Metal Forming Processes

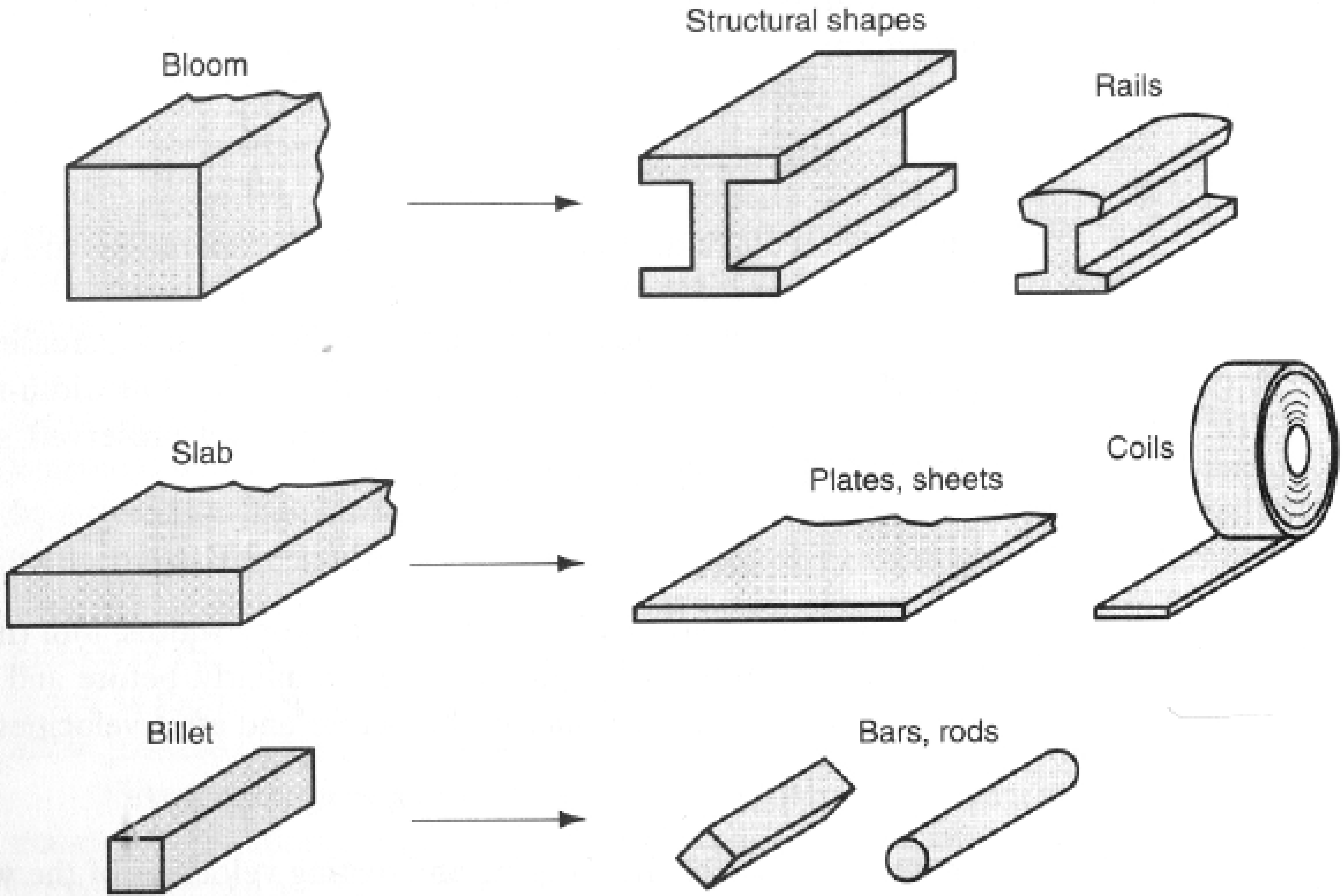
It is a Primary Manufacturing Process

The initial material being used normally remains in

- slab (500-1800 mm wide and 50-300 mm thick)
- billets (40-150 sq mm)
- blooms (150-400 sq mm)

Slabs billets and blooms are normally obtained from casting
These shapes are further processed by different forming
Processes to produce plates, sheets, rods, tubes and structural
sections

In any forming process the starting material is deformed.
The main mechanisms of deformation is by slipping or twinning


Structural shapes
Bloom
Rails
Slab
Coils
Plates, sheets
Billet
Bars, rods

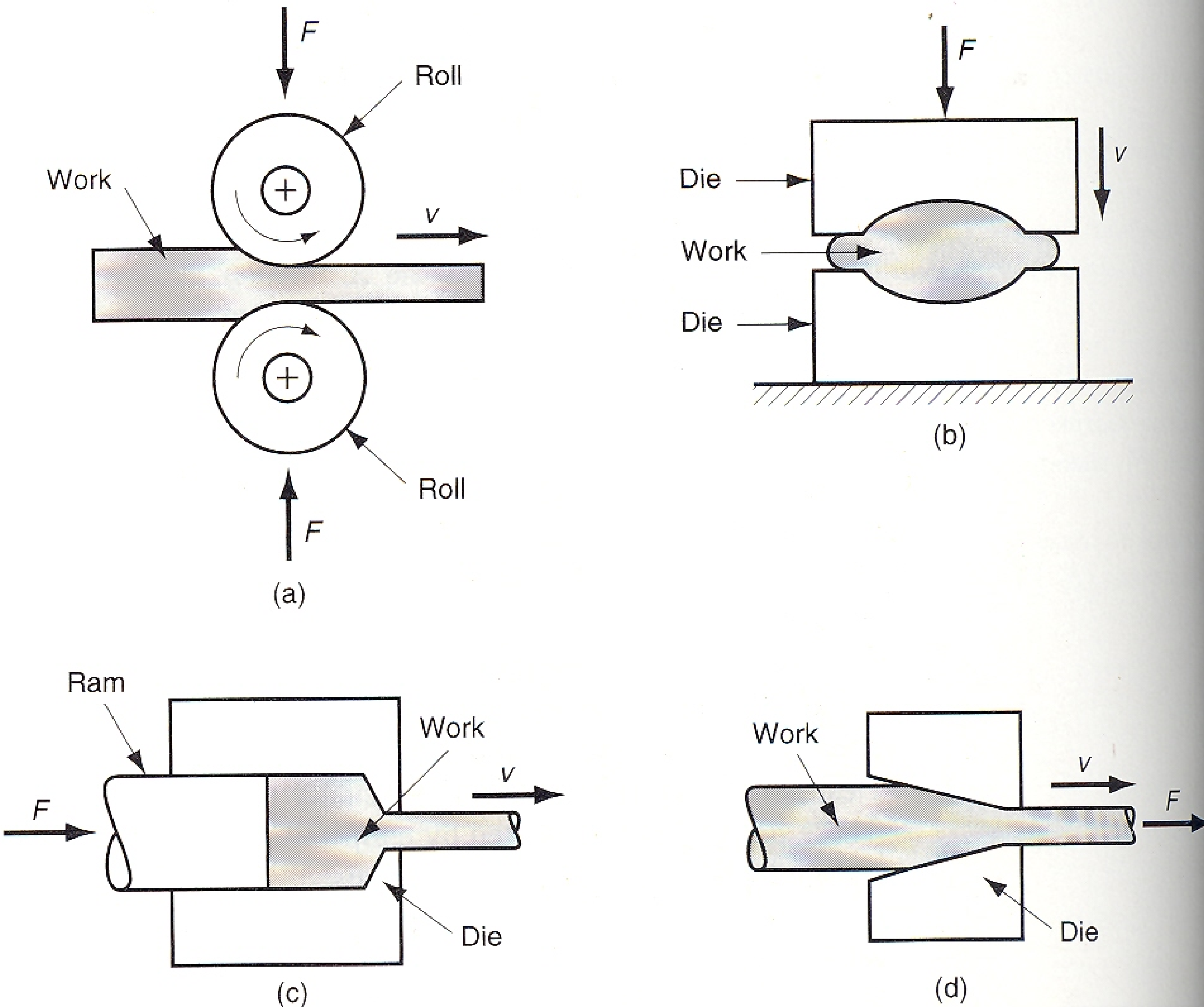
Different Metal Forming Processes

Bulk Deformation Processes

- Rolling
- Forging
- Extrusion
- Wire Drawing

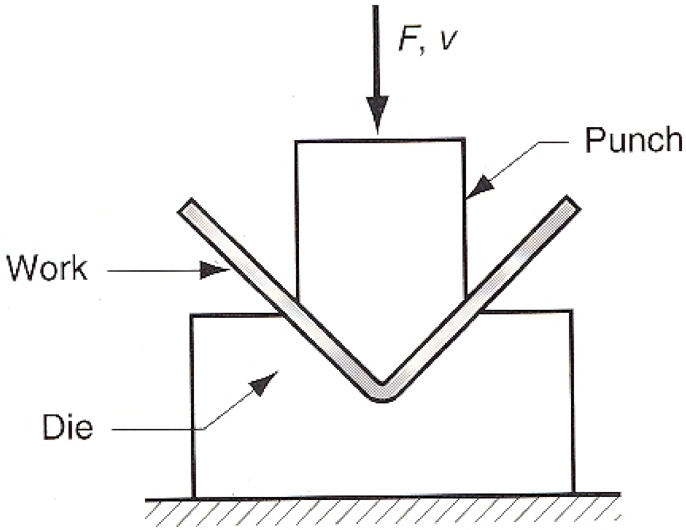
Press Tool work

- bending
- shearing
- deep drawing
- coining

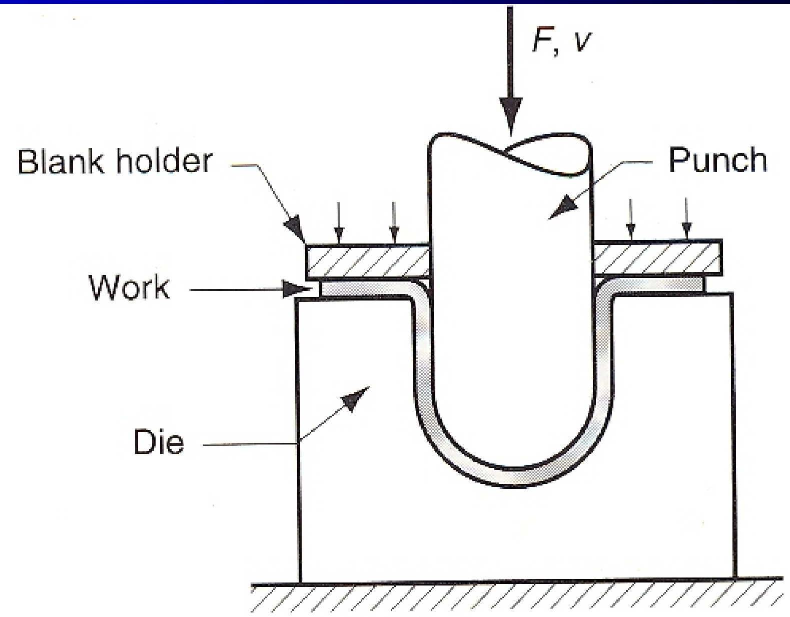


Bulk Deformation Processes

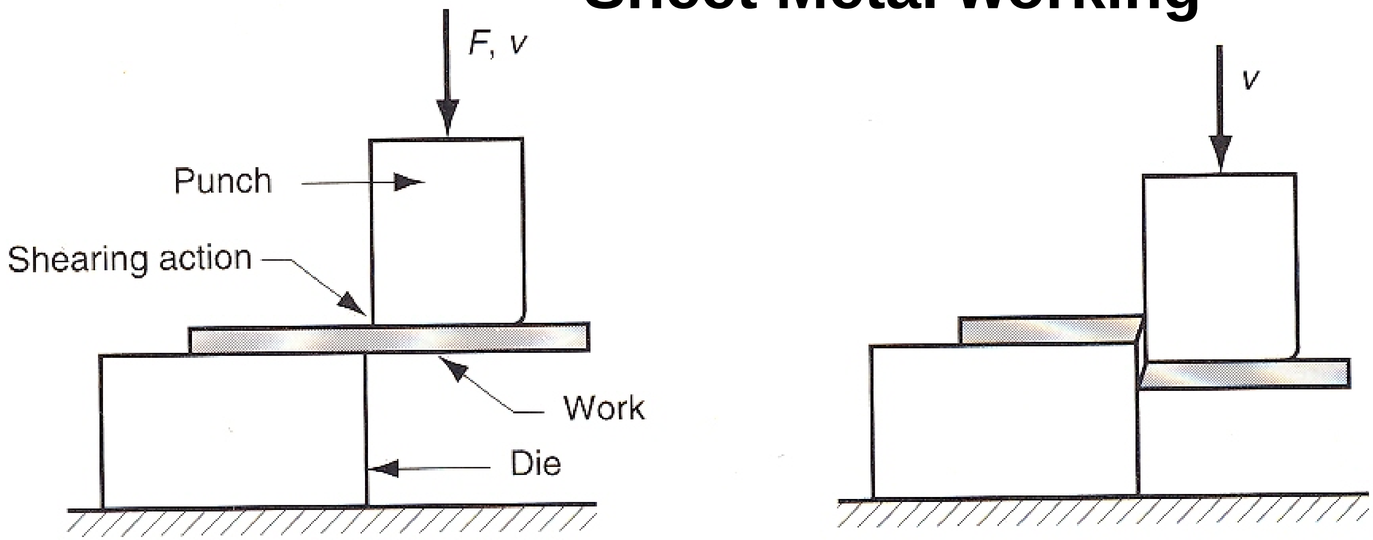
Sheet Metal working



(a)



(b)



(1) (2)

(c)

Broad Classification Metal Forming Operations

- Hot Working of Materials
- Cold Working of Materials

Hot Working

Metal working operations are carried out at temperature Just above the re-crystallization temperature

Advantages of Hot working

- No strain hardening results so any amount of deformation
- At higher temperature material have higher ductility
- It requires much less force
- A favorable grain size can be achieved

Limitations

- some metals become brittle at higher temperature
- scale formation in some metals take place

Cold Working

Deformation process conducted at temperature below the re-crystallization temperature

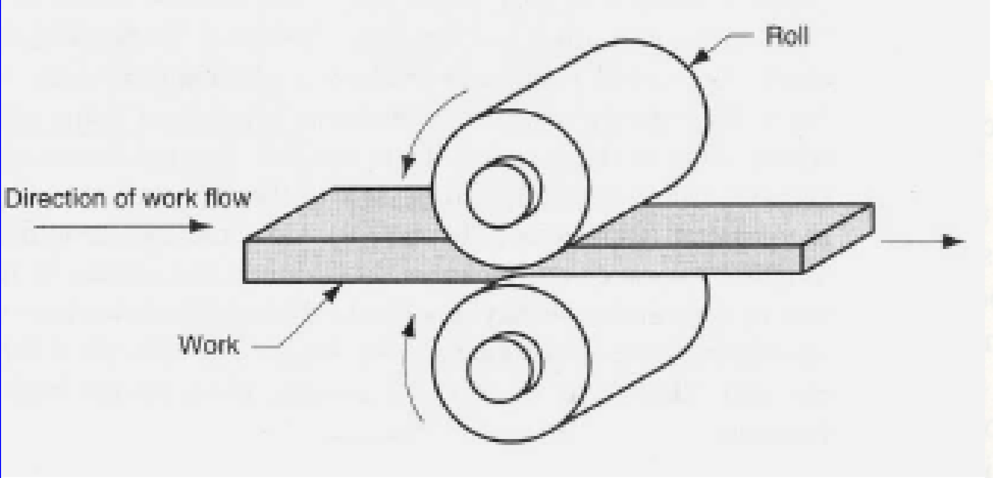
Advantages of Cold working

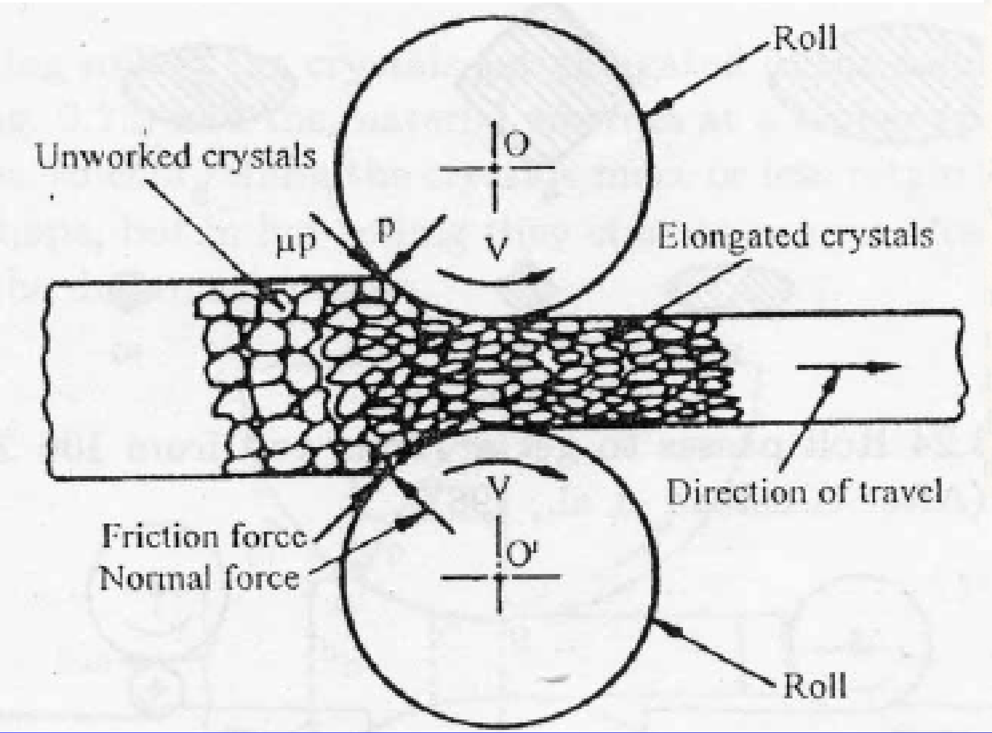
- Strength and hardness increases because of strain hardening
- no surface oxide, surface finish is good
- better dimensional accuracy

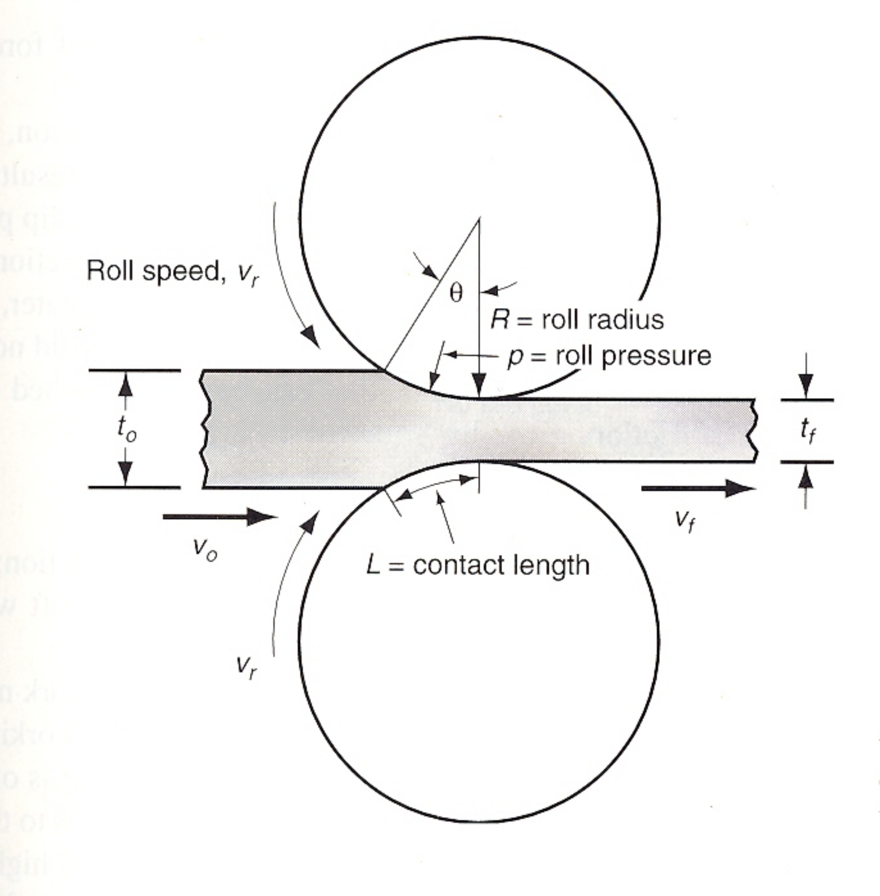
Limitations

- Larger forces are required
- Many brittle materials cannot be cold worked

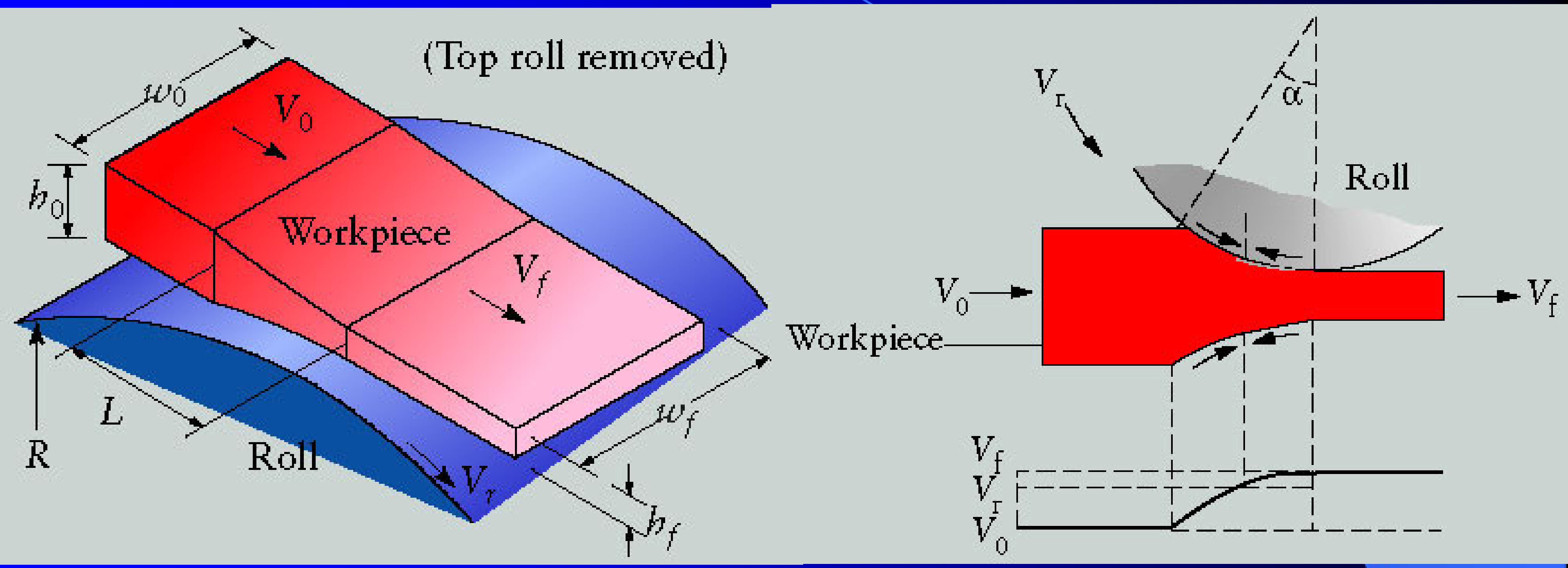
ROLLING PROCESS





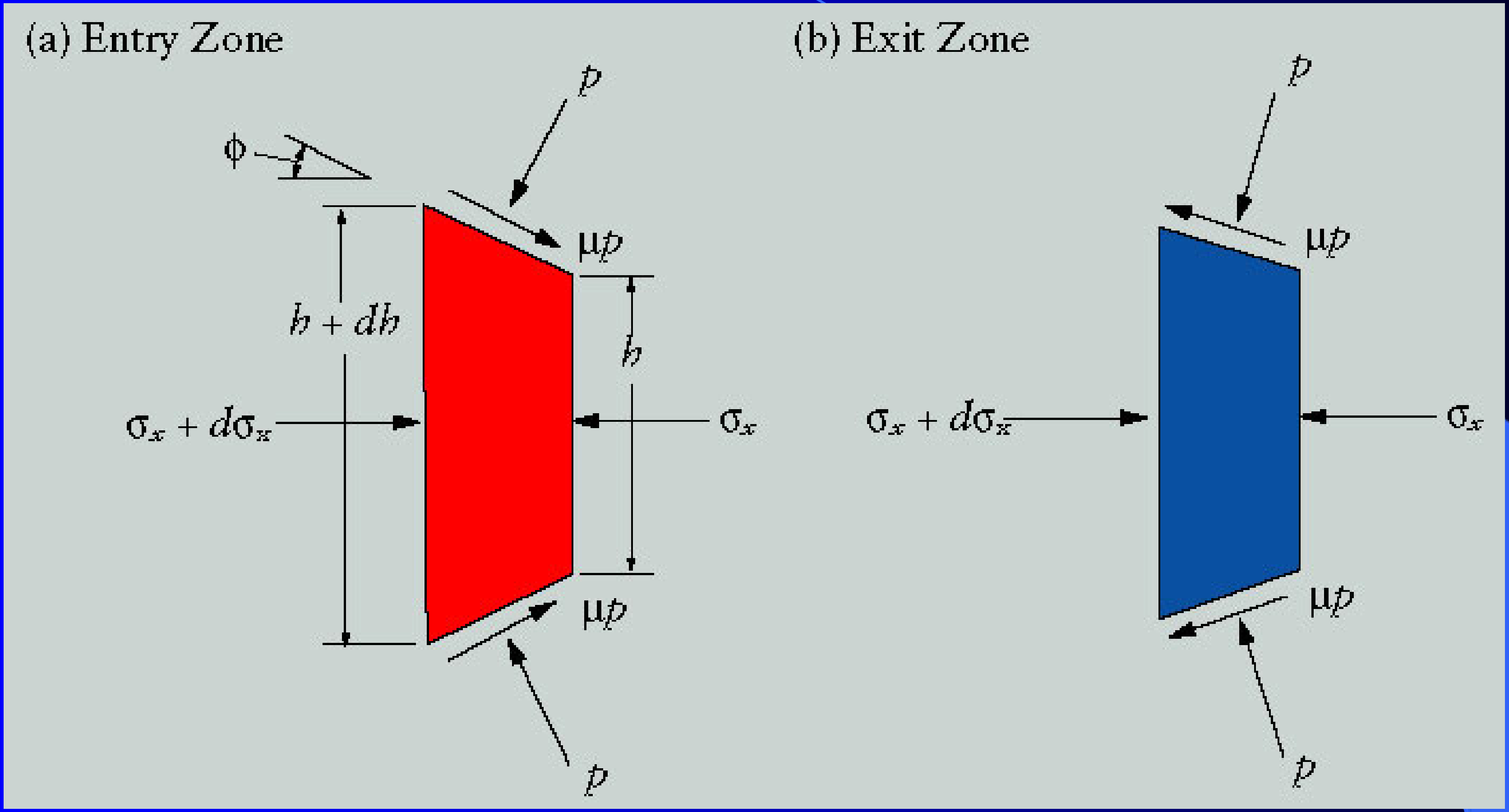


Flat-Rolling Process



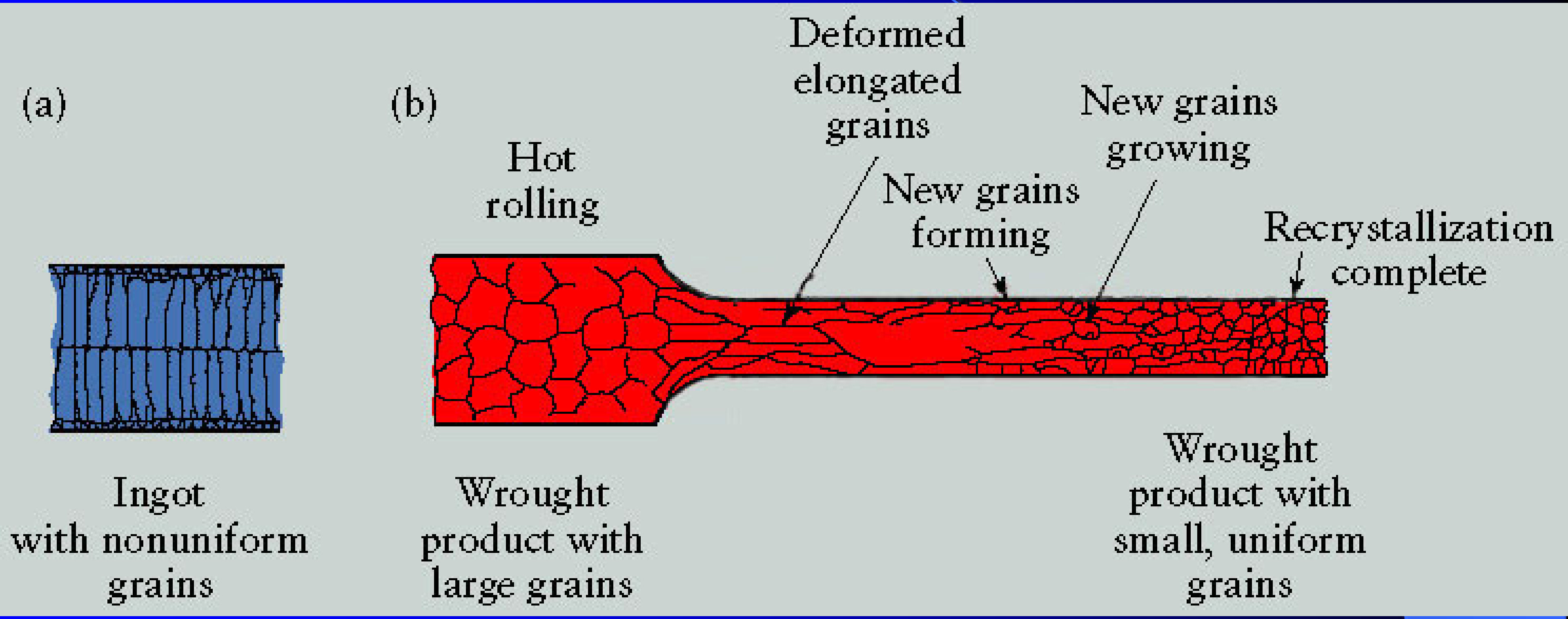
A greater volume of metal is formed by rolling than by any other metalworking process.

Stresses In Rolling

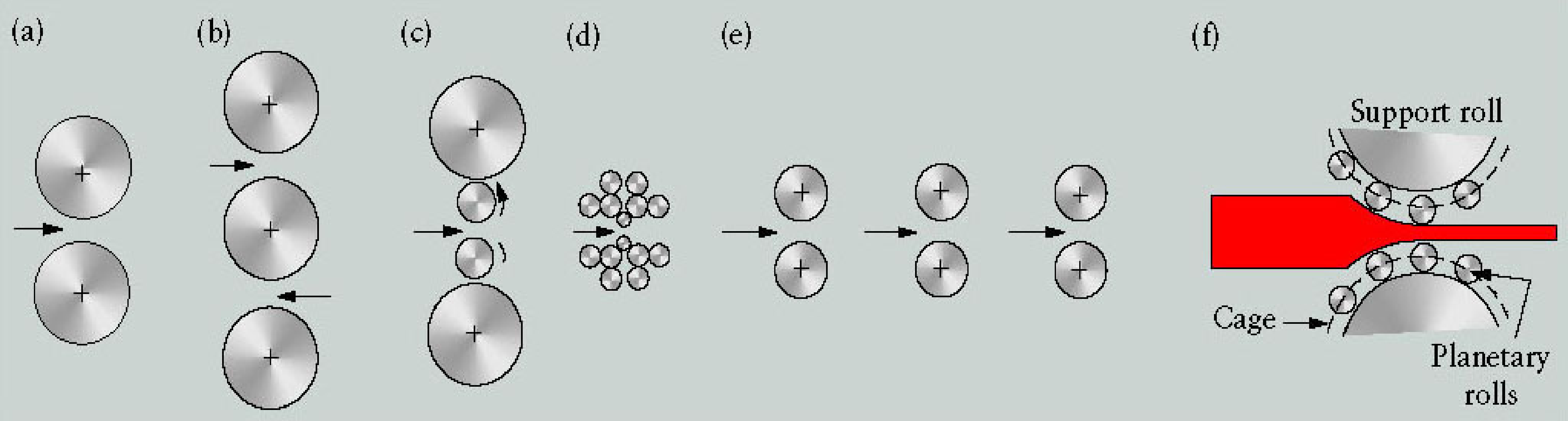


Stresses on an element in rolling: (a) entry zone and (b) exit zone.

CHANGE IN GRAIN STRUCTURE DURING ROLLING

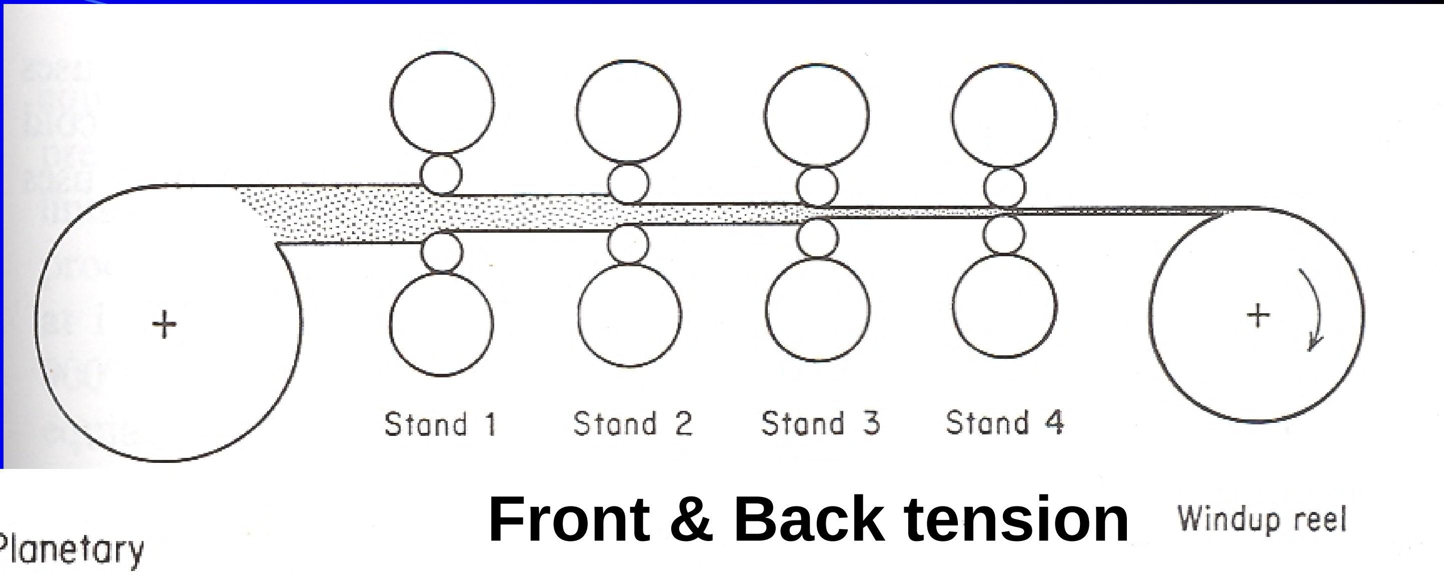


Various Roll Arrangements

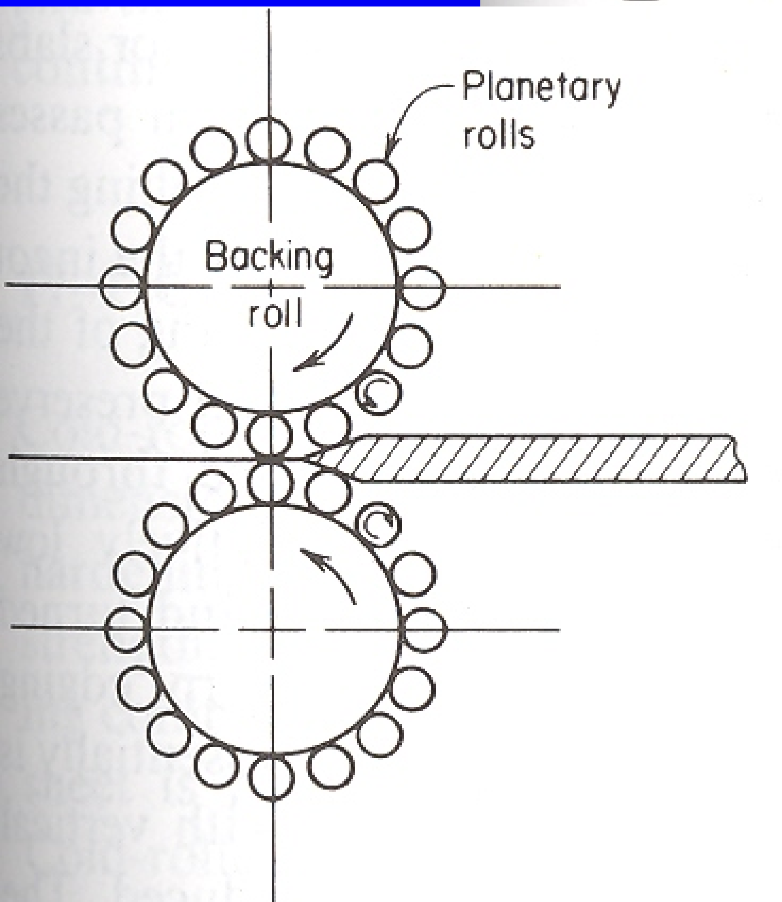


Schematic illustration of various roll arrangements:

(a) two high; (b) three high; (c) four high; (d) cluster; (e) tandem rolling with three stands; (f) planetary.

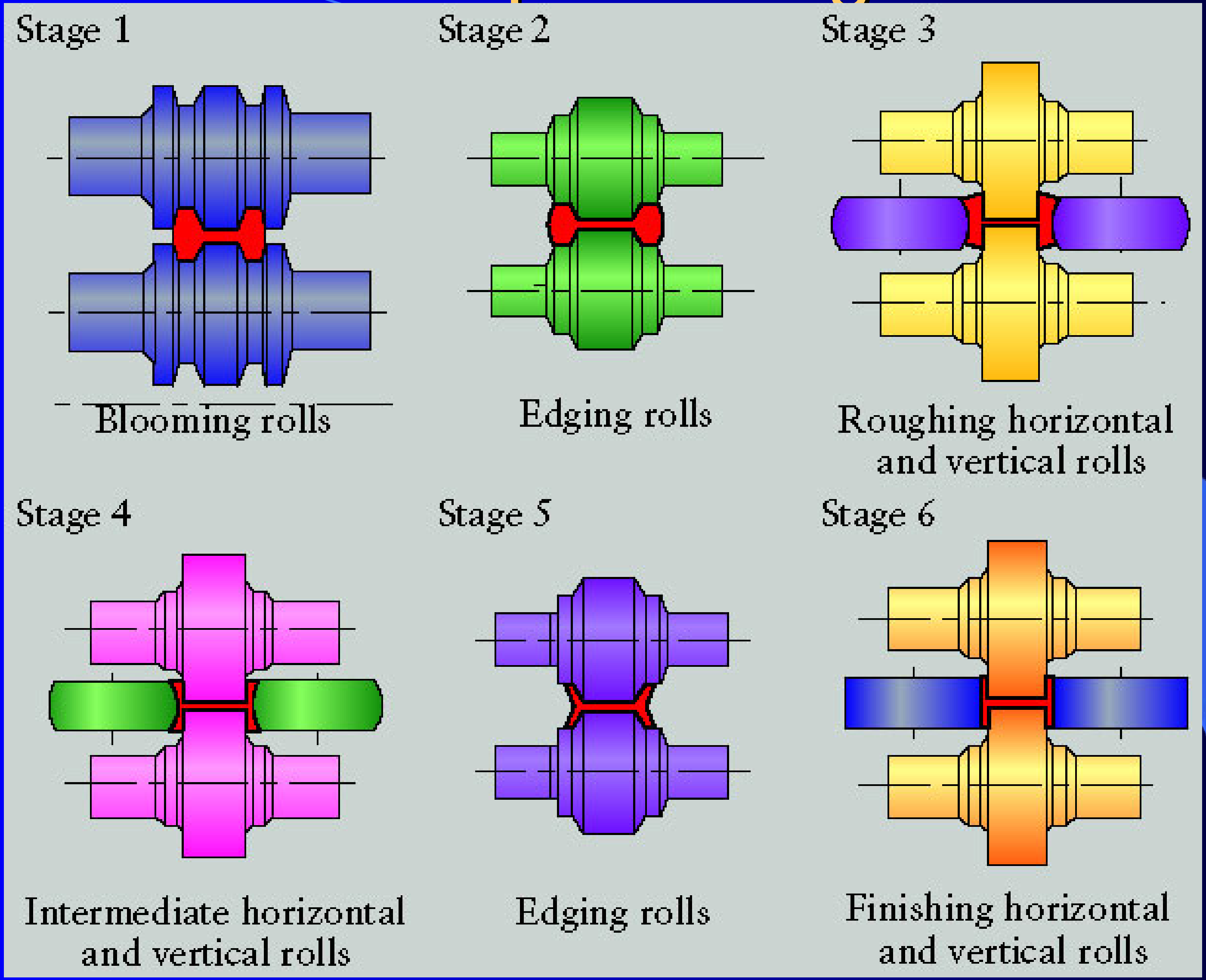


Front & Back tension



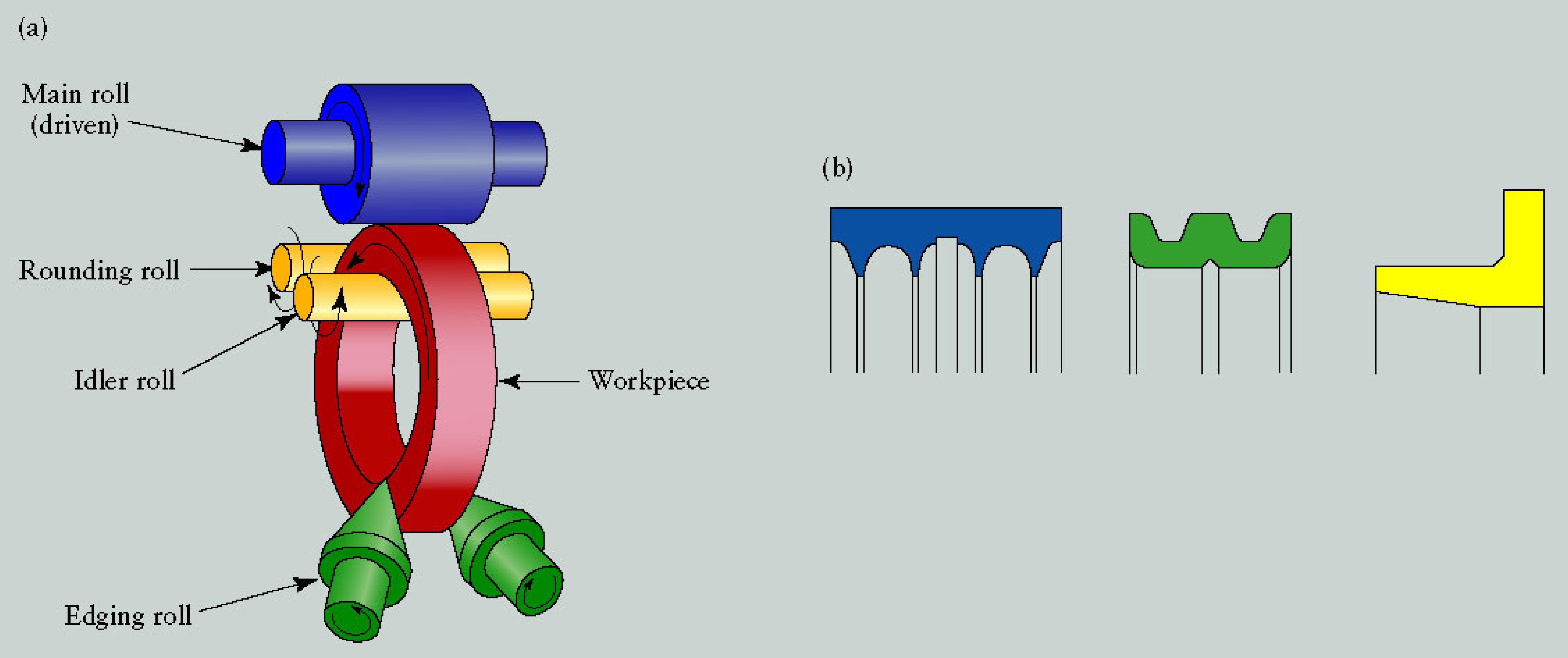
Planetary Rolling Mill

Shape Rolling



Stages in shape rolling of an H-section part. Various other structural sections, such as channels and I-beams, are also rolled by this process

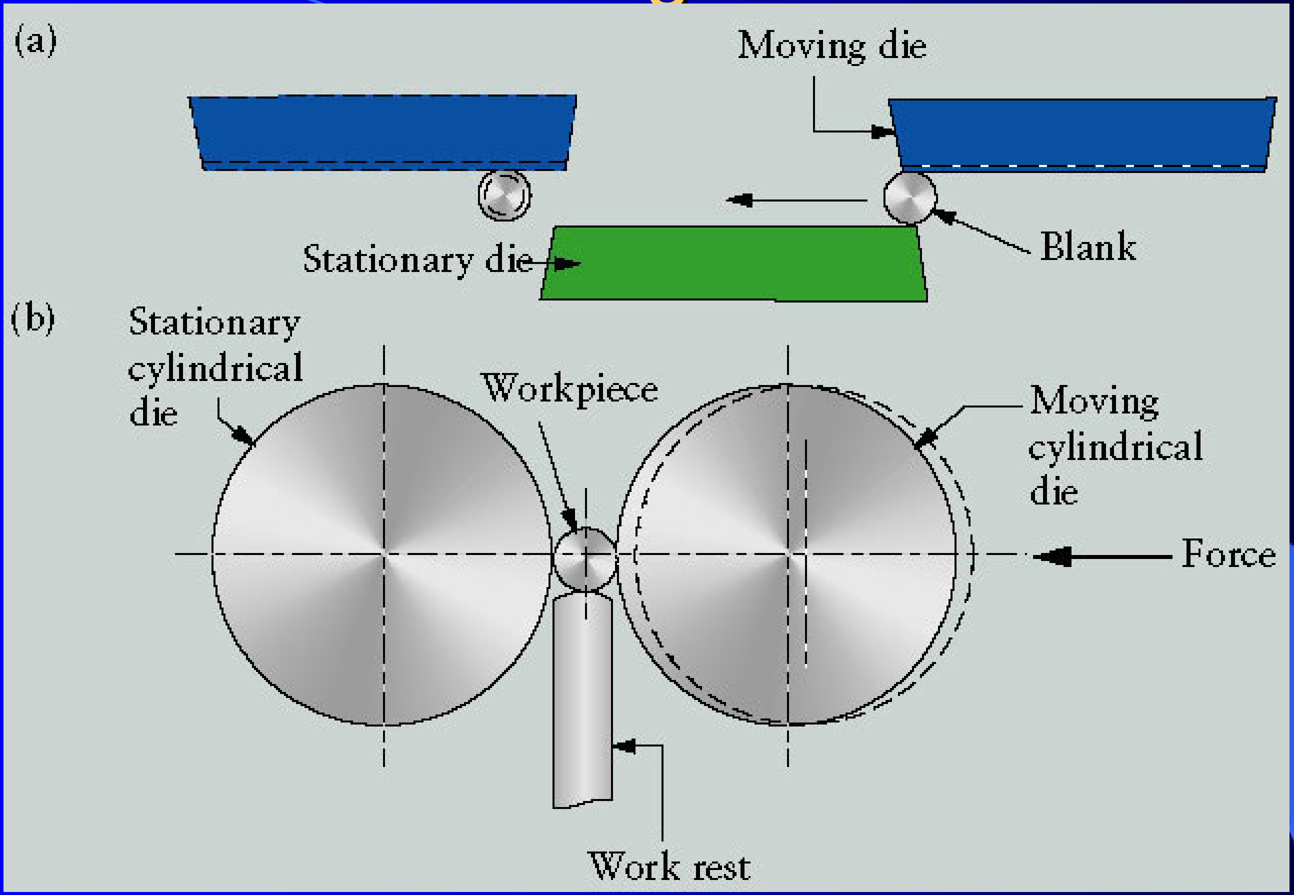
Ring-Rolling



Schematic illustration of a ring-rolling operation. Reducing the thickness results in an increase in the part’s diameter.

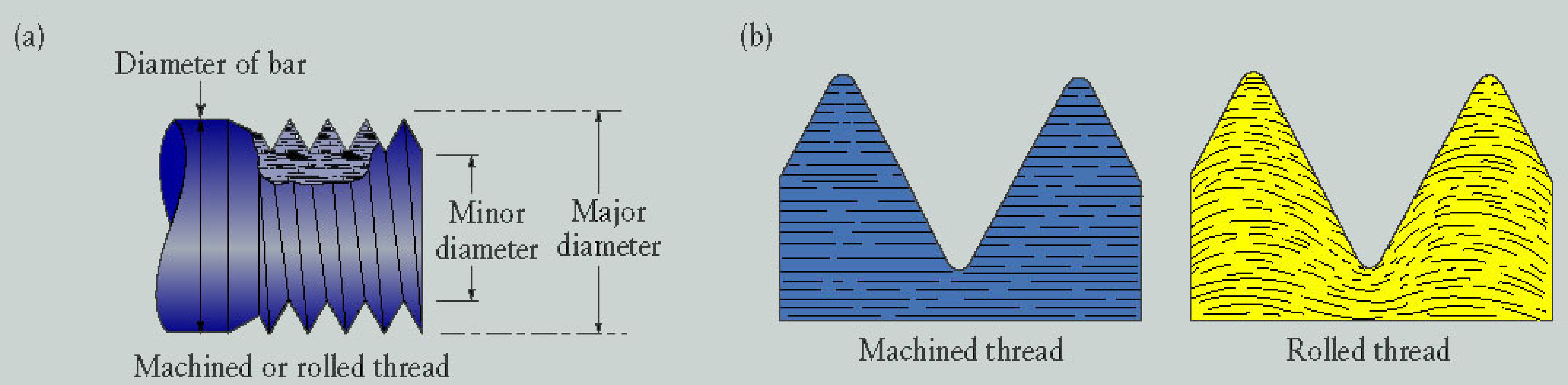
(b) Examples of cross-sections that can be formed by ring rolling.

Thread-Rolling Processes



Thread-rolling processes: (a) flat dies and (b) two-roller dies. These processes are used extensively in making threaded fasteners at high rates of production.

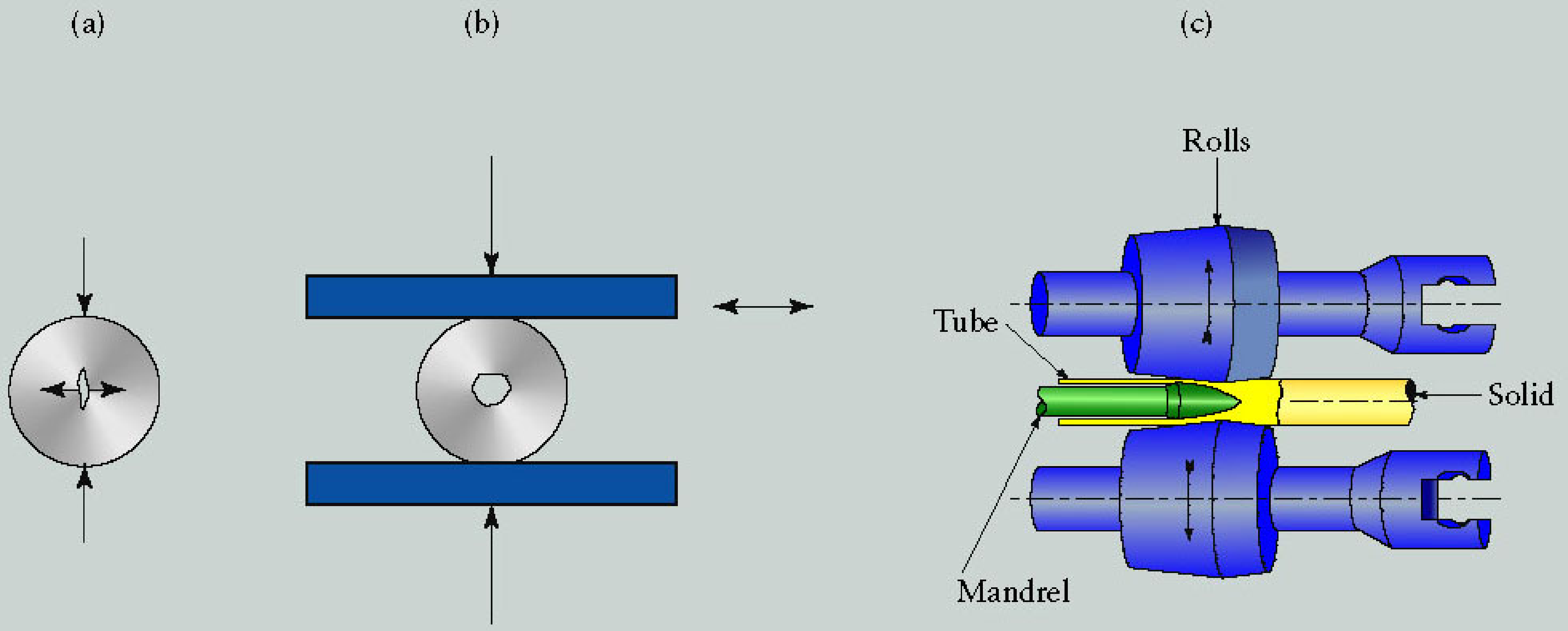
Machined And Rolled Threads



(a) Schematic illustration of machined or rolled threads.

(b) Grain-flow lines in machined and rolled threads. Unlike machined threads, which are cut through the grains of the metal, rolled threads follow the grains and are stronger, because of the cold working involved.

Mannesmann Process



Cavity formation by secondary tensile stresses in a solid round bar and its use in the rotary-tube-piercing process. This procedure uses the principle of the Mannesmann mill for seamless tube making. The mandrel is held in place by the long rod, although techniques have been developed in which the mandrel remains in place without the rod.

Salient features of Rolling

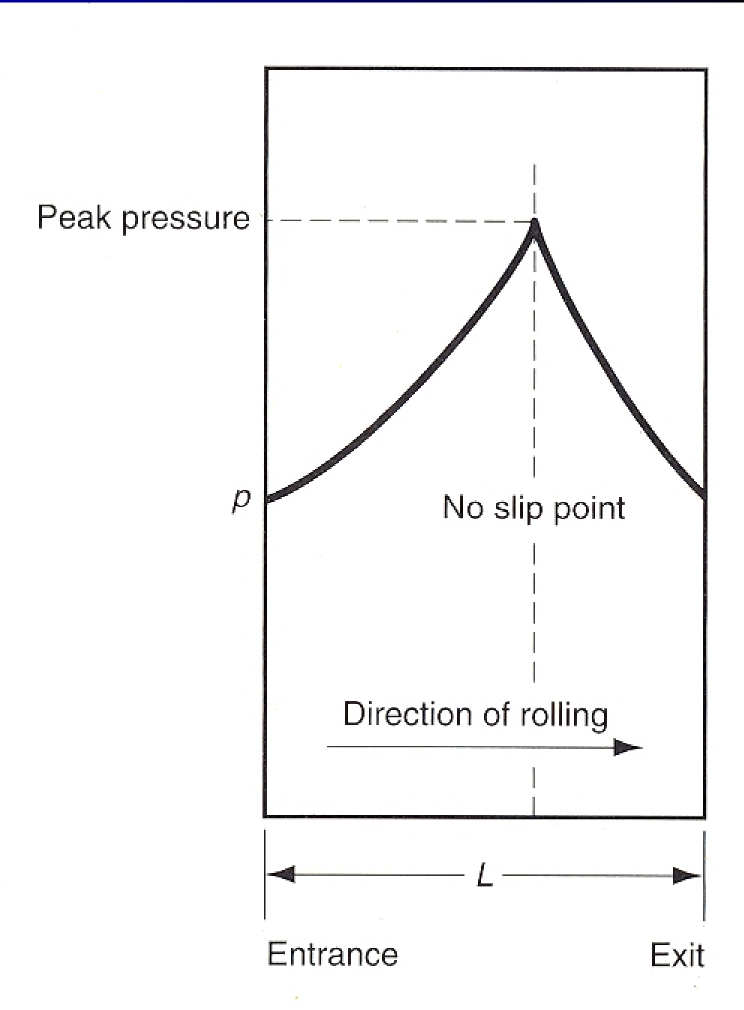
- It is an extensively used metal forming operation
- The material is normally sucked up in the rolling gap because of friction between the roll and the workpiece
- Compressive forces help in changing the cross section
- Geometry of the product can be varied by changing the contour of the rolls
- Rolls for hot forming are made rough so that they can bite the workpiece significantly while cold rolls are normally smooth and polished for good finish
- In cold rolling the crystals get elongated along the rolling direction but in hot rolling they start reforming after coming out of the deformation zone
- Peripheral velocity of rolls at entry must exceed the velocity of the strip and at exit it is more than the roll velocity
- Hence there is a neutral point where roll velocity and workpiece velocity are same At this point the direction of friction reverses

Pressure variation during Rolling

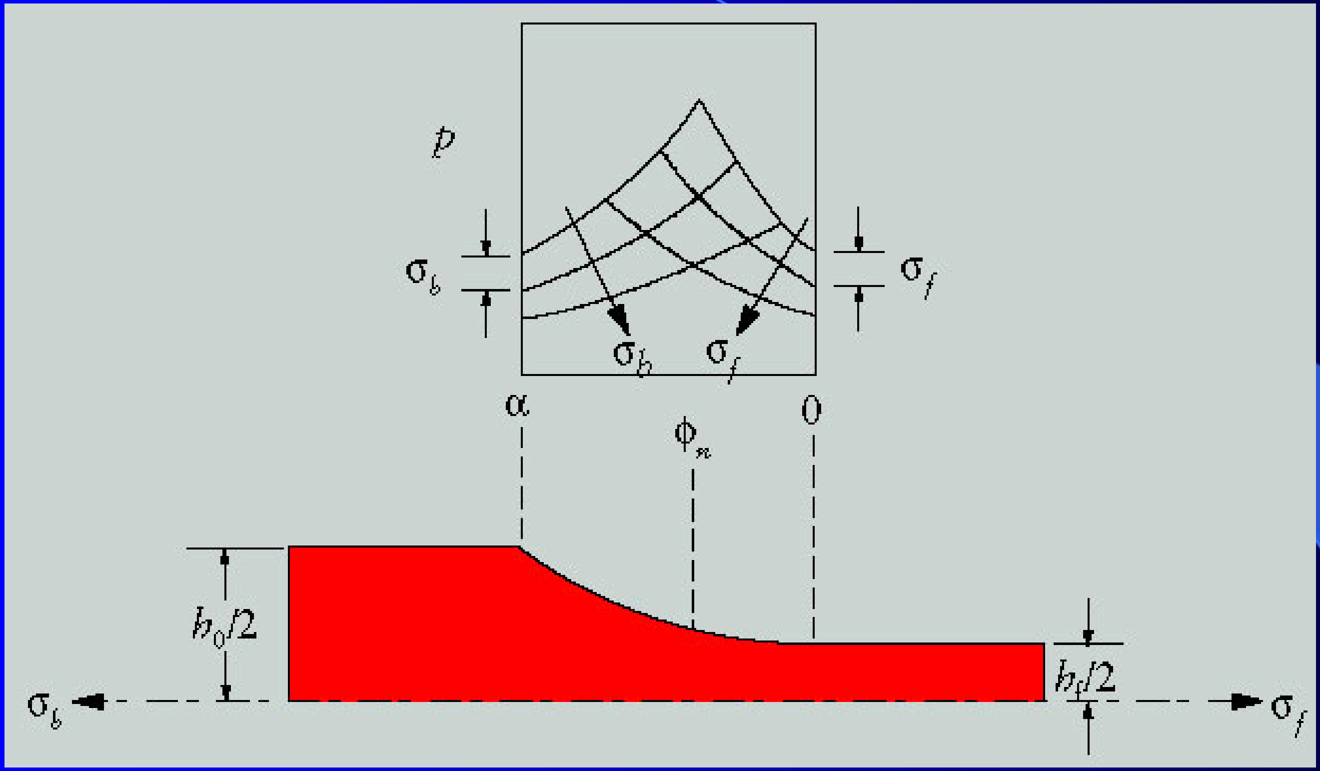
Distribution of Pressure along the Arc of contact

Hot rolling results in higher friction
(coefficient of friction around 0.4)
Sometimes sticking occurs during
Hot rolling and then the friction
Increases to 0.7

Cold rolling results in lesser friction
(coefficient of friction 0.1-0.2)

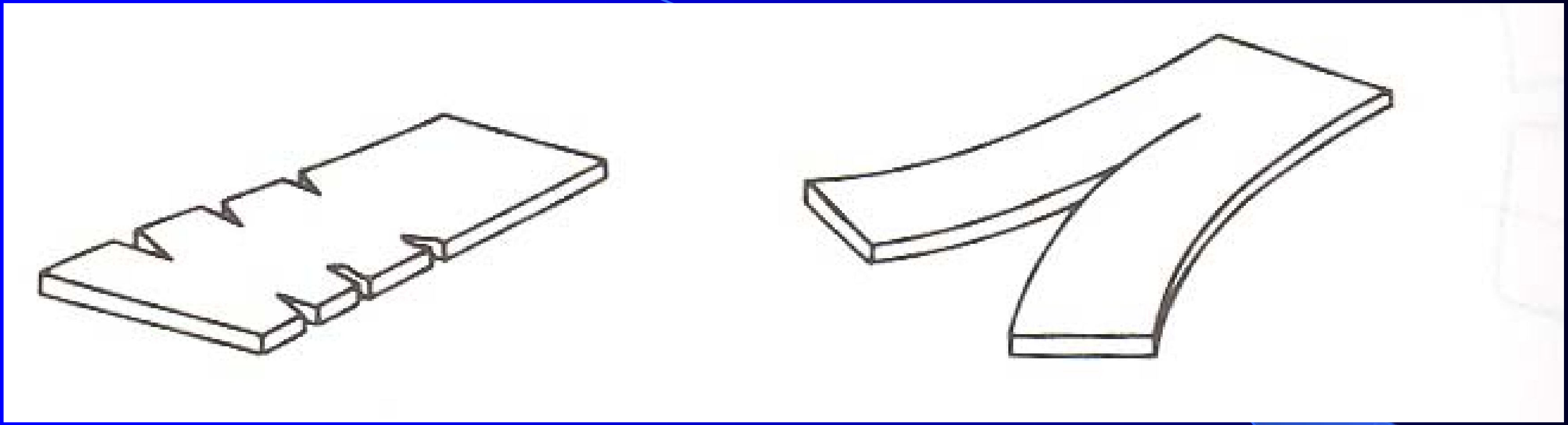


Effects of Front And Back Tension



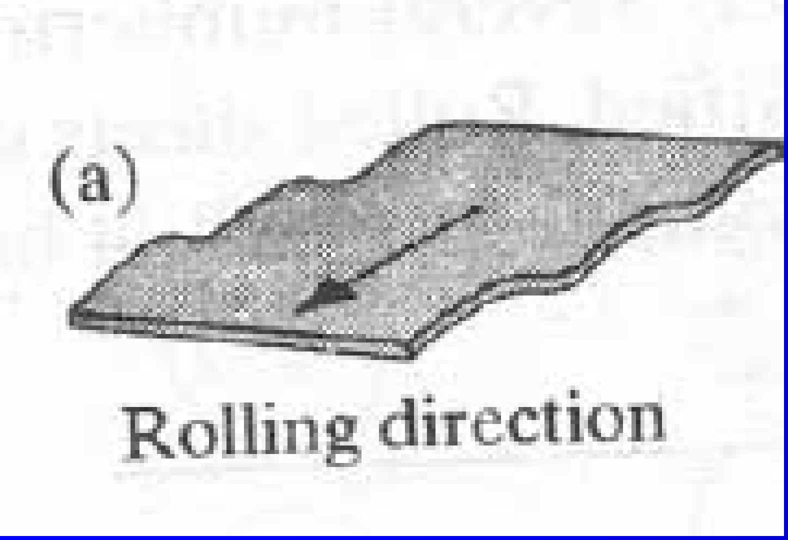
Pressure distribution as a function of front and back tension. Note the shifting of the neutral point and the reduction in the area under the curves with increasing tension.

Defects in Rolling



Edge Cracking;
Due to excessive thickness redn.

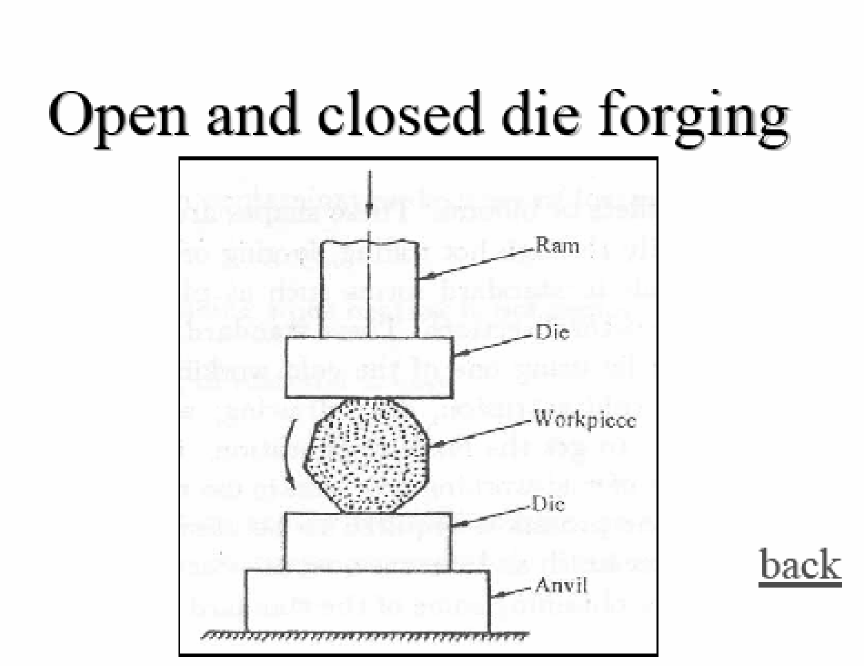
Alligatoring:
Due to Ratio of slab thickness to length of contact 1.4 to 1.7



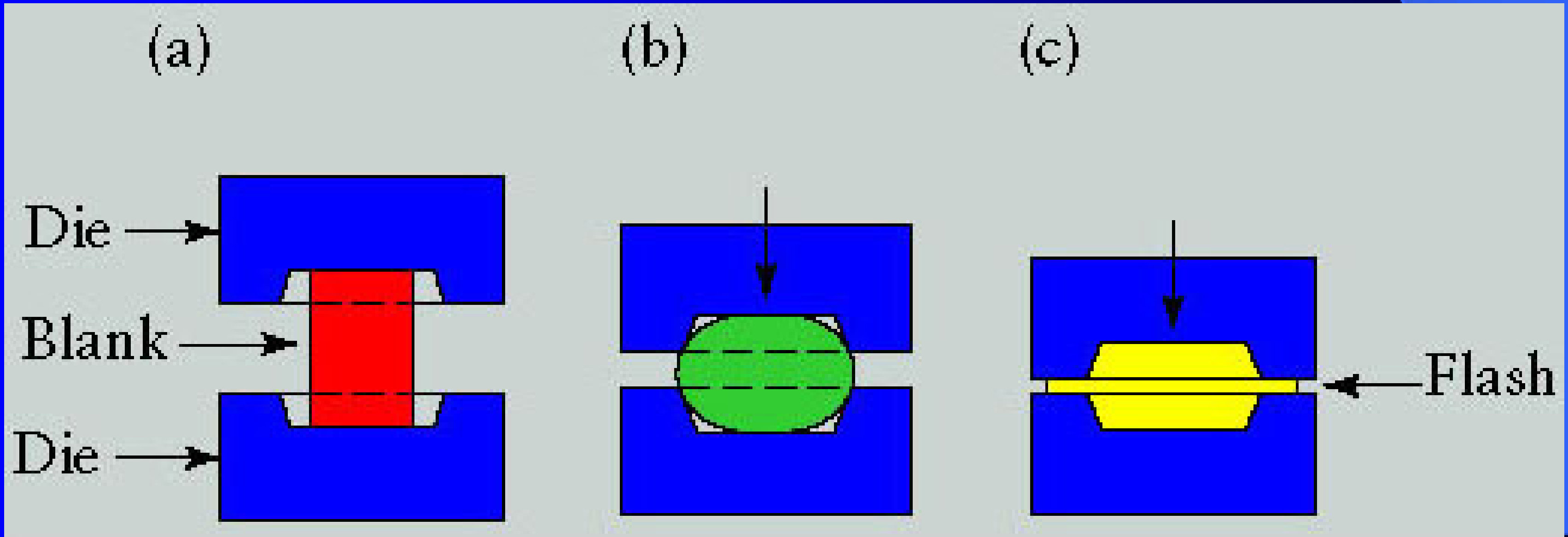
Folds: due to low reduction per pass

FORGING

- Open Die Forging
- Closed Die Forging

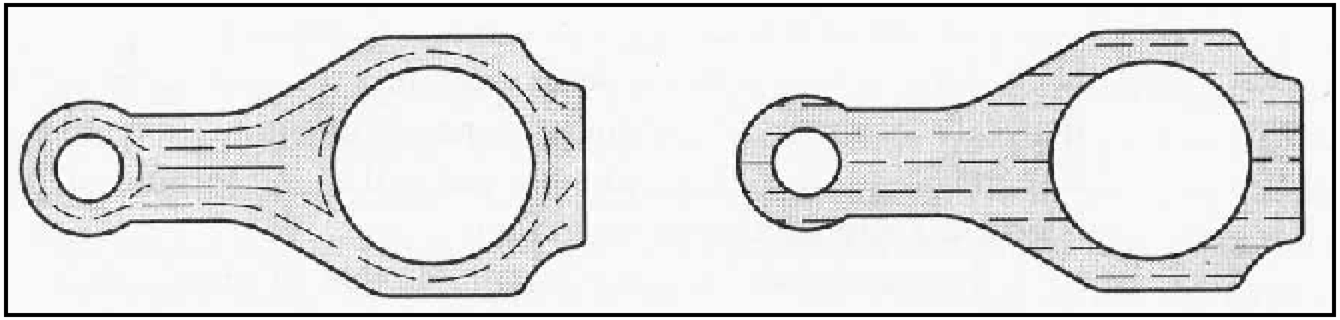


Closed Die Forging



Favourable grain structure obtained in Forging

Grain orientation in forging



Forging Machining

back

Merits of Open Die Forging

- Improves flow and microstructure
- Refines microstructure and removes defects
- Batch or Mass production possible
- Low cost per piece

Limitation

- Poor dimensional accuracy and finish

Closed Die Forging

Advantages

- Greater consistency of product
- Closer tolerance
- Better surface finish with min. surplus
- Greater strength
- Lesser cost

Limitations of closed die forging

- High cost of forging dies if shapes are intricate
- Viable only for mass scale production

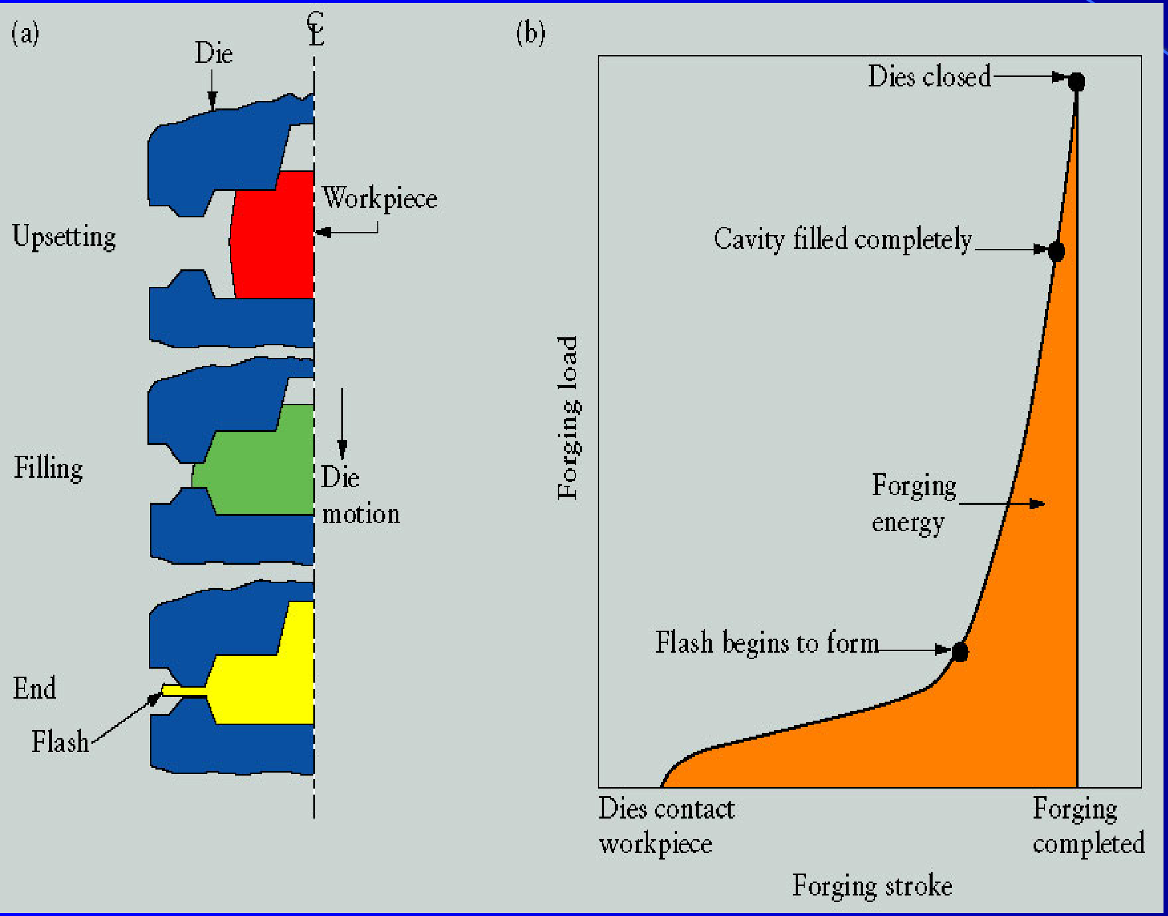
Two types of Closed Die Forging

- **Conventional Die forging**
- **Flashless die forging**

Flash removed by trimming. Flash has an important role. Due to flash in the die gap friction increases restricting the metal to be within the die cavity. It is more predominant in hot forging where the thin flash cools down quickly increasing the friction largely.

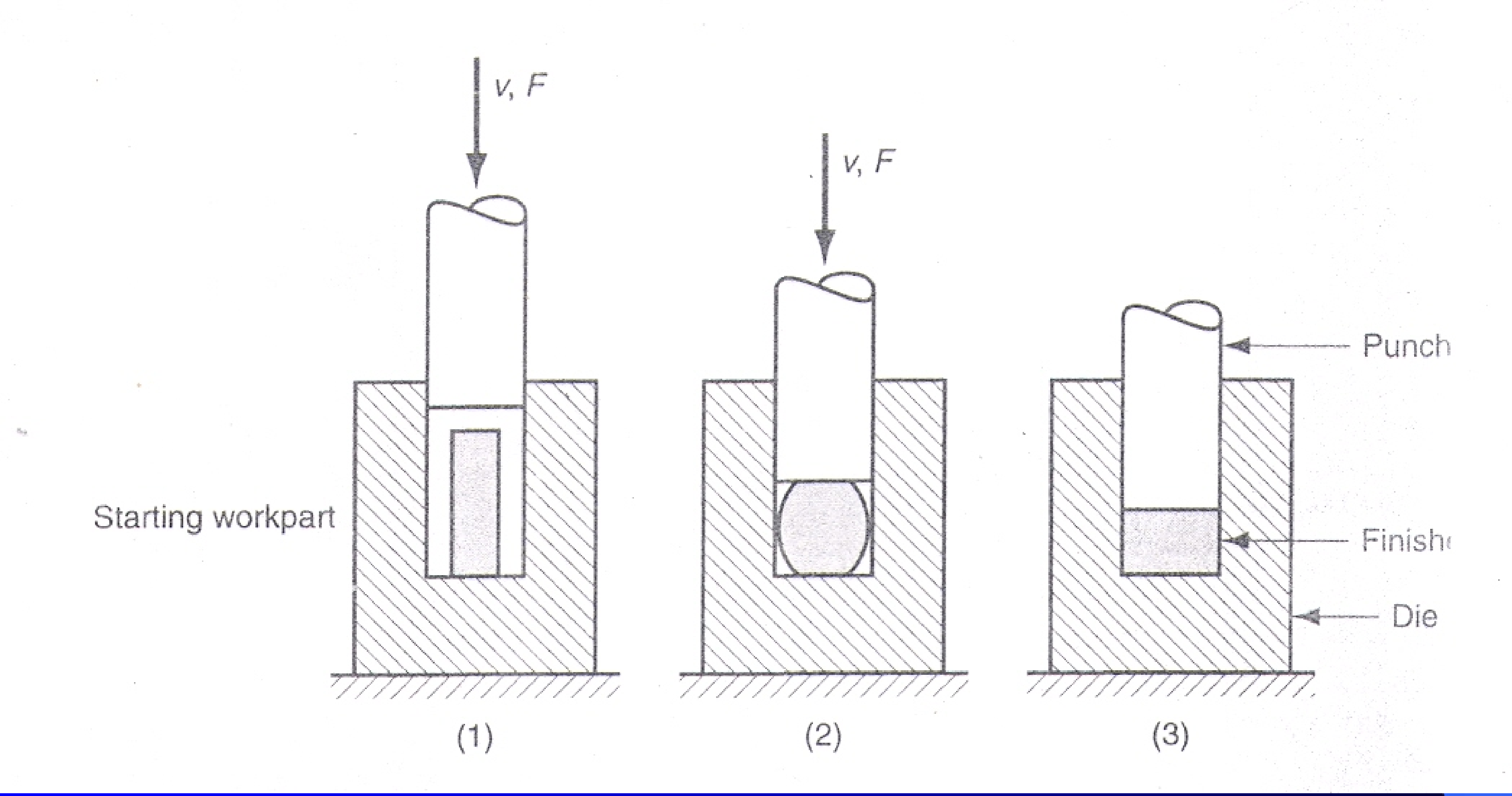
Such impression die forging process can produce forgings with thinner sections, complex geometries, closer tolerances and sometimes elimination of machining allowances possible. Common work matls for precision forging are aluminium and titanium

Load-Stroke Curve in Closed-Die Forging



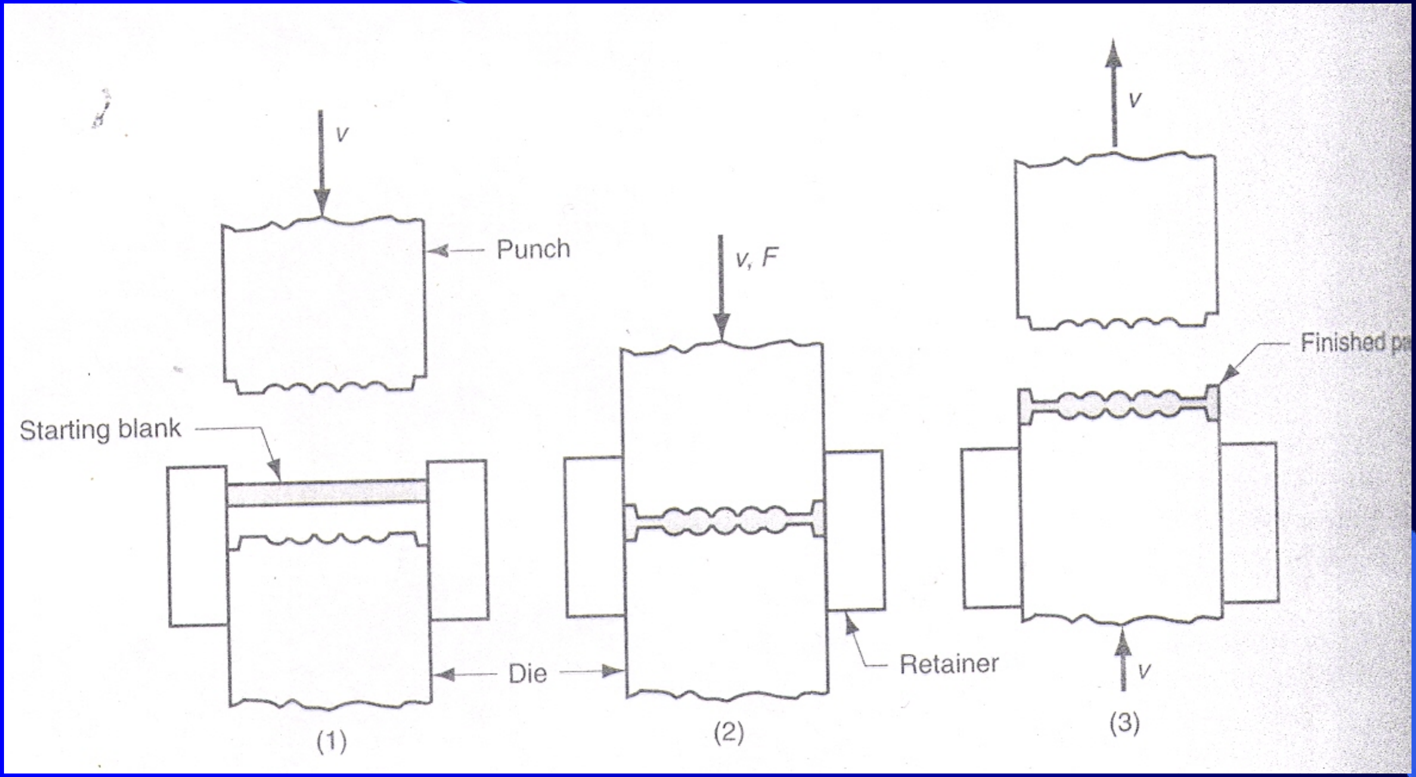
Typical load-stroke curve for closed-die forging. Note the sharp increase in load after the flash begins to form. In hot-forging operations, the flash requires high levels of stress, because it is thin-that is, it has a small *h*-and cooler than the bulk of the forging. *Source*: After T. Altan.

Flashless Forging



The starting blank must not be too large or too small. It is applied to the part geometries that are simple and symmetrical. Common work materials are Al and Mg and their alloys.

COINING



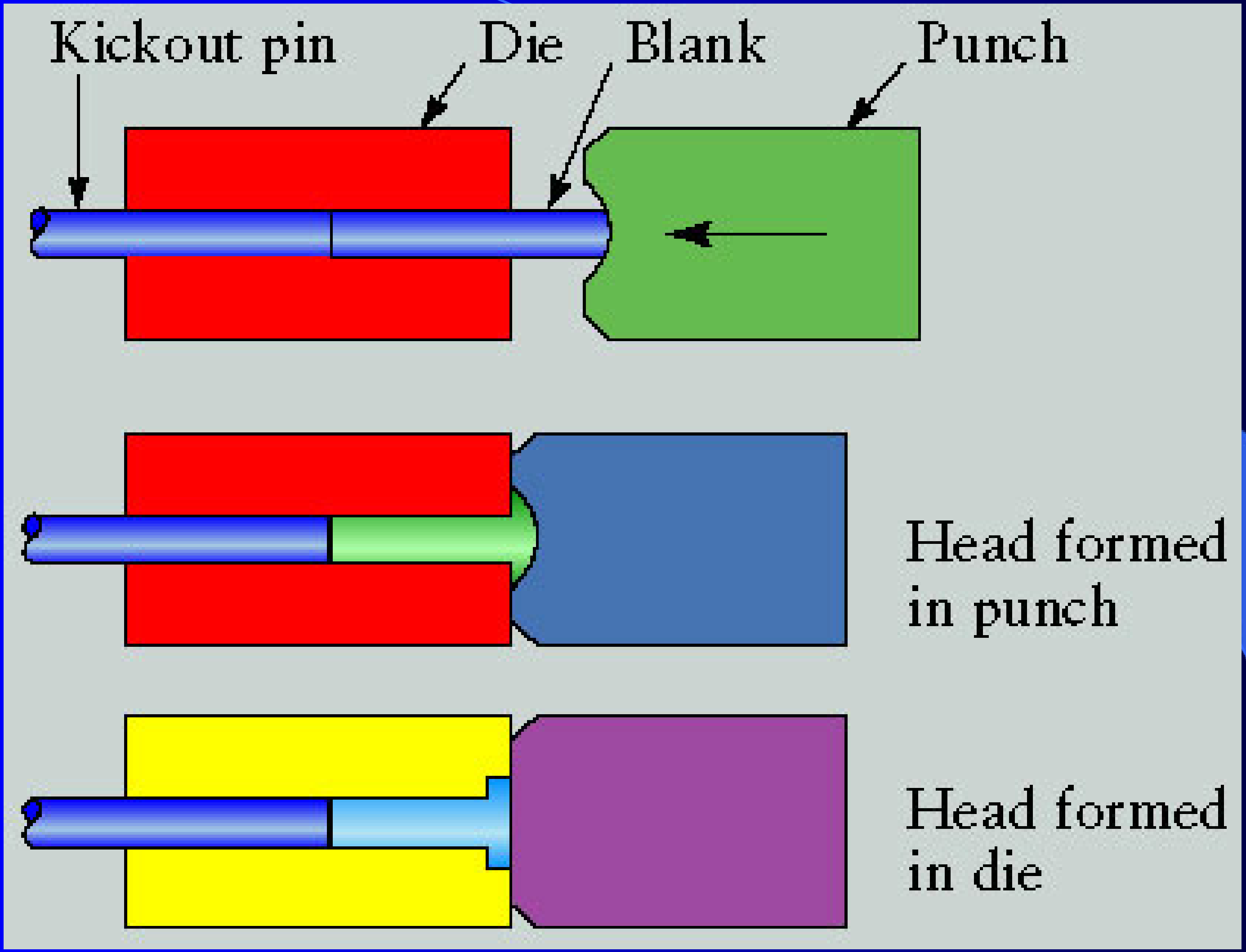
Advantages

Good surface finish

High dimensional accuracy

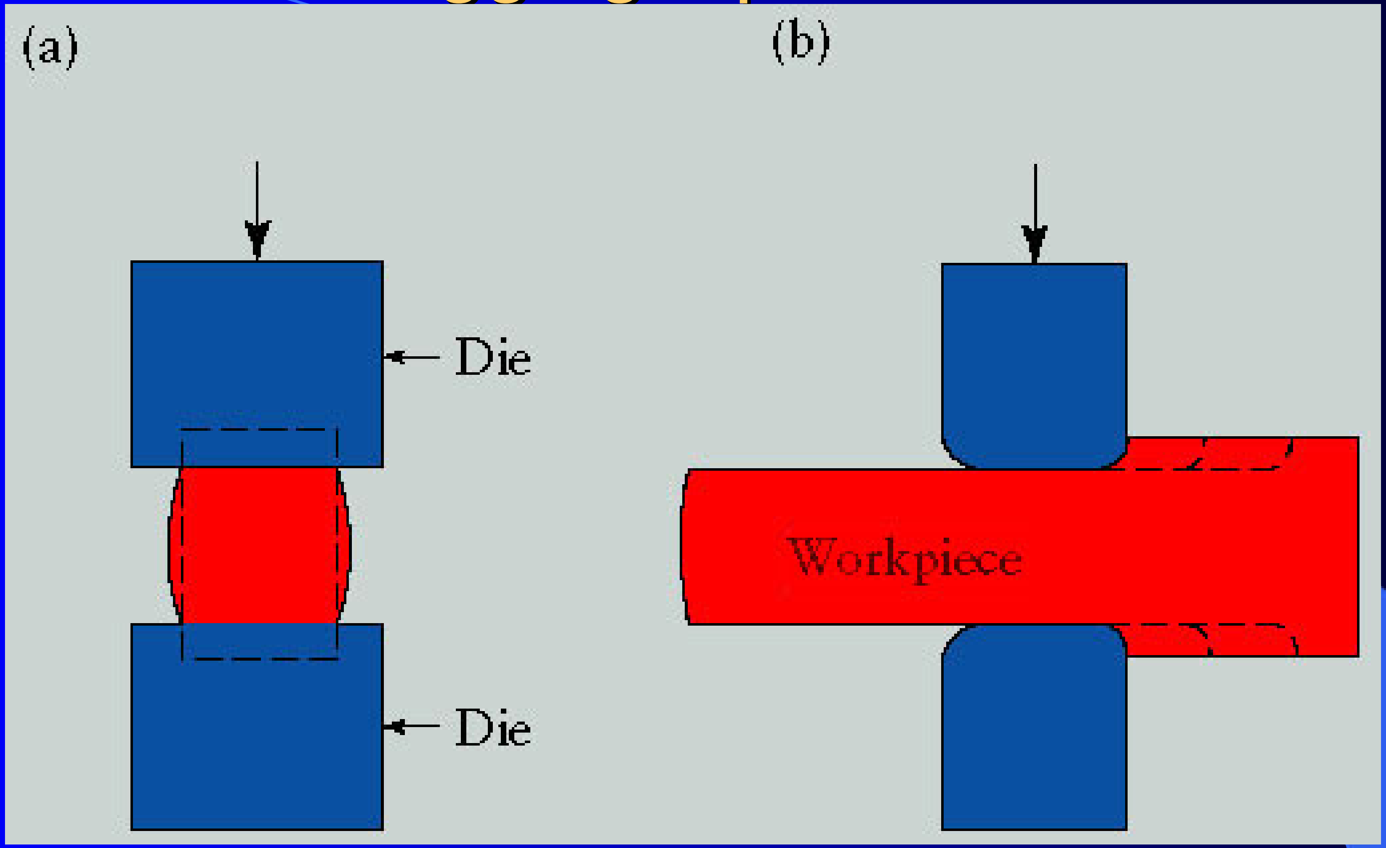
High productivity

Heading



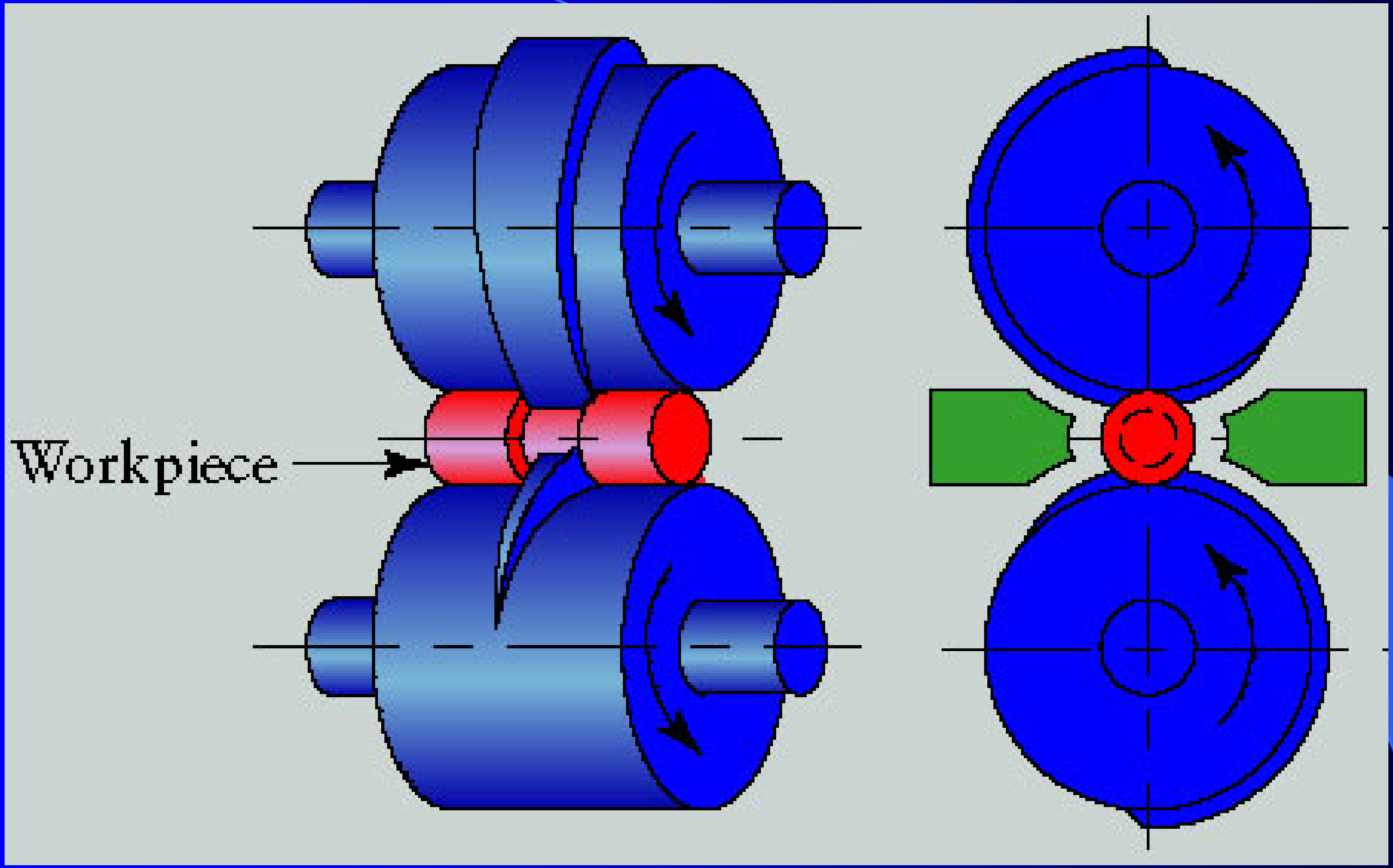
Forging heads on fasteners such as bolts and rivets. These processes are called *heading*.

Cogging Operation



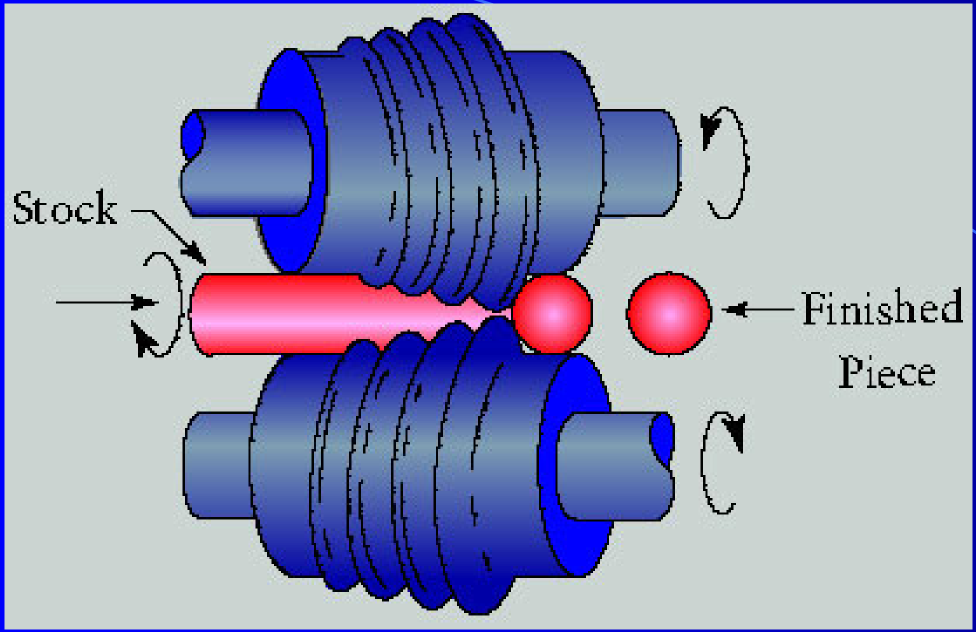
Schematic illustration of a cogging operation on a rectangular bar. With simple tools, the thickness and cross-section of a bar can be reduced by multiple cogging operations. Note the barreling after cogging. Blacksmiths use a similar procedure to reduce the thickness of parts in small increments by heating the workpiece and hammering it numerous times.

Roll Forging Operation



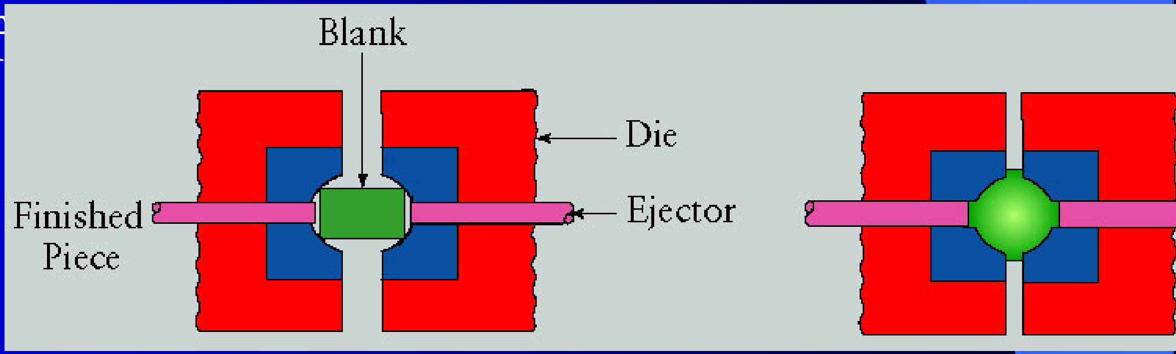
Schematic illustration of a roll forging (cross-rolling) operation. Tapered leaf springs and knives can be made by this process with specially designed rolls. *Source*: After J. Holub.

Manufacture of Spherical Blanks



Production of steel balls for bearings by the skew-rolling process.

Production of steel balls by upsetting of a cylindrical blank. Note the formation of flash. The balls are subsequently ground and polished for use as ball bearings and in other mechanical components.



Equipment for Forging work

(a) For few small object (Black Smithy) – Hammers & Anvil

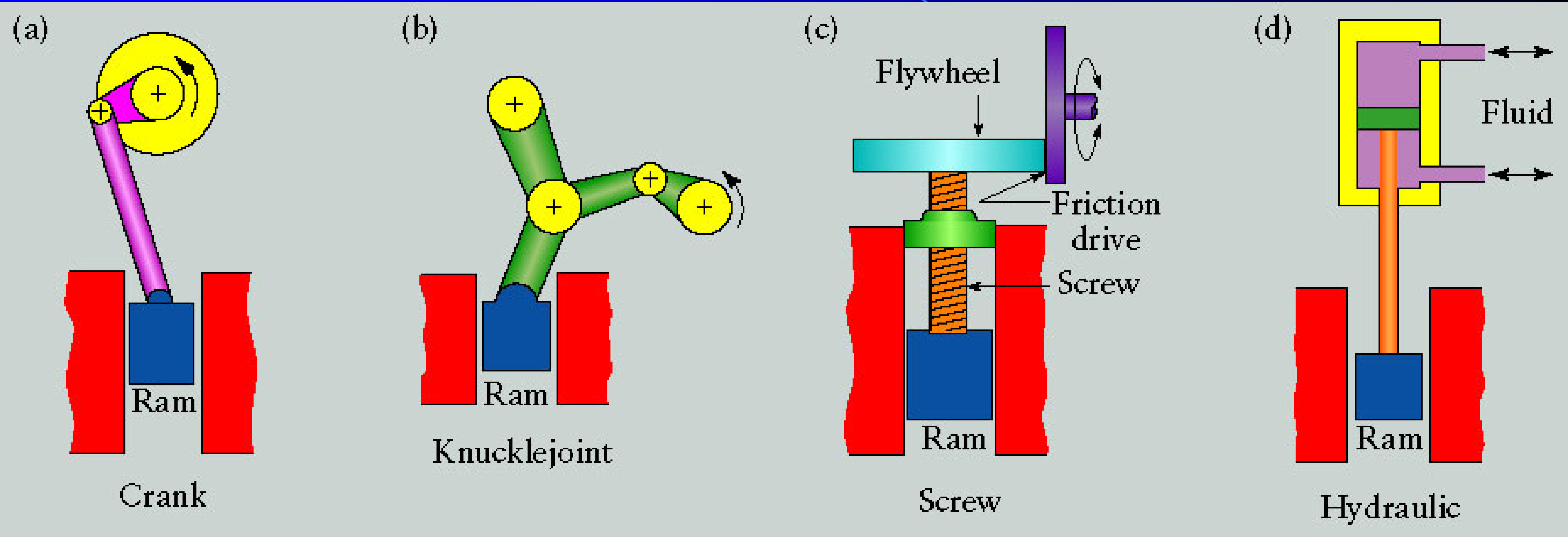
(b) For lot production of medium size objects (drop forging)

(i) Mechanical power hammer
(ii) Pneumatic power hammer
(iii) Steam powered hammer

(c) For lot production of large jobs (pressing)

(i) Hydraulic Press
(ii) Mechanical Press

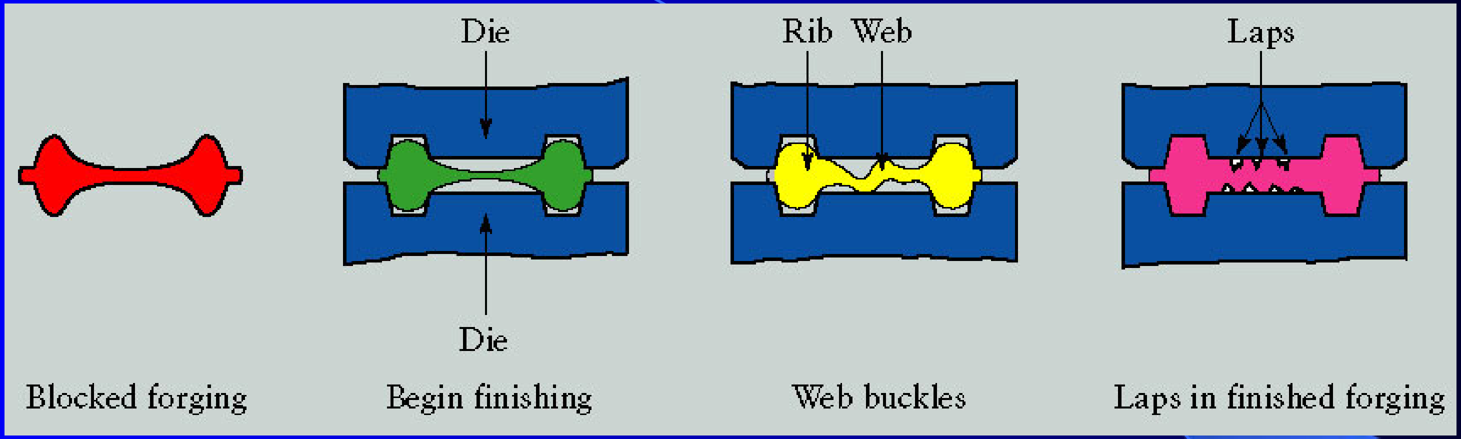
Presses Used In Metalworking



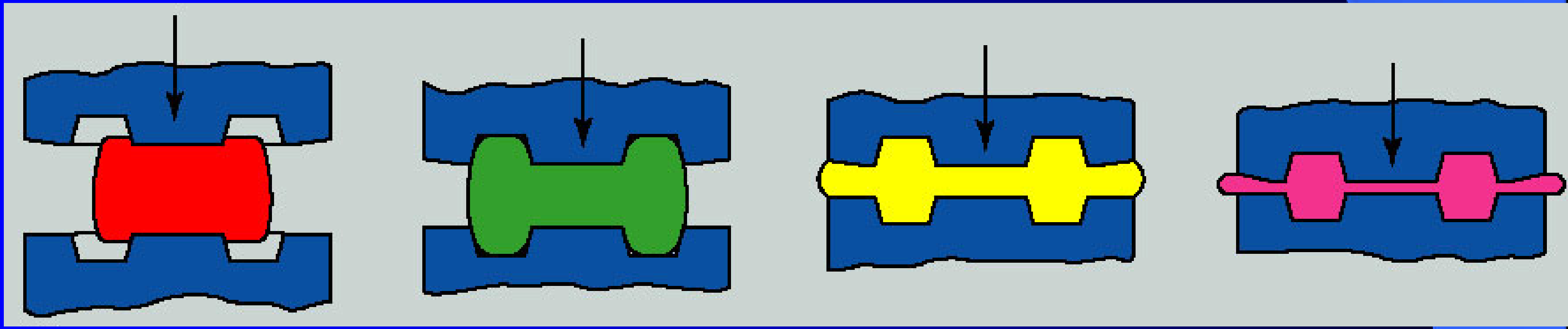
Schematic illustration of various types of presses used in metalworking. The choice of the press is an important factor in the overall operation.

Internal Defects In Forging

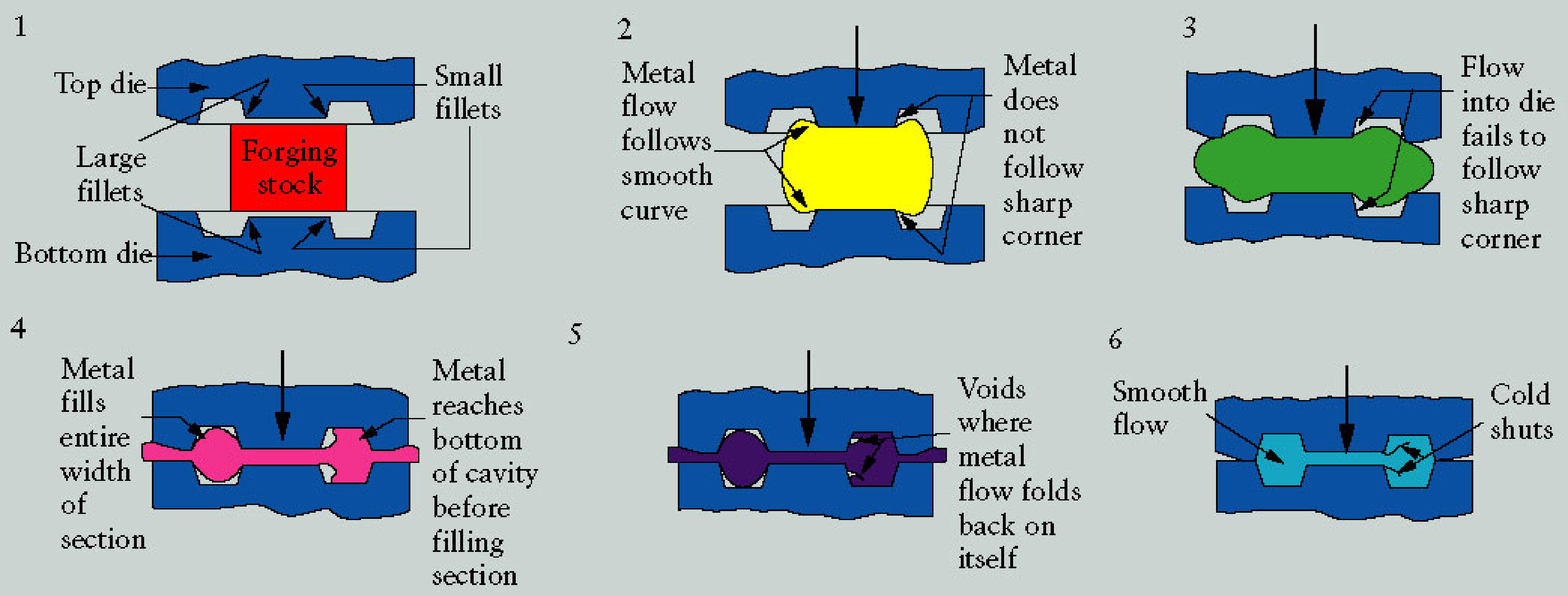
Laps formed by buckling of the web during forging.



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



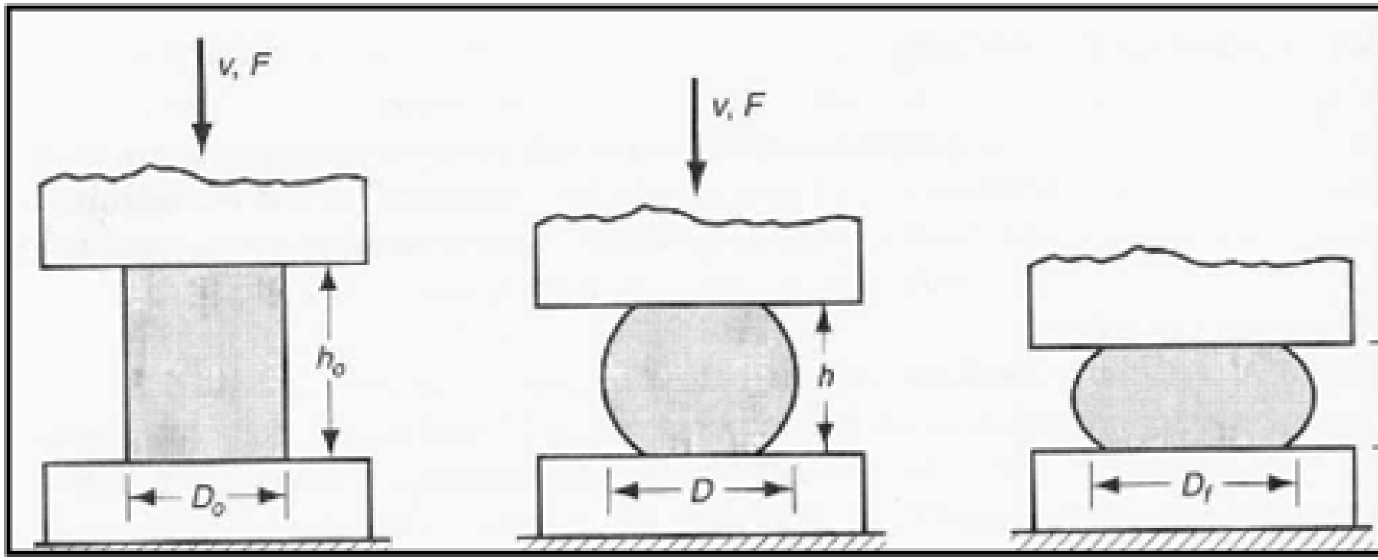
Defect Formation In Forging



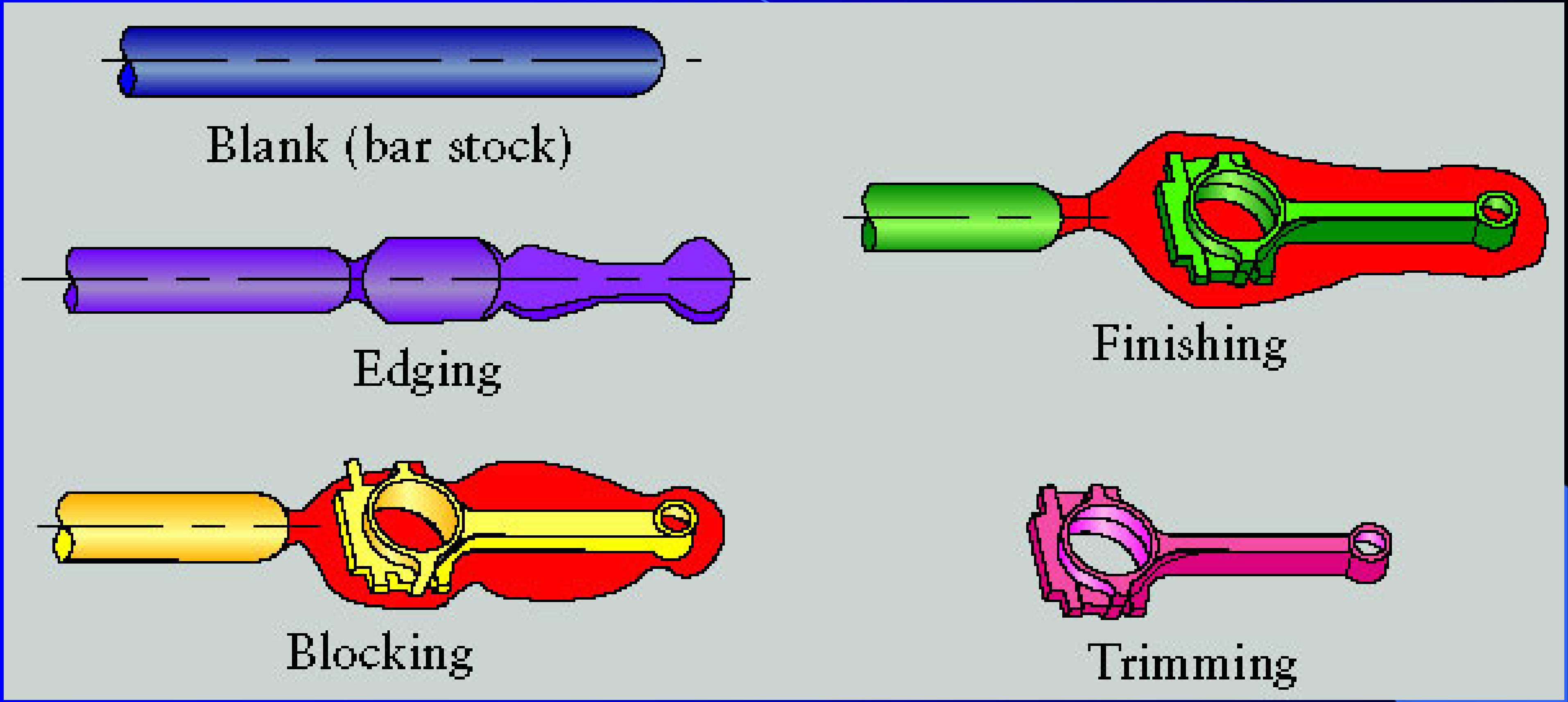
Effect of fillet radius on defect formation in forging. Small fillets (right side of drawings) cause the defects. *Source*: Aluminum Company of America.

Forging Defect

Barreling in forging



Forging A Connecting Rod



Stages in forging a connecting rod for an internal combustion engine. Note the amount of flash that is necessary to fill the die cavities properly.

EXTRUSION

It is a compression forming process in which the work metal is forced to flow through a die opening to produce a desired cross sectional shape.

Normally non ferrous metals and alloys like copper, brass, aluminium, zinc and magnesium are extruded.

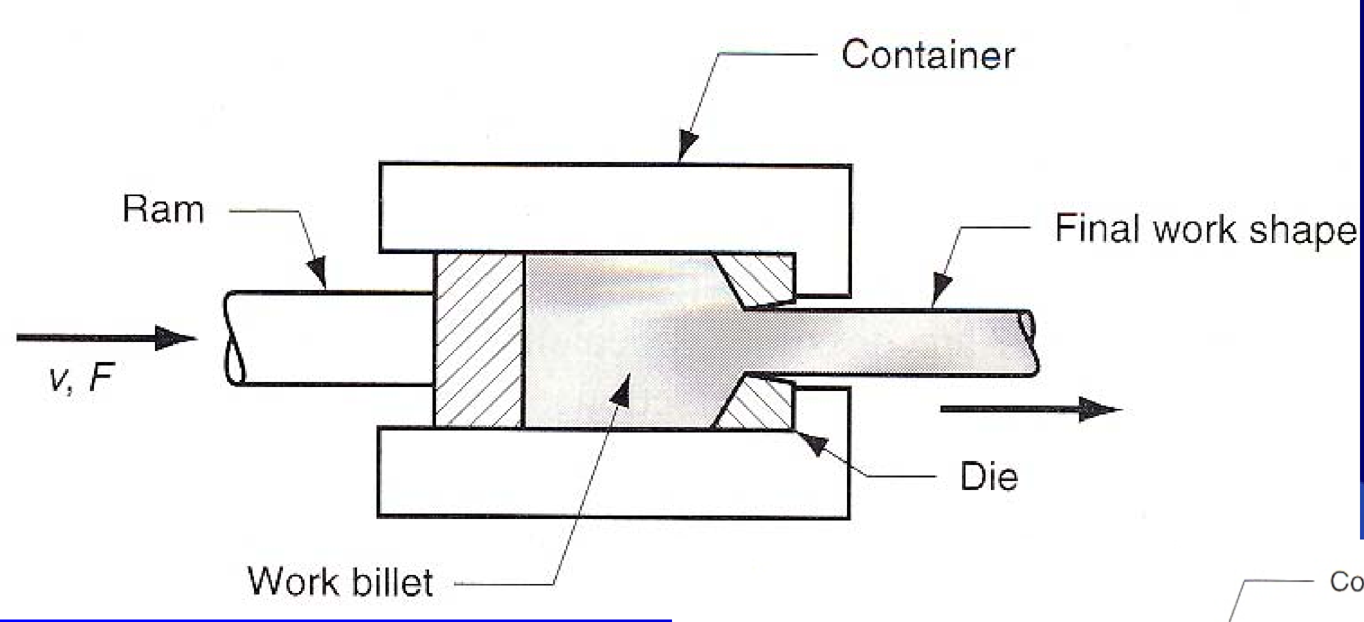
These days by proper choice of suitable lubricants and tooling metals such as steel, titanium, refractory metals, uranium and thorium can also be extruded.Stocks used are mainly cast ingot or rolled billet free of surface defects.

Advantages of Extrusion

A variety of shapes possible
Grain structure and strength can be enhanced in cold and warm extrusion
Close tolerances are possible
It is mostly a near net shape process

Two main varieties of extrusion possible

- Direct / forward extrusion
- Indirect / backward extrusion



Direct Extrusion

Production of hollow Or semi-hollow Cross sections by Direct extrusion

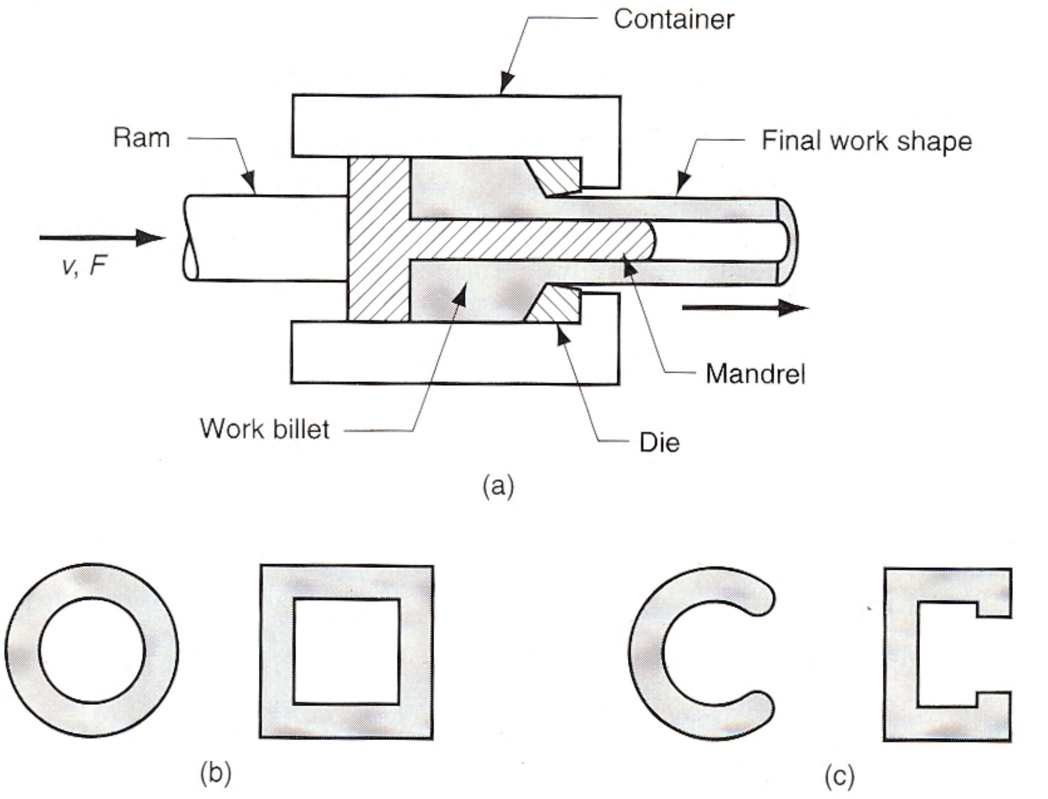
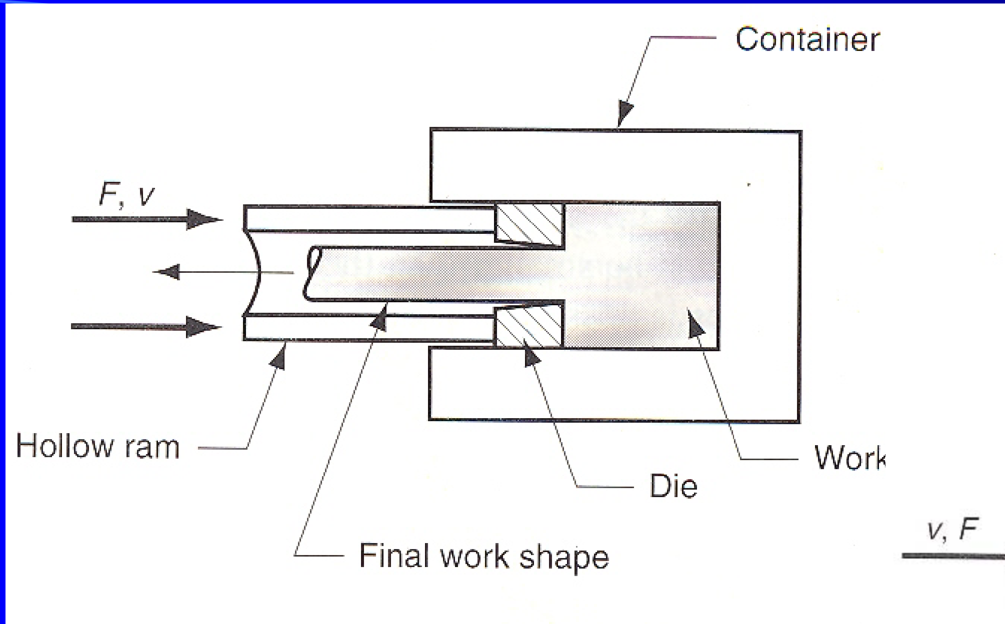
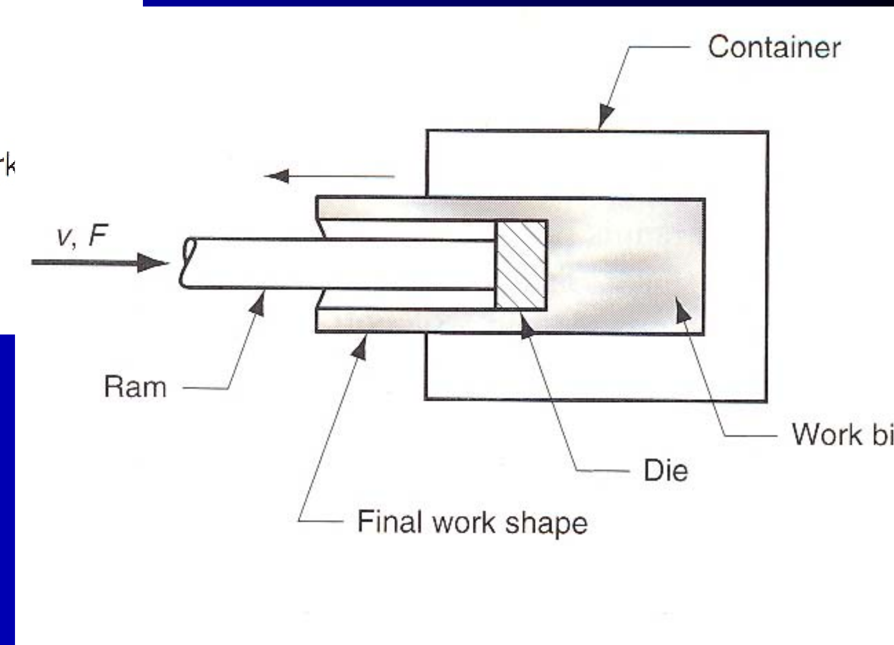


FIGURE 21.32 (a) Direct extrusion to produce a hollow or semihollow cross sec-



Indirect Extrusion

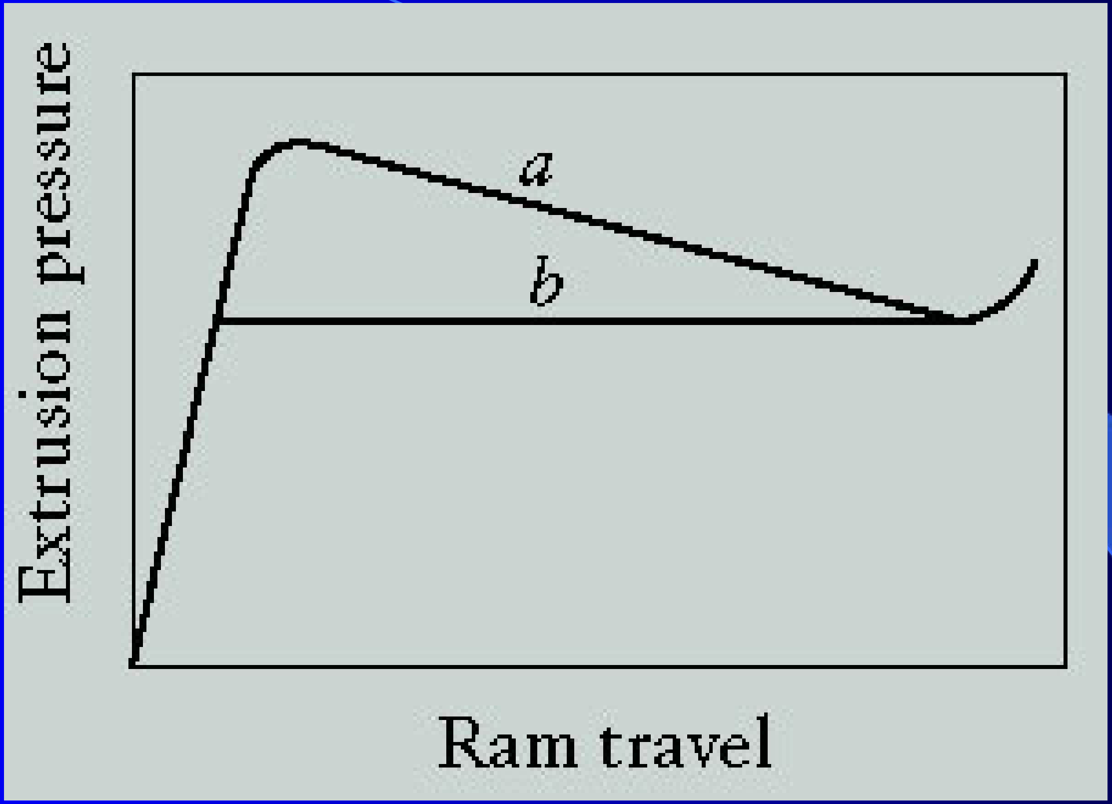


Indirect extrusion to produce hollow bars

Friction is low and waste scrap is only 5%. However tooling cost and press required are expensive.

Work length is limited. Ram support to be provided if work length is higher.

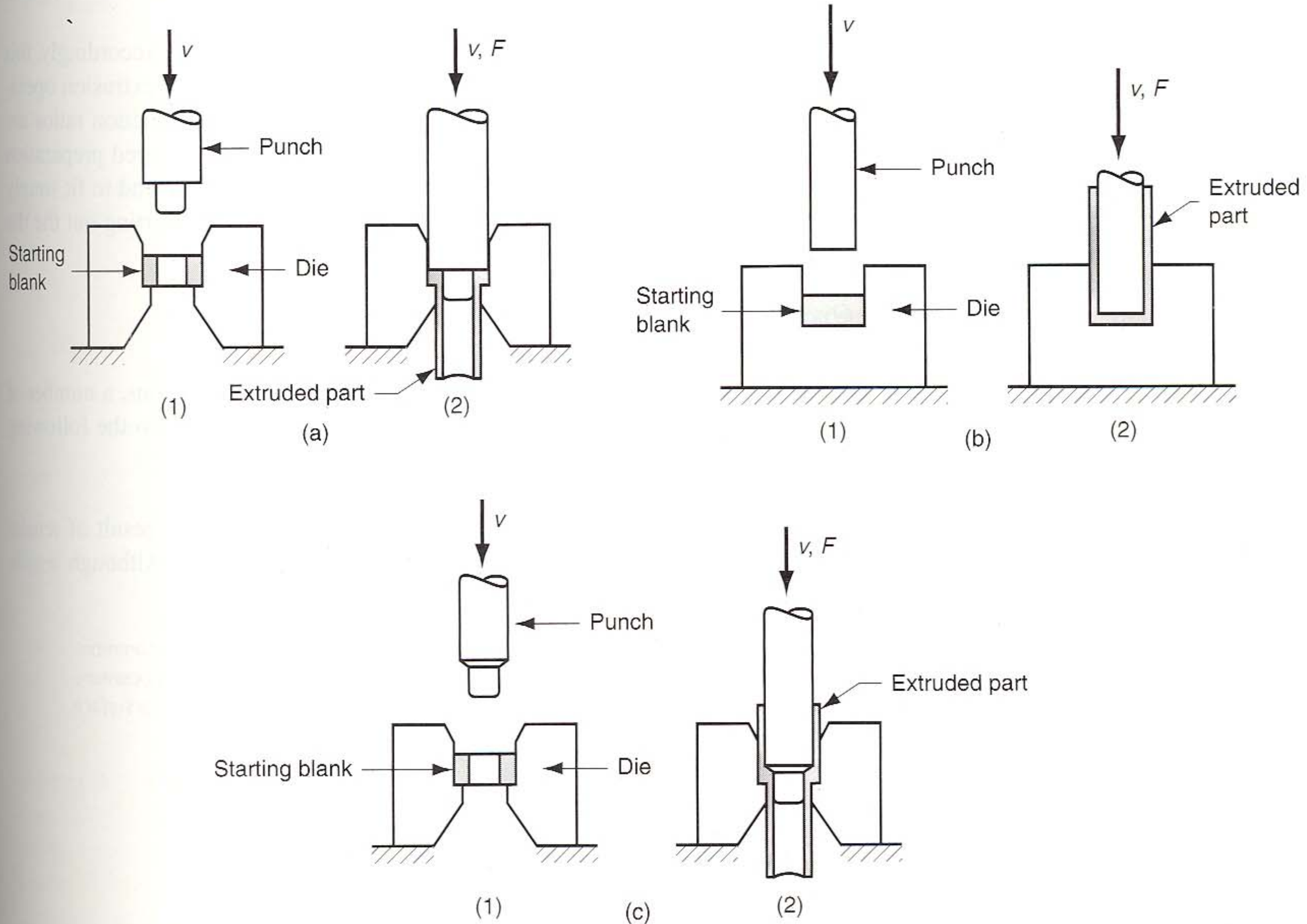
Extrusion Pressure



Schematic illustration of typical extrusion pressure as a function of ram travel: (a) direct extrusion and (b) indirect extrusion. The pressure in direct extrusion is higher because of frictional resistance in the chamber as the billet moves toward the die.

Impact Extrusion

FIGURE 21.40 Several examples of impact extrusion: (a) forward, (b) backward, and (c) combination of forward and backward.



Main features of Impact extrusion

It can be forward, backward or a combination of these.

Done under ambient condition on a variety of metals.

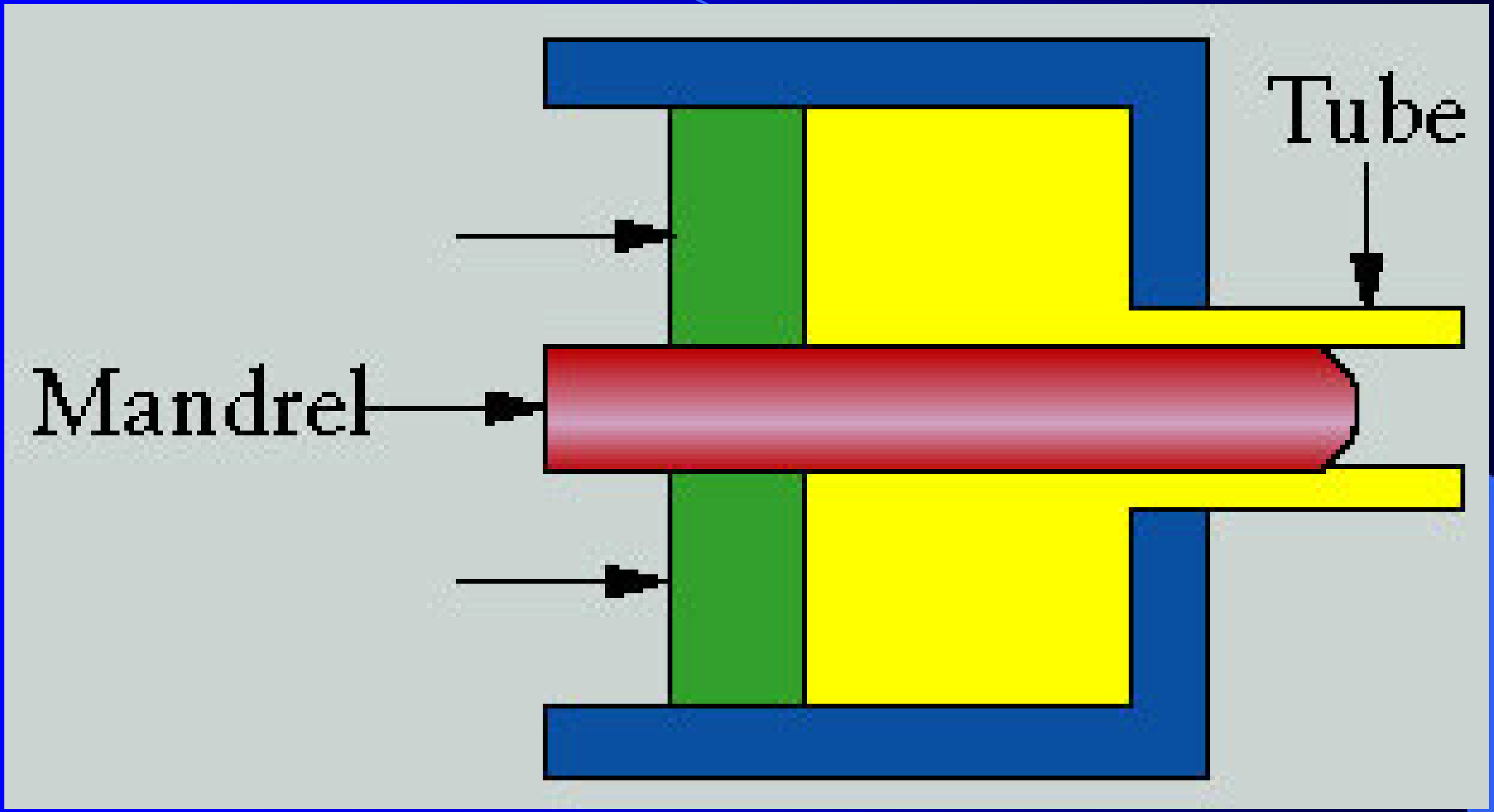
Backward extrusion is the most common.

Products made by this process includes toothpaste tubes and battery cases.

Very thin walls are possible on extruded parts.

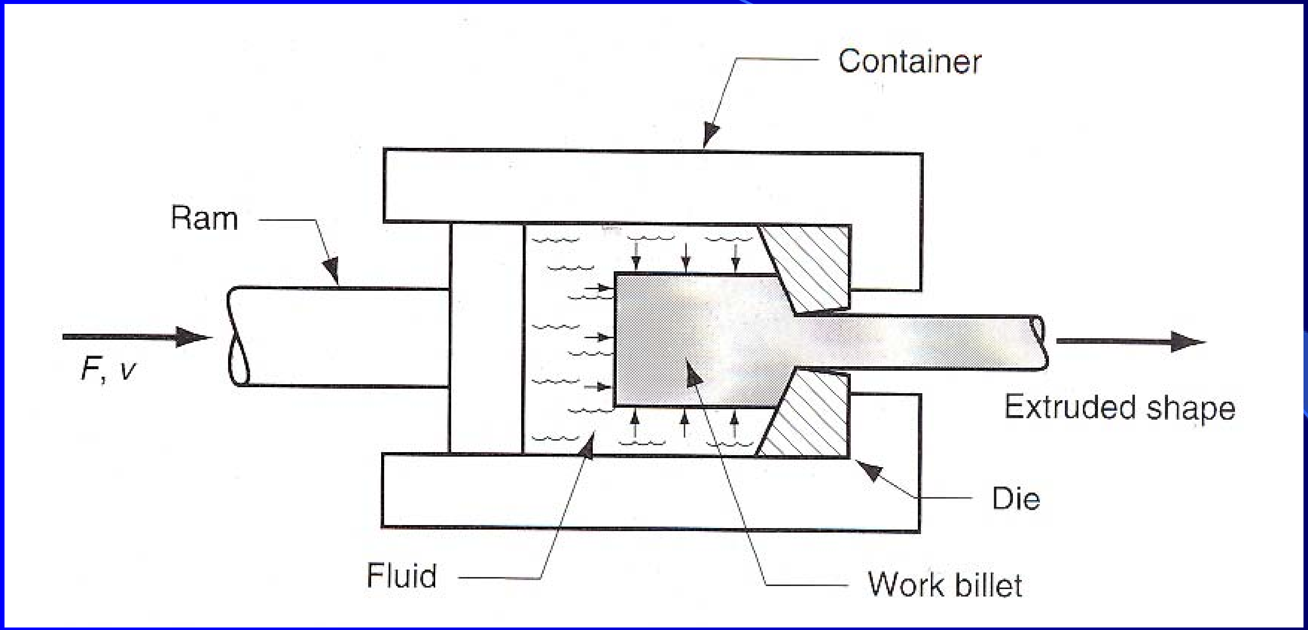
Larger reductions and high productivity can be achieved.

Extrusion of Seamless Tube



Extrusion of a seamless tube. The hole in the billet may be prepunched or pierced, or it may be generated during extrusion.

Hydrostatic Extrusion



Friction between billet and container gets reduced.The hydrostatic pressure increases work material ductility and hence suitable also for brittle materials. Limitation is that the starting material must have a taper at one end so that it can get fitted into the die entry angle. The taper actually acts as a seal preventing the fluid from coming out of the die hole.

Defects in Extrusion

- **Surface cracking**
- **Piping**
- **Internal cracking**

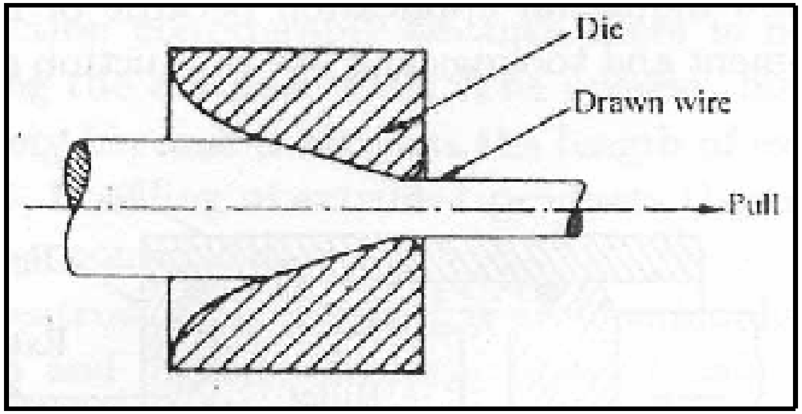
Surface cracking occurs when extrusion temp. is too high, Extrusion speed or friction is high. It can also happen at low Temp. especially when sticking of the extruded matl. With Die takes place

Piping occurs when surface oxides or impurities present In the material are drawn towards the centre of the billet. to prevent piping sometimes machining of the billet is performed to remove surface scales and impurities

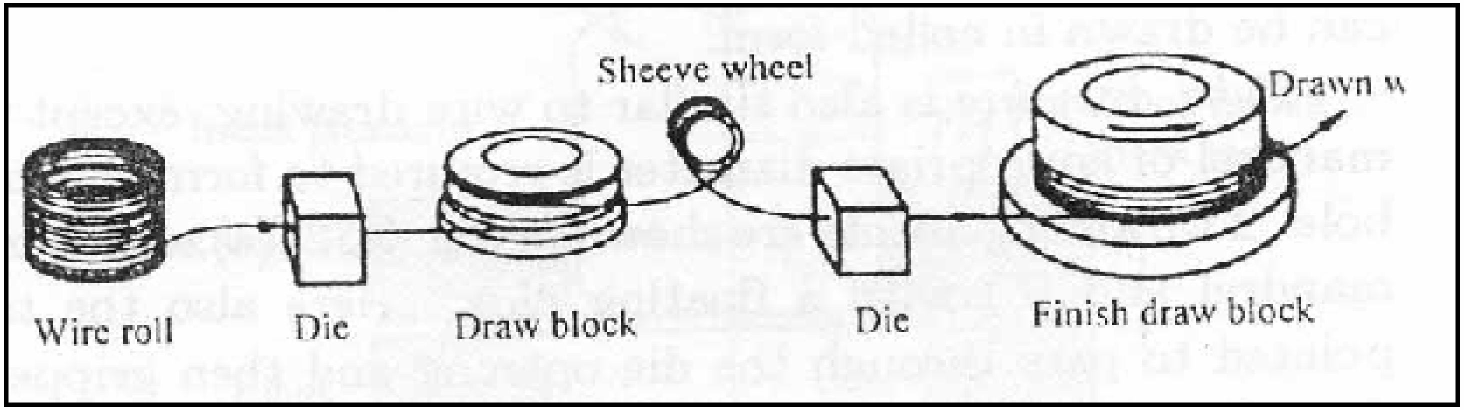
The centre of an extruded product may develop cracks known as centerbursts due to a state of hydrostatic tensile Stress at the centerline of the deformation zone in the die

Drawing

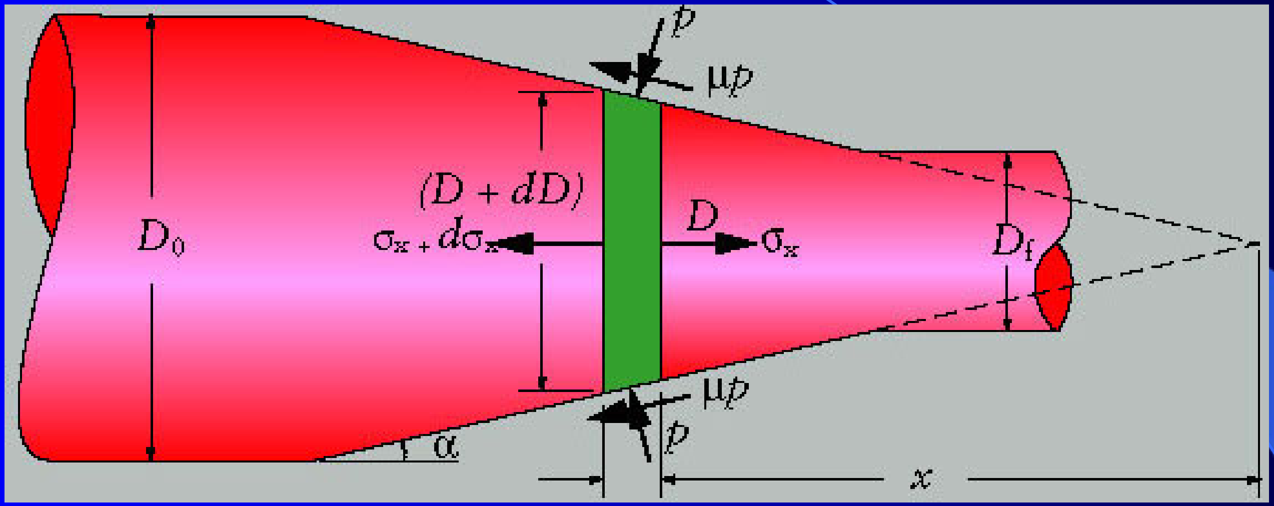
- Large quantities of wires, rods, tubes and other sections are produced by drawing process which is basically a cold working process. In this process the material is pulled through a die in order to reduce it to the desired shape and size.
- In a typical wire drawing operation, once end of the wire is reduced and passed through the opening of the die, gripped and pulled to reduce its diameter.



- By successive drawing operation through dies of reducing diameter the wire can be reduced to a very small diameter.
- Annealing before each drawing operation permits large area reduction.
- Tungsten Carbide dies are used to for drawing hard wires, and diamond dies is the choice for fine wires.



Stress On Wire

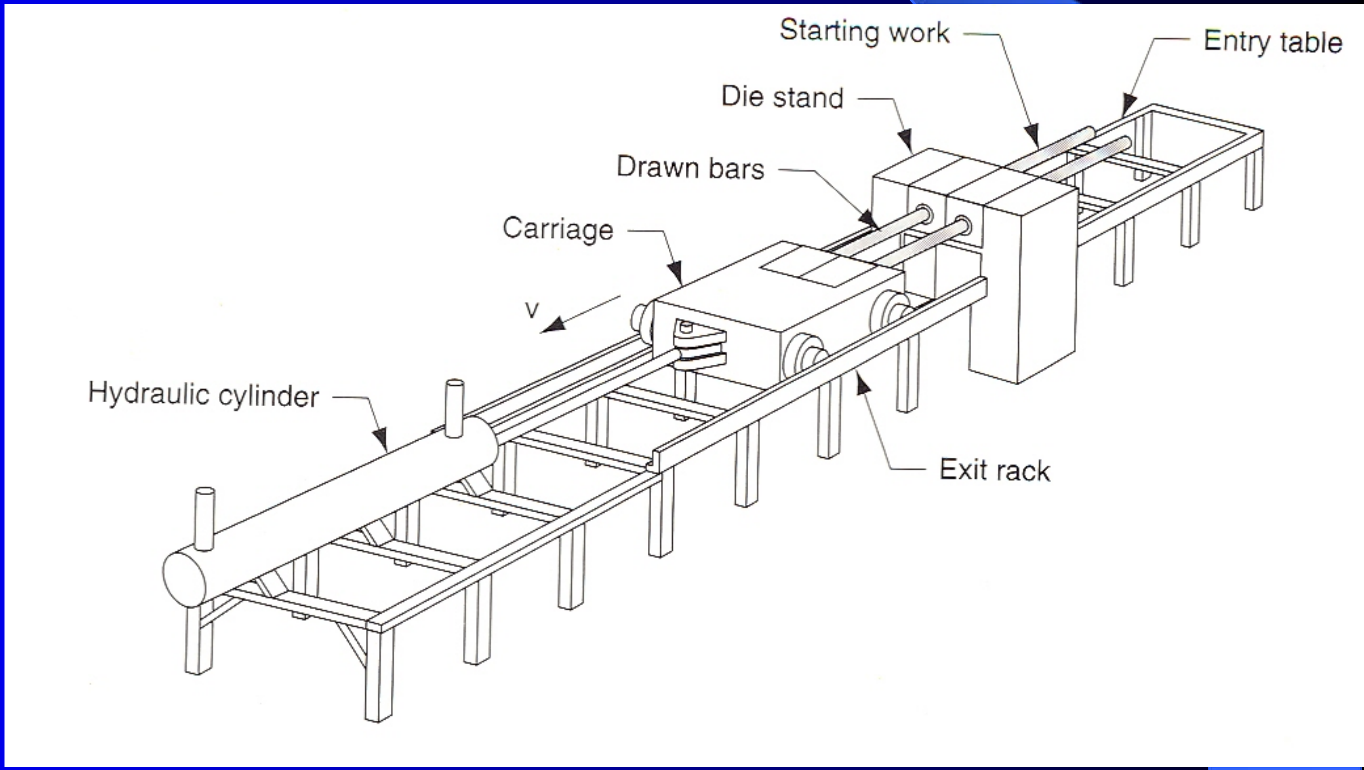


Stresses acting on an element in drawing of a solid cylindrical rod or wire through a conical converging die.

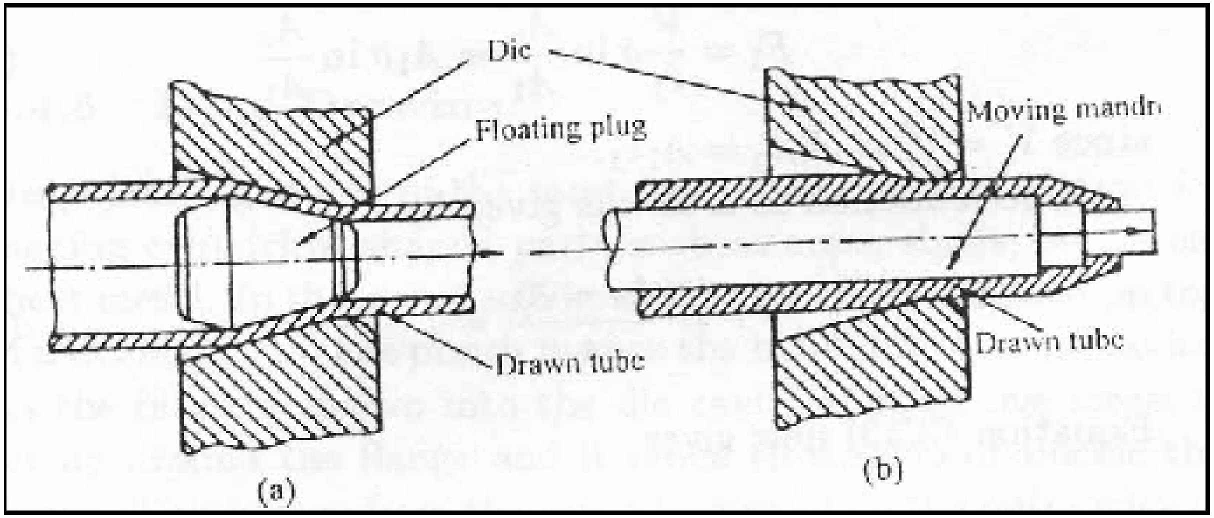
Advantages of Drawing

- Close dimensional tolerance
- Good surface finish
- Improved mechanical properties
- Adaptability to economic batch or mass production

Drawing Equipment

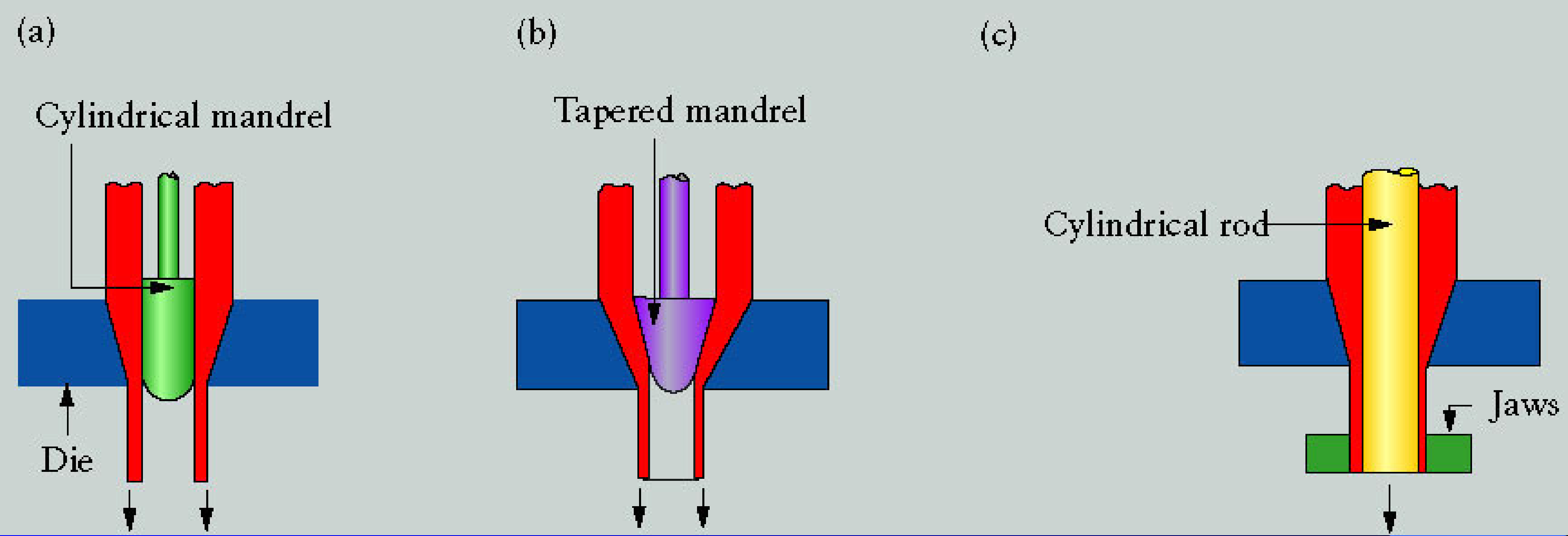


Tube drawing



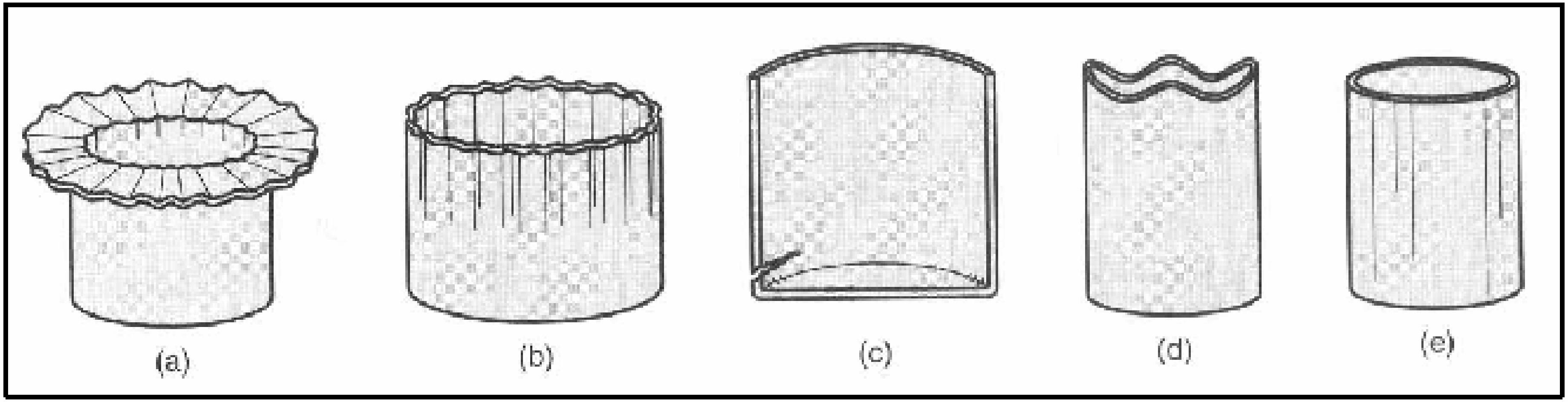
- Tube drawing is also similar to wire drawing, except that a mandrel of appropriate diameter is required to form the internal hole.
- Here two arrangements are shown in figure (a) with a floating plug and (b) with a moving mandrel
- The process reduces the diameter and thickness of the tube.

Tube Drawing



Various methods of tube drawing.

Defects in drawing



(a)Wrinkling in the flange or (b) in the wall (c) tearing,
(d) earing, (e) surface scratches

Sheet Metal working

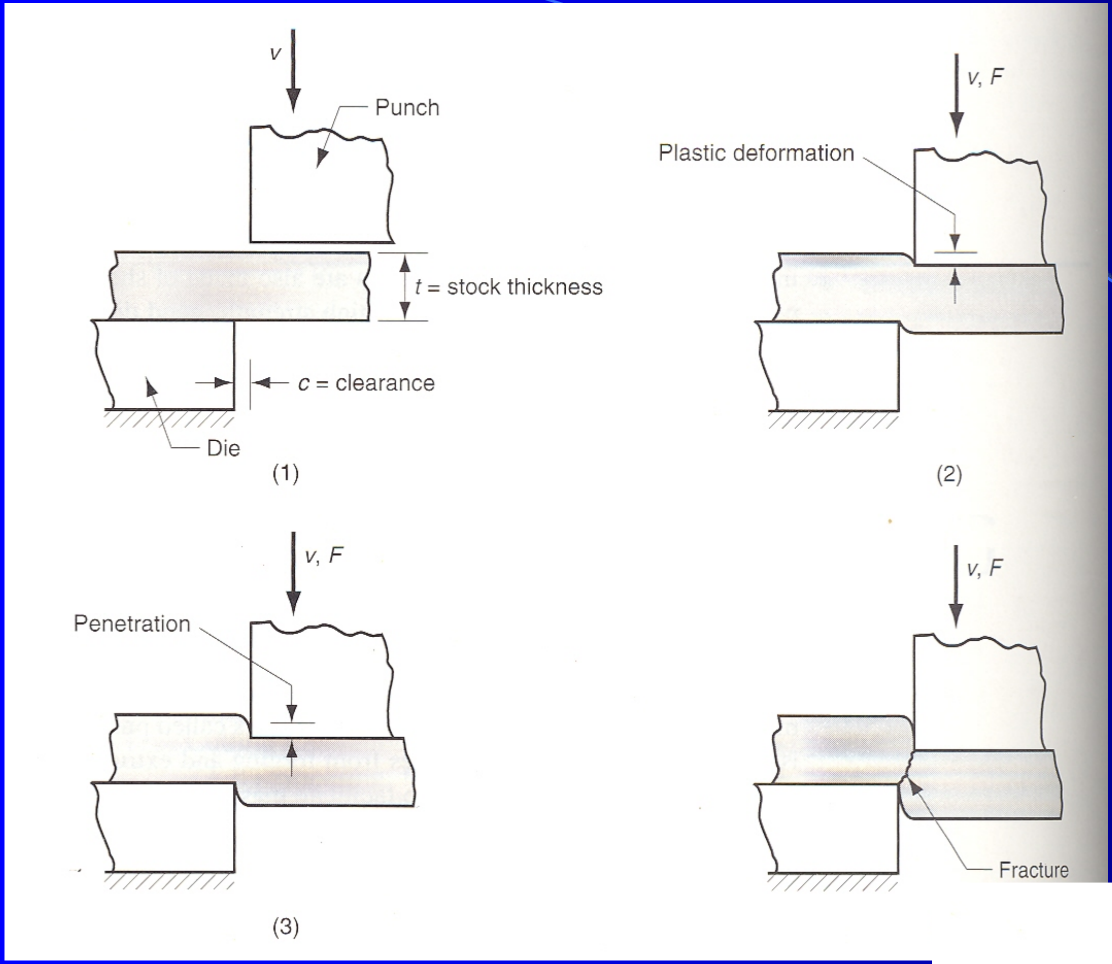
Sheet metals are characterized by

- High strength
- Good dimensional accuracy
- Good surface finish
- Relatively low cost

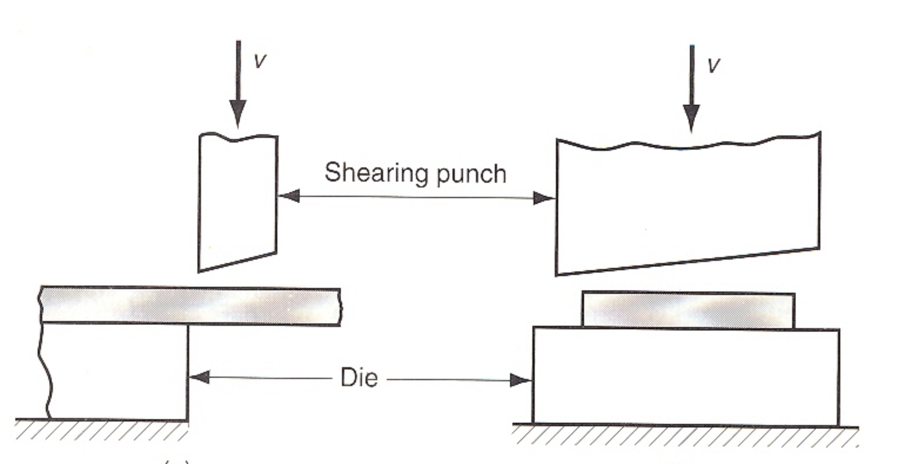
Sheet Metal operations(press working) can be broadly divided into two groups:

- Cutting operations like shearing, cut off, parting, blankin
- punching, notching, shaving
- Shape forming operations like bending, deep drawing, embossing, coining, stretch forming

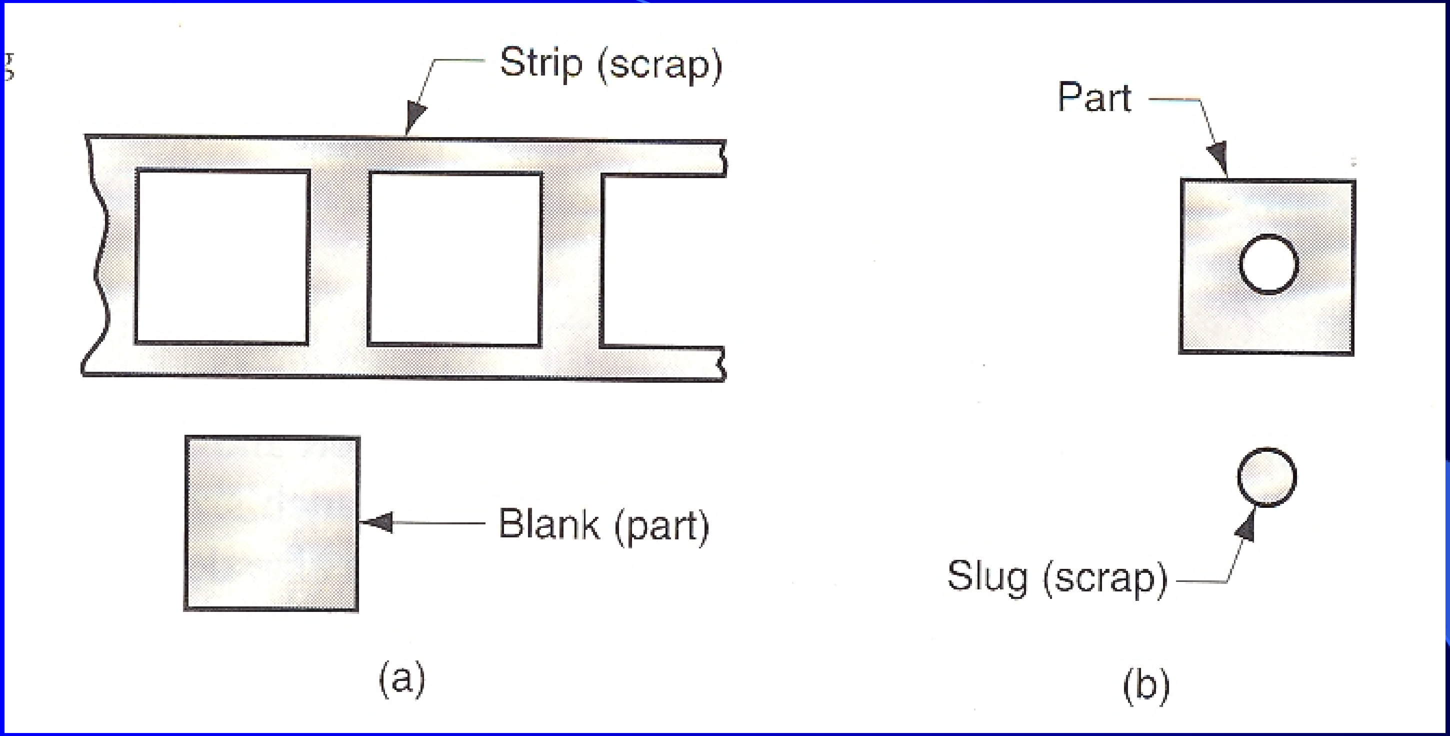
Cutting Operations



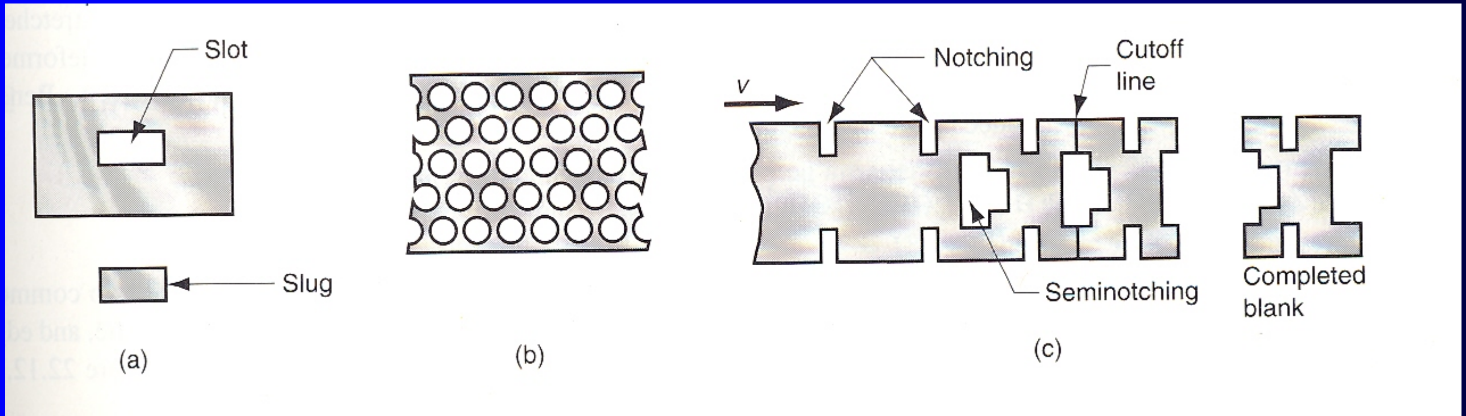
Shearing



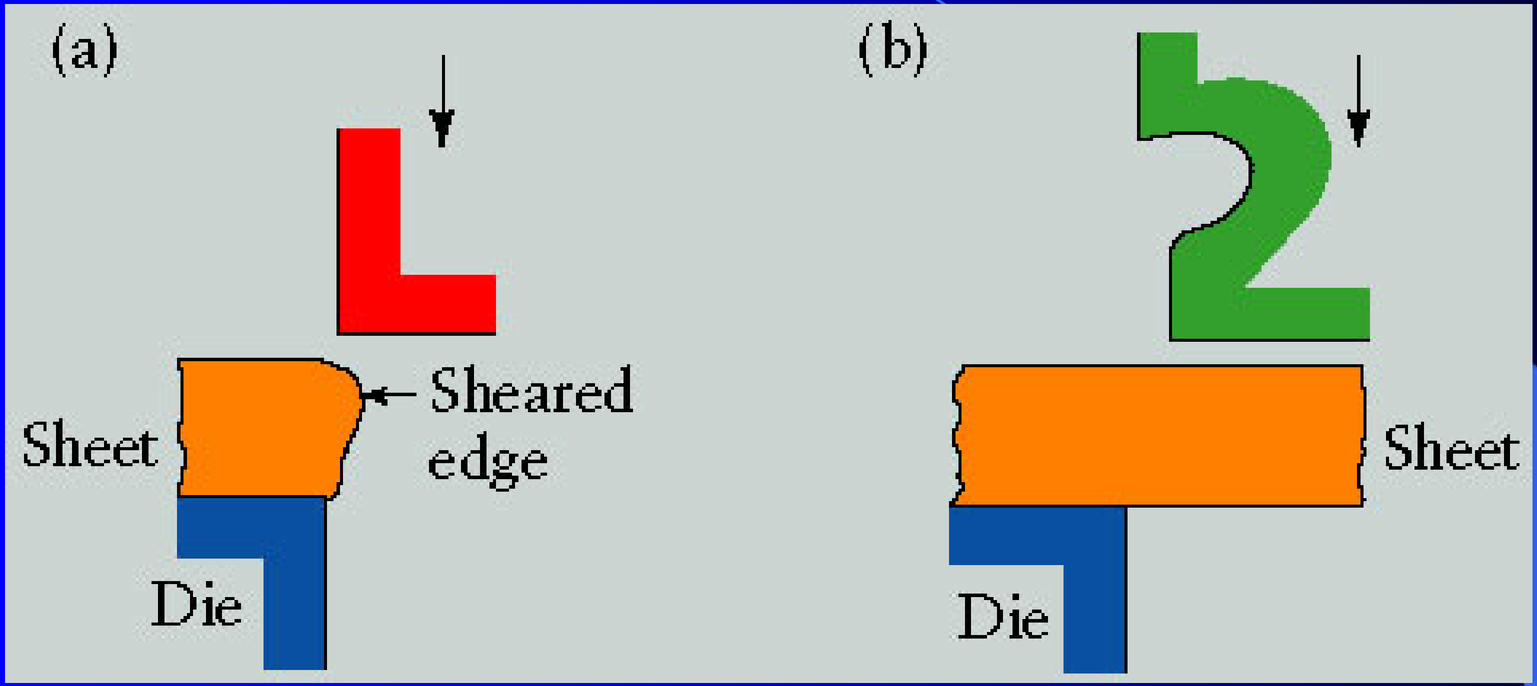
Blanking Punching



Slotting Perforating Notching



Shaving Operation



Shaving

Shearing shaving combined

Bending Operation

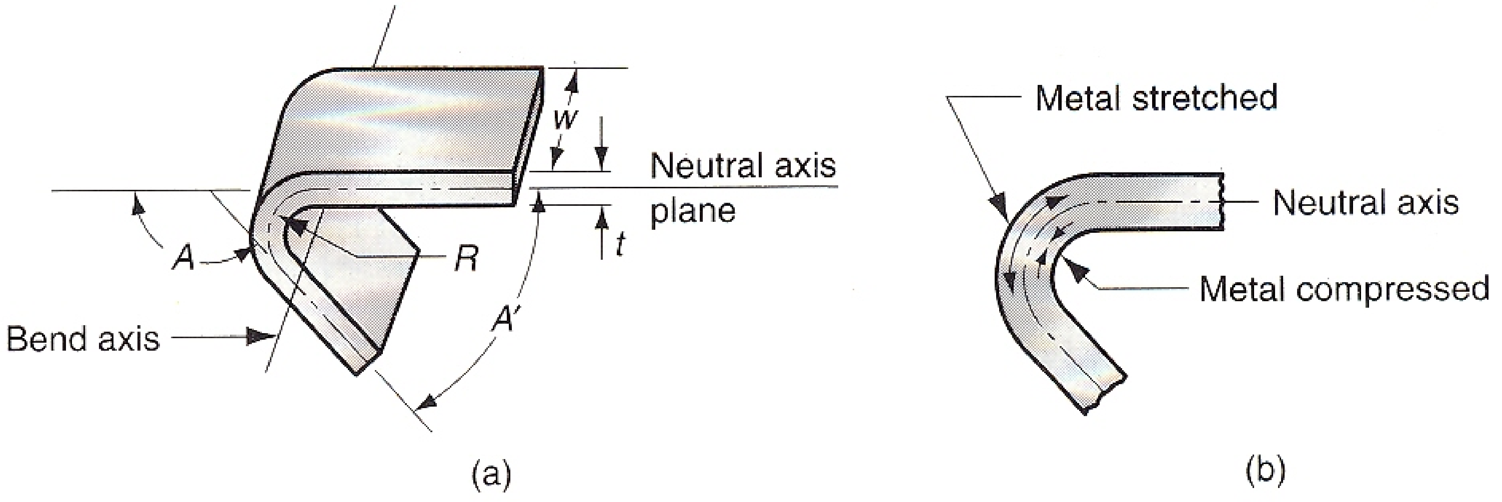
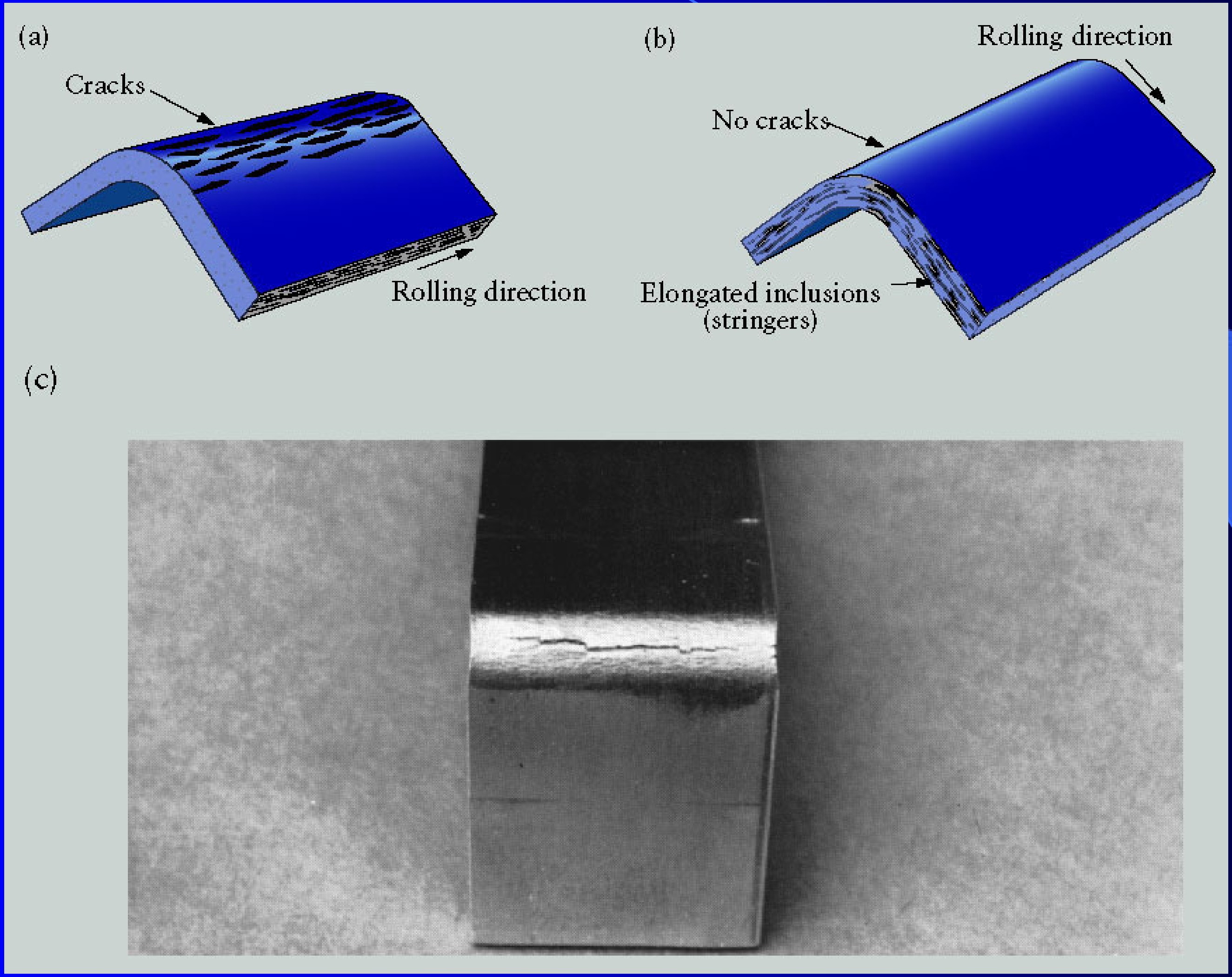


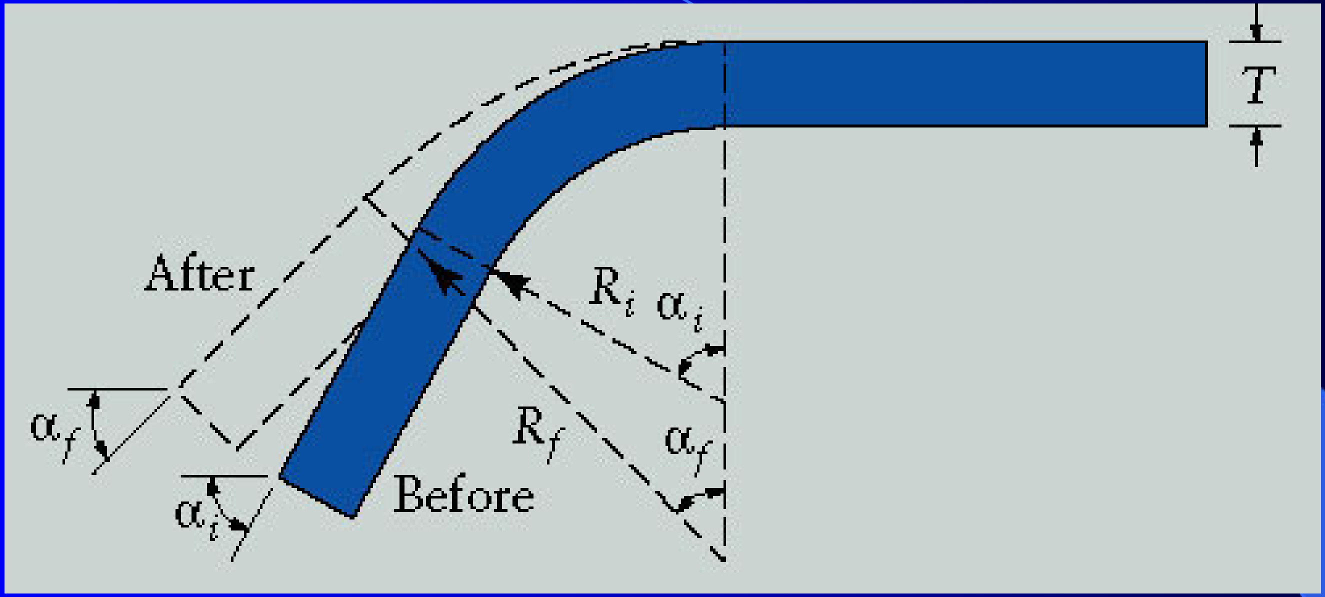
FIGURE 22.11 (a) Bending of sheet metal; (b) both compression and tensile elongation of the metal occur in bending.

Bending is the straining of the metal around a straight axis
Metal on the inside of the neutral plane is compressed while the metal on the outside is stretched.
Bending produces little or no change in thickness.

The Effect of Elongated Inclusions

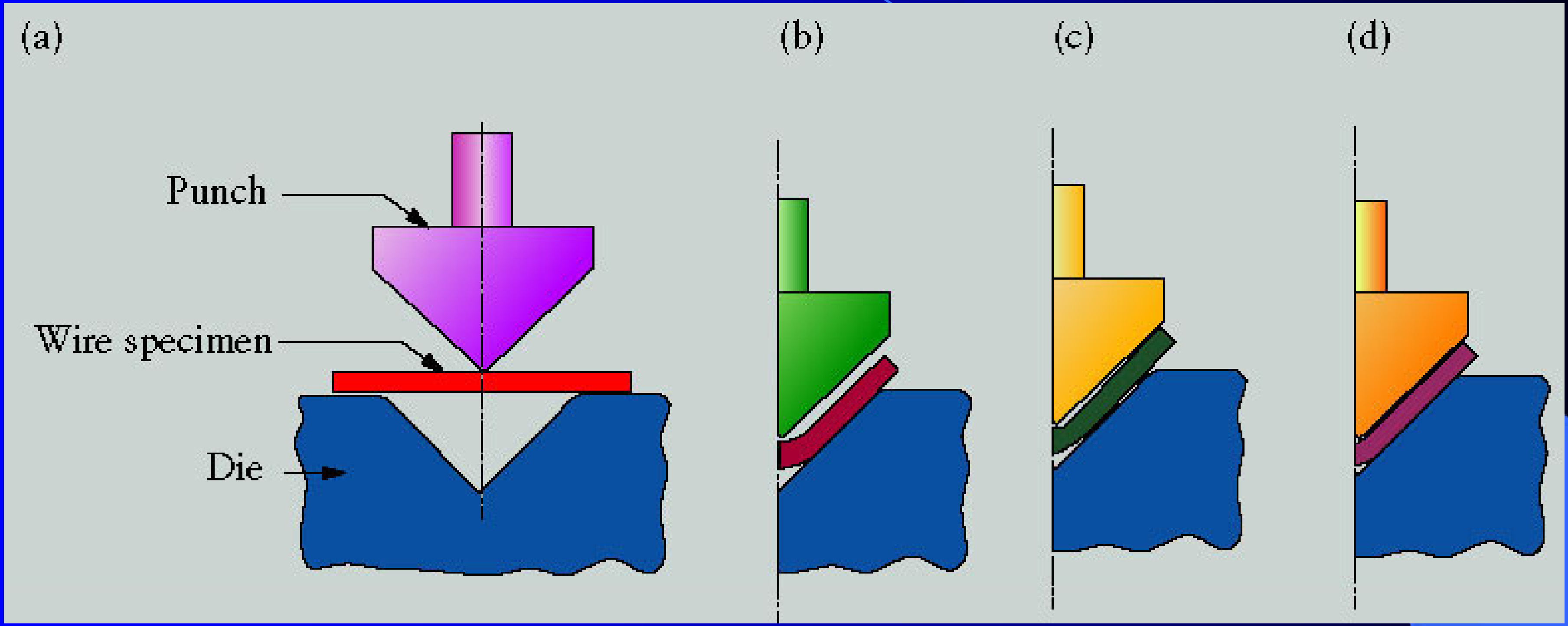


The Effect of Springback in Bending

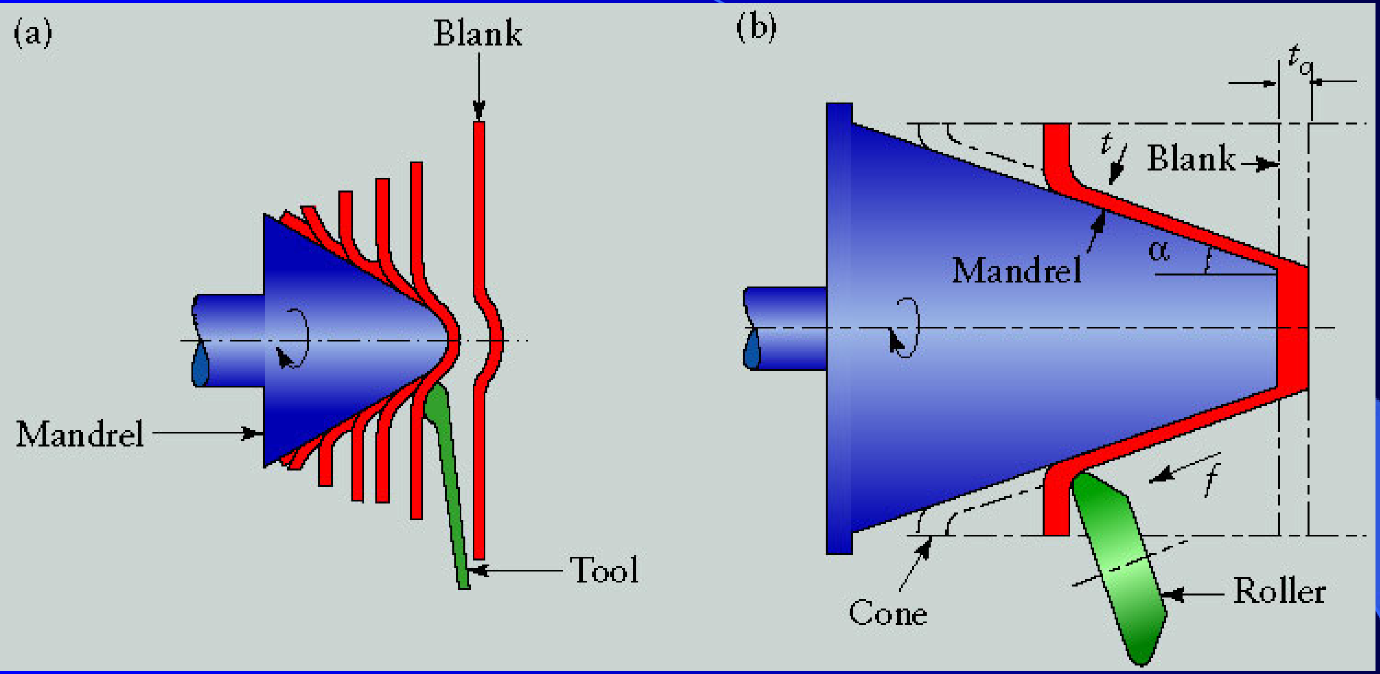


Springback is caused by the elastic recovery of the material upon unloading. In this example, the material tends to recover toward its originally flat shape. However, there are situations where the material bends farther upon unloading (negative springback).

Negative Springback

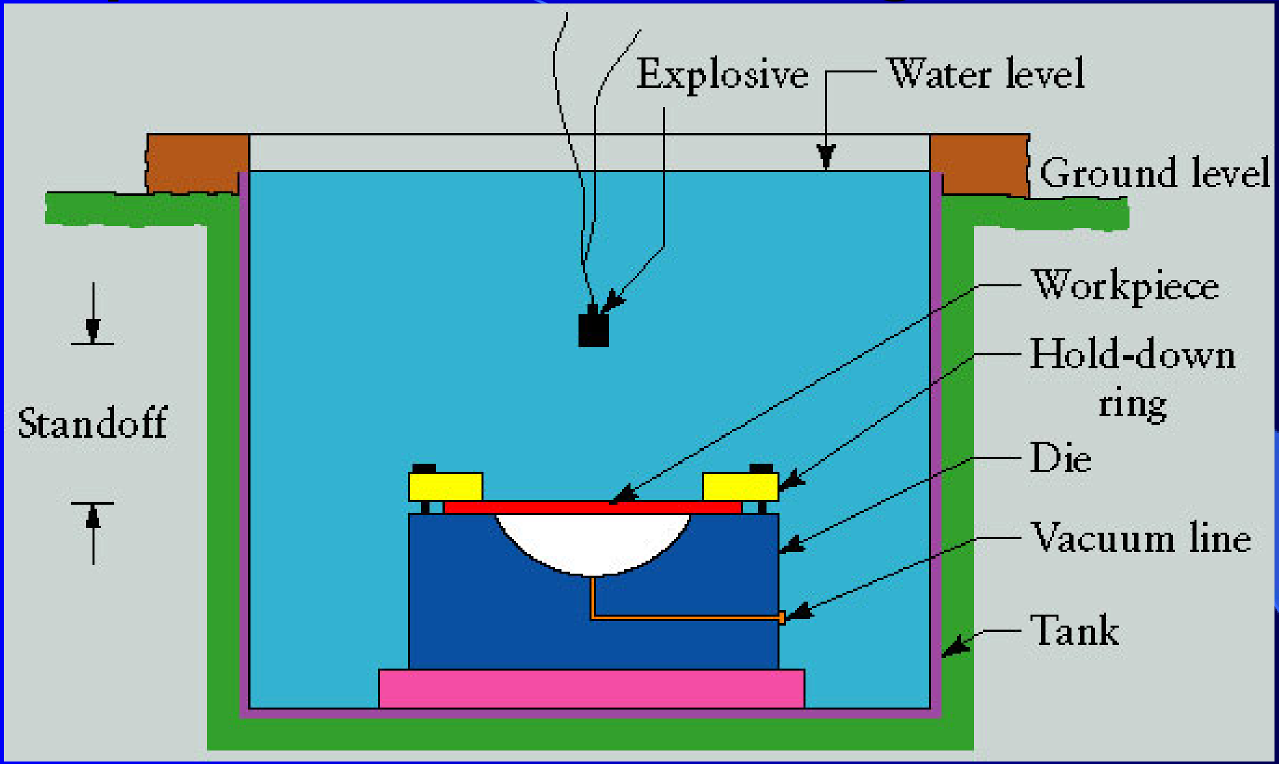


Spinning Processes



Schematic illustration of spinning processes: (a) conventional spinning and (b) shear spinning. Note that in shear spinning, the diameter of the spun part, unlike in conventional spinning, is the same as that of the blank. The quantity f is the feed (in mm/rev or in./rev).

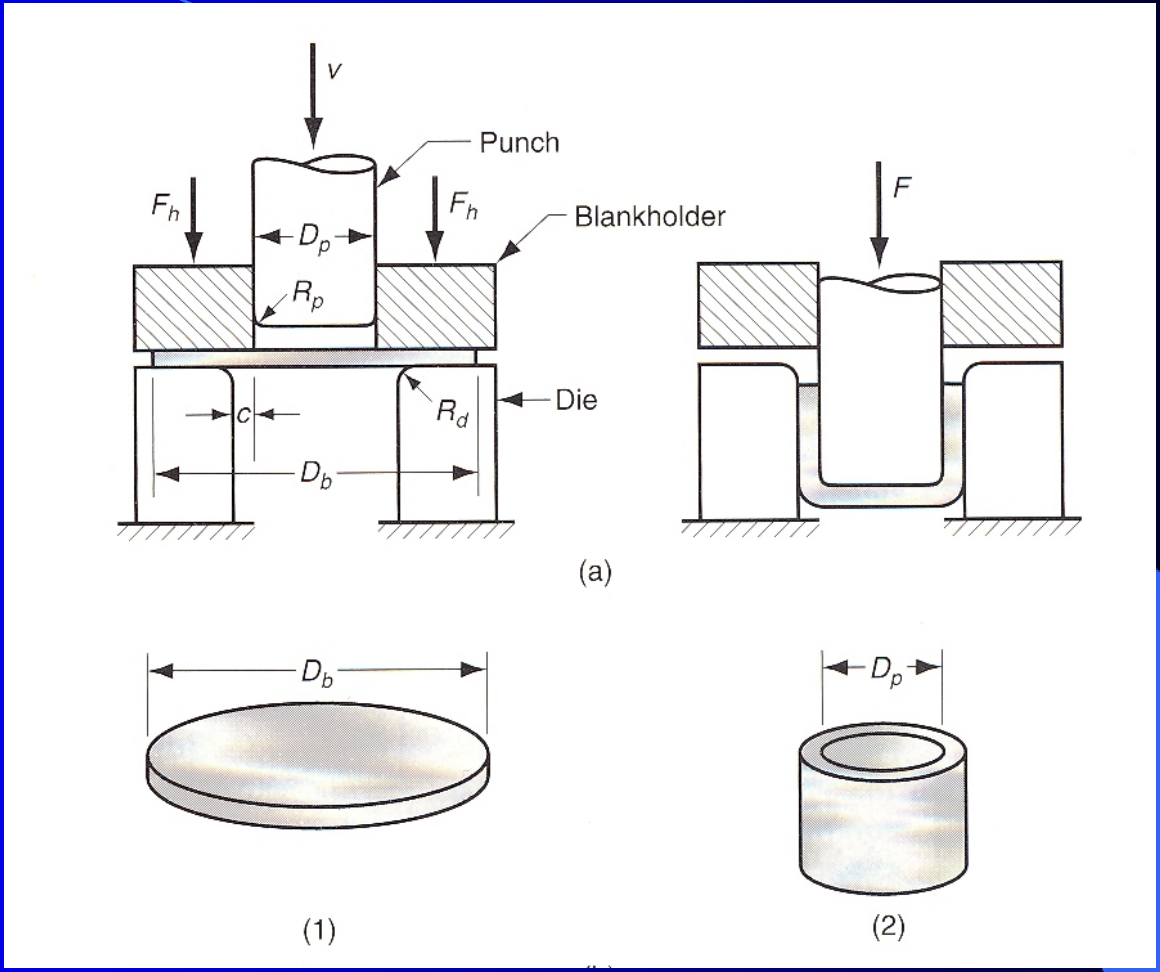
Explosive Forming Process



Schematic illustration of the explosive-forming process. Although explosives are generally used for destructive purposes, their energy can be controlled and employed in forming large parts that would otherwise be difficult or expensive to produce by other methods.

Sheet Metal Working

Deep Drawing



Common products are beverage cans, ammunition shells, cooking pots, automobile body panels.

Comparison of metal forming processes

Metal Forming Process	Advantages	Limitations
Open-die forging	• Inexpensive tooling and equipment. • Simple to operate. • Wide range of workpiece sizes can be used. • Suitable for low production volume.	• Can be used for simple shapes only. • Fairly skilled operators are required. • Production rate is low. • Dimensional accuracy and surface finish achieved are poorer. • Finishing required for achieving final shape.
Closed-die forging	• Suitable for high production rate. • Can be used for production of complex shapes. • Good dimensional accuracy and reproducibility	• High equipment and tooling cost. • Appropriate die set for production of each component. • More than one step required for each forging. • Finishing required for achieving final shape.
Hot rolling	• High production rate. • Suitable for large reduction. • Wide range of shapes (Billets, blooms, slabs, sheets, bars, tubes, structural sections, etc.) can be produced	• High equipment cost • Suitable for production of large sections. • Poor dimensional accuracy and finish.

Metal Forming Process	Advantages	Limitations
Cold rolling	• High production rate. • Suitable for production of plates, sheets, foils, etc. • Good dimensional accuracy and finish.	• High equipment cost. • Deformation limited to small reductions.
Hot extrusion	• Moderate cost of equipment and toolings. • Suitable for large reduction. • Complex sections and long products can be produced.	• Only constant cross-section can be produced. • Components with thin walls are difficult to produce. • Lubrication is necessary. • Dimensional accuracy and finish achieved are not good.
Impact extrusion	• High production rate. • Good finish and dimensional accuracy. • Generally no finishing is required. • Suitable for production of thin sections.	• Suitable for production of light components from softer materials. • Deformation limited to small reductions.

Metal Forming Process	Advantages	Limitations
Drawing	• Low equipment and tooling cost. • Good surface finish and dimensional accuracy. • High production rate. • Long lengths of rounds, tubings, square, angles, etc. can be produced.	• Deformation limited to small reductions. • Production of constant cross-sections only. • Lubrication is necessary.
Deep drawing	• High production rate. • Moderate equipment and tooling cost. • Good surface finish.	• Limited to forming of thin sheets. • Forming of shallow or deep parts of simple shapes only. • Finishing required
Punching and blanking	• High production rate. • Low cost of labour. • Almost any shape can be obtained. • Moderate equipment cost.	• Limited to thin sheet applications. • Cost of tooling can be high.