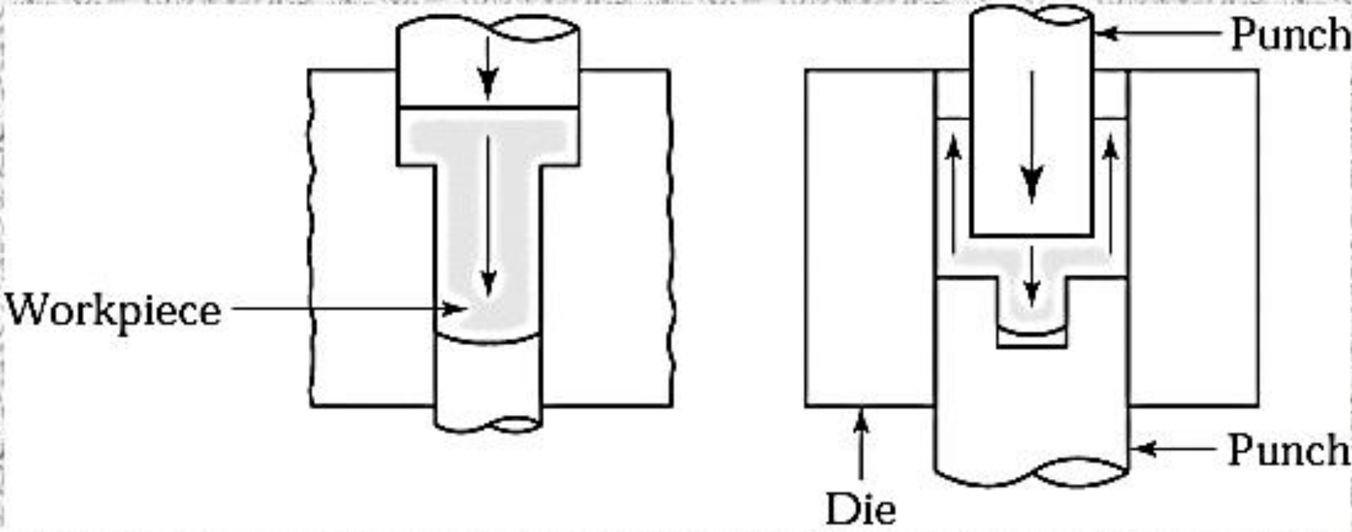
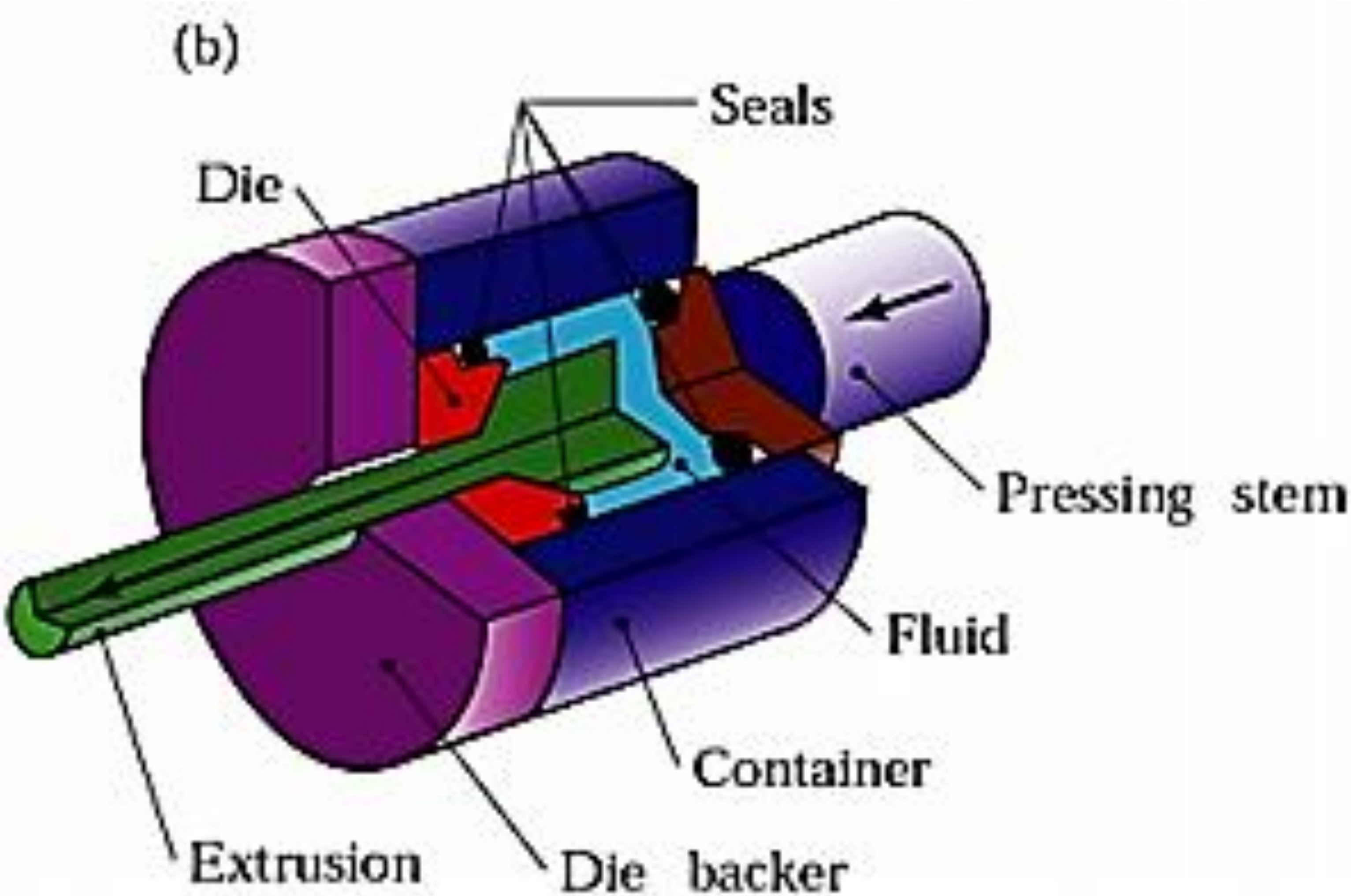


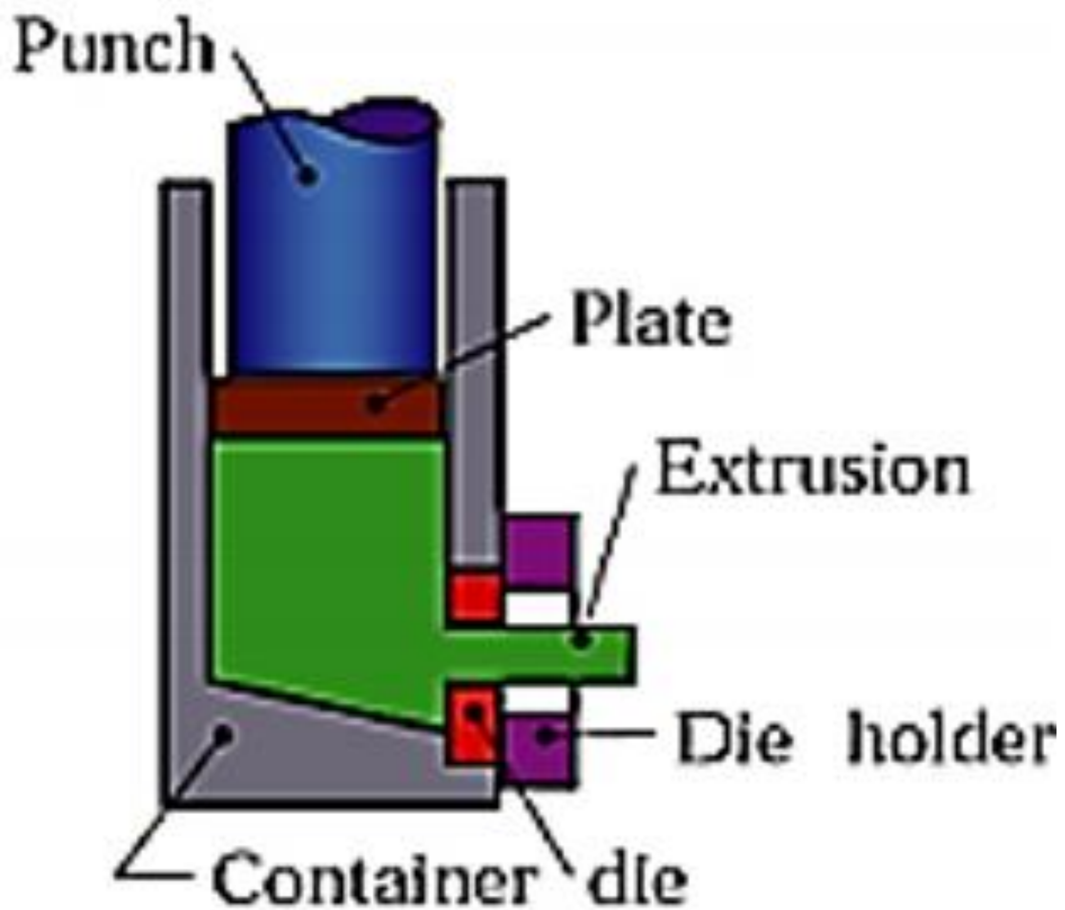
Figure 15.11 Two examples of cold extrusion. Thin arrows indicate the direction of metal flow during extrusion.

HYDROSTATIC EXTRUSION_Cold Extrusion Forward

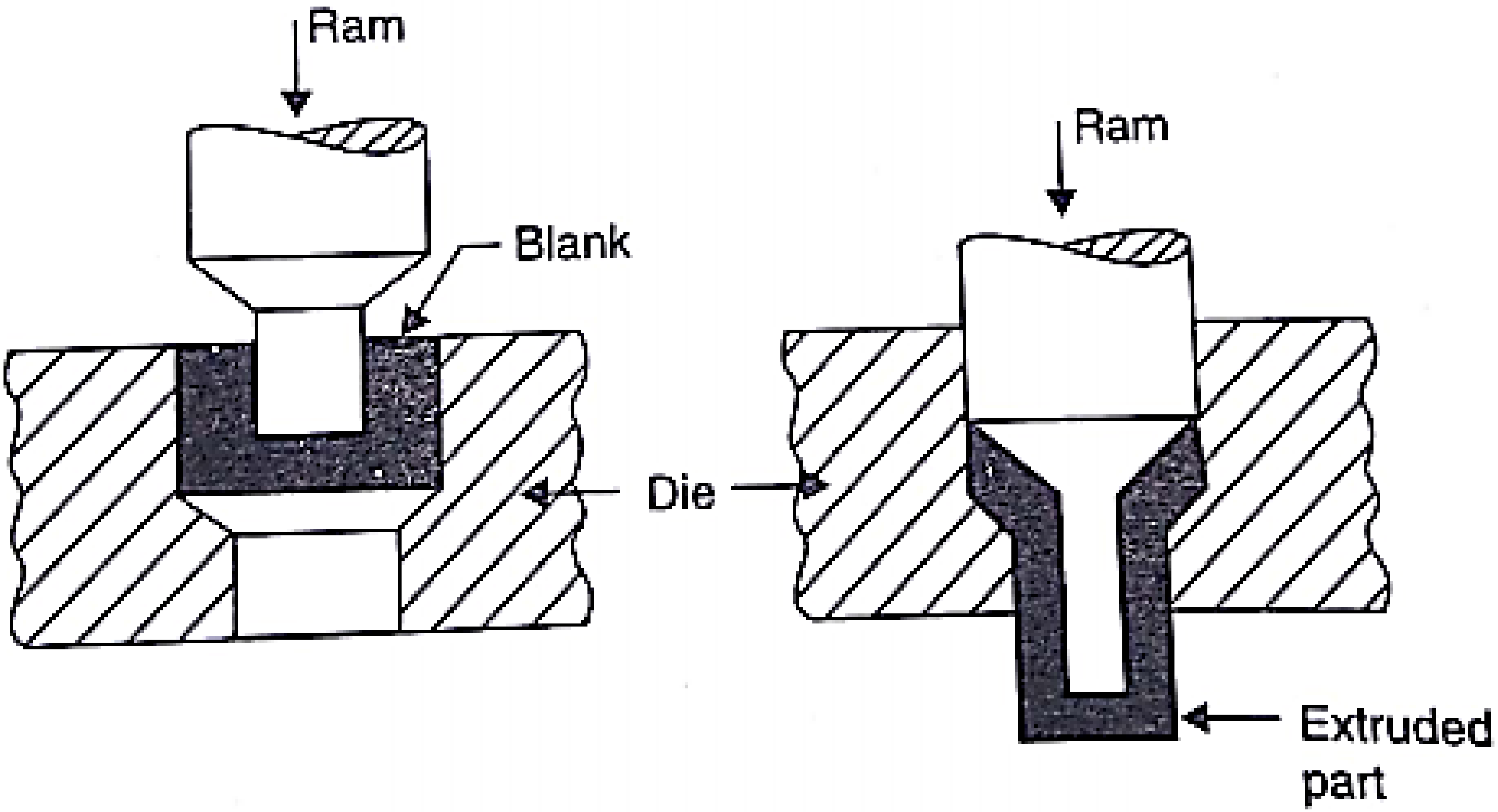


LATERAL EXTRUSION

(c)



HOOKER EXTRUSION



Cold Extrusion_ Backward

Impact Extrusion

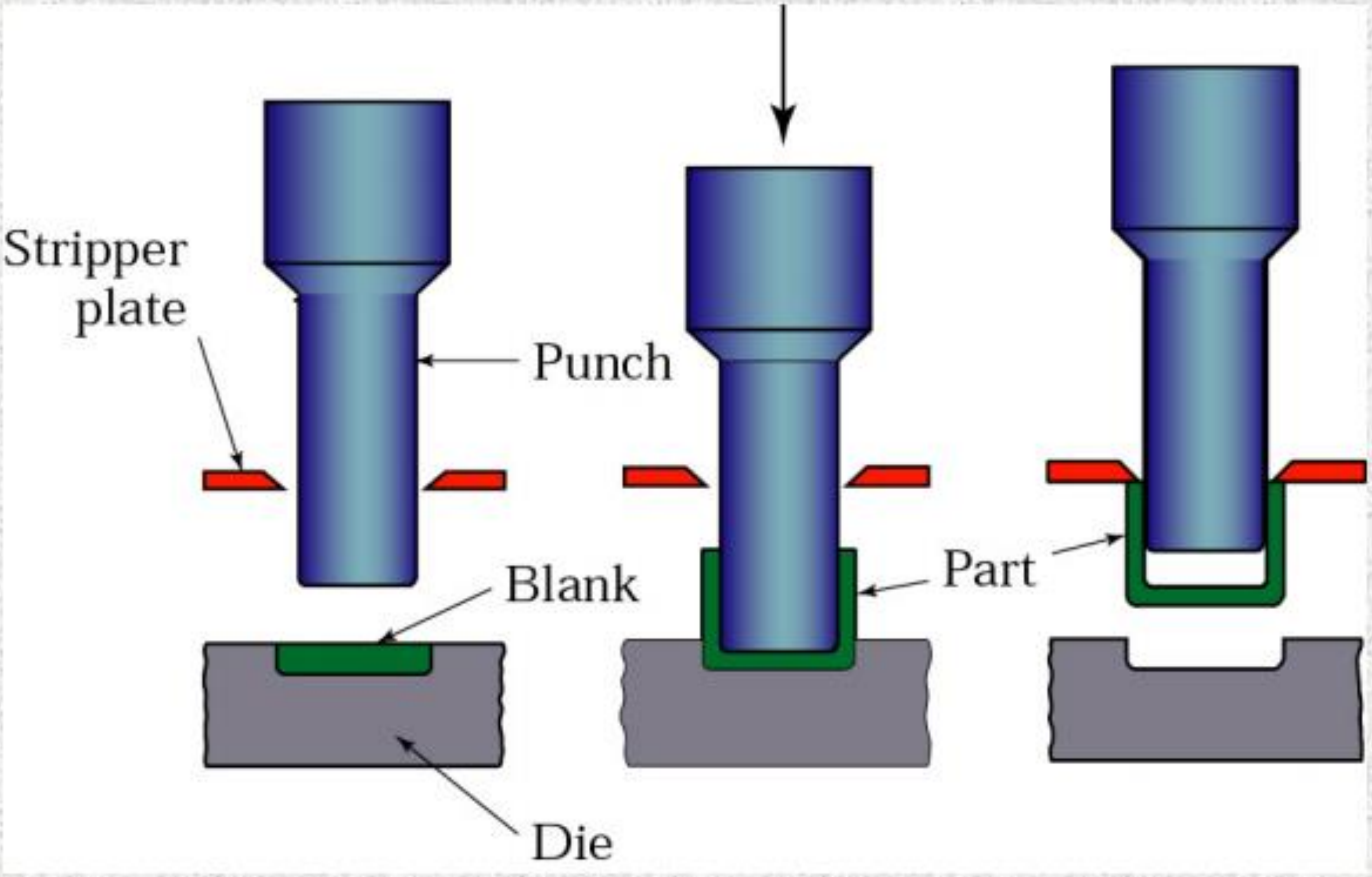
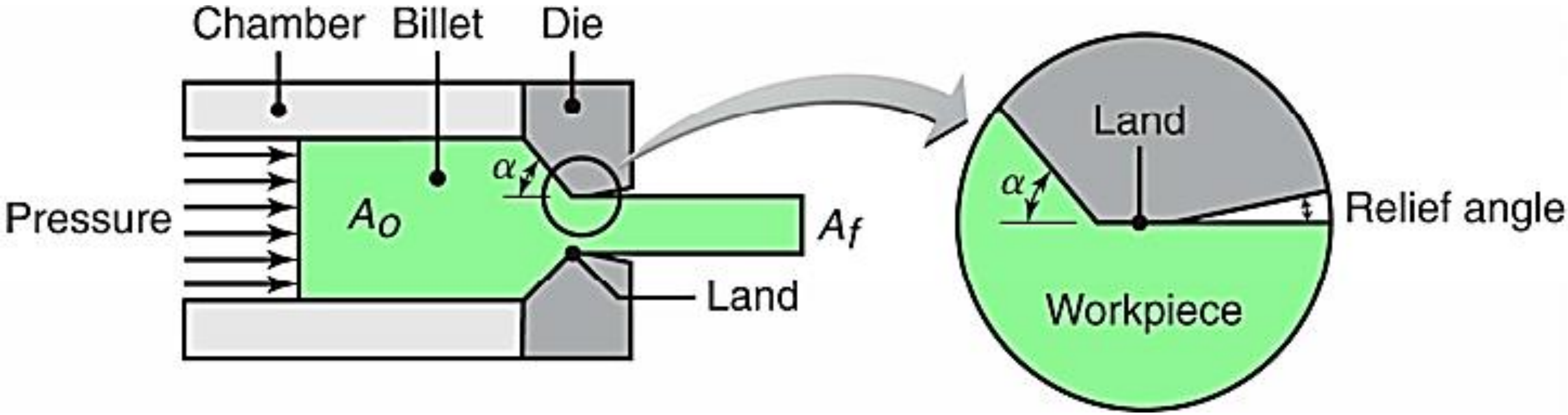
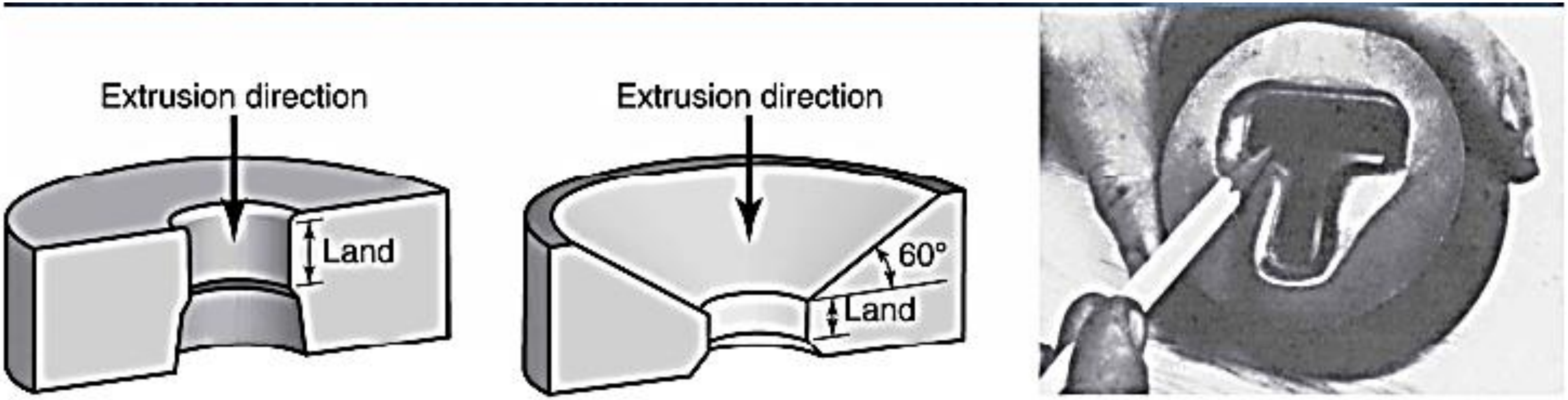


Figure 15.14 Schematic illustration of the impact-extrusion process. The extruded parts are stripped by the use of a stripper plate, because they tend to stick to the punch.



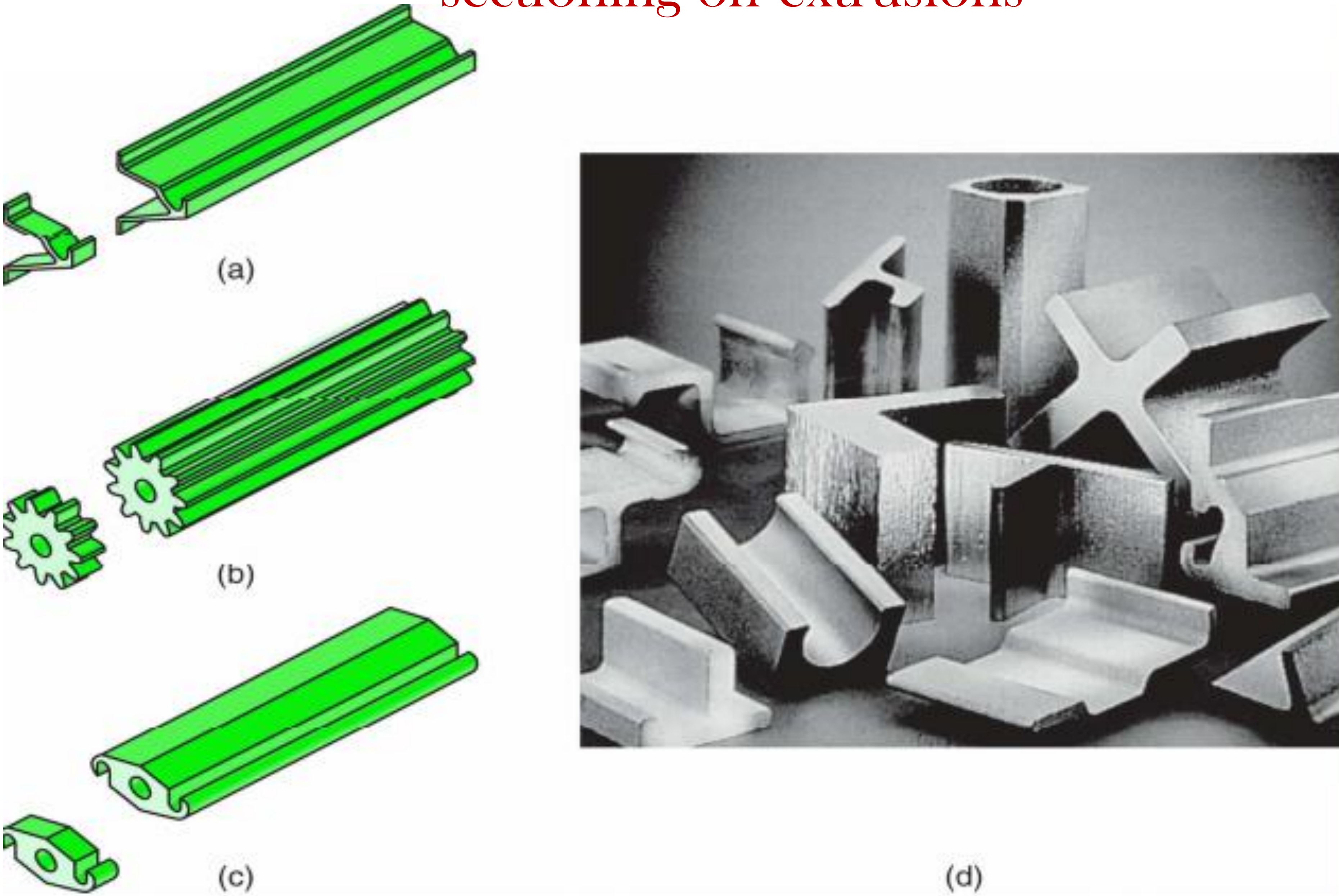
<u>Process variables in direct extrusion</u>. The die angle, reduction in cross section, extrusion speed, billet temperature, lubrication all affect the extrusion pressure.

Typical extrusion–die configurations: (a) die for nonferrous metals; (b) die for ferrous metals; (c) die for a T die for a T-shaped extrusion made of hot-work die steel and used with molten glass as a lubricant

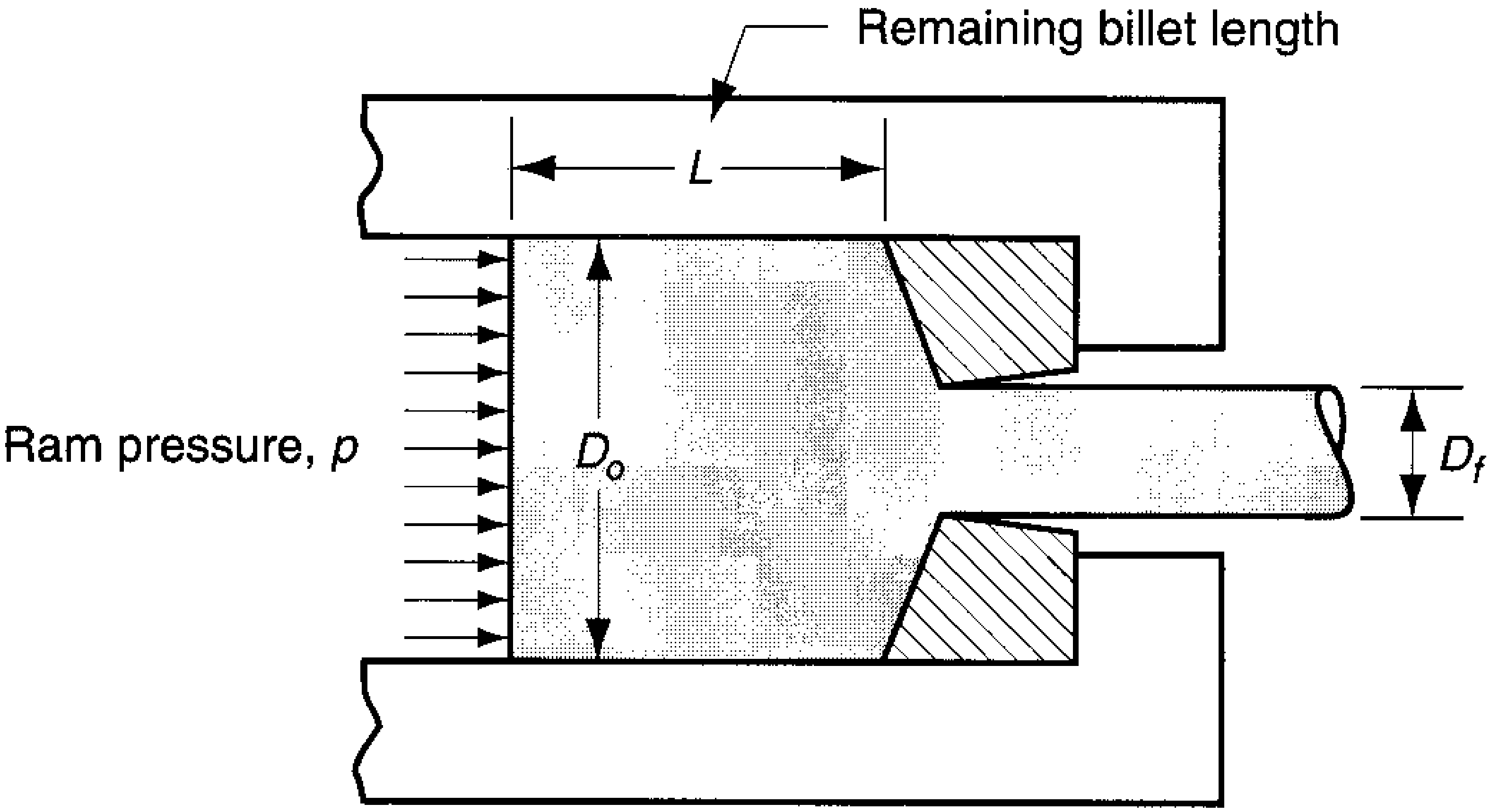


(a) (b) (c)

Extrusions and examples of products made by sectioning off extrusions



Extrusion ratio, $r_x = \dfrac{A_o}{A_f}$



Chevron Cracking

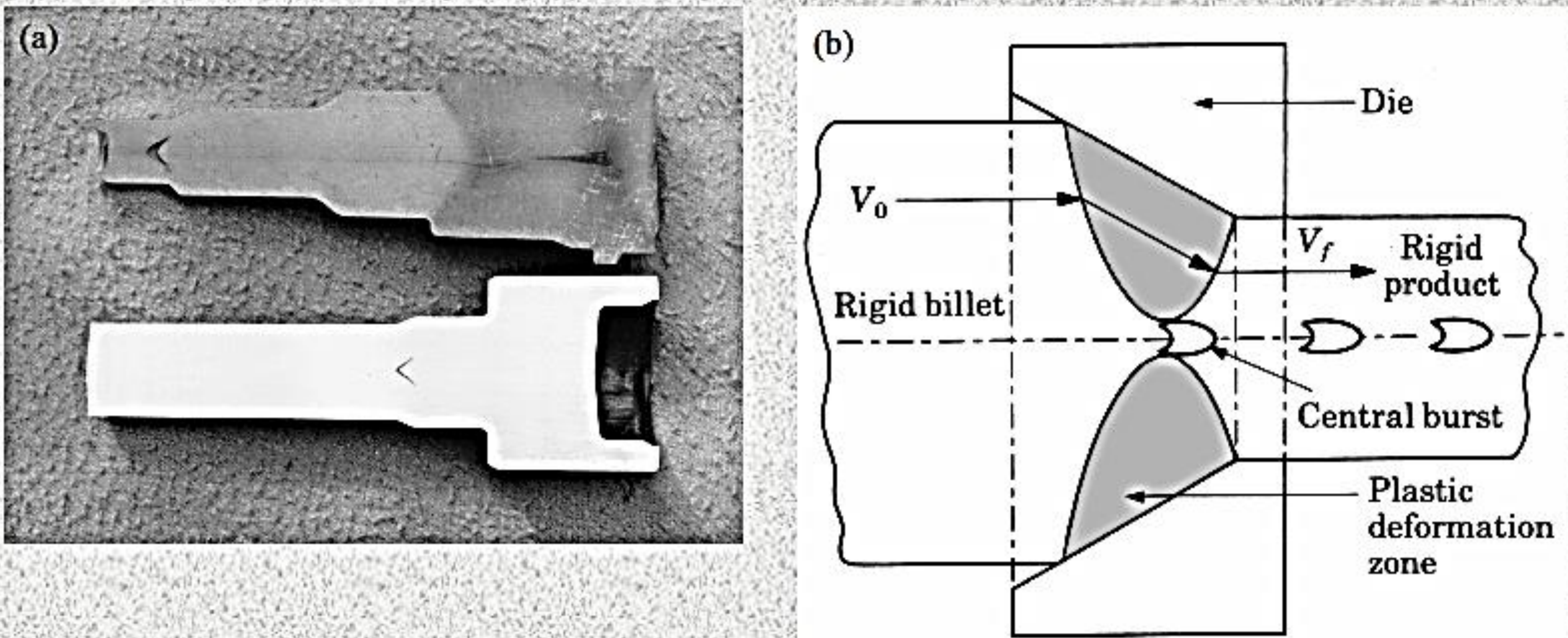
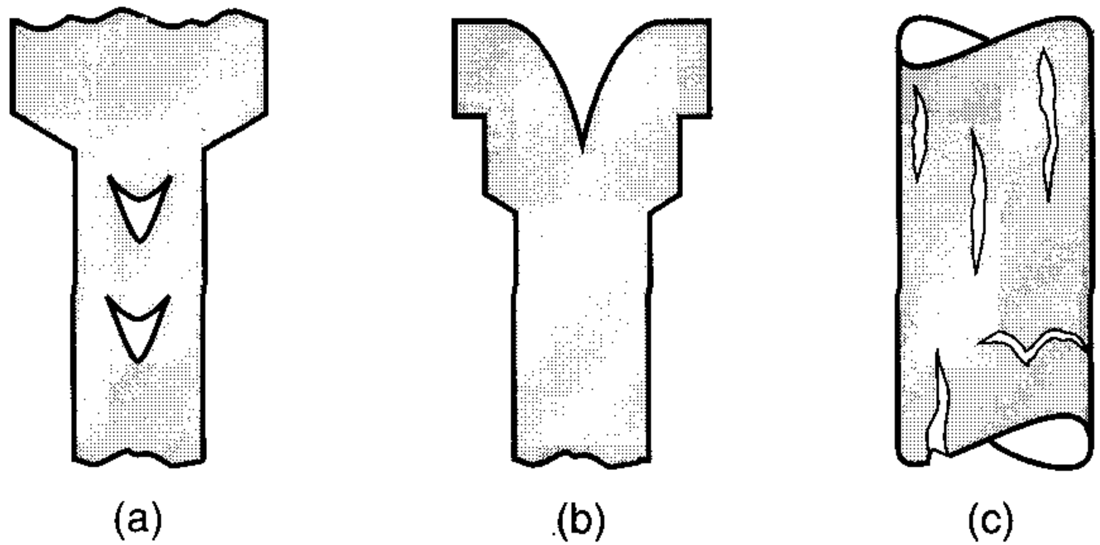


Figure 15.16 (a) Chevron cracking (central burst) in extruded round steel bars. Unless the products are inspected, such internal defects may remain undetected, and later cause failure of the part in service. This defect can also develop in the drawing of rod, of wire, and of tubes. (b) Schematic illustration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

Extrusion Defects



a) Centre-burst: internal crack due to excessive tensile stress at the centre possibly because of high die angle, low extrusion ratio.

b) Piping: sink hole at the end of billet under direct extrusion.

c) Surface cracking: High part temperature due to low extrusion speed and high strain rates.

Extrusion Force

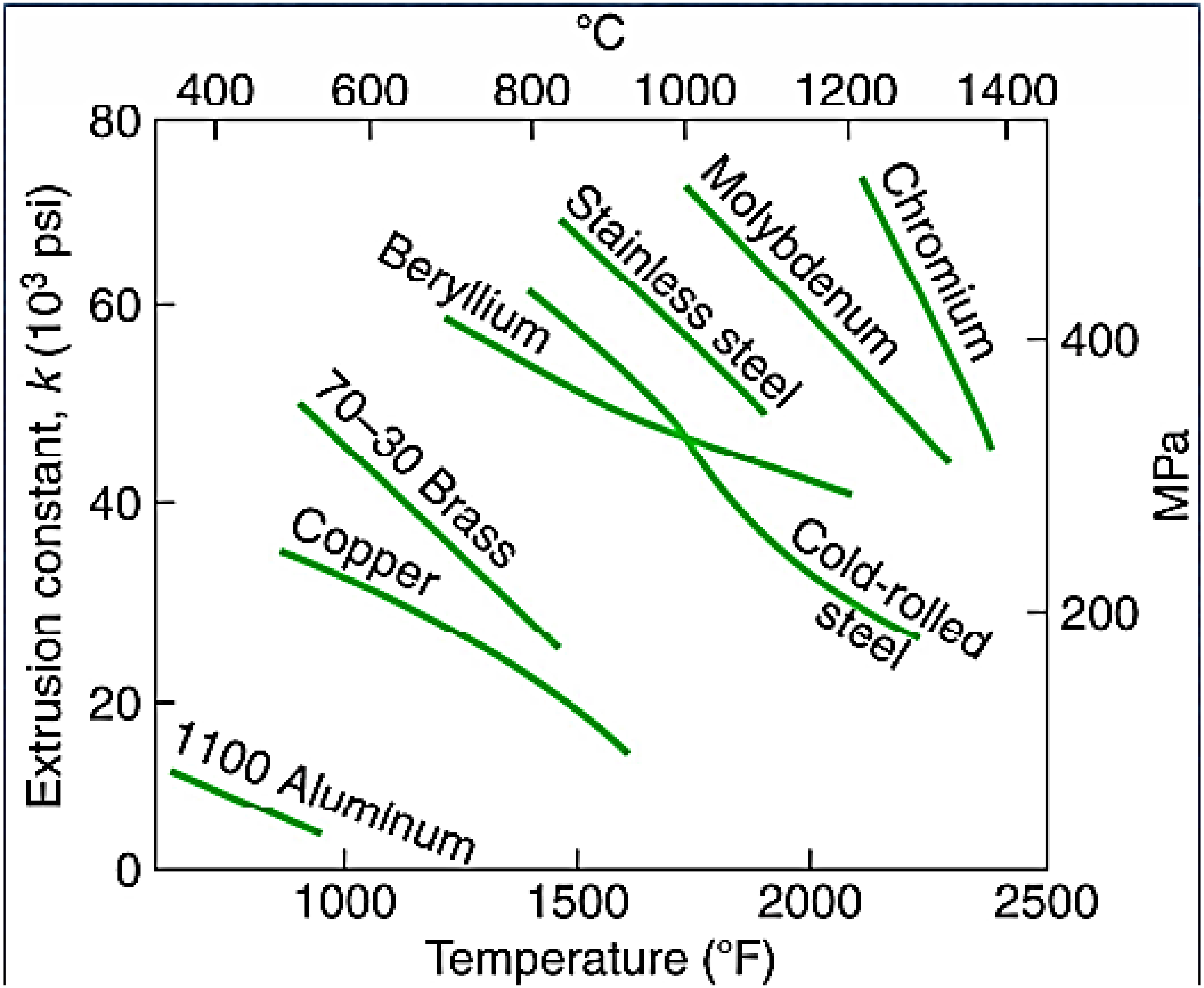
Force, F, depends on:

- ✓ Strength of billet material
- ✓ Extrusion Ratio, R, A_o/A_f
- ✓ Friction between billet and chamber & die surfaces
- ✓ Process variables: temperature, velocity

$$F = A_0 k \ln(A_0/A_f)$$

The Extrusion constant, k, is determined experimentally.

Extrusion constant k for various metals at different temperatures



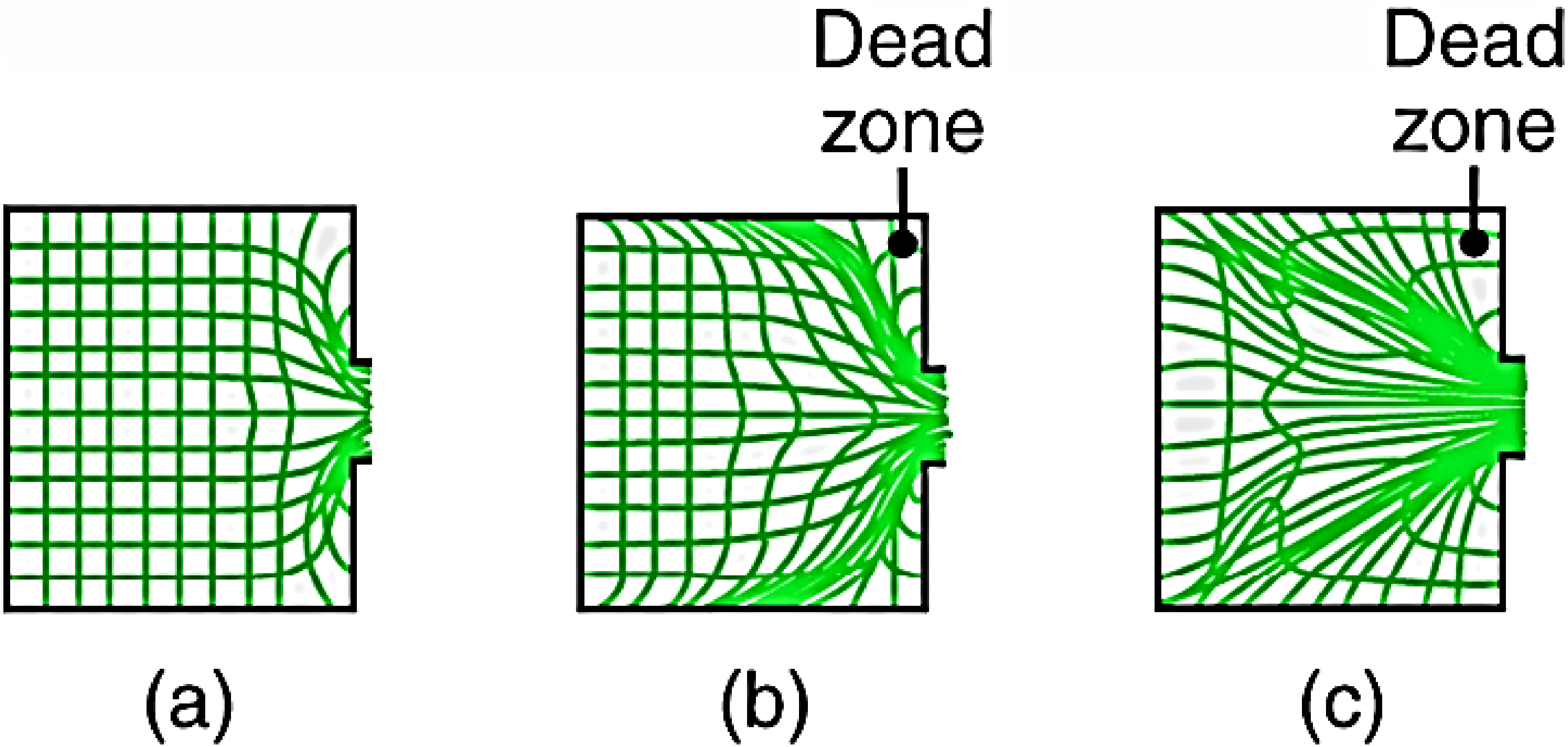
Metal Flow in Extrusion

- Influences quality & mechanical properties of extruded product
- Material flows longitudinally
- Elongated grain structure

Types of metal flow in extruding with square dies.

(a) Flow pattern obtained at low friction or in indirect extrusion.

(b) Pattern obtained with high friction at the billet–chamber interfaces.



(c) Pattern obtained at high friction or with cooling of the outer regions of the billet in the chamber. This type of pattern, observed in metals whose strength increases rapidly with decreasing temperature, leads to a defect known as pipe (or extrusion) defect.

HOT EXTRUSION

- Use higher temperatures to improve ductility & metal flow
- Can cause excessive die wear, result of abrasion from surface oxides
- Can have non uniform deformation caused by cooling surfaces of billet and die
    - Improve by preheating die
- Surface oxides on product may be undesirable when good surface finish is important
- Can prevent extrusion of surface oxides by making the diameter of the dummy block a little smaller than the container; this keeps a thin shell *("skull")* of oxides in the container

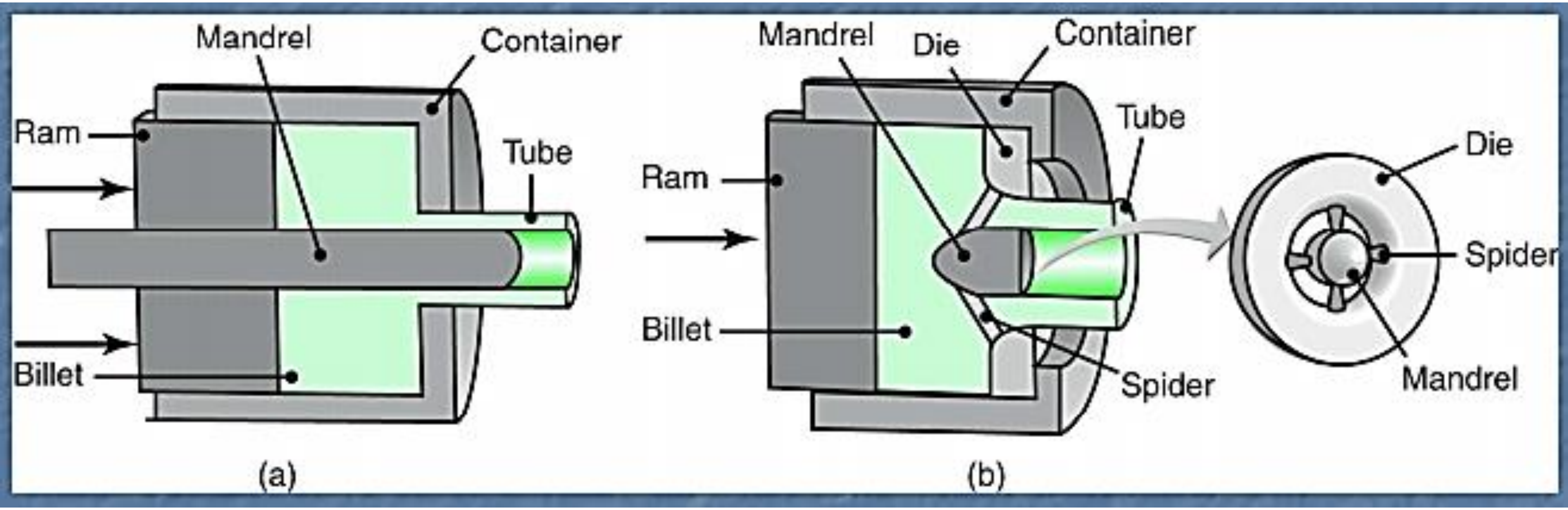
Typical Extrusion Temperature Ranges for Various Metals and Alloys

	°C
Lead	200–250
Aluminum and its alloys	375–475
Copper and its alloys	650–975
Steels	875–1300
Refractory alloys	975–2200

Extrusion of a seamless tube

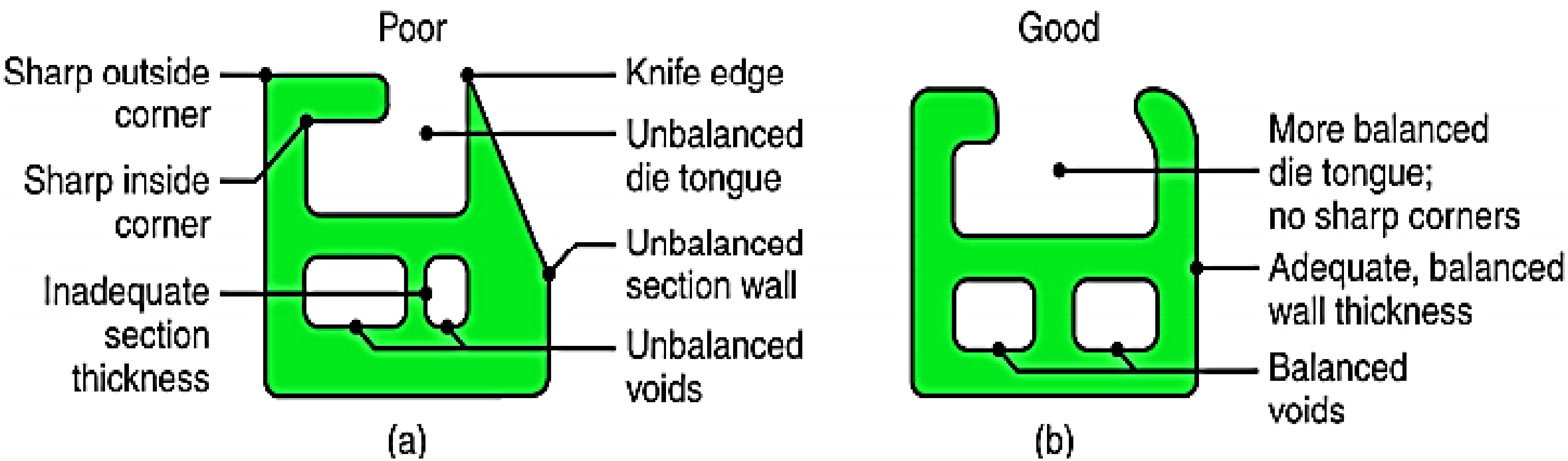
(a)using an internal mandrel that moves independently of the ram. (An alternative arrangement has the mandrel integral with the ram.)

(b) using a spider die to produce seamless tubing.



Poor and good examples of cross sections to be extruded Poor and good examples examples of cross sections sections to be extruded extruded.

Note the importance of eliminating sharp corners and of keeping section thicknesses uniform.



Lubrication

Useful in hot extrusion:

- ✓ Material flow during extrusion
- ✓ Surface finish & integrity
- ✓ Product quality
- ✓ Extrusion forces

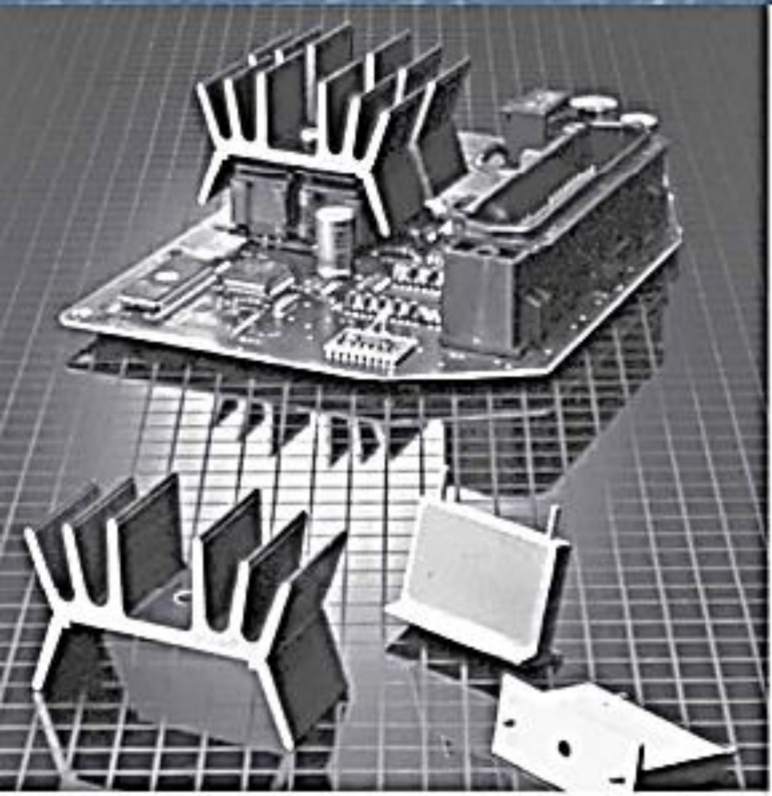
Glass is excellent lubricant for:

- Steels
- Stainless steels
- High-temperature metals & alloys

Glass applied as powder to billet surface or

Insert glass pad at die entrance; when heated, melted glass lubricates die surface

(a) Aluminum extrusion used as a heat sink for a printed circuit board,
(b) Extrusion die and extruded heat sinks.
Source: Courtesy of Aluminum Extruders Council.


(a)


(b)

Cold Extrusion

- Uses slugs cut from cold finished or hot rolled bars, wire, or plates
- Smaller slugs (≤ 40 mm or 1.5” 40 mm or 1.5”) are sheared; ends squared if necessary
- Larger slugs are machined to specific lengths
- Stresses on tool dies are very high
- Lubrication is critical, especially with steels
- Apply phosphate-conversion coating on workpiece, conversion coating on workpiece, followed by soap or wax

Cold Extrusion

$$\text{Force} = F = 1.7 A_o\, Y_{avg}\, \acute{\varepsilon}$$

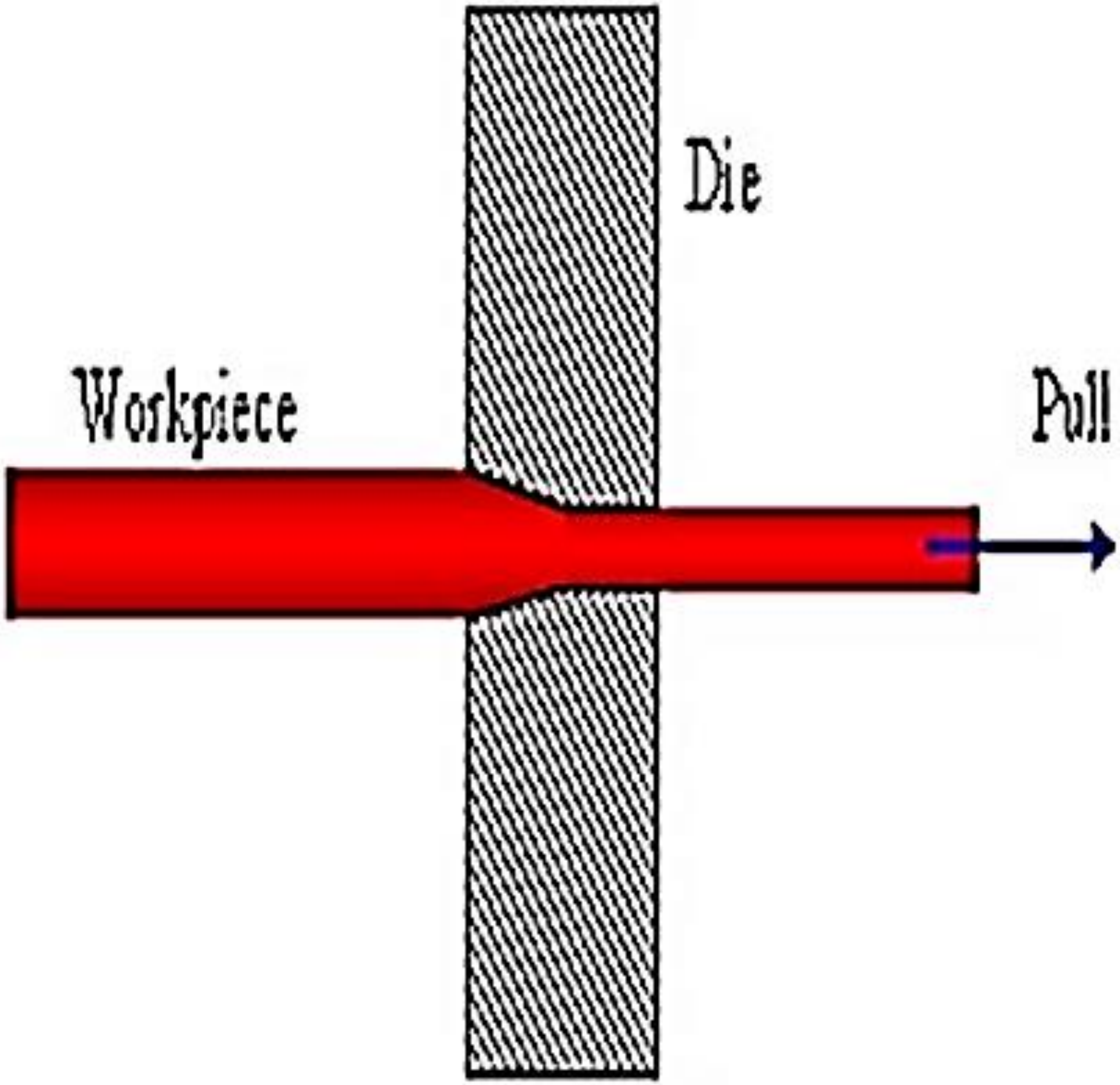
A_o is cross sectional area of blank

Y_{avg} is average flow stress of metal

$\acute{\varepsilon}$ is true strain that piece undergoes

$= \ln(A_o/A_f)$

DRAWING



Drawing

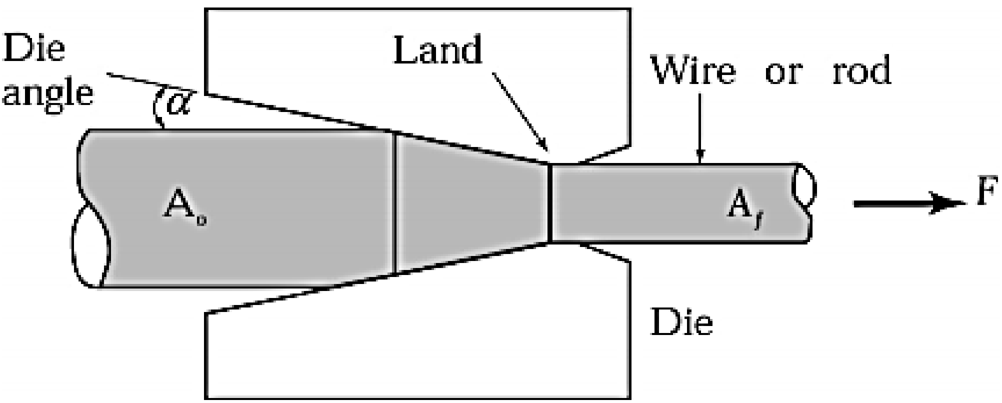
- Changing the cross-sectional area or shape of a solid rod, wire, or tubing by pulling it through a die
- Rod is the term for larger cross sections, wire for smaller
- Typical products: Electrical wiring, Cable, Tension-loaded structural members, Welding electrodes, Springs, Paper clips, Bicycle wheel spokes, Musical instrument strings.

Die and mandrel materials typically tool steels (chromium plated) and carbides (titanium nitride coated), diamond for fine wire

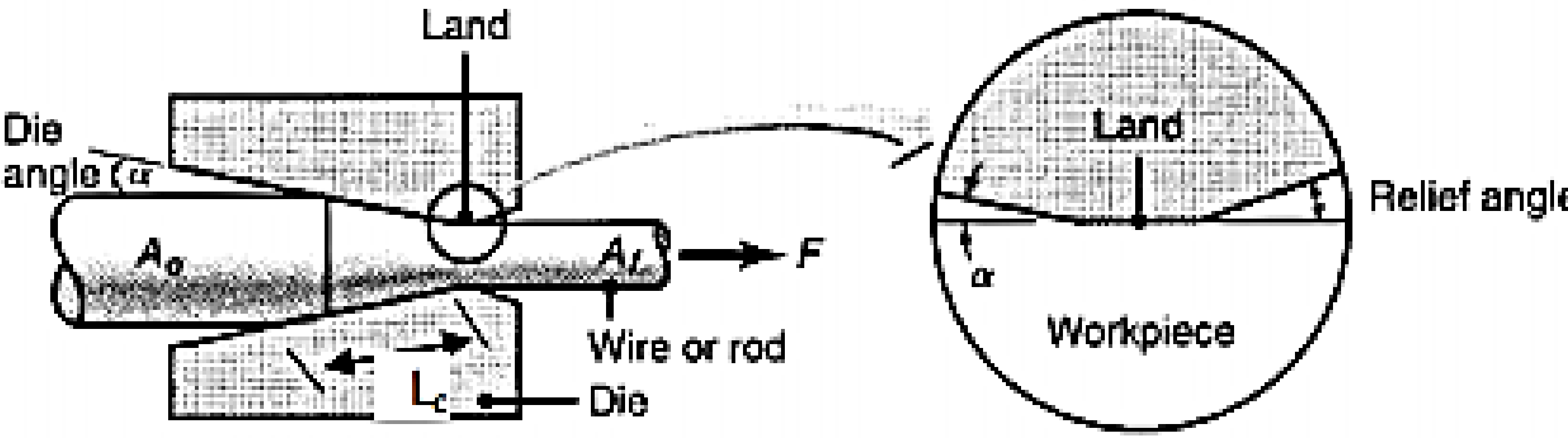
Drawing Parameters

- Parameters include die angle (a), 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



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



In drawing, the cross section of a long rod or wire is reduced or changed by pulling (hence the term drawing) it through a die called a draw die

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

Tube Drawing:

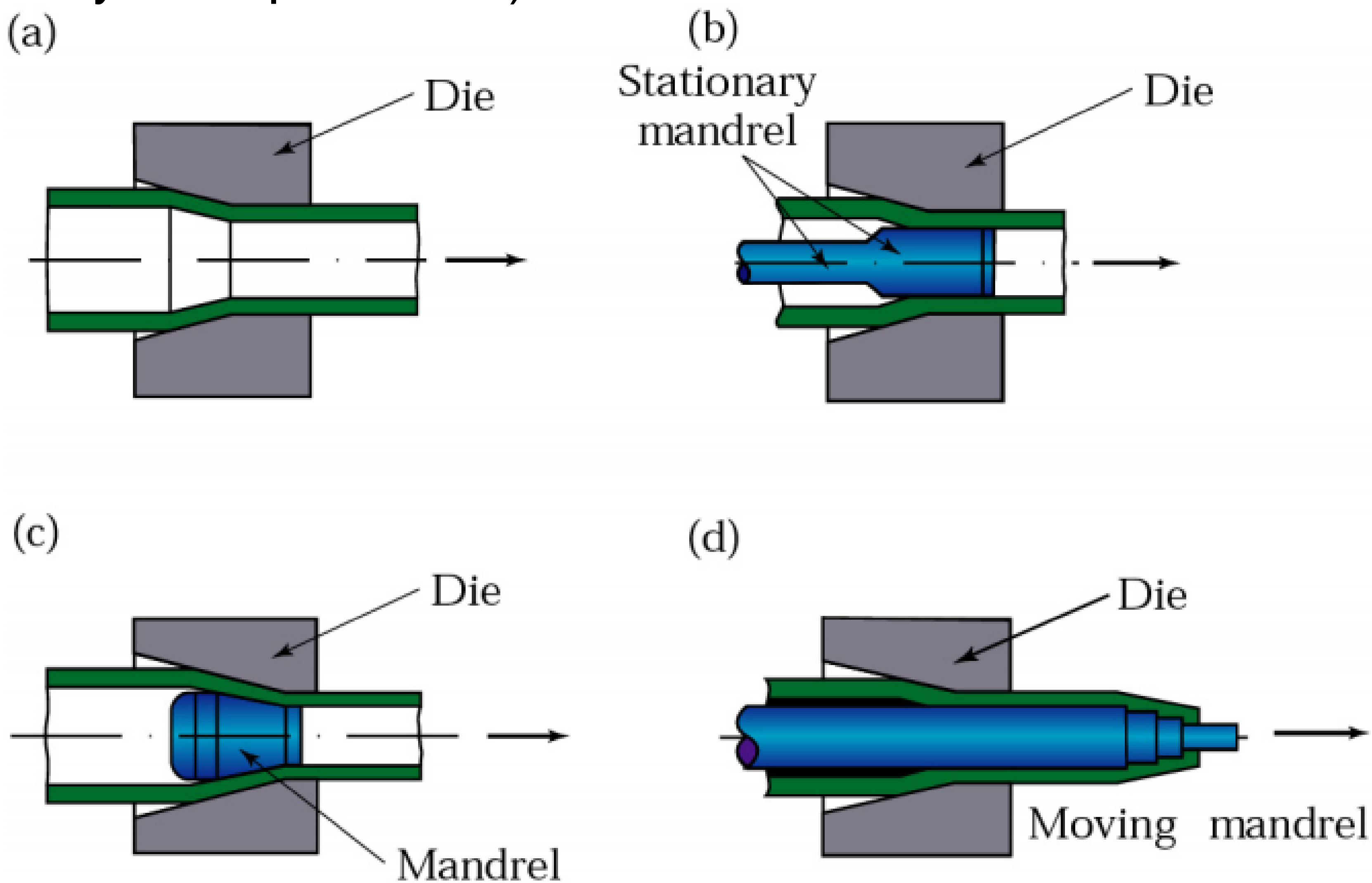
Drawing can be used to reduce the diameter or wall thickness of seamless tubes and pipes, after the initial tubing has been produced by some other process such as extrusion.

Tube drawing can be carried out either with or without a mandrel.

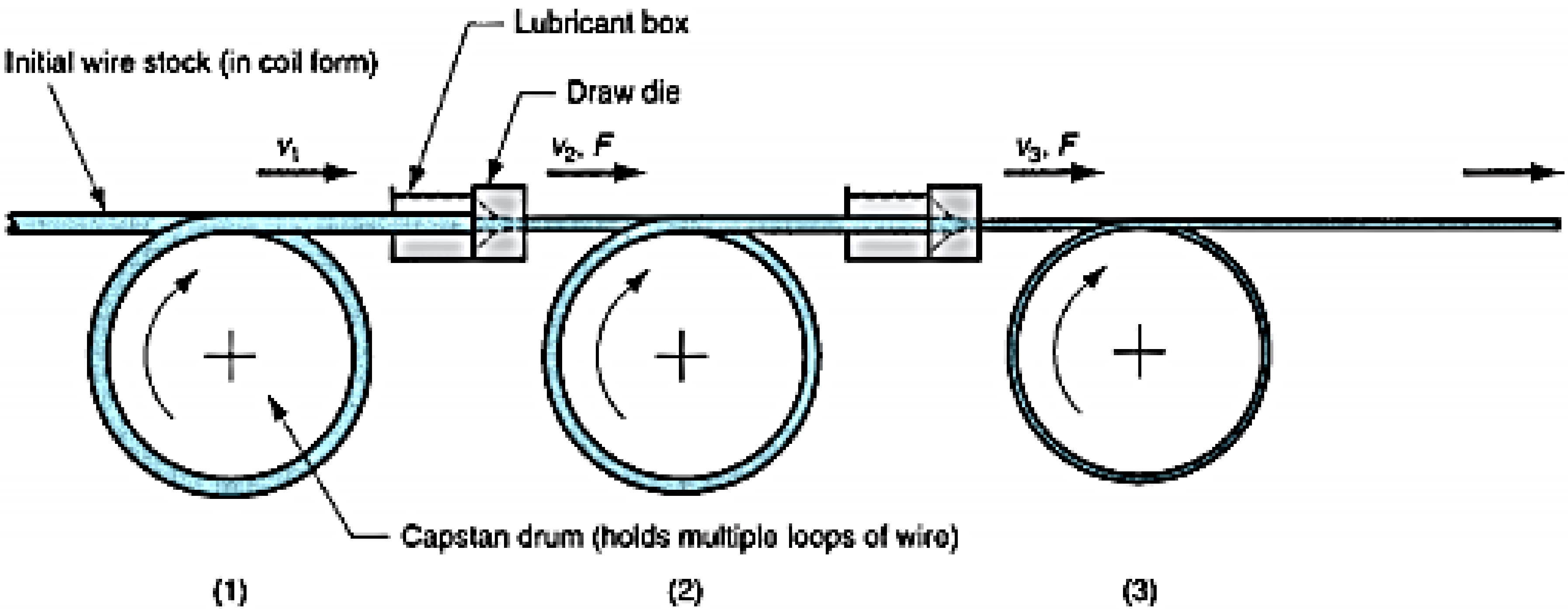
The simplest method uses no mandrel and is used for diameter reduction.

The term tube sinking is sometimes applied to this operation.

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).



Wire sizes down to 0.03 mm (0.001 in) are possible in wire drawing



Continuous drawing of wire

- ✓ Wire drawing is done on continuous drawing machines that consist of multiple draw dies, separated by accumulating drums between the dies.

- ✓ Each drum, called a capstan, is motor driven to provide the proper pull force to draw the wire stock through the upstream die.

- ✓ It also maintains a modest tension on the wire as it proceeds to the next draw die in the series.

- ✓ Each die provides a certain amount of reduction in the wire, so that the desired total reduction is achieved by the series.

- ✓ Depending on the metal to be processed and the total reduction, annealing of the wire is sometimes required between groups of dies in the series.