Manufacturing Processes
UTA026

Introduction to Metal Forming

METAL FORMING

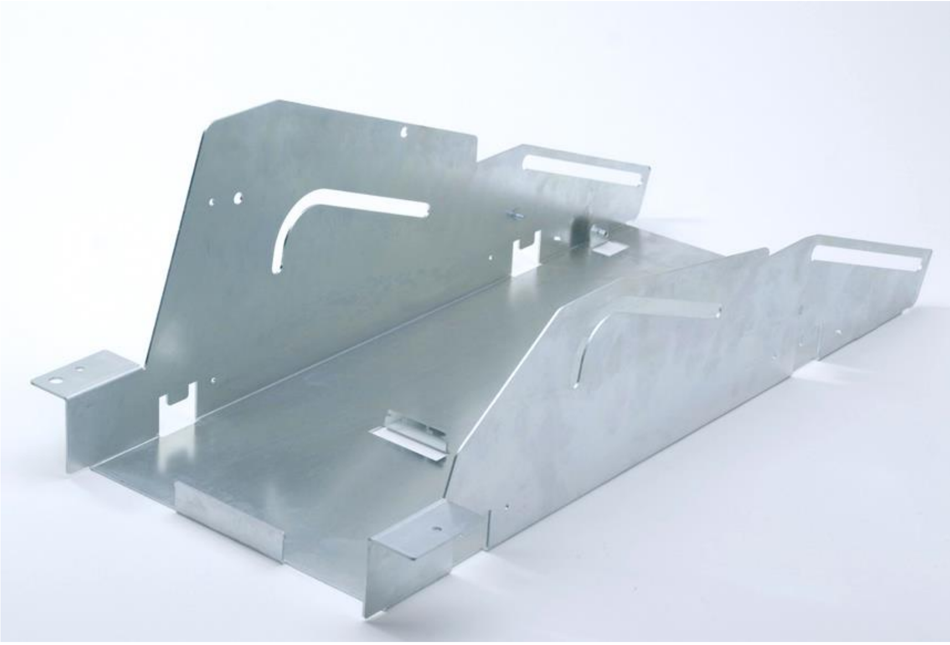
- ***Metal forming*** includes a large group of manufacturing processes in which ***plastic deformation*** is used ***to change the shape*** of metal workpieces.
- Deformation results from the use of a tool, usually called a ***die*** in metal forming, which applies stresses that ***exceed the yield strength*** of the metal.
- The metal therefore ***deforms*** to take a shape determined by the ***geometry of the die***.

METAL FORMING

- Stresses applied to ***plastically deform*** the metal are usually ***compressive***.
- However, some forming processes ***stretch*** the metal, while others ***bend*** the metal, and still others apply ***shear*** stresses to the metal.

METAL FORMING

METAL FORMING



Remembering stress strain diagram

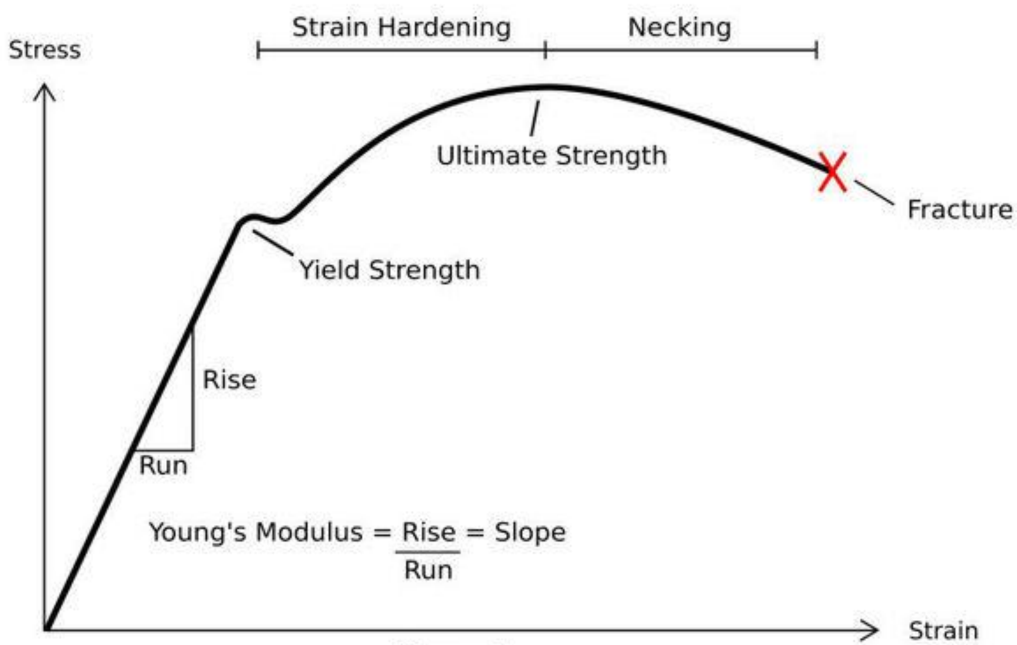
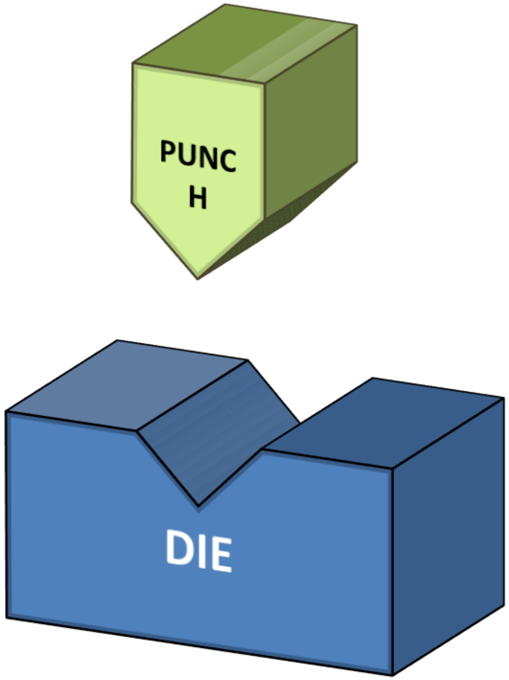
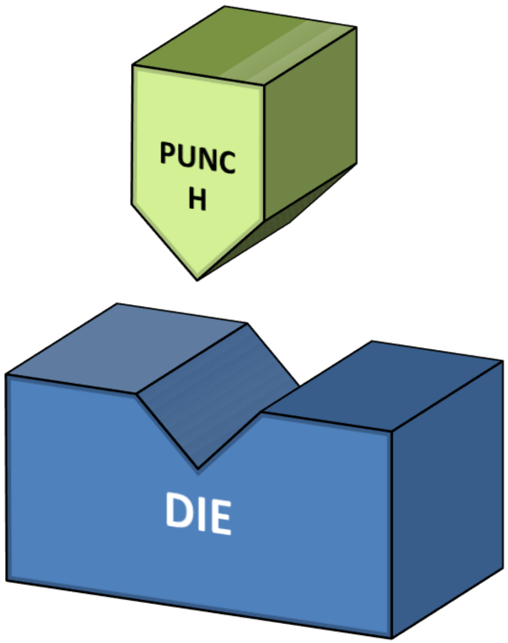


Figure 1

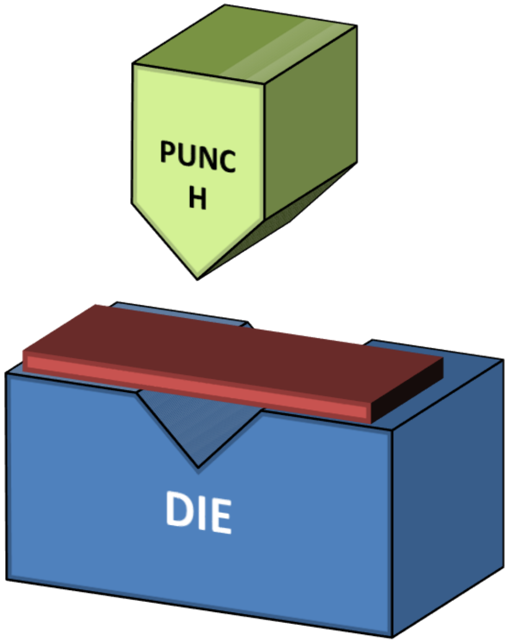
PUNCH AND DIE



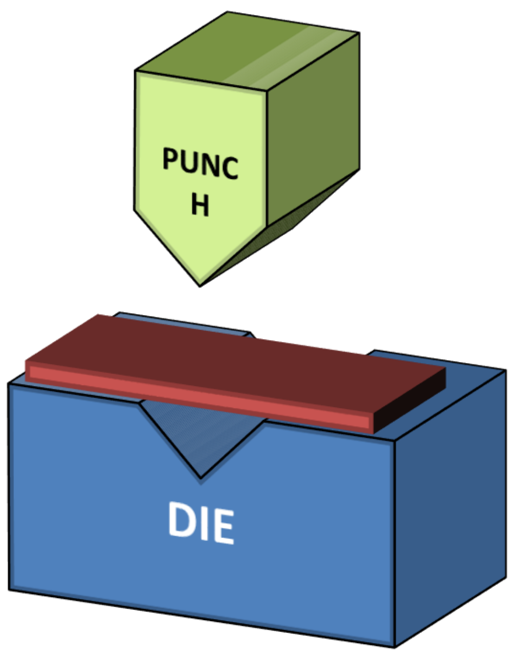
METAL FORMING



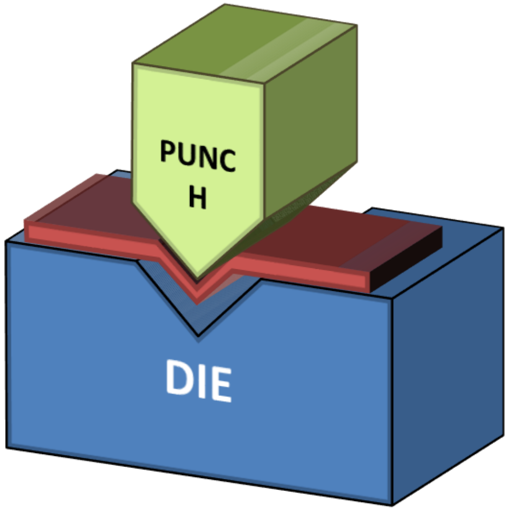
METAL FORMING



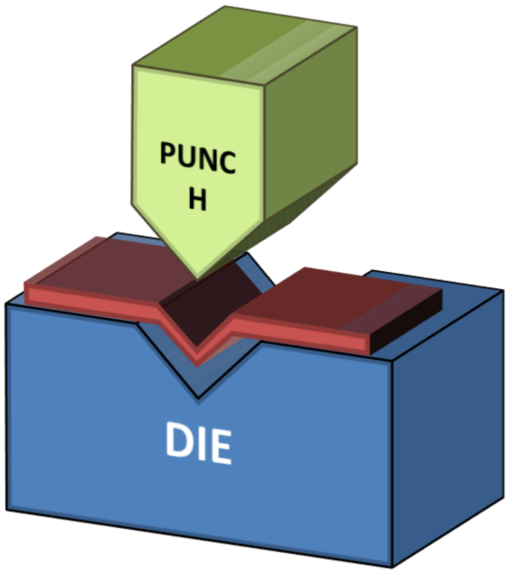
METAL FORMING



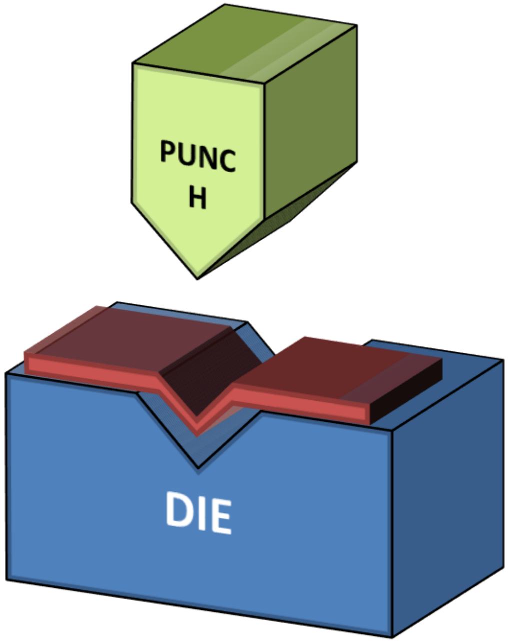
METAL FORMING



METAL FORMING



METAL FORMING



METAL FORMING

- Since the material is ***simply moved*** (or ***rearranged***) to produce the shape, as opposed to cutting away unwanted regions, the amount of ***waste can be substantially reduced***.
- Unfortunately, the ***forces required*** are often ***high***.
- Machinery and tooling can be quite expensive for metal forming operations.

METAL FORMING

- To be successfully formed, a metal must possess certain properties.
- Desirable properties include
  - ***low yield strength*** and
  - ***high ductility***.
- These properties are affected by ***temperature***.

EFFECT OF TEMPERATURE

- In metalworking operations, workpiece ***temperature*** can be one of the ***most important process variables***.
- In general, an ***increase*** in ***temperature*** brings about a ***decrease in strength***, an ***increase in ductility***, and a ***decrease in the rate of strain hardening***—all effects that would tend to promote ***ease of deformation***.

EFFECT OF TEMPERATURE

- Forming processes tend to be classified as
  - ***Cold Working***
  - ***Warm Working***
  - ***Hot Working***

COLD WORKING

- The plastic deformation of metals ***below the recrystallization temperature*** is known as cold working .
- Here, the deformation is usually performed at ***room temperature***, but ***mildly elevated*** temperatures may be used to provide increased ductility and reduced strength.

COLD WORKING ADVANTAGES

1. No heating is required.
2. ***Better*** surface finish is obtained.
3. ***Superior*** dimensional control is achieved since the tooling sets dimensions at room temperature.
4. Products possess ***better*** reproducibility and interchangeability.
5. Strength, fatigue, and wear properties are all improved through ***strain hardening***.
6. ***Contamination*** problems are ***minimized***

COLD WORKING DISADVANTAGES

1. ***Higher forces*** are required to initiate and complete the deformation.
2. ***Heavier*** and more powerful equipment and stronger tooling are required.
3. ***Less ductility*** is available.
4. Metal surfaces must be clean and scale-free.
5. Intermediate anneals(heating) may be required to compensate for the loss of ductility that accompanies strain hardening.
6. ***Undesirable residual stresses*** may be produced.

WARM WORKING

- Because plastic deformation properties are normally enhanced by increasing workpiece temperature, forming operations are sometimes performed at temperatures somewhat ***above room temperature*** **BUT** ***below the recrystallization temperature.***
- The term warm working is applied to this second temperature range.

WARM WORKING

- The dividing line between cold working and warm working is often expressed in terms of the melting point for the metal.
- The dividing line is usually taken to be ***0.4 T_m***
- ***T_m*** = is the melting point (absolute temperature) for the particular metal.

WARM WORKING

- The lower strength and strain hardening at the intermediate temperatures, as well as higher ductility, provide warm working with the following advantages over cold working:

1. lower forces and power,
2. more intricate work geometries possible,
3. need for annealing may be reduced or eliminated

HOT WORKING

- ***Hot working*** (also called hot forming) involves deformation at temperatures above the recrystallization temperature.
- The recrystallization temperature for a given metal is about one-half of its melting point on the ***absolute scale (Kelvin or Rankine)***.
- In practice, hot working is usually carried out at temperatures somewhat ***above 0.6 T_m*** .
- In some books it has been given ***above 0.5 T_m*** .

HOT WORKING

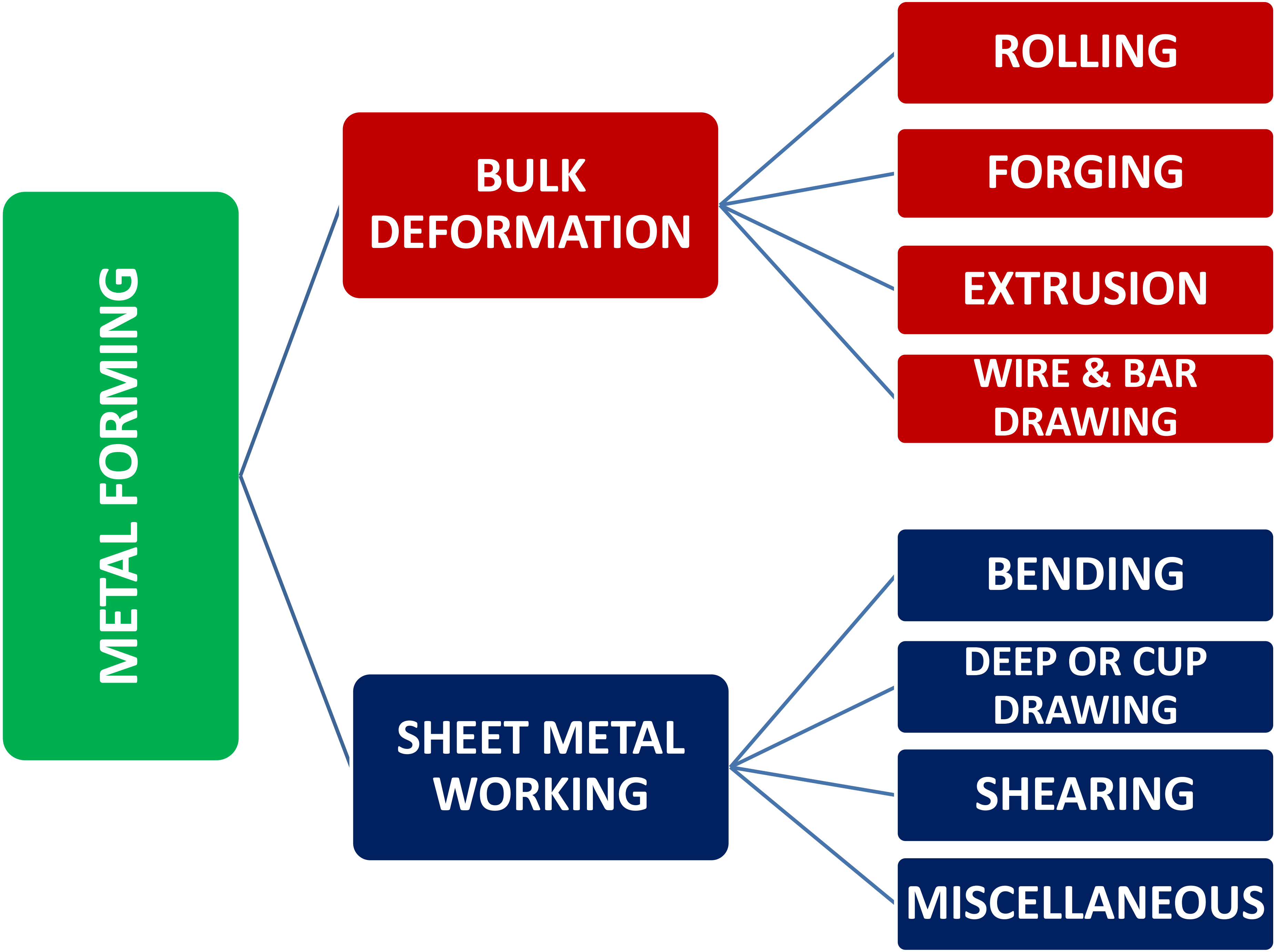
- ***Scale*** *(a coating of oxide formed on heated metal)* on the work surface is accelerated at higher temperatures.
- Accordingly, hot working temperatures are usually maintained with in the range ***0.5*** $\boldsymbol{T_m}$ to ***0.75*** $\boldsymbol{T_m}$.

HOT WORKING ADVANTAGES

1. The shape of the workpart can be ***significantly*** altered
2. ***Lower forces*** and power are required to deform the metal
3. Metals that usually fracture in cold working ***can be hot formed***
4. No strengthening of the part occurs from work hardening.

HOT WORKING DISADVANTAGES

1. Lower dimensional accuracy
2. Higher total energy required (due to the thermal energy to heat the workpiece),
3. Work surface oxidation (scale),
4. Poorer surface finish, and
5. Shorter tool life.


METAL FORMING
BULK DEFORMATION
SHEET METAL WORKING
ROLLING
FORGING
EXTRUSION
WIRE & BAR DRAWING
BENDING
DEEP OR CUP DRAWING
SHEARING
MISCELLANEOUS

BULK DEFORMATION PROCESSES

- ***Bulk deformation*** processes are those where the ***thicknesses*** or cross sections are ***reduced*** or ***shapes*** are ***significantly changed***.
- Since the volume of the material remains constant, changes in one dimension require proportionate changes in others.
- Thus the enveloping ***surface area*** changes significantly, usually ***increasing*** as the product lengthens or the shape becomes more complex.

BULK DEFORMATION PROCESSES

- ***Starting geometry*** of the raw material may be:
  - cylindrical bars and billets
  - rectangular billets and slabs
  - or any of the above similar shapes

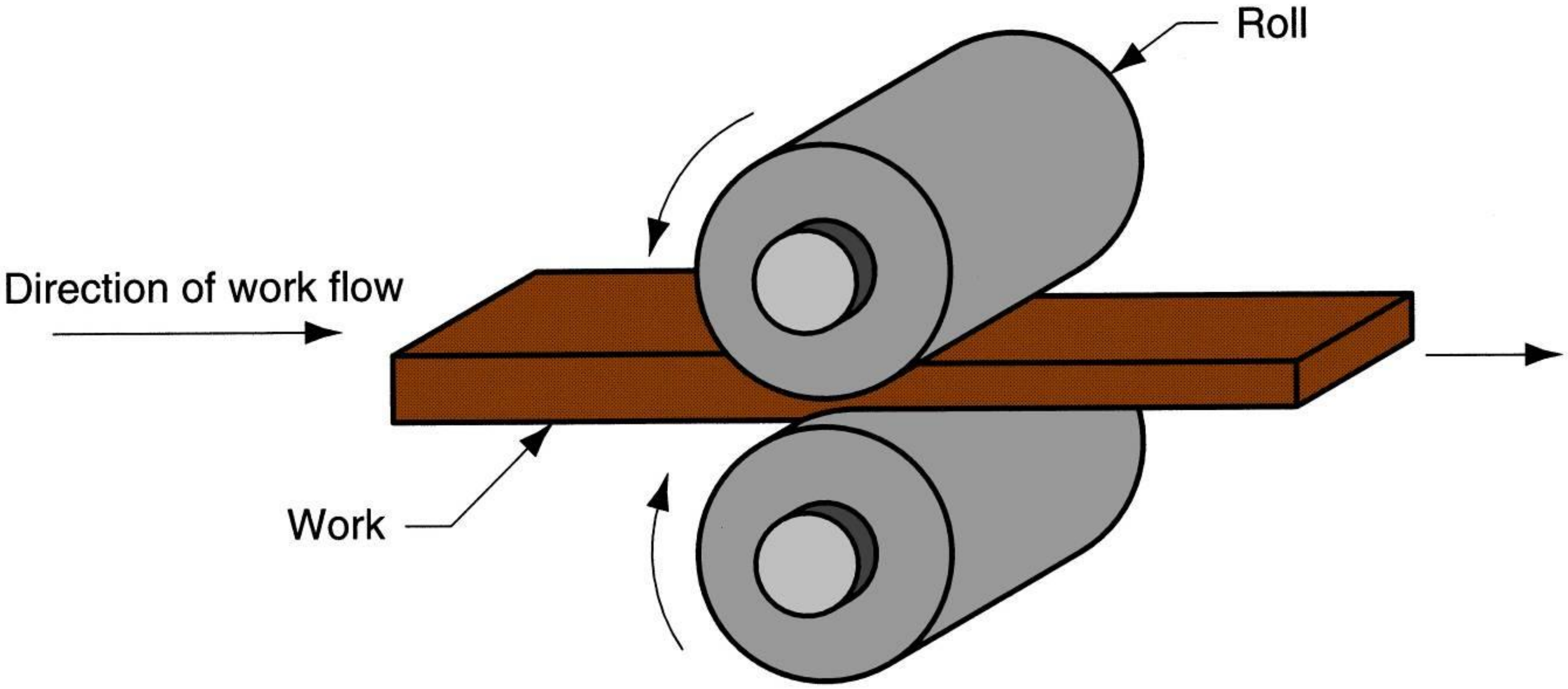
[redacted]

[redacted]

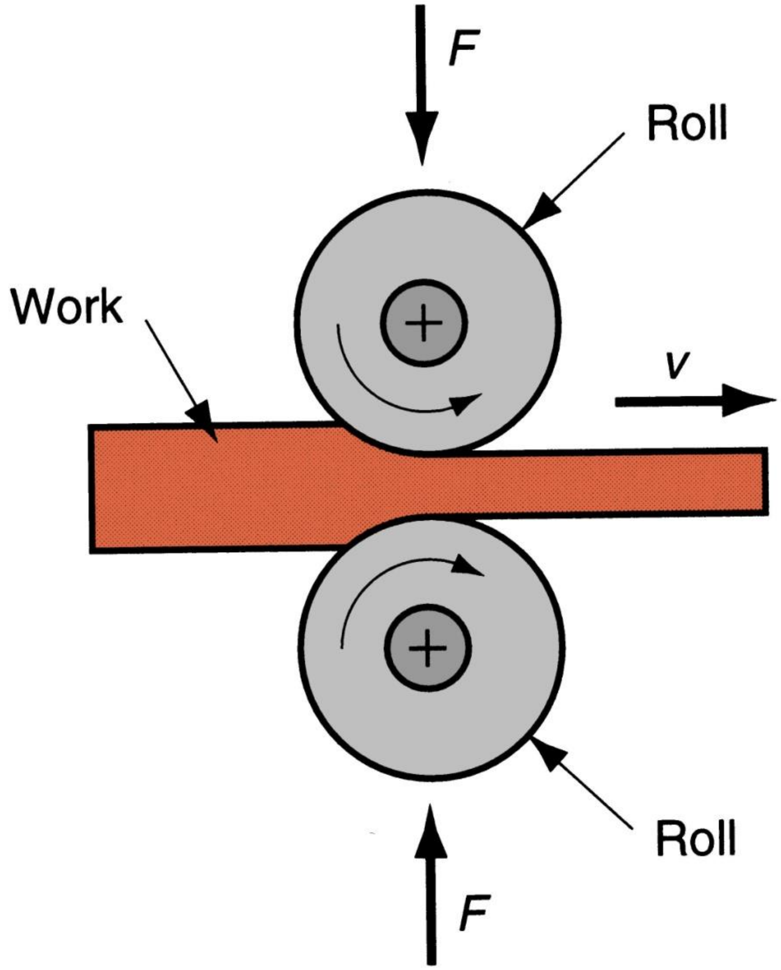
(1) ROLLING

- Rolling is a ***deformation process*** in which the ***thickness*** of the work is ***reduced*** by ***compressive forces*** exerted by two opposing rolls.
- Rolling operations ***reduce the thickness*** or ***change the cross section*** of a material through compressive forces exerted by rolls.

(1) ROLLING



(1) ROLLING



(1) ROLLING

- Rotating rolls perform two main functions:
  - Pull the work into the gap between them by friction between workpart and rolls
  - Simultaneously squeeze the work to reduce its cross section

(1) ROLLING

- Most rolling processes are ***very capital intensive***, requiring massive pieces of equipment, called rolling mills, to perform them.
- Most rolling is carried out by hot working, called ***hot rolling***, owing to the large amount of deformation required.
- Hot-rolled metal is generally free of residual stresses, and its properties are isotropic.
- Disadvantages of hot rolling are that the product cannot be held to close tolerances, and the surface has a characteristic oxide scale.

(1) ROLLING

- Rolling is often the first process that is used to convert material into a finished ***wrought product*** (*Products such as; sheet, rod, bar, tube, plate and wire that are produced by rolling and extrusion mills as well as forging*).
- Thick starting stock can be rolled into ***blooms, billets, or slabs,*** or these shapes can be obtained directly from continuous casting.

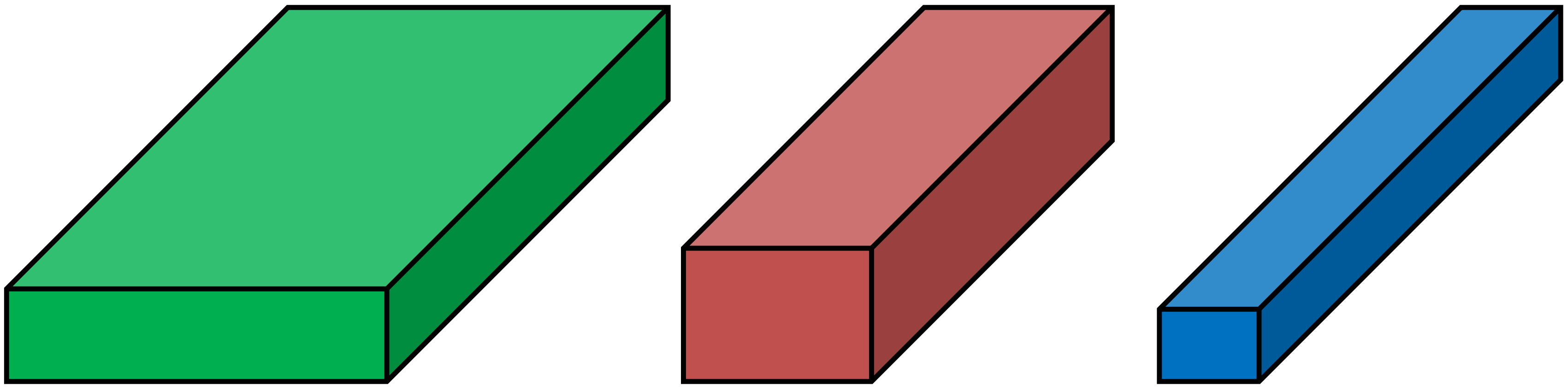
(1) ROLLING

- A ***slab*** is a rectangular solid where the width is greater than twice the ***thickness*** (***25cm x 4 cm or more***). **Or 50 – 150mm thick and width ½ to 1.5 meters**
- Slabs can be further rolled to produce plate, sheet, and strip .
- A ***bloom*** has a ***square or rectangular*** cross section, with a thickness greater than ***15 cm*** and a width no greater than twice the thickness. **(150 –300mm.)**

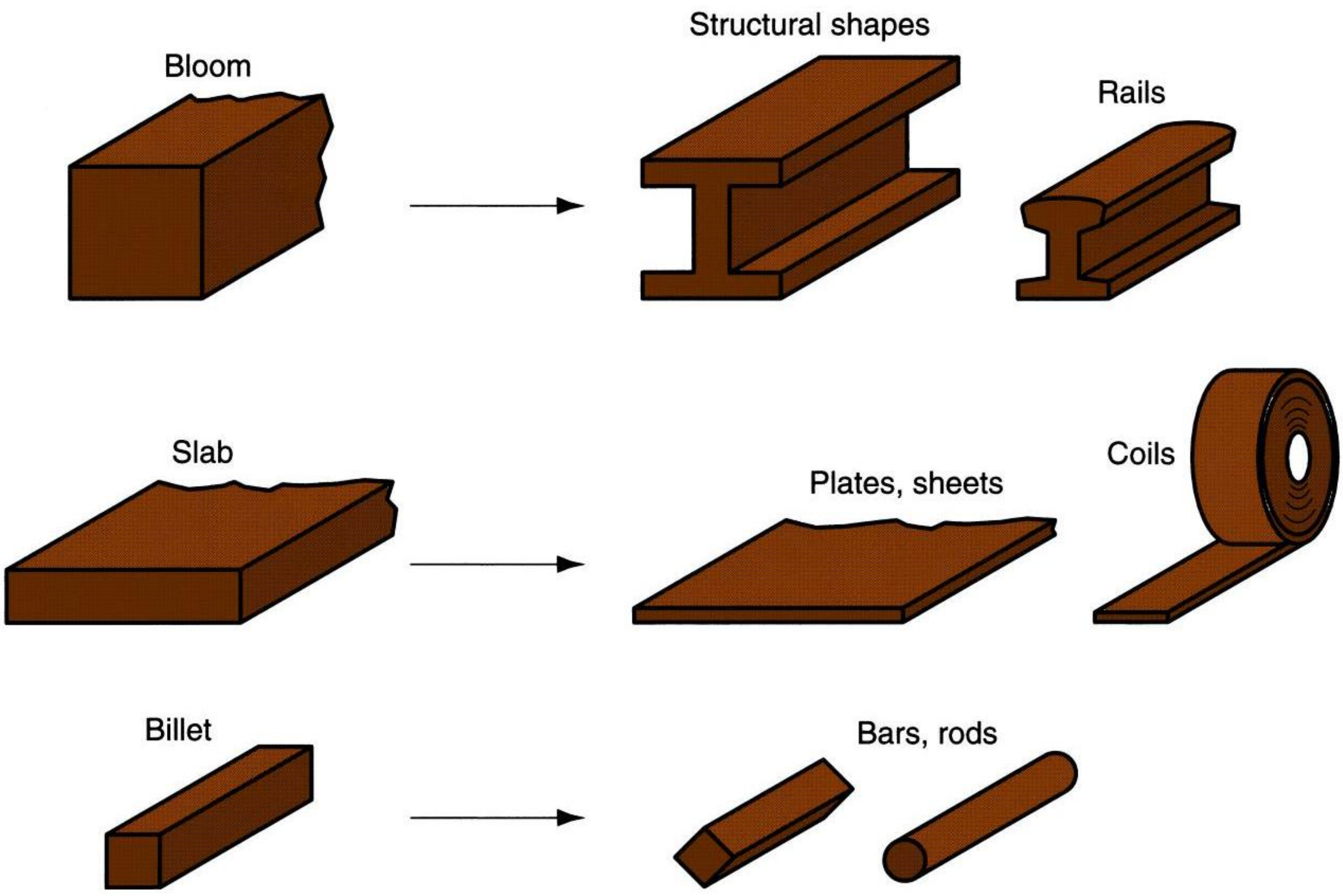
(1) ROLLING

- A ***billet*** is usually ***smaller than a bloom*** and has a ***square or circular cross section*** (***4cm x 4 cm or more***).
- Billets are usually produced by some form of deformation process, such as rolling or extrusion.
- ***Plates*** have thickness greater than ***6 mm*** while ***sheet and strip*** range from ***6 mm to 0.1 mm***.

(1) ROLLING



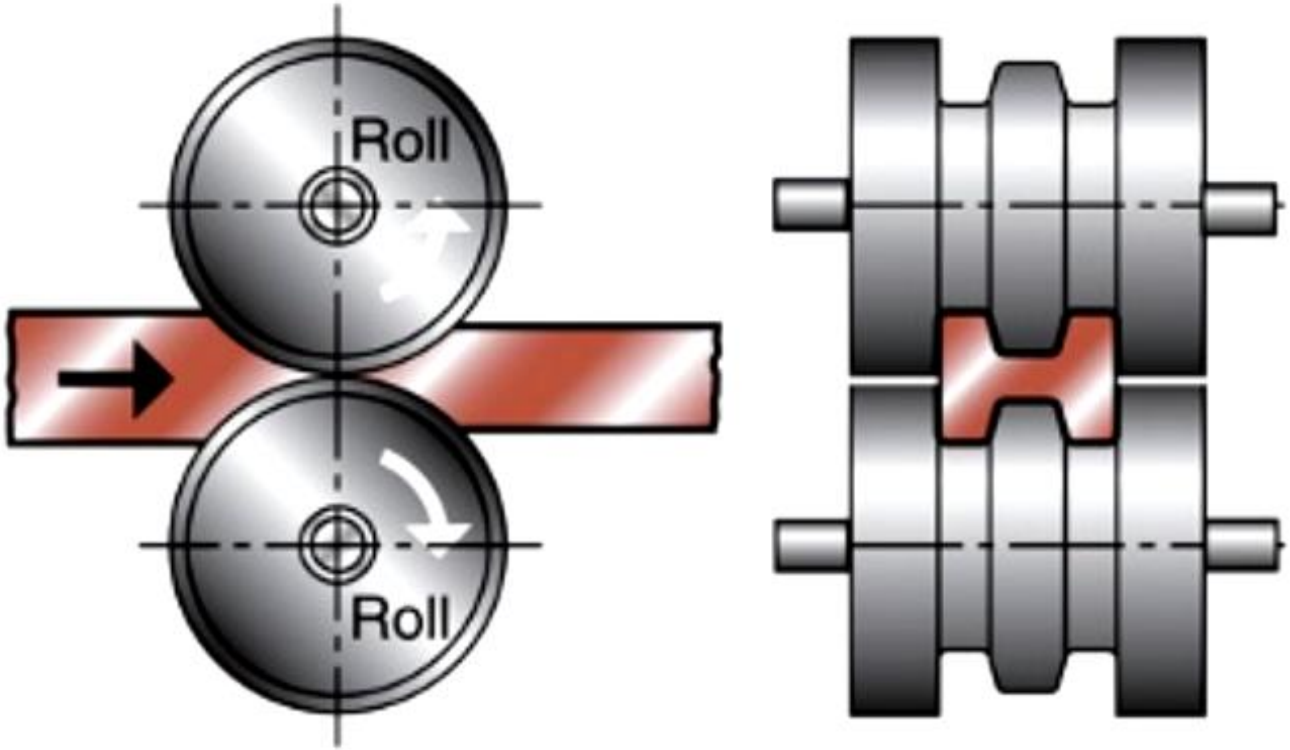
SLAB **BLOOM** **BILLET**


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

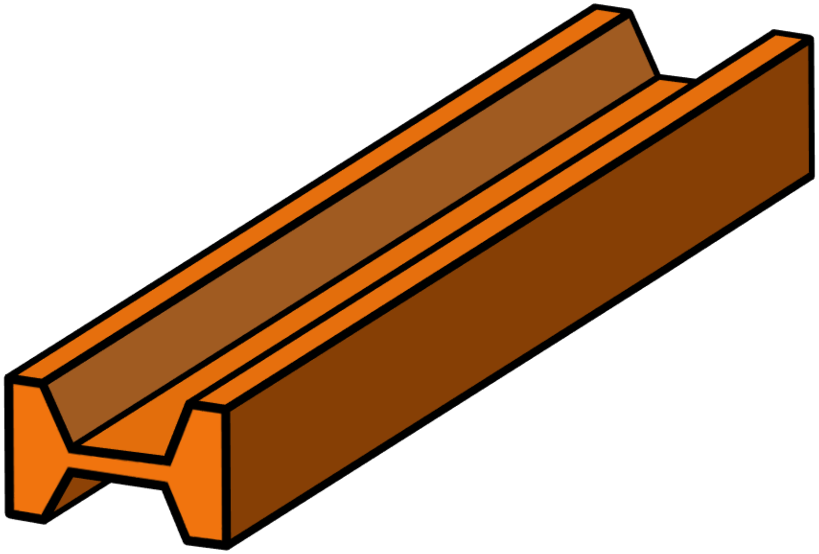
(1.1) SHAPE ROLLING

- In shape rolling, the ***work is deformed*** into a ***contoured cross section***.
- Products made by shape rolling include construction shapes such as ***I-beams, L-beams***, and ***U-channels***; ***rails*** for railroad tracks; and ***round and square*** bars and rods.
- The process is accomplished by passing the work through ***rolls*** that have the ***reverse of the desired shape.***

(1.1) SHAPE ROLLING



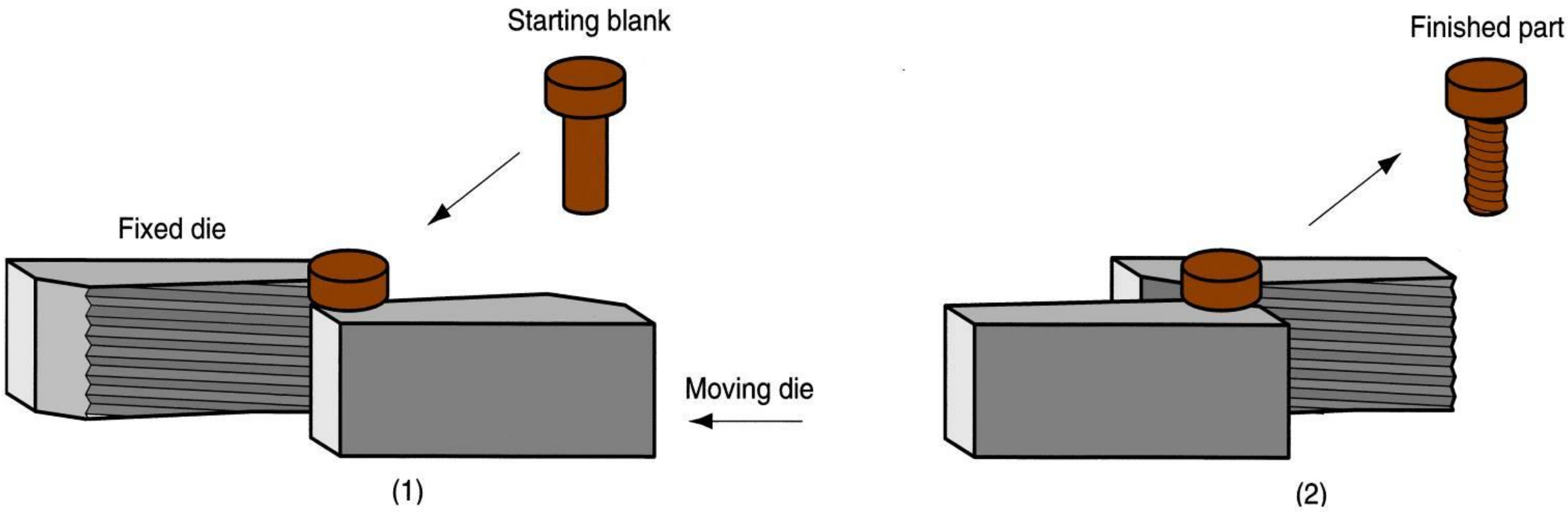
(1.1) SHAPE ROLLING



(1.2) Thread Rolling

- Bulk deformation process used to form threads on cylindrical parts by rolling them between two dies
- Important commercial process for mass producing bolts and screws
- Performed by cold working in thread rolling machines
- Advantages over thread cutting (machining):
  - Higher production rates
  - Better material utilization
  - Stronger threads and better fatigue resistance due to work hardening

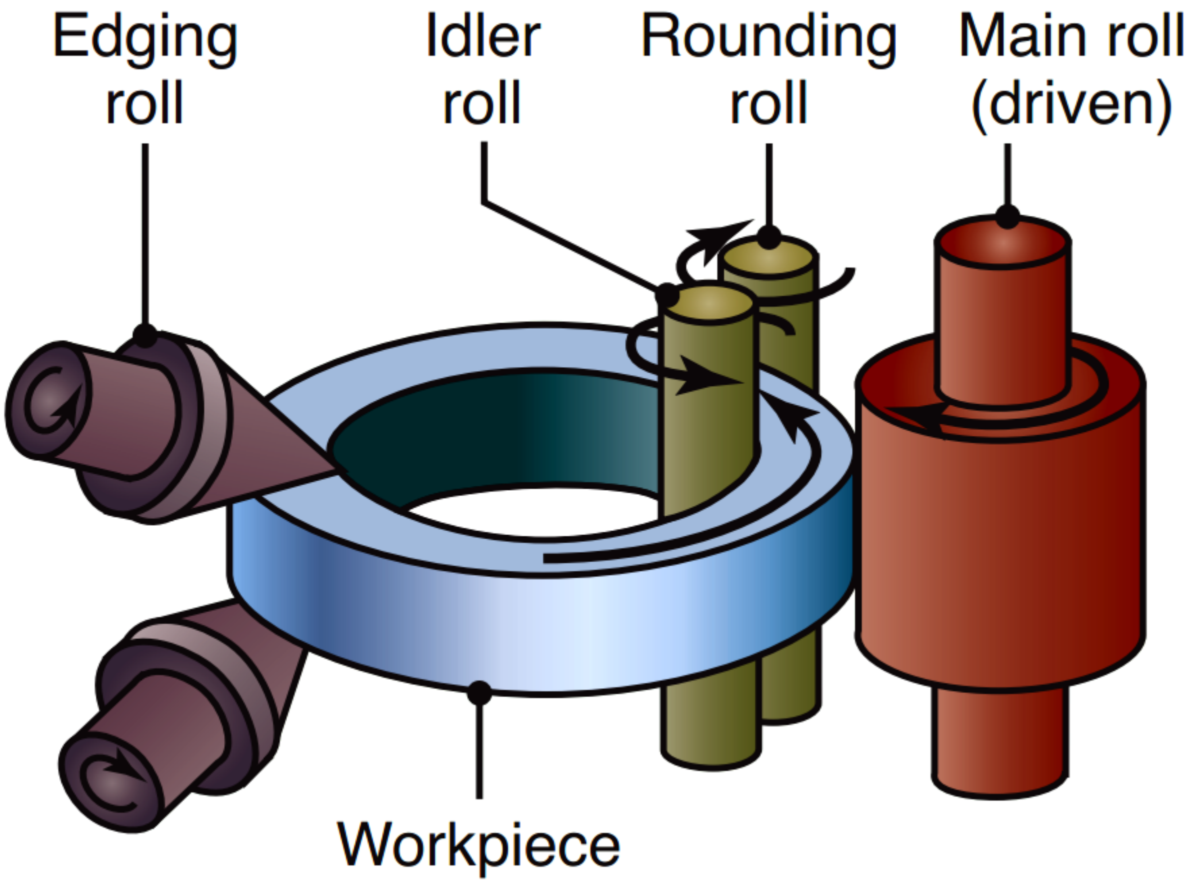
(1.2) Thread Rolling



(1.3) Ring Rolling

- Ring rolling is a deformation process in which a thick-walled ring of smaller diameter is rolled into a thin-walled ring of larger diameter.
- As the thick-walled ring is compressed, the deformed material elongates, causing the diameter of the ring to be enlarged.
- Ring rolling is usually performed as a hot-working process for large rings and as a cold-working process for smaller rings.

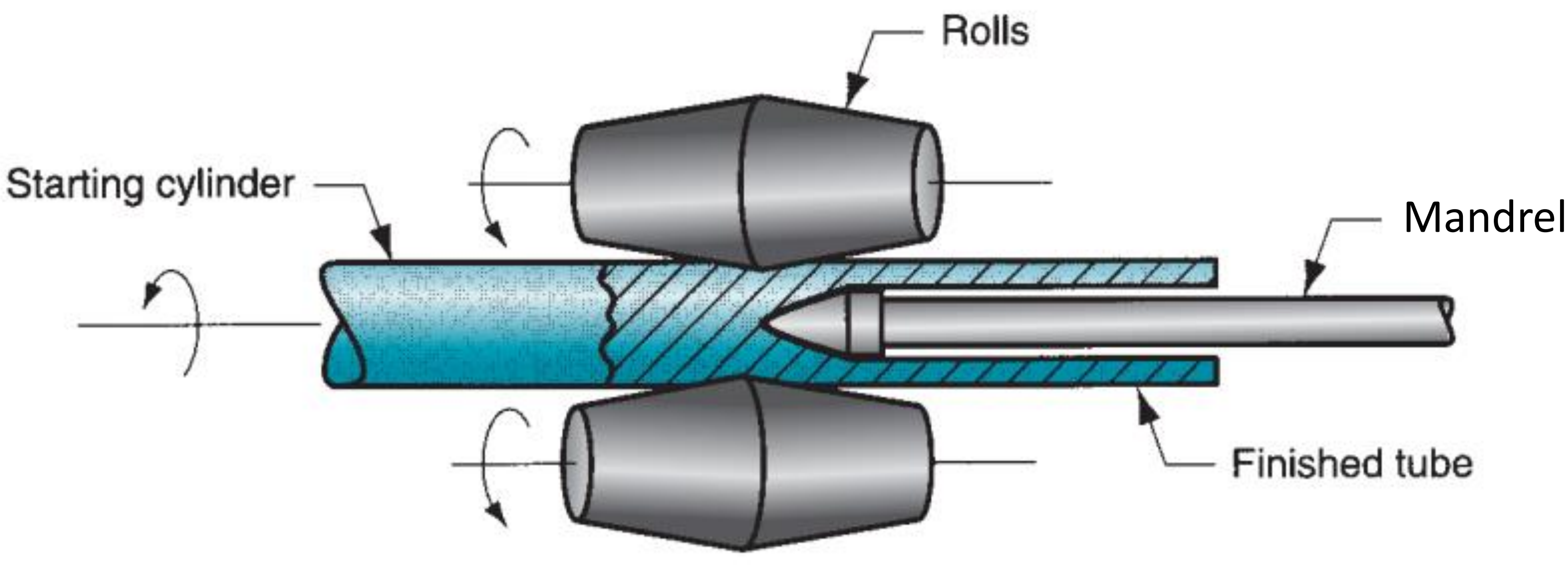
(1.3) Ring Rolling



Reducing the ring thickness results in an increase in its diameter.

(1.4) Roll Piercing

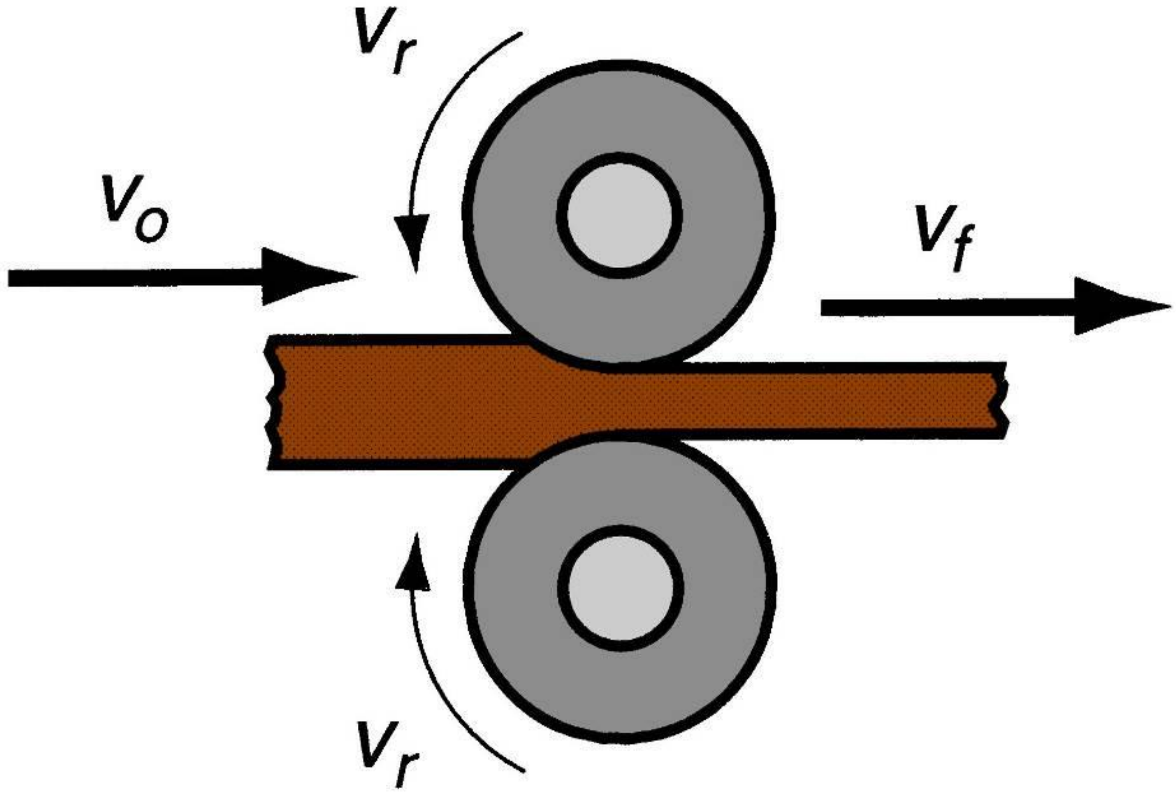
- Roll Piercing is a specialized hot working process for making seamless thick-walled tubes.
- It utilizes two opposing rolls, and hence it is grouped with the rolling processes.



(1) ROLLING MILLS CONFIGURATIONS

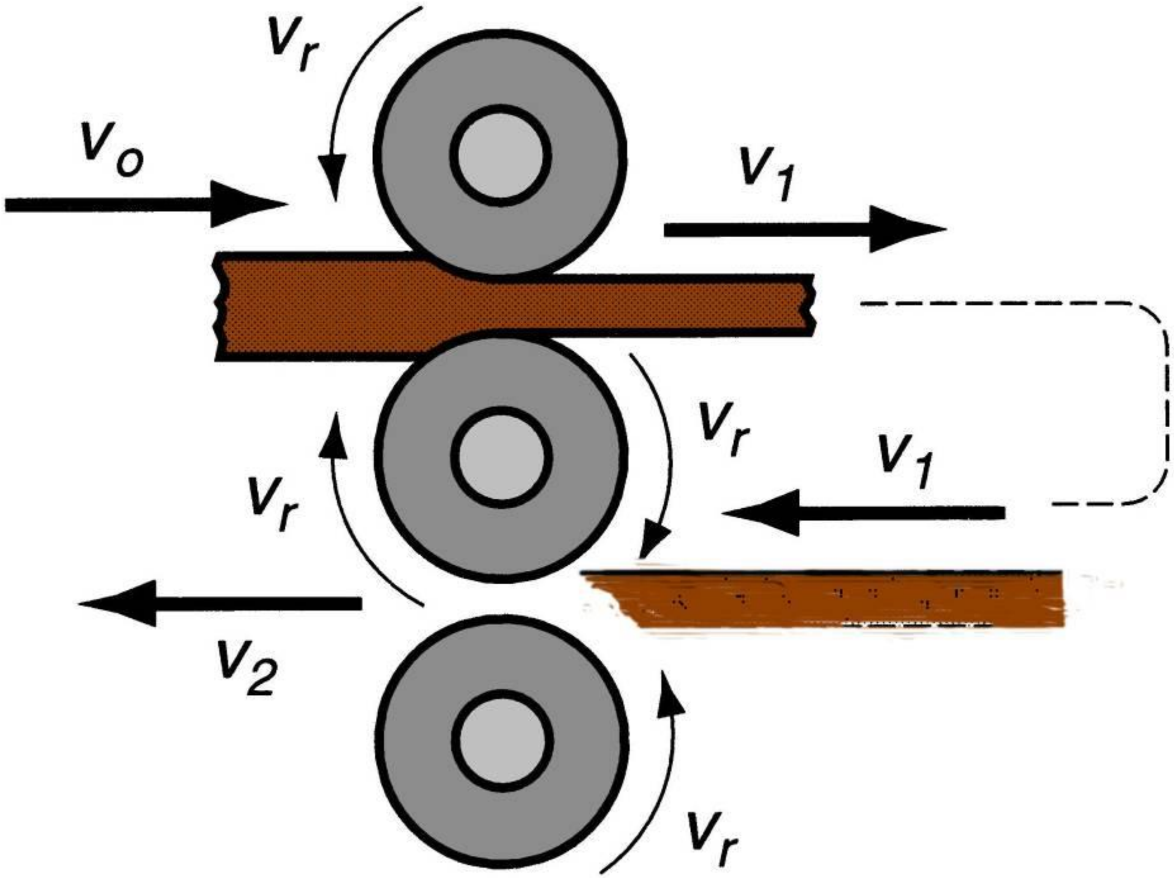
- Various rolling mill configurations are available to deal with the variety of applications and technical problems in the rolling process.
  - ***Two-high*** – two opposing rolls
  - ***Three-high*** – work passes through rolls in both directions
  - ***Four-high*** – backing rolls support smaller work rolls
  - ***Cluster mill*** – multiple backing rolls on smaller rolls
  - ***Tandem rolling mill*** – sequence of two-high mills

(1.a) Two-High Rolling Mill



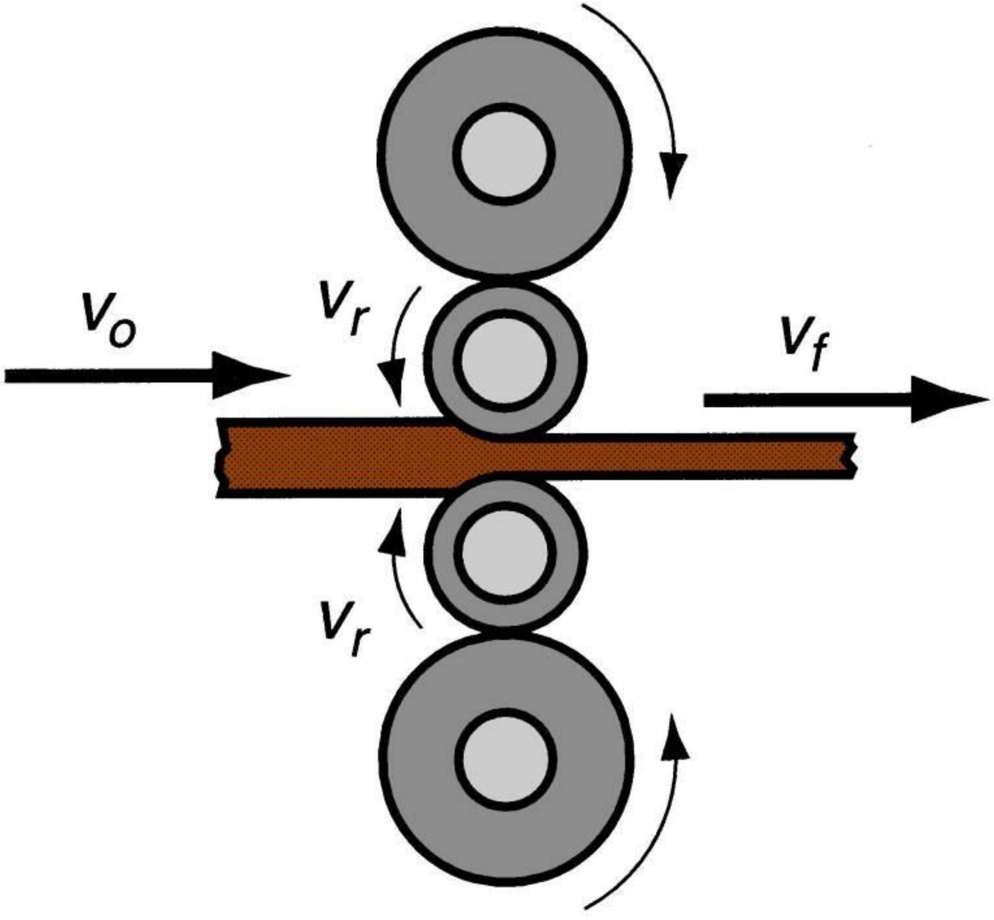
(a)

(1.b) Three-High Rolling Mill



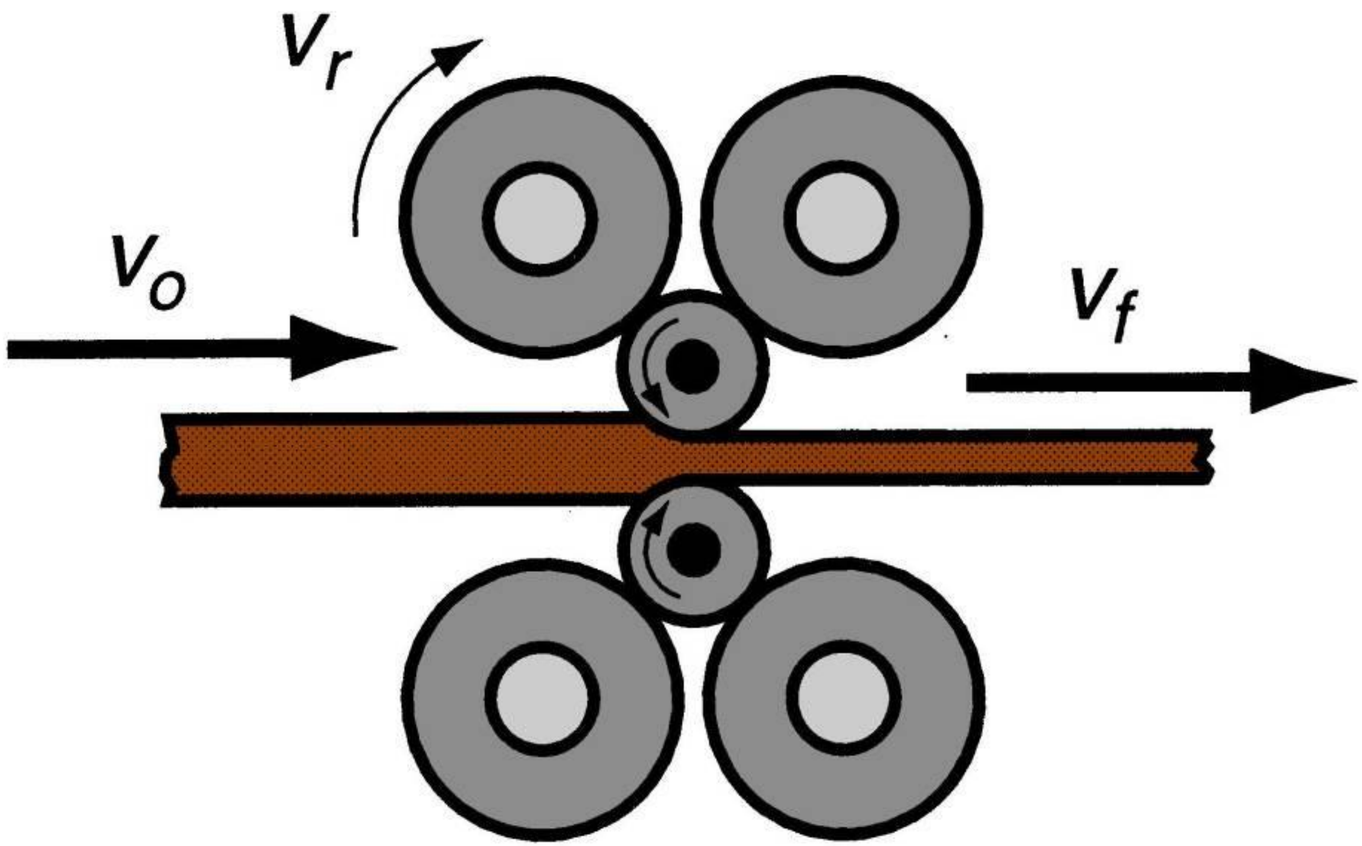
(b)

(1.c) Four-High Rolling Mill



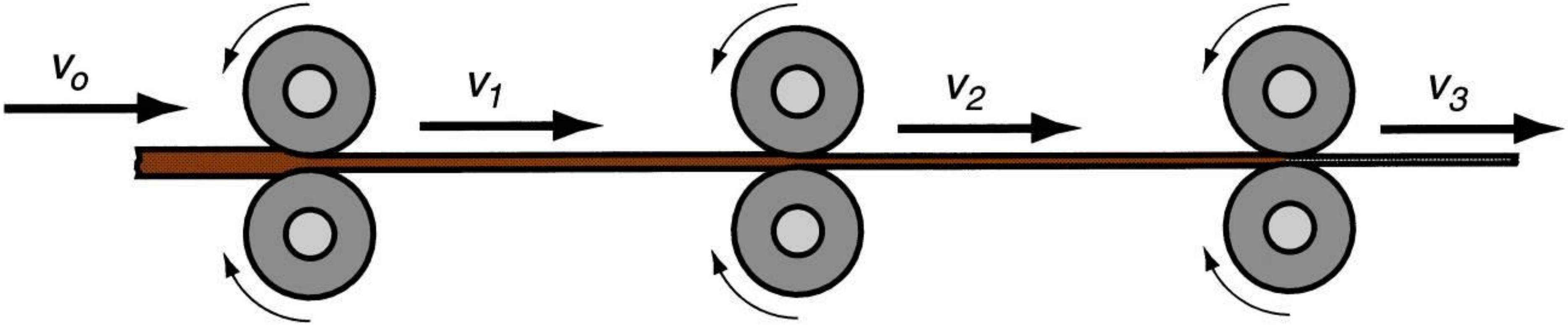
(c)

(1.d) Cluster Mill



(d)

(1.e) Tandem Rolling Mill



(e)

FLAT ROLLING ANALYSIS

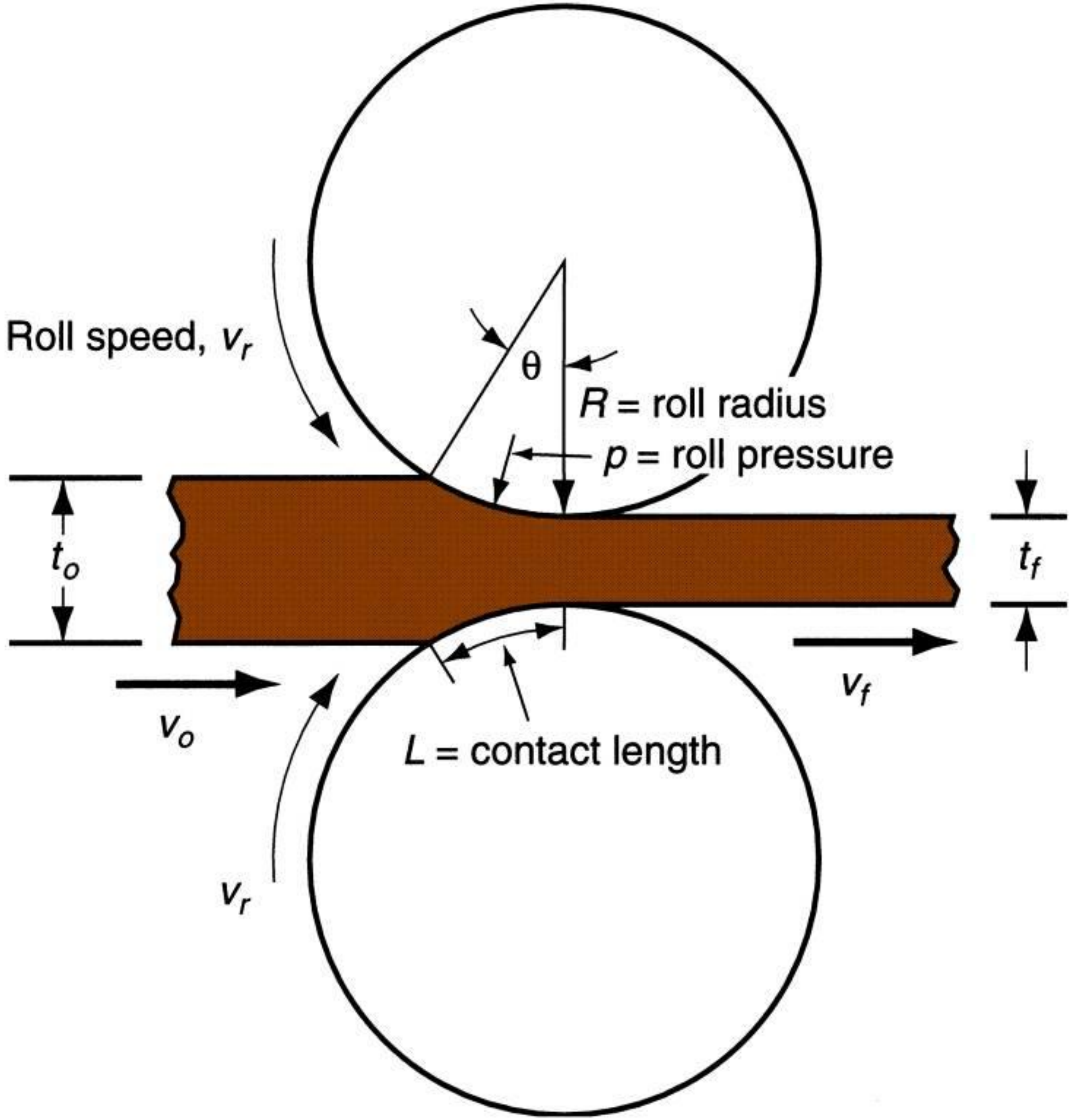
- In flat rolling, the work is squeezed between two rolls so that its thickness is reduced by an amount called the ***DRAFT***:

$$d = t_o - t_f \qquad \textbf{(1)}$$

d = draft, mm

t_o = starting thickness, mm

t_f = final thickness, mm


Roll speed, v_r
θ
R = roll radius
p = roll pressure
t_o
t_f
v_o
v_f
L = contact length
v_r

FLAT ROLLING ANALYSIS

- Conservation of matter is preserved, so the ***volume of metal exiting*** the rolls equals the ***volume entering***

$$t_o w_o L_o = t_f w_f L_f \qquad \textbf{(2)}$$

w_o and w_f are the before and after work widths, mm

L_o and L_f are the before and after work lengths, mm

FLAT ROLLING ANALYSIS

- Similarly, before and after volume rates of material flow must be the same, so ***the before and after velocities*** can be related

$$t_o w_o v_o = t_f w_f v_f \qquad \textbf{(3)}$$

v_o and v_f are the entering and exiting velocities of the work.

FLAT ROLLING ANALYSIS

- The rolls contact the work along an arc defined by the angle θ.
- Each roll has radius R , and its rotational speed gives it a surface velocity v_r .
- This velocity is greater than the entering speed of the work v_o and less than its exiting speed v_f .
- Since the metal flow is continuous, there is a gradual change in velocity of the work between the rolls.

FLAT ROLLING ANALYSIS

- However, there is ***one point*** along the arc where ***work velocity equals roll velocity***.
- This is called the ***no-slip point***, also known as the ***neutral point***.
- On either side of this point, slipping and friction occur between roll and work.

FLAT ROLLING ANALYSIS

- The amount of ***slip*** between the rolls and the work can be measured by means of the ***FORWARD SLIP***, a term used in rolling that is defined as

$$s = \frac{v_f - v_r}{v_r} \qquad \textbf{(4)}$$

v_f = final (exiting) work velocity, m/s

v_r = roll speed, m/s

FLAT ROLLING ANALYSIS

- There is a limit to the ***maximum possible draft*** that can be accomplished in flat rolling with a given coefficient of friction, defined by:

$$\boxed{d_{max} = \mu^2 R} \qquad (5)$$

d_{max} = maximum draft, mm

μ = coefficient of friction

R = roll radius mm

FLAT ROLLING ANALYSIS

- The roll ***force F*** required to maintain separation between the two rolls is given by:

$$\boxed{F = \sigma w L} \qquad (6)$$

σ = average flow stress, N/mm^2

$w L$ = roll-work contact area, mm^2

FLAT ROLLING ANALYSIS

- ***Contact length*** can be approximated by

$$L = \sqrt{R(t_o - t_f)} \qquad (7)$$

FLAT ROLLING ANALYSIS

- ***Torque for each roll is***

$$T = 0.5\,FL \qquad (8)$$

FLAT ROLLING ANALYSIS

- The ***power required to drive each roll*** is

$$P = 2\pi NT \qquad (9)$$

FLAT ROLLING NUMERICAL 1

- A ***40 mm*** thick plate is to be reduced to ***30 mm*** in one pass in a rolling operation. ***Entrance speed = 16 m/min***. ***Roll radius = 300 mm***, and ***rotational speed = 18.5 m/min***. Determine: (a) the minimum required coefficient of friction that would make this rolling operation possible, (b) exit velocity under the assumption that the plate widens by 2% during the operation, and (c) forward slip.

FLAT ROLLING NUMERICAL 1

- t_o = ***40 mm***
- t_f = ***30 mm***.
- v_o = ***16 m/min***.
- R = ***300 mm***
- ***rotational speed = 18.5 m/min***.
- plate ***widens by 2%*** during the operation

FLAT ROLLING NUMERICAL 1

(a) Maximum draft $\boxed{d_{max} = \mu^2 R}$ **(5)**

Given that $d = t_o - t_f = 40 - 30 = 10$ mm,

$\mu^2 = 10/300 = 0.0333$

$\mu = (0.0333)^{0.5} = \mathbf{0.1826}$

FLAT ROLLING NUMERICAL 1

(b) Plate widens by 2%.

$$\boxed{t_o w_o v_o = t_f w_f v_f} \qquad \textbf{(3)}$$

$$w_f = 1.02\ w_o$$

$$40(w_o)(16) = 30(1.02w_o)v_f$$

$$v_f = 40(w_o)(16)/\ 30(1.02w_o)$$

$$= 640/30.6 = \mathbf{20.915\ m/min}$$

FLAT ROLLING NUMERICAL 1

(c) $\boxed{s = (v_f - v_r)/v_r}$ **(4)**

$= (20.915 - 18.5)/18.5 = \mathbf{0.13}$

FLAT ROLLING NUMERICAL 2

- A ***2.0 in thick*** slab is ***10.0 in wide*** and ***12.0 ft*** long. Thickness is to be reduced in ***three steps*** in a hot rolling operation. ***Each step*** will reduce the slab to ***25%*** of its previous thickness. It is expected that for this metal and reduction, the slab will ***widen by 3%*** in each step. If the entry speed of the slab in the first step is ***40 ft/min***, and ***roll speed is the same for the three steps***, determine: (a) length and (b) exit velocity of the slab after the final reduction.

FLAT ROLLING NUMERICAL 2

- t_o = ***2 in***
- w_o = ***10 in***.
- L_o = ***12 ft***.
- ***Each step*** will reduce the slab to ***25%*** of its previous thickness
- ***widen by 3%*** in each step
- v_o = ***40 ft/min (same for the three steps)***

FLAT ROLLING NUMERICAL 2

(a) After three passes,

$$t_f = (0.75)(0.75)(0.75)(2.0)$$

$$= 0.844 \text{ in.}$$

$$w_f = (1.03)(1.03)(1.03)(10.0)$$

$$= 10.927 \text{ in.}$$

FLAT ROLLING NUMERICAL 2

$$\boxed{t_o w_o L_o = t_f w_f L_f} \qquad (2)$$

$$(2.0)(10.0)(12 \text{ x } 12) = (0.844)(10.927)L_f$$

$L_f = 312.3$ in. $=$ **26.025 ft**

FLAT ROLLING NUMERICAL 2

(b) *Given that entry speed is the same at all three steps*

$$t_o w_o v_o = t_f w_f v_f \qquad \mathbf{(3)}$$

Step 1

$$v_f = (2.0)(10.0)(40)/(0.75 \text{ x } 2.0)(1.03 \text{ x } 10.0)$$

$$v_f = 51.78 \text{ ft/min.}$$

FLAT ROLLING NUMERICAL 2

Step 2

$$v_f = (0.75 \text{ x } 2.0)(1.03 \text{ x } 10.0)(40)/(0.75^2 \text{ x } 2.0)(1.03^2 \text{ x } 10.0)$$

$$v_f = 51.78 \text{ ft/min.}$$

FLAT ROLLING NUMERICAL 2

Step 3

$$v_f = (0.75^2 \text{ x } 2.0)(1.03^2 \text{ x } 10.0)(40)/(0.75^3 \text{ x } 2.0)(1.03^3 \text{ x } 10.0)$$

$$v_f = 51.78 \text{ ft/min.}$$

FLAT ROLLING NUMERICAL 3

- A series of cold rolling operations are to be used to reduce the thickness of a plate from ***50 mm down to 25 mm*** in a reversing two-high mill. ***Roll diameter = 700 mm*** and ***coefficient of friction*** between rolls and work = ***0.15.*** The specification is that the ***draft is to be equal on each pass***. Determine: (a) minimum number of passes required, and (b) draft for each pass?

FLAT ROLLING NUMERICAL 3

- t_o = ***50 mm***
- t_f = ***25 mm***.
- R = ***700/2 mm = 350 mm***
- μ = ***0.15***
- ***draft is to be equal on each pass***.

FLAT ROLLING NUMERICAL 3

(a) Maximum draft $d_{max} = \mu^2 R$

$$= (0.15)^2 (350) = 7.875 \text{ mm}$$

Minimum number of passes $= (t_o - t_f)/d_{max}$

$= (50 - 25)/7.875 =$ **3.17 → 4 passes**

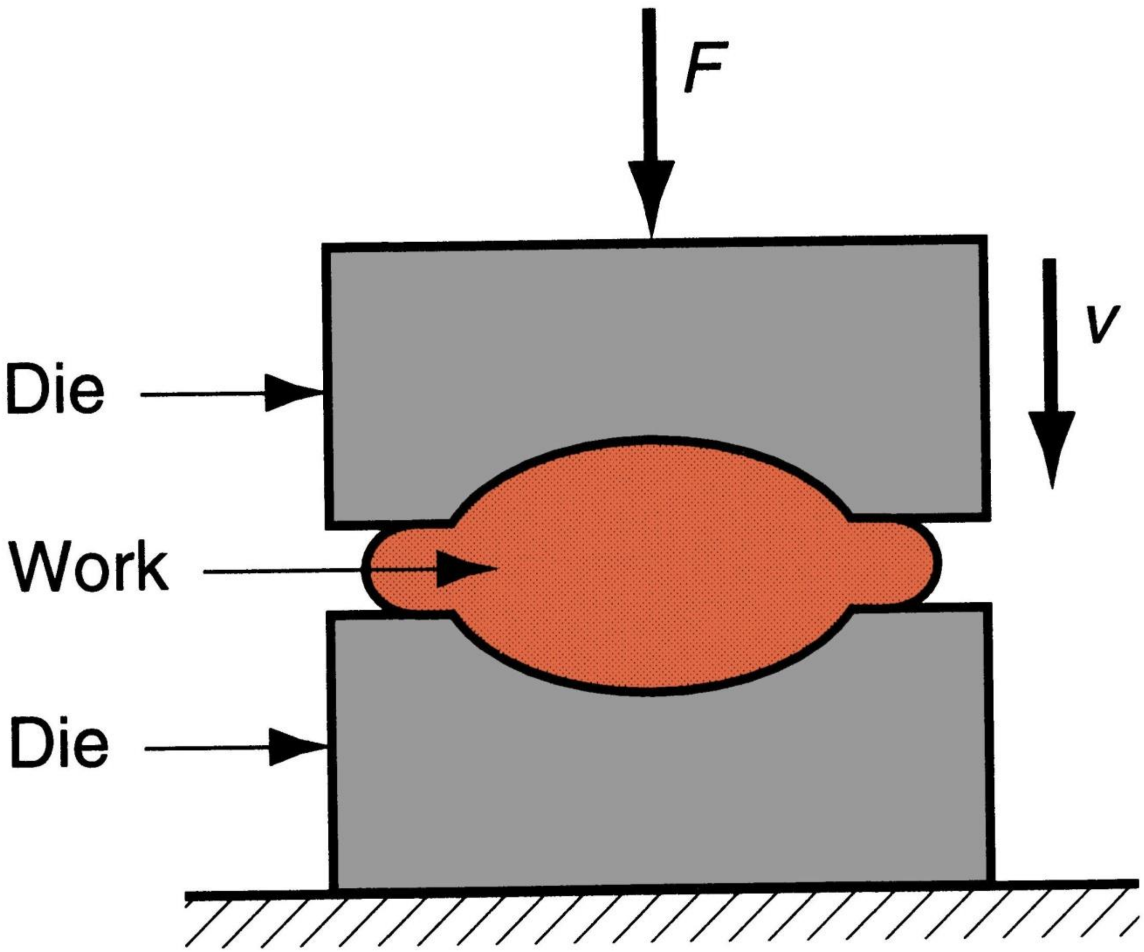
(b) Draft per pass $d = (50 - 25)/4 =$ **6.25 mm**

FORGING

(2) FORGING

- Forging is a ***deformation process*** in which the work is ***compressed*** between two ***dies***, using either impact or gradual pressure to form the part.
- It is the oldest of the metal forming operations, dating back to perhaps 5000 BC.
- Today, forging is an important industrial process used to make a variety of ***high-strength components*** for ***automotive, aerospace, and other applications.***

(2) FORGING



(2) FORGING

- These components include engine ***crankshafts and connecting rods***, ***gears***, aircraft structural components, and jet engine turbine parts.

(2) FORGING CLASSIFICATION

- One way to classify the operations is by working ***temperature***.
- ***Hot or warm forging*** – most common, due to the significant deformation and the need to reduce strength and increase ductility of work metal
- ***Cold forging*** – advantage: increased strength that results from strain hardening

(2) FORGING CLASSIFICATION

- Either ***IMPACT OR GRADUAL pressure*** is used in forging.
- The distinction derives more from the type of equipment used than differences in process technology.
- A forging machine that applies an ***impact load*** is called a ***forging hammer***, while one that applies ***gradual pressure*** is called a ***forging press***.

(2) FORGING CLASSIFICATION

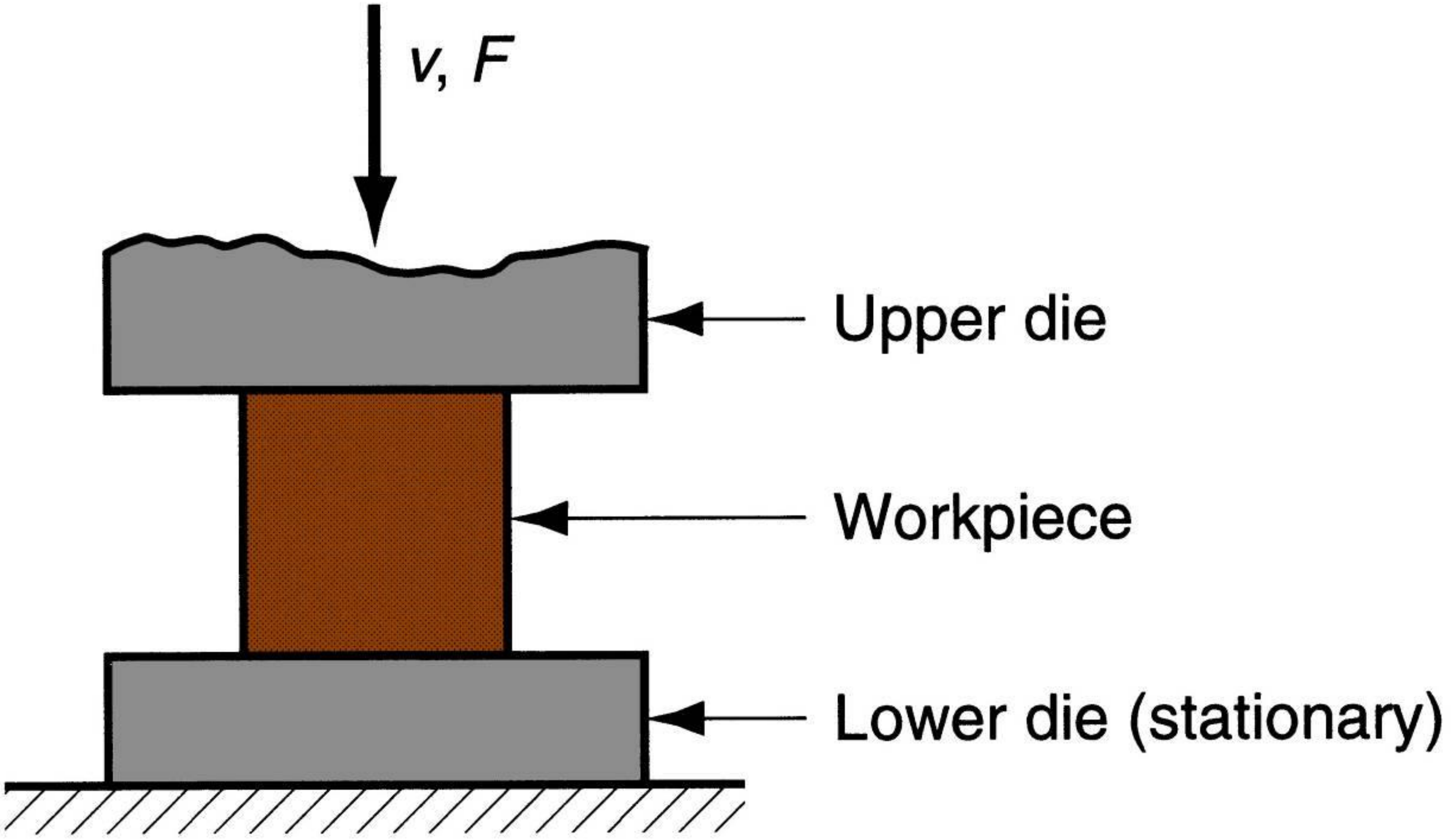
- Another difference among forging operations is the degree to which the ***flow*** of the work metal is ***constrained by the dies***.
- By this classification, there are three types of forging operations, shown in Figure :

(a) Open-die Forging,

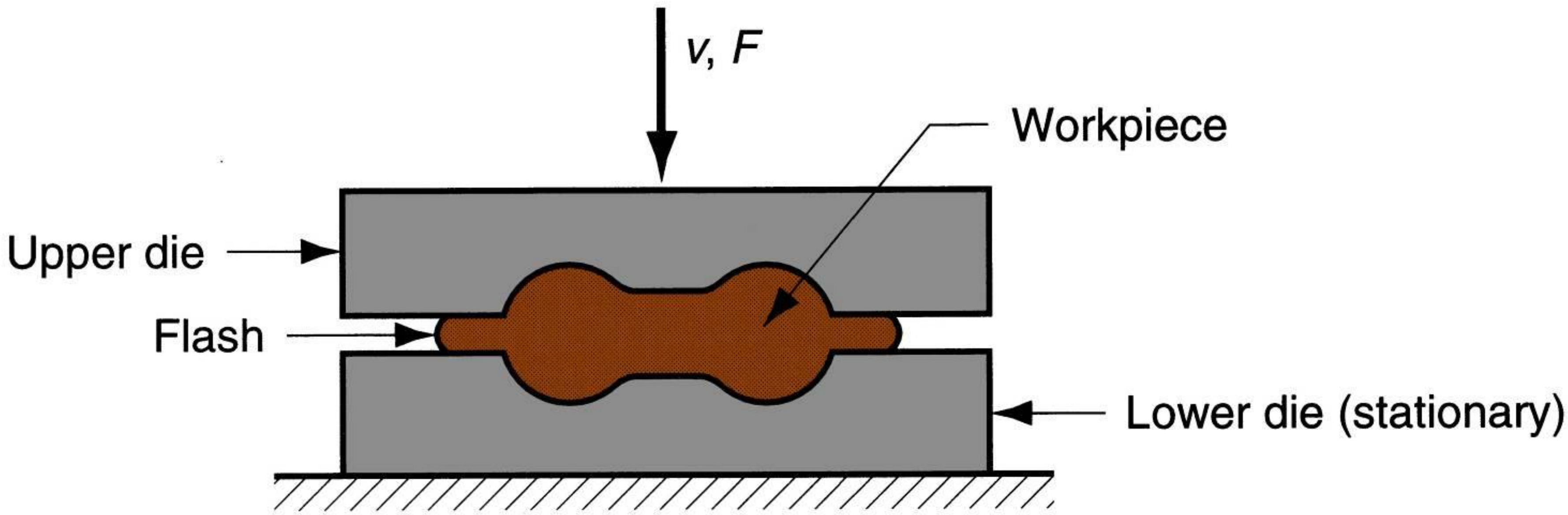
(b) Impression-die Forging, and

(c) Flashless Forging.

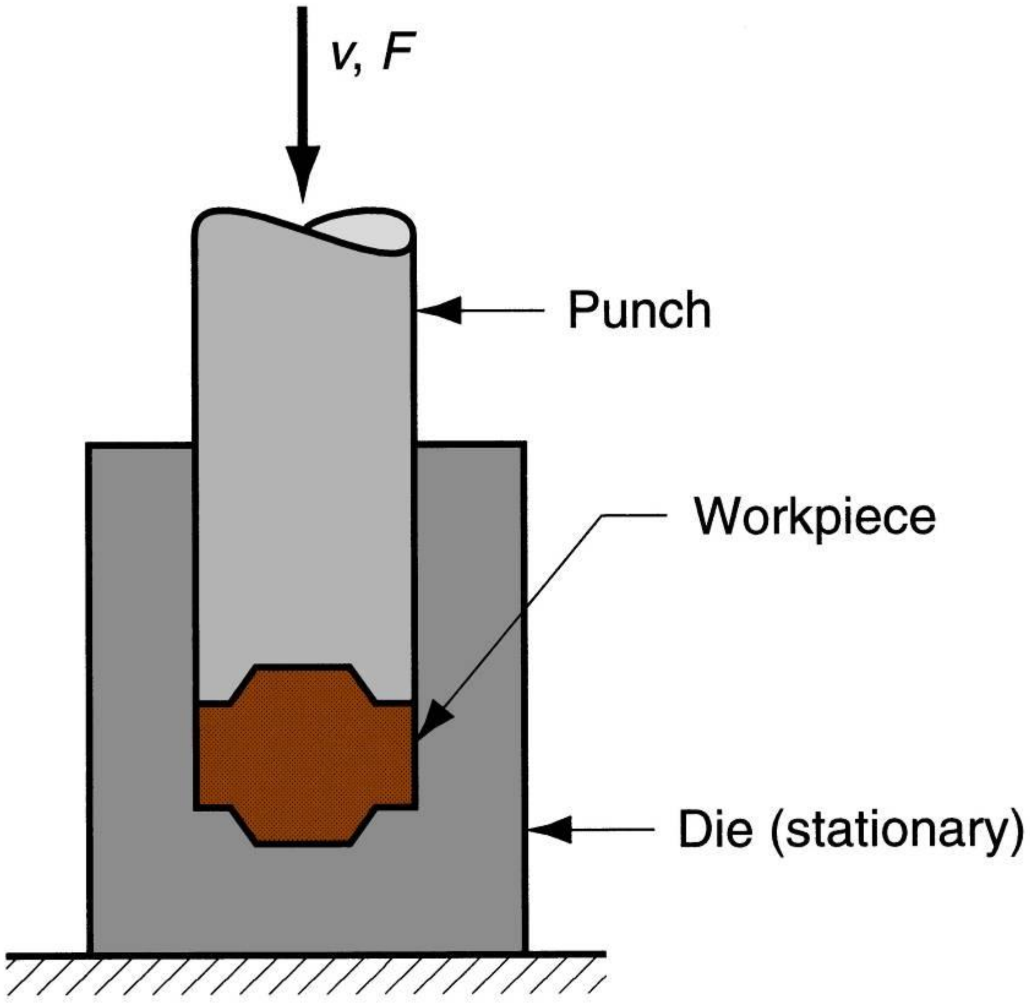
(2) CLASSIFICATION- Open-die Forging



(2) CLASSIFICATION- Impression-die Forging



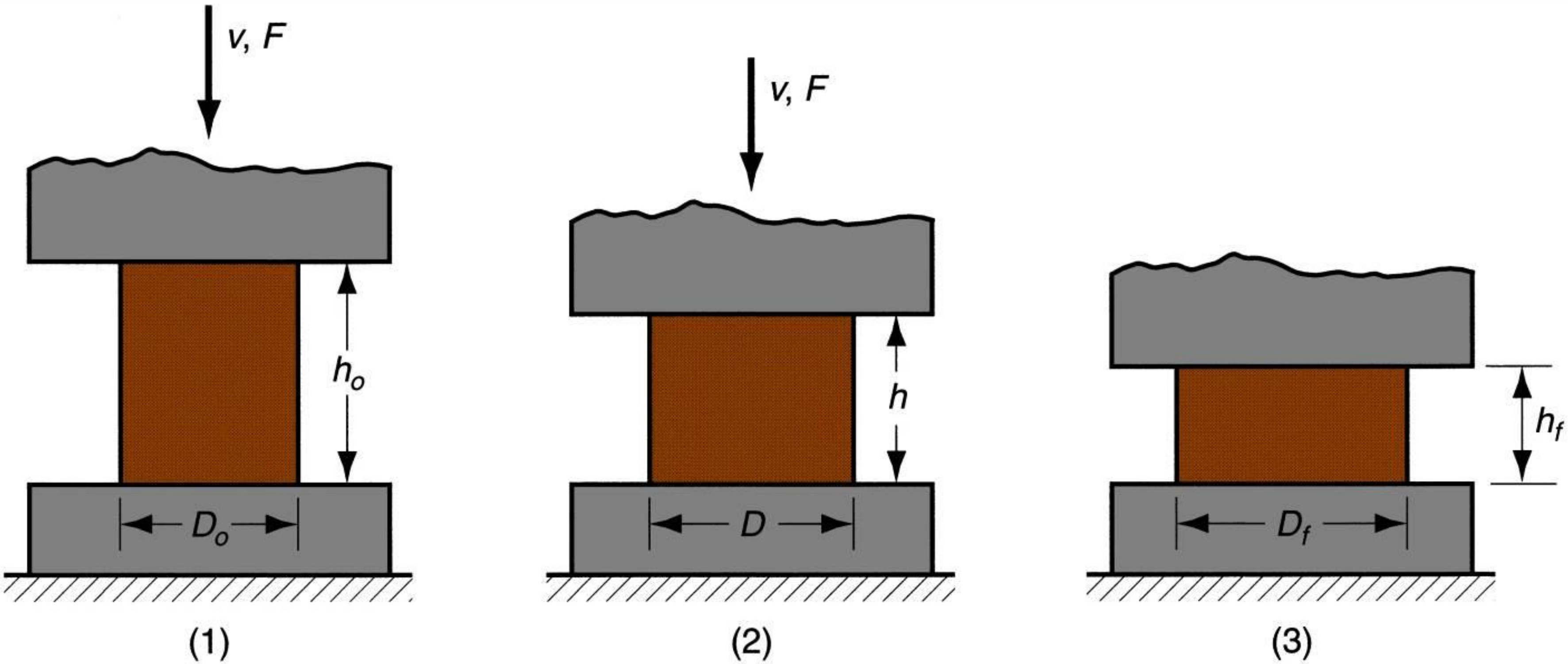
(2) CLASSIFICATION- Flashless Forging



(2.1) OPEN-DIE FORGING

- The simplest case of open-die forging involves compression of a workpart of cylindrical cross section between two flat dies.
- This forging operation, known as ***upsetting or upset forging*** , ***reduces the height*** of the work and ***increases its diameter***.

(2.1) OPEN-DIE FORGING with No-Friction

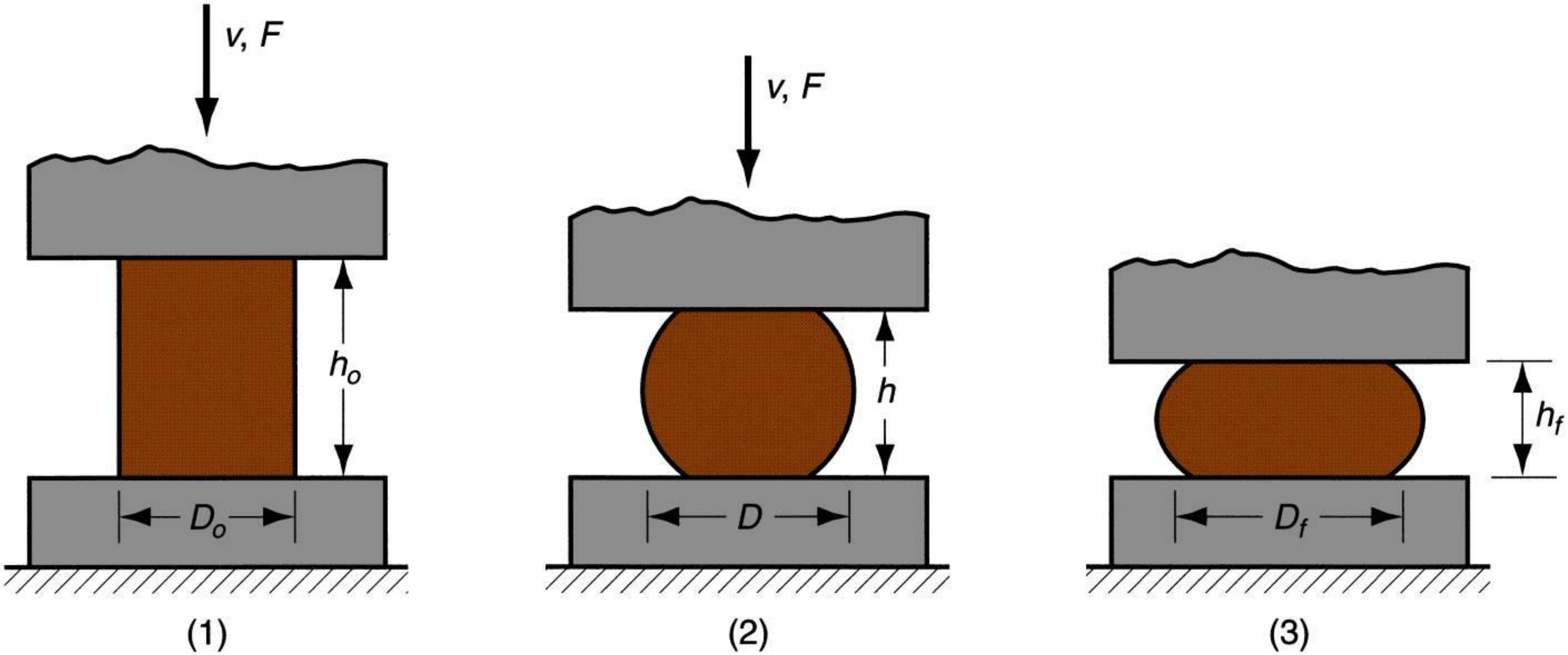


Homogeneous deformation of a cylindrical workpart under ideal conditions in an open-die forging operation: (1) start of process with workpiece at its original length and diameter, (2) partial compression, and (3) final size.

(2.1) OPEN-DIE FORGING with Friction

- ***Friction*** between work and die surfaces constrains lateral flow of work, resulting in ***barreling effect***.
- When performed on a hot workpart with cold dies, the barreling effect is even more pronounced.
- This results from a ***higher coefficient of friction*** typical in hot working and heat transfer at and near the die surfaces, which cools the metal and increases its resistance to deformation.
- The hotter metal in the middle of the part flows more readily than the cooler metal at the ends.

(2.1) OPEN-DIE FORGING with Friction

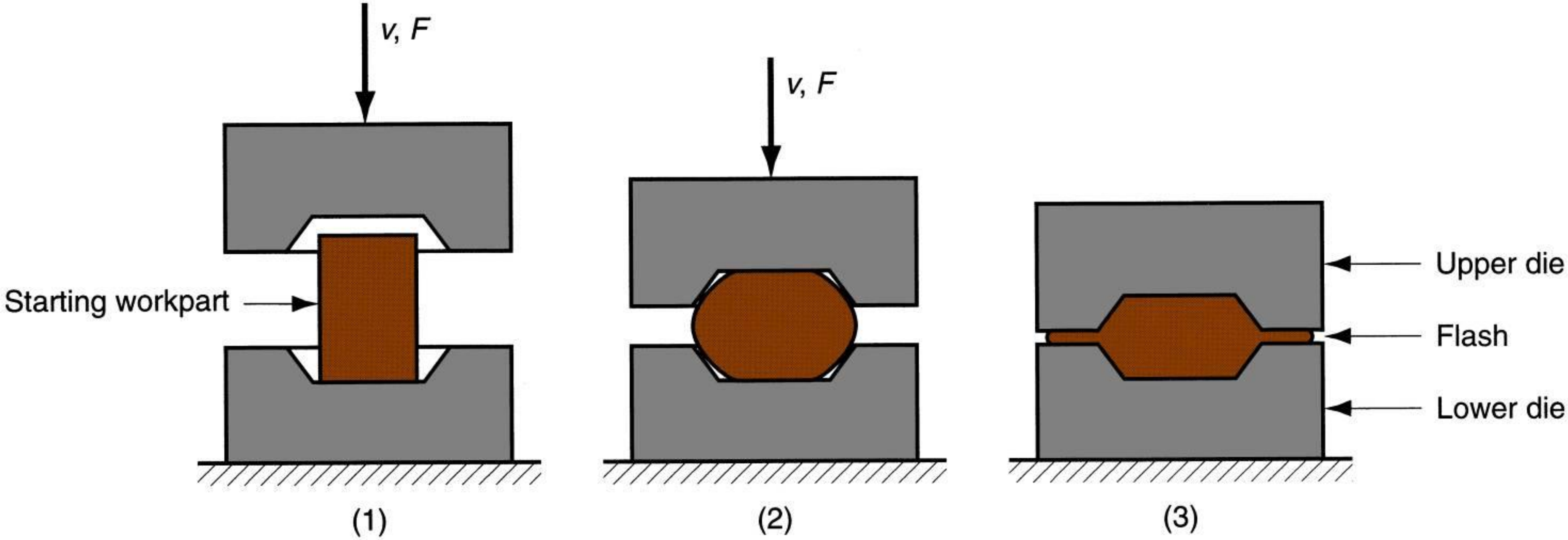


Actual deformation of a cylindrical workpart in open-die forging, showing pronounced *barreling*: (1) start of process, (2) partial deformation, and (3) final shape.

(2.2) IMPRESSION-DIE FORGING

- Impression-die forging, sometimes called ***closed-die forging*** , is performed with dies that contain the inverse of the desired shape of the part.
- The process is illustrated in a three-step sequence in Figure.
- The raw workpiece is shown as a cylindrical part similar to that used in the previous open-die operation .

(2.2) IMPRESSION-DIE FORGING

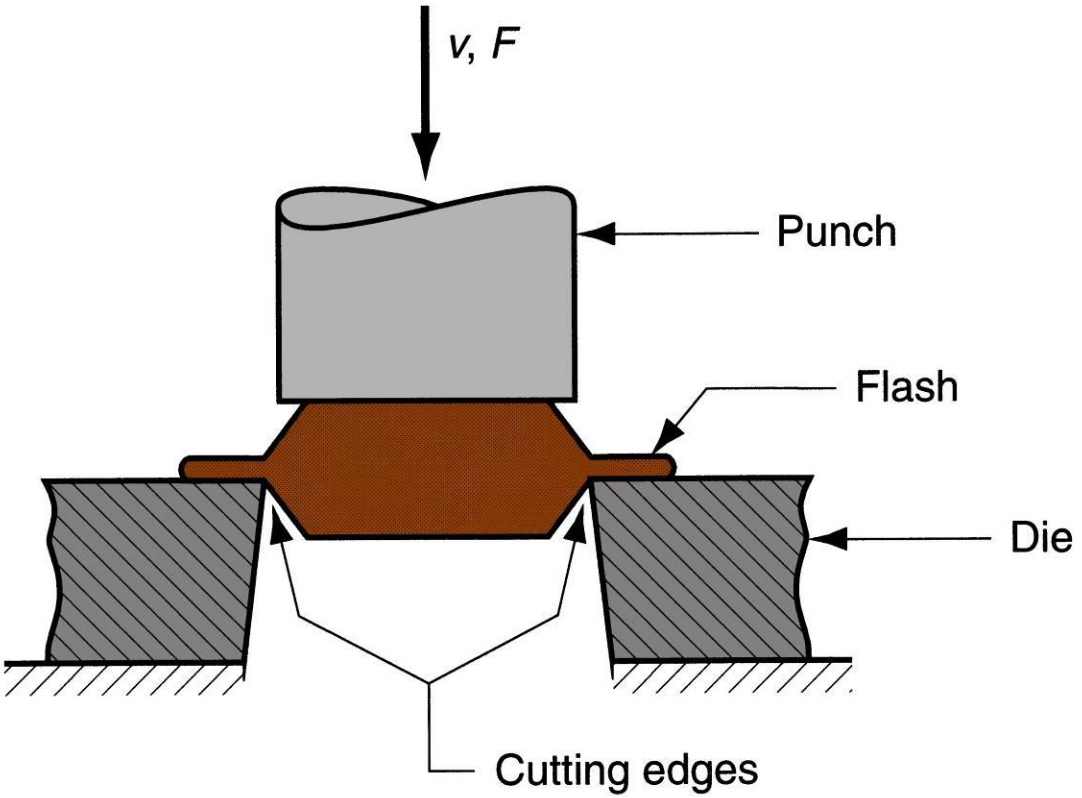


Sequence in impression-die forging: (1) just prior to initial contact with raw workpiece, (2) partial compression, and (3) final die closure, causing flash to form in gap between die plates.

(2.2) IMPRESSION-DIE FORGING

- As the die closes to its final position , ***flash is formed*** by metal that flows beyond the die cavity and in to the small gap between the die plates.
- Although this flash ***must be cut away*** from the part in a subsequent trimming operation, it actually serves two important functions during impression-die forging.
  - *As flash forms, friction resists continued metal flow into gap, constraining material to fill die cavity*
  - *In hot forging, metal flow is further restricted by cooling against die plates*

(2.2) IMPRESSION-DIE FORGING

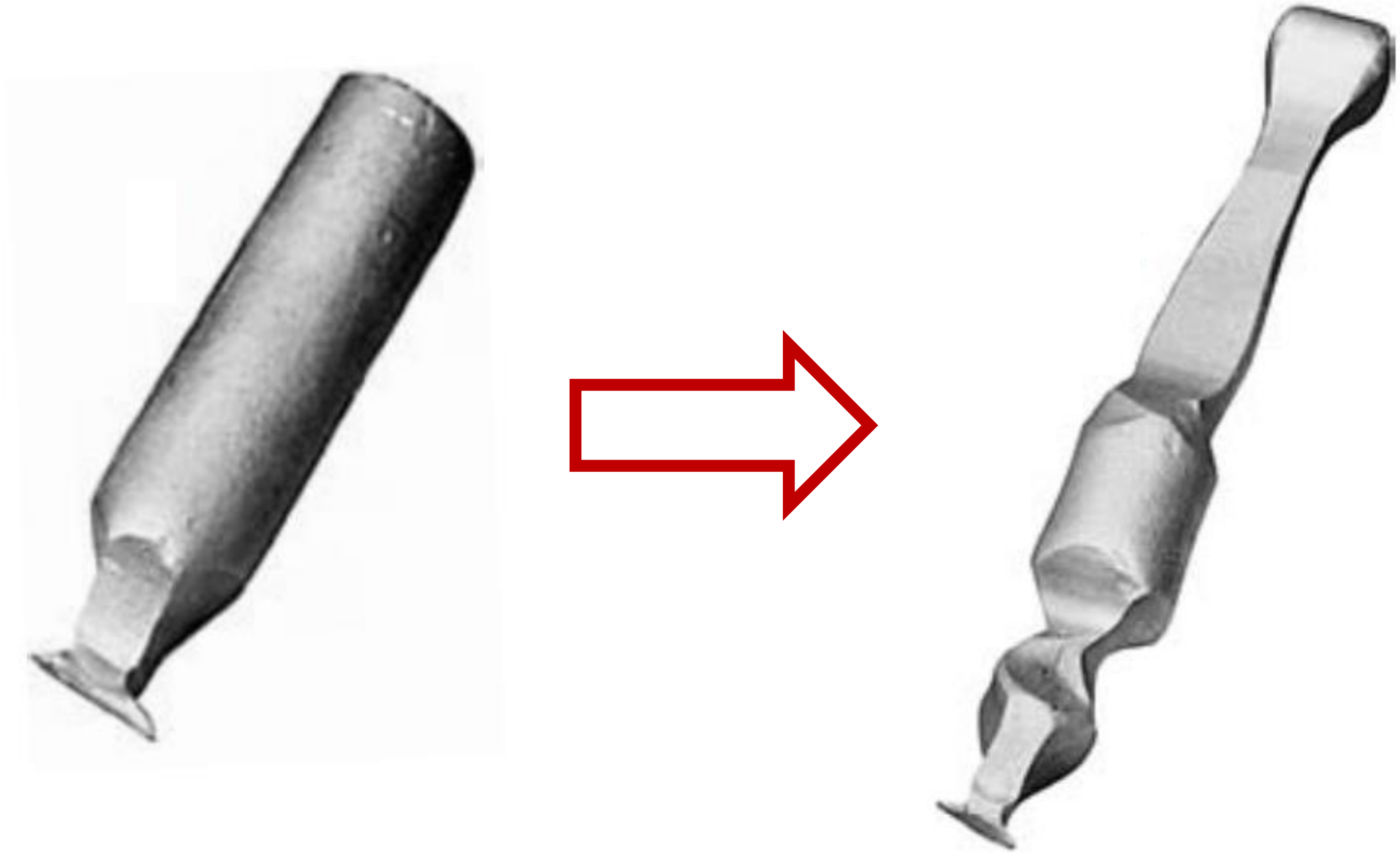


Trimming operation (shearing process) to remove the flash after impression-die forging.

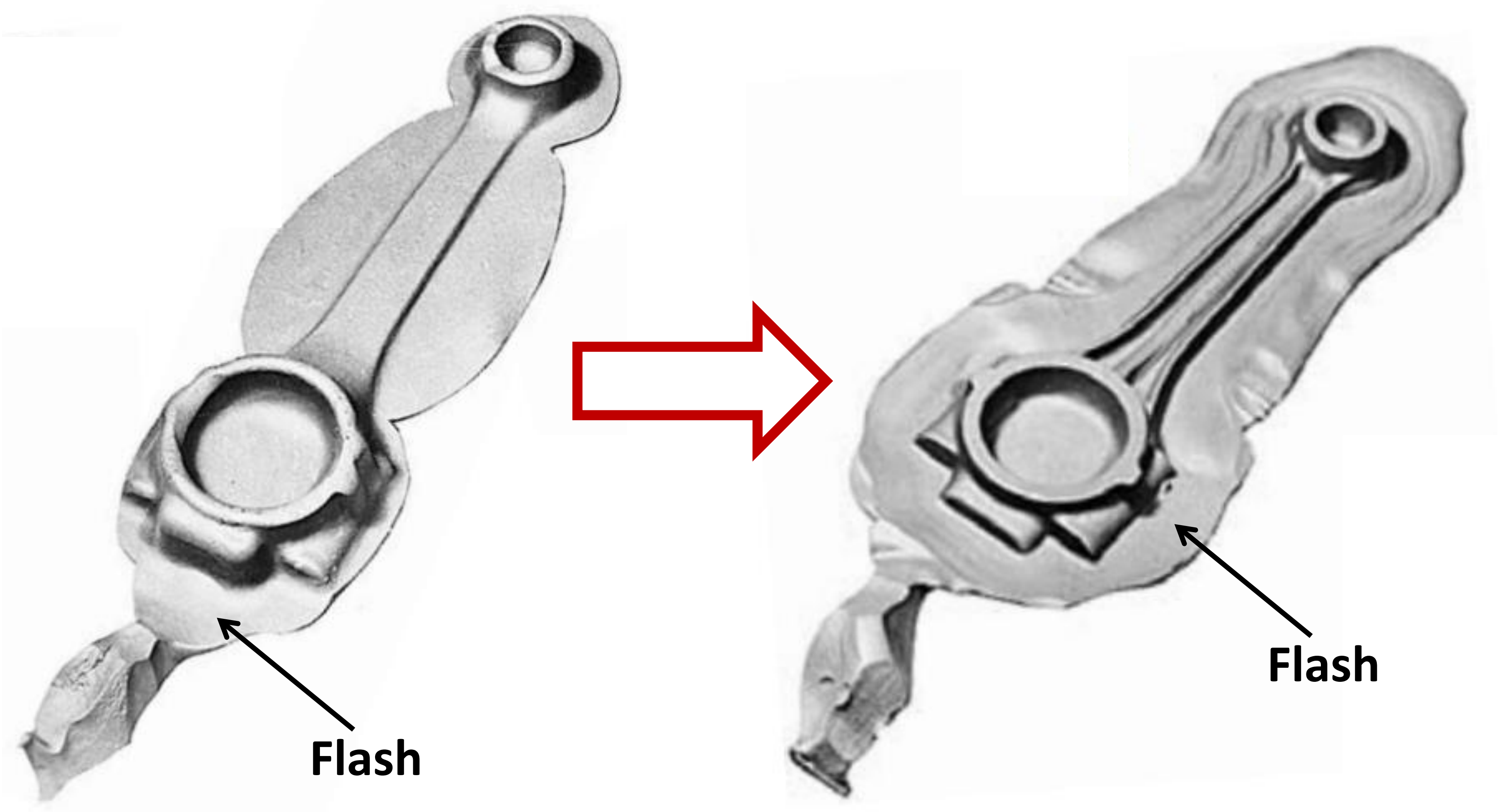
(2.2) IMPRESSION-DIE FORGING

- ***Advantages*** of impression-die forging compared to machining :
  - Higher production rates
  - Less waste of metal
  - Greater strength
  - Favorable grain orientation in the metal
- ***Limitations***:
  - Not capable of close tolerances
  - Machining often required to achieve accuracies and features needed

(2.2) IMPRESSION-DIE FORGING (connecting rod)



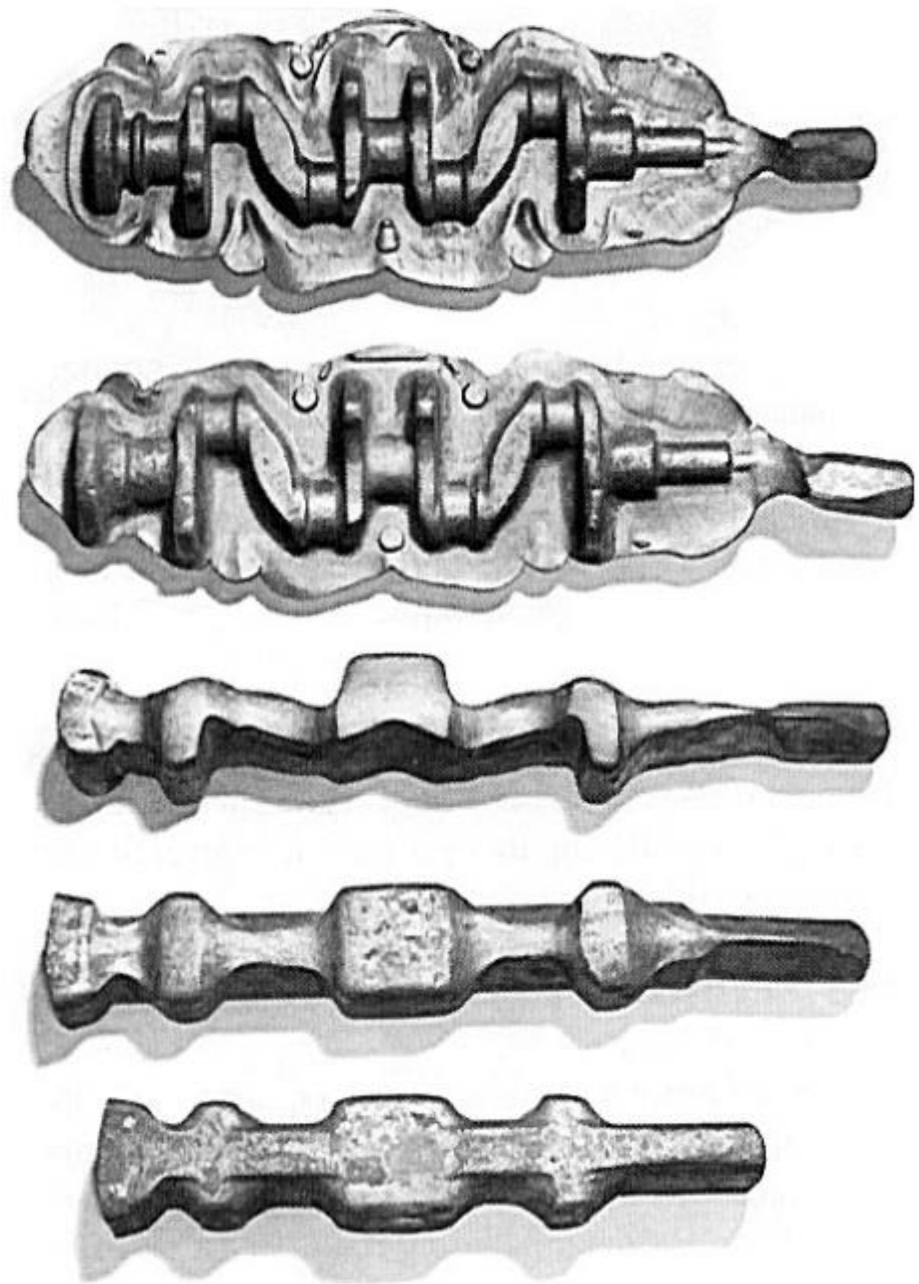
(2.2) IMPRESSION-DIE FORGING (connecting rod)



(2.2) IMPRESSION-DIE FORGING (connecting rod)

(2.2) IMPRESSION-DIE FORGING (open wrench)

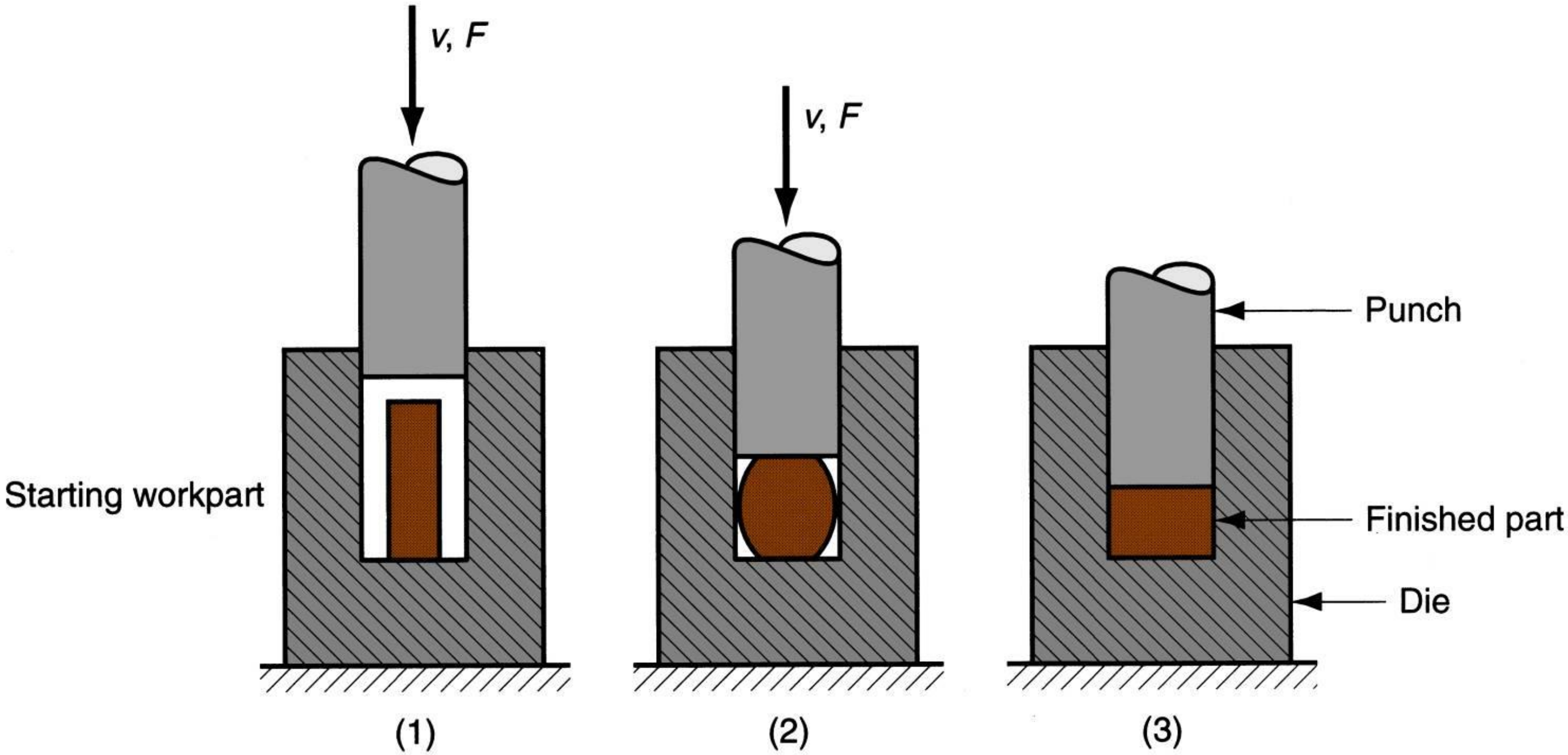
(2.2)
IMPRESSION-DIE
FORGING
(crank shaft)



(2.3) FLASHLESS FORGING *(PRECISION FORGING)*

- ***Impression-die*** forging is ***sometimes called closed-die forging*** in industry terminology.
- However, there is a technical ***distinction*** between impression-die forging and true closed-die forging.
- The distinction is that in ***closed-die forging***, the raw workpiece is ***completely contained*** with in the die cavity during compression , and ***no flash is formed*** .
- The process sequence is illustrated in Figure.

(2.3) FLASHLESS FORGING *(PRECISION FORGING)*



Flashless forging: (1) just before initial contact with workpiece, (2) partial compression, and (3) final punch and die closure.

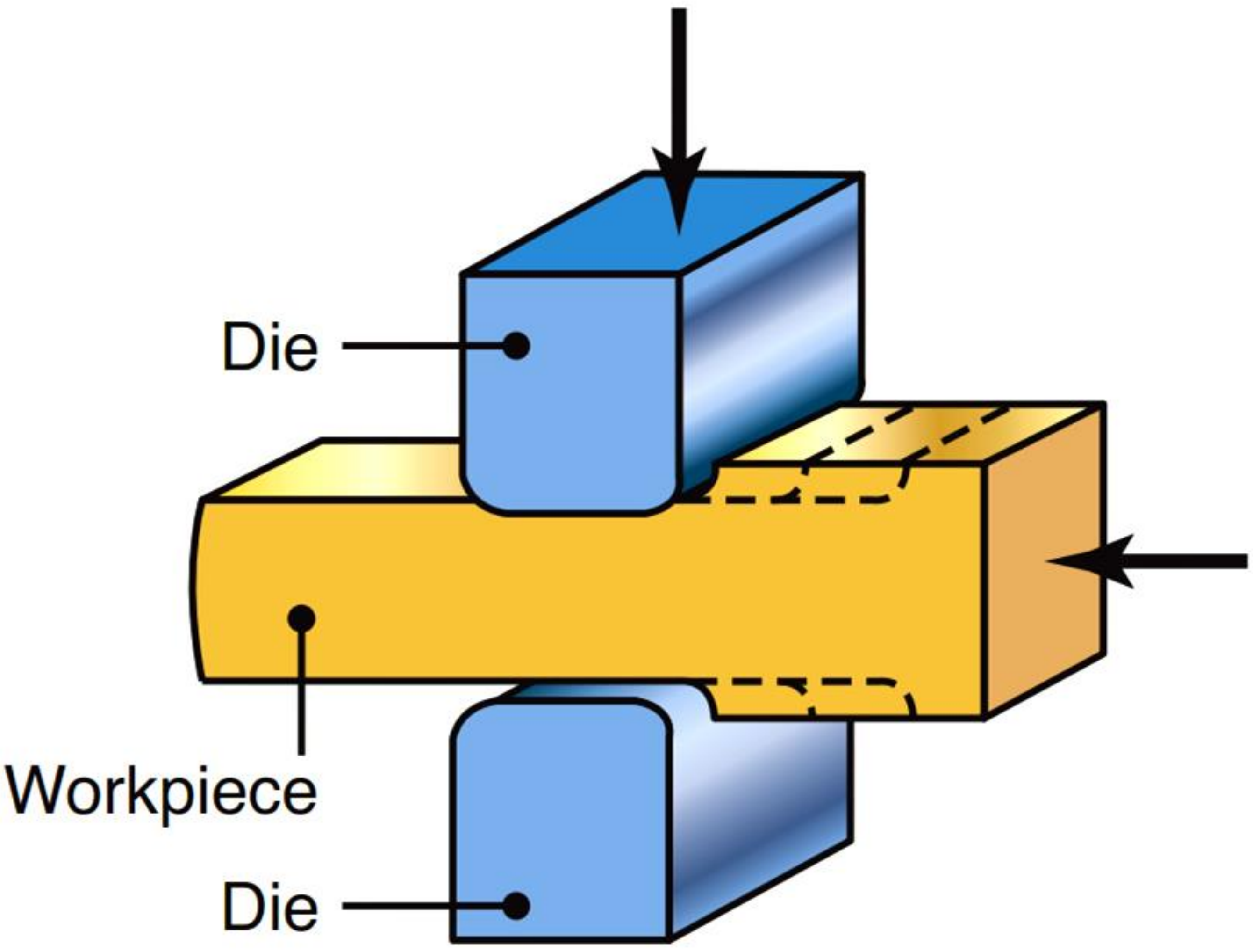
(2.3) FLASHLESS FORGING *(PRECISION FORGING)*

- ***Flashless*** forging imposes requirements on process control that are more demanding than impression- die forging.
- Most important is that the ***work volume must equal the space*** in the die cavity with in a very close tolerance.
- If the starting blank is too large, ***excessive pressures may*** cause ***damage*** to the ***die*** or press.
- If the ***blank is too small*** , the ***cavity*** will ***not*** be ***filled***.

(2.3) FLASHLESS FORGING *(PRECISION FORGING)*

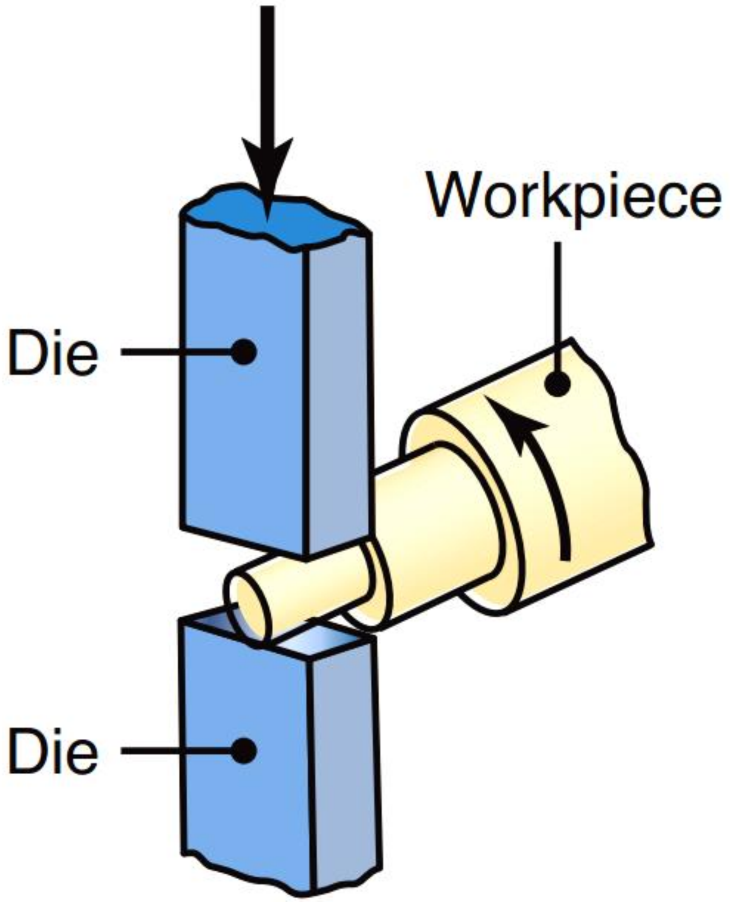
- Because of the special demands made by flash less forging, the process lends itself best to ***part geometries*** that are usually ***simple and symmetrical***, and to work materials such as aluminium and magnesium and their alloys.
- Flashless forging is often referred as a ***precision forging process.***

Examples: Open Die Forging



Schematic illustration of a cogging operation on a rectangular bar. Blacksmiths use a similar procedure to reduce the thickness of parts in small increments by heating the workpiece and hammering it numerous times along the length of the part.

Examples: Open Die Forging

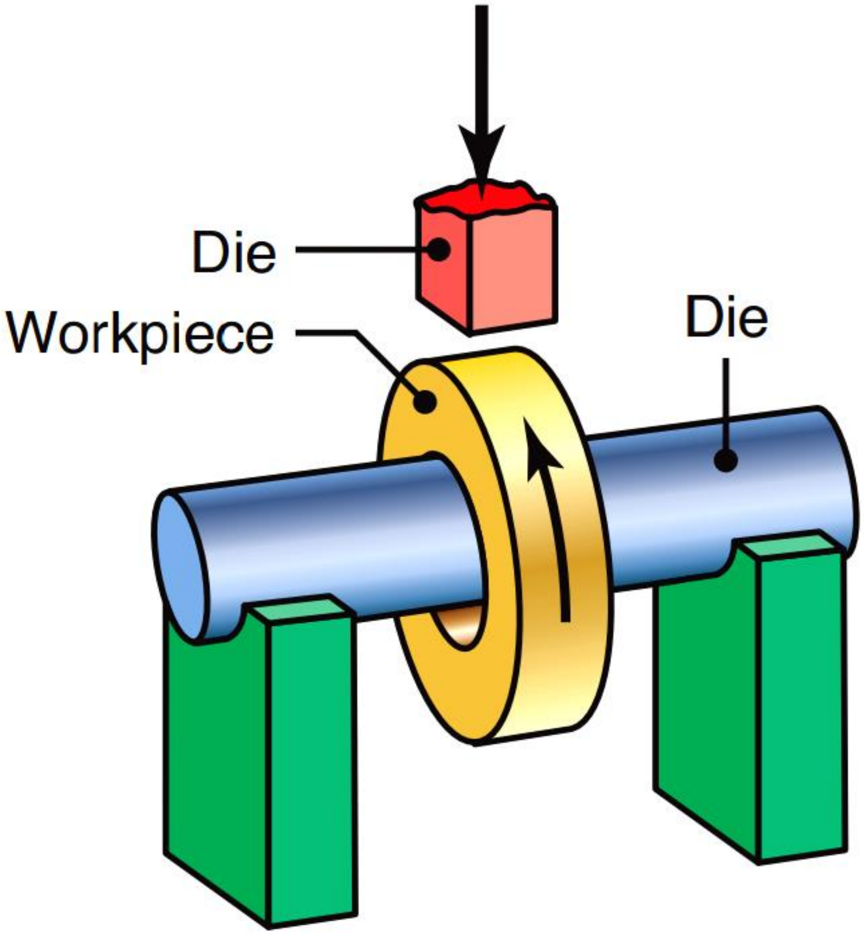


Reducing the diameter of a bar by open-die forging

Or

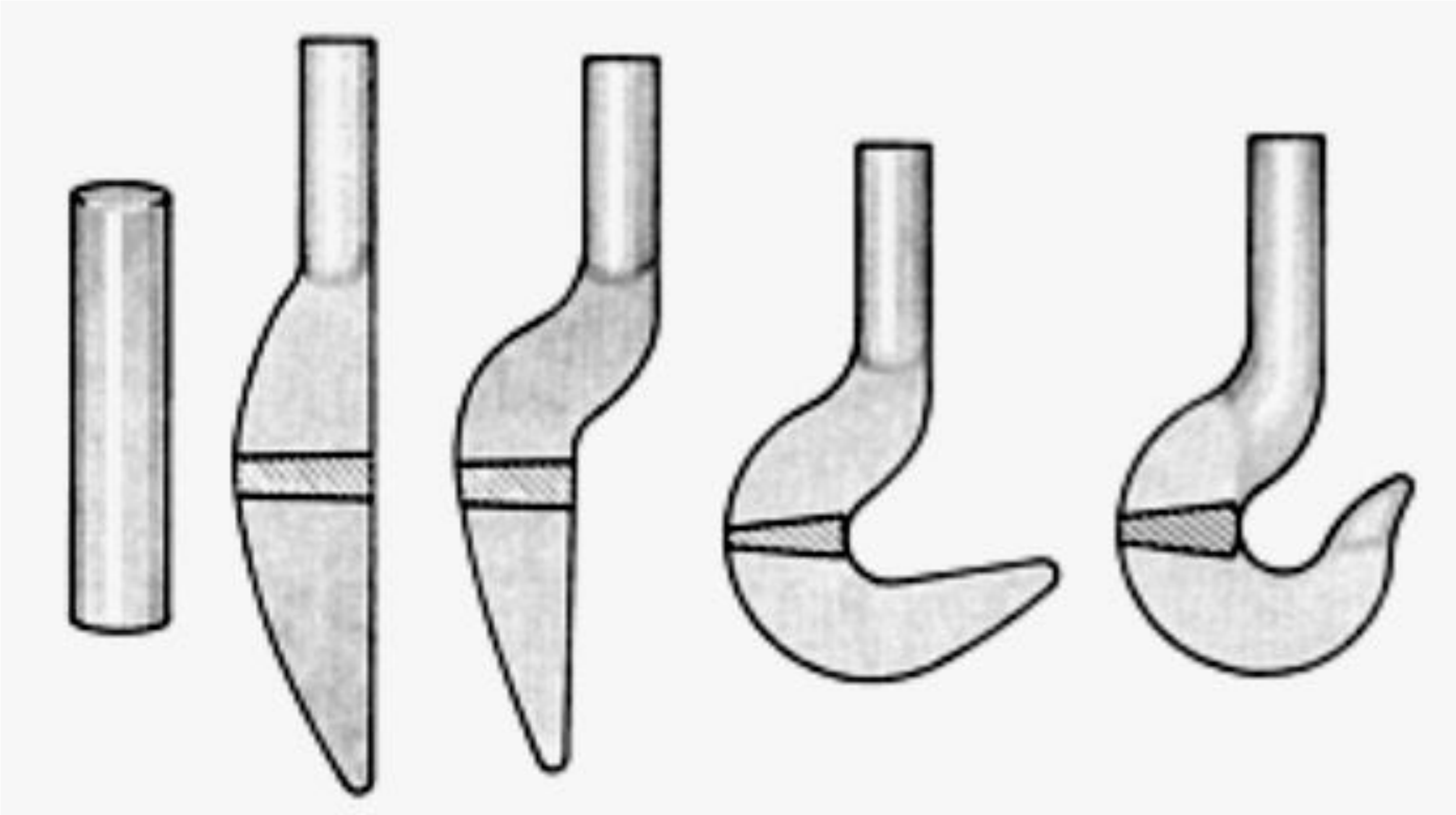
Open Die Forging of a multi diameter shaft

Examples: Open Die Forging



The thickness of a ring being reduced by open-die forging

Examples: Open Die Forging



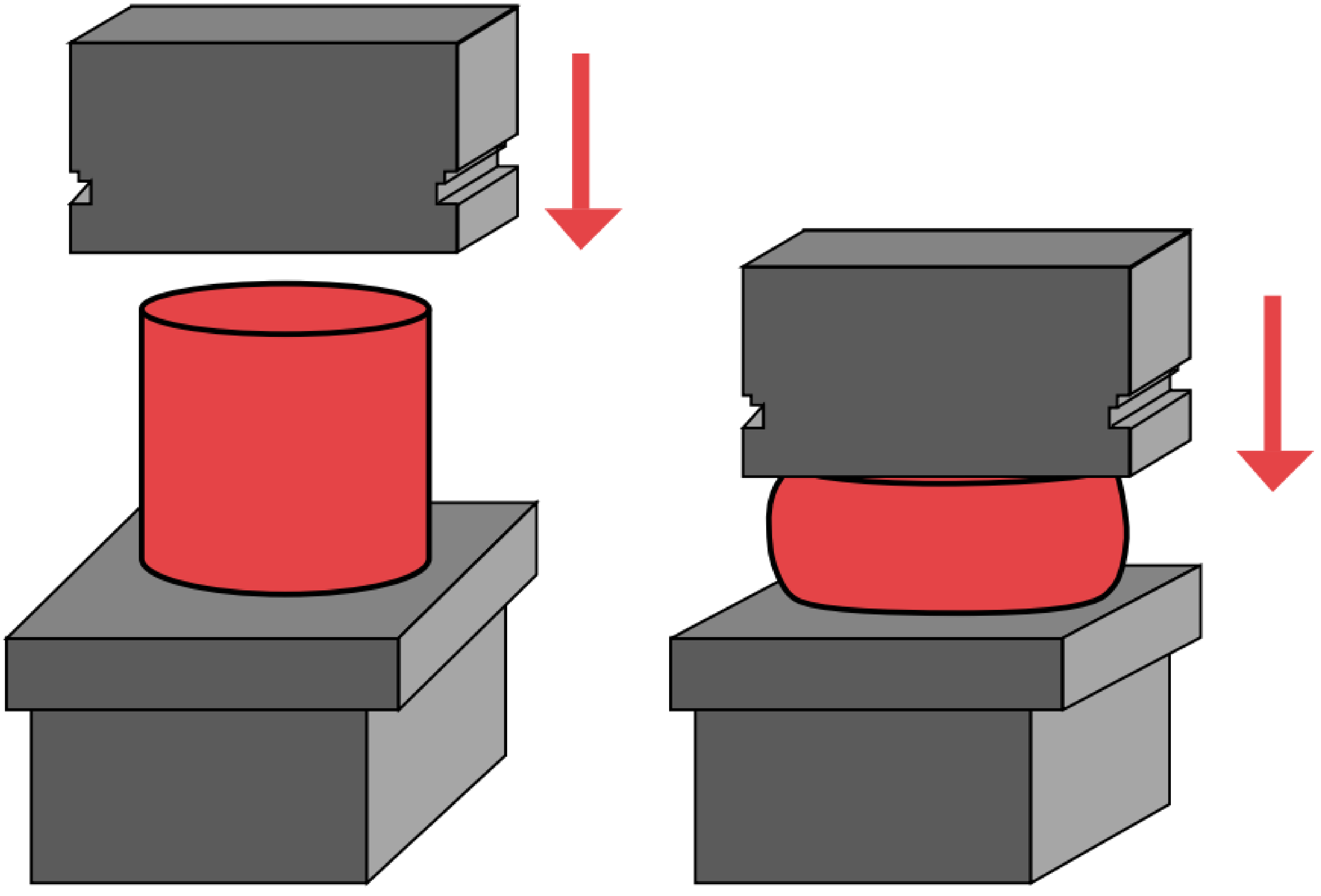
Making of a crane hook by open die forging

Seamless Rolled Ring Forging Process Operations

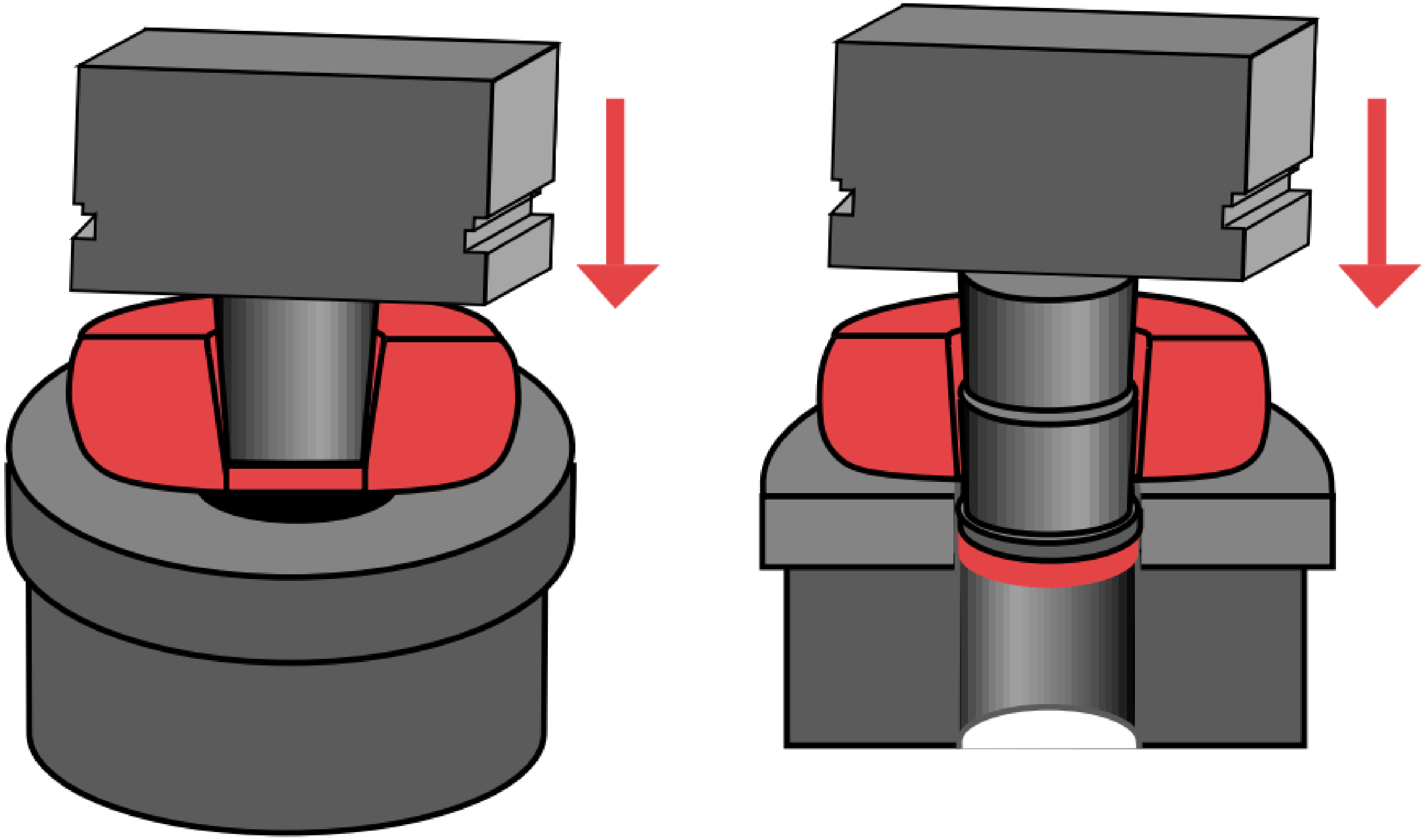
- The production of seamless forged rings is often performed by a process called ring rolling on rolling mills.
- The process starts with a circular preform of metal that has been previously upset and pierced (using the open die forging process) to form a hollow "donut".
- This donut is heated above the recrystallization temperature and placed over the idler or mandrel roll.

Seamless Rolled Ring Forging Process Operations

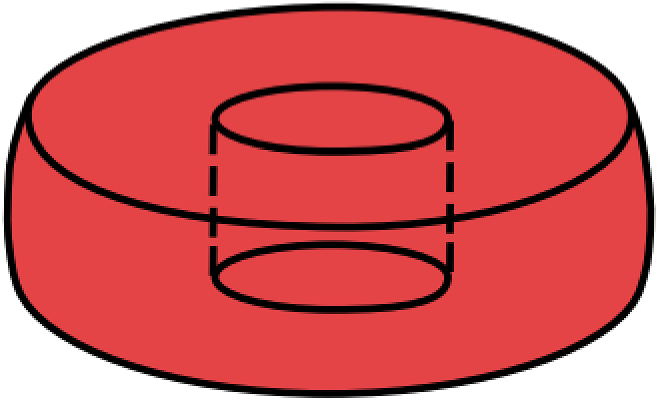
- This idler roll then moves under pressure toward a drive roll that continuously rotates to reduce the wall thickness, thereby increasing the diameters of the resulting ring.



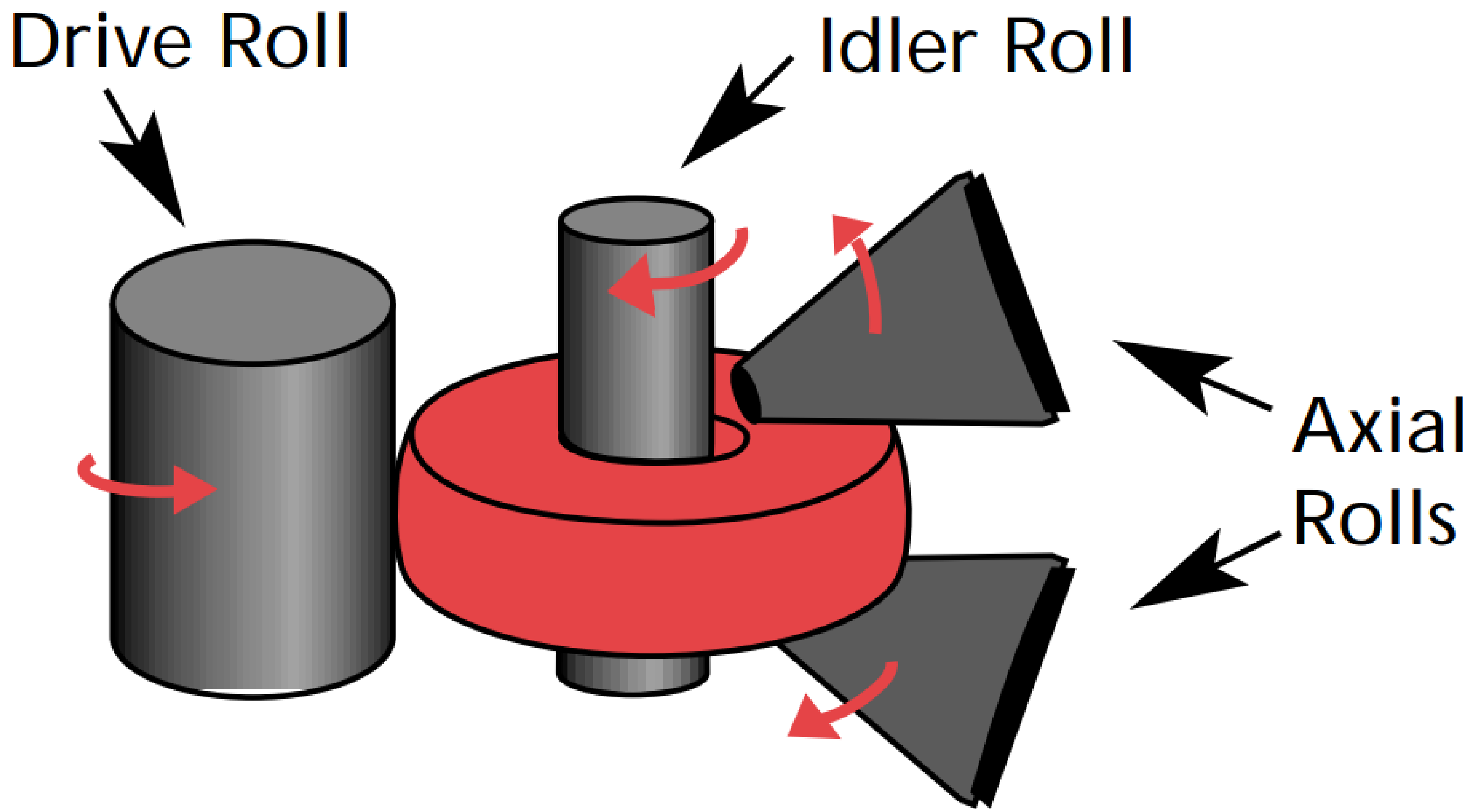
Starting stock cut to size by weight is first rounded, then upset to reduce the height.



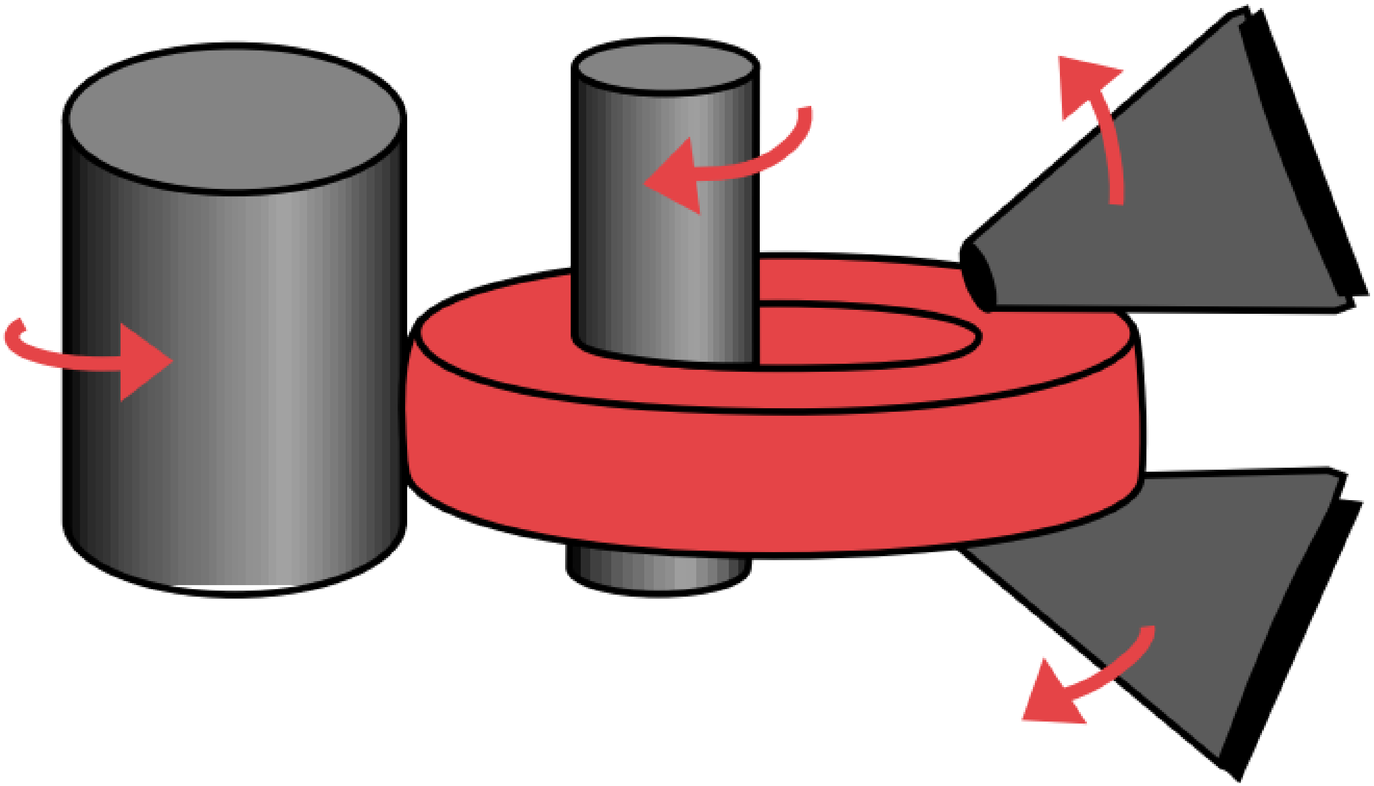
Workpiece is punched, then pierced to achieve starting “donut” shape needed for ring rolling process.



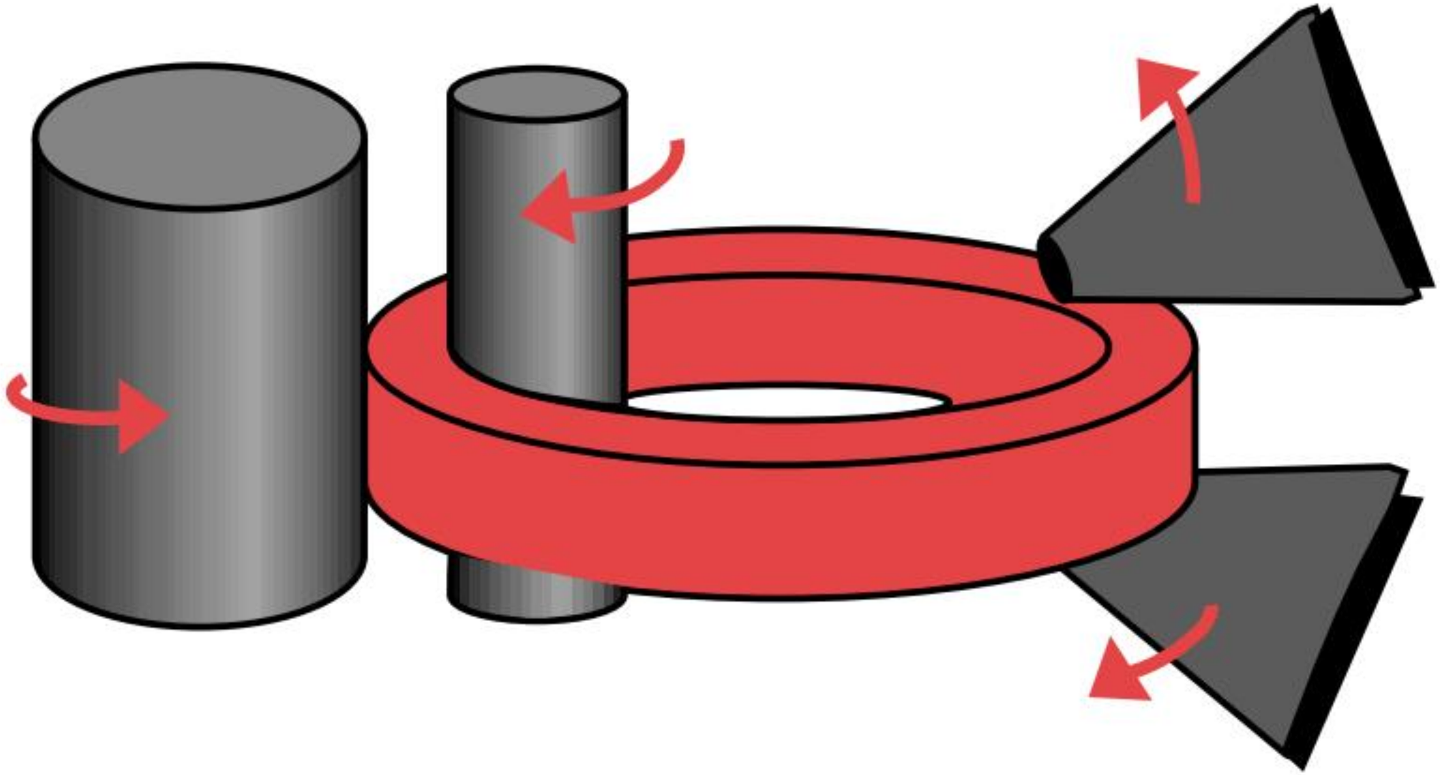
Completed preform ready for placement on ring mill for rolling.



Ring rolling process begins with the idler roll applying pressure to the preform against the drive roll.



Ring diameters are increased as the continuous pressure reduces the wall thickness. The axial rolls control the height of the ring as it is being rolled.



The process continues until the desired size is attained.

Forging Hammers (Drop Hammers)

Apply impact load against workpart

- Two types:
  - ***Gravity drop hammers*** - impact energy from falling weight of a heavy ram
  - ***Power drop hammers*** - accelerate the ram by pressurized air or steam
- Disadvantage: impact energy transmitted through anvil into floor of building
- Commonly used for ***impression-die forging***

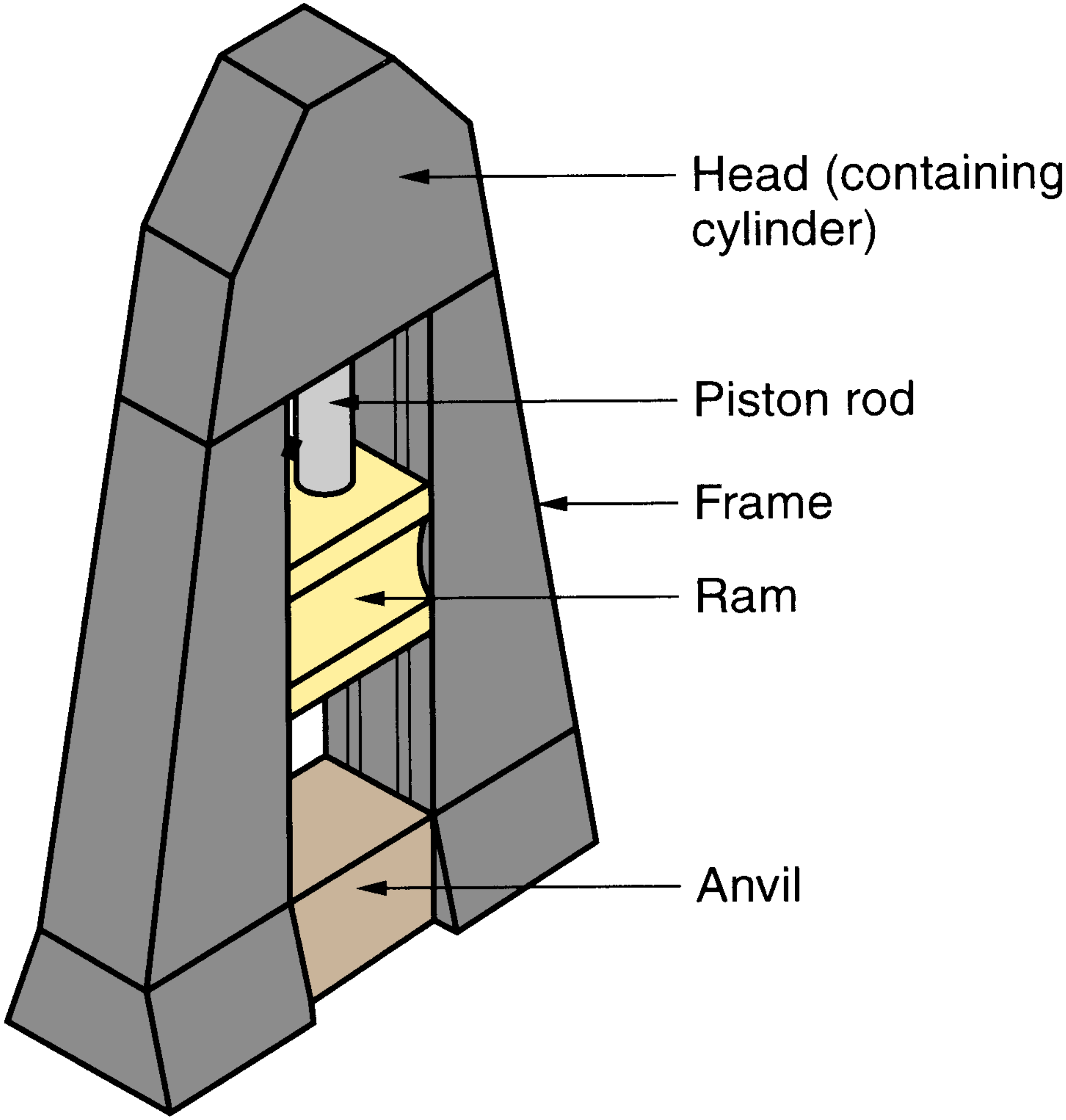
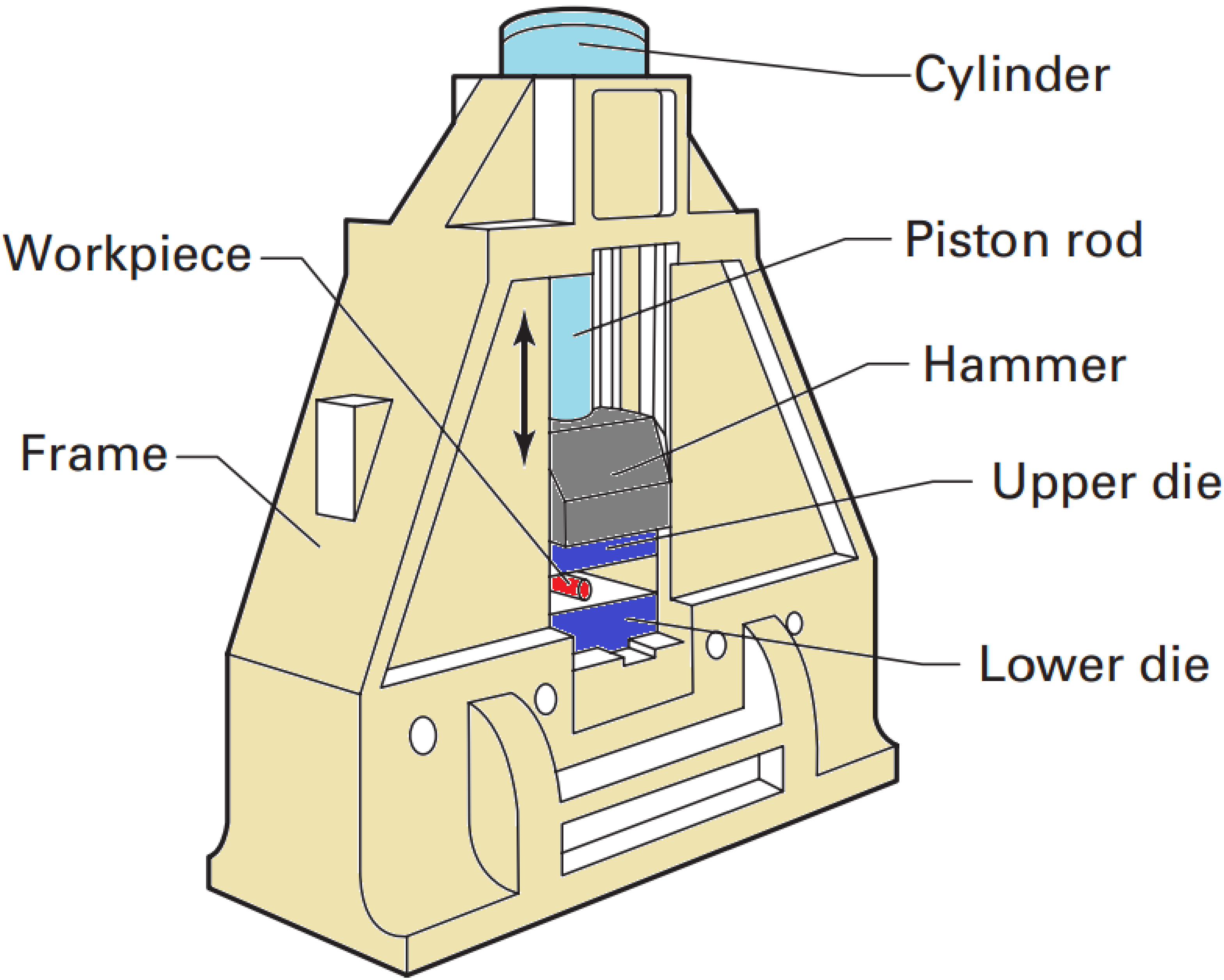


Diagram showing details of a drop hammer for impression-die forging.

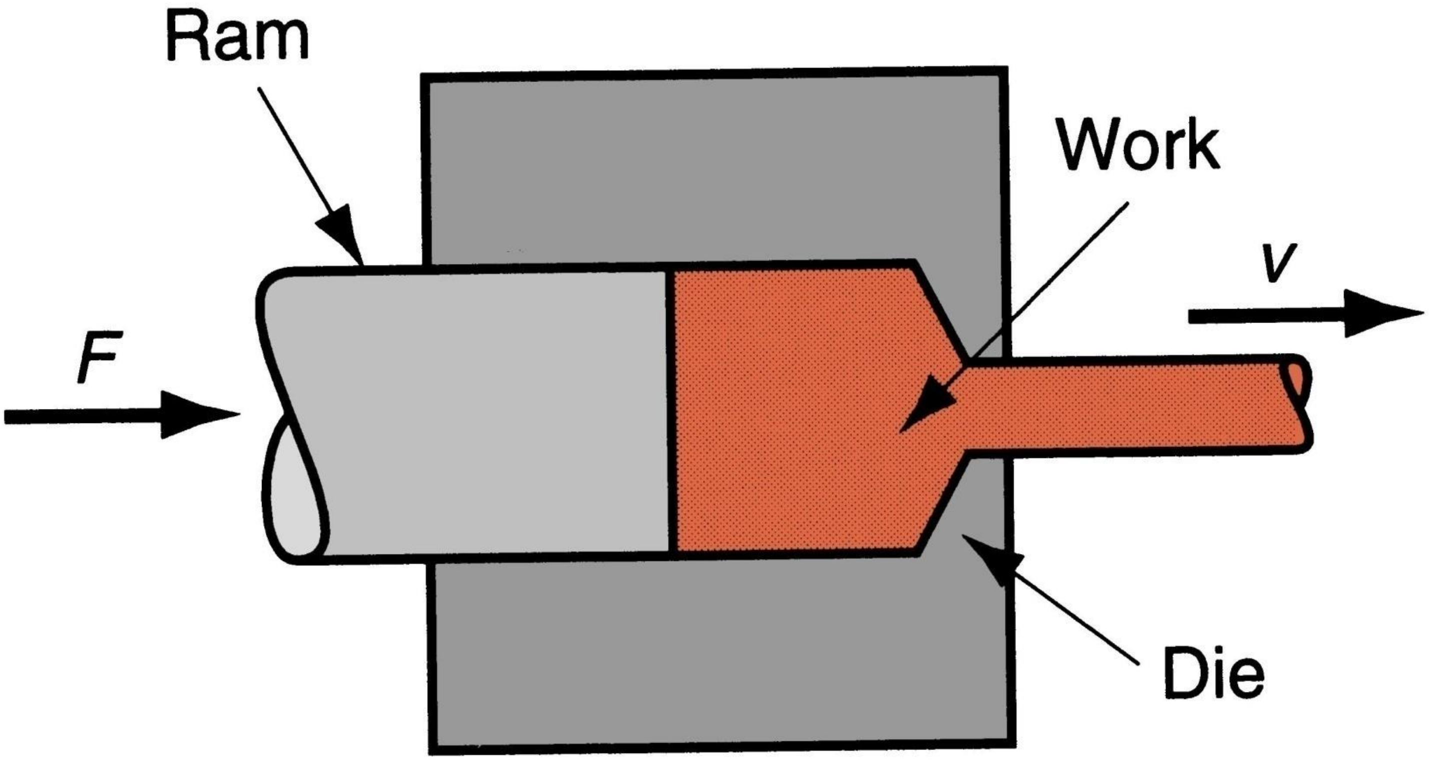

Cylinder
Piston rod
Hammer
Upper die
Lower die
Workpiece
Frame

(3) EXTRUSION

(3) EXTRUSION

- Extrusion is a ***compression process*** in which the work metal is ***forced to flow*** through a ***die*** opening to produce a ***desired cross-sectional shape.***
- The process can be likened to ***squeezing toothpaste*** out of a toothpaste tube.

(3) EXTRUSION



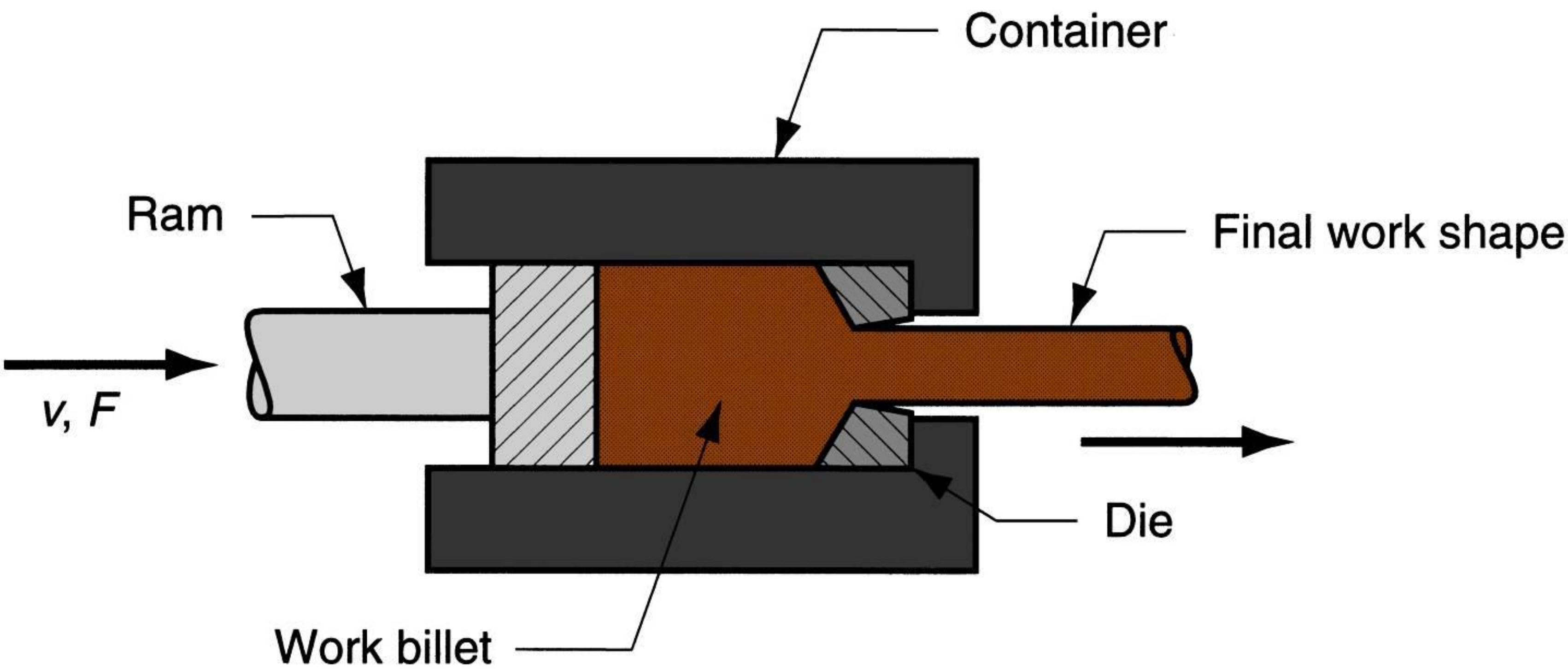
(3) TYPES OF EXTRUSION

- In general, extrusion is used to **produce long parts** of **uniform cross sections**
- Two basic types:
  - **Direct extrusion**
  - **Indirect extrusion**

(3) TYPES OF EXTRUSION (DIRECT)

- ***Direct extrusion*** (also called ***forward extrusion***)is shown in Figure.
- A ***metal billet*** is loaded into a container, and a ***ram compresses*** the material, forcing it to ***flow*** through one or more ***openings*** in a die at the opposite end of the container.
- As the ram approaches the die, a small portion of the billet remains that cannot be forced through the die opening.

(3) TYPES OF EXTRUSION (DIRECT)



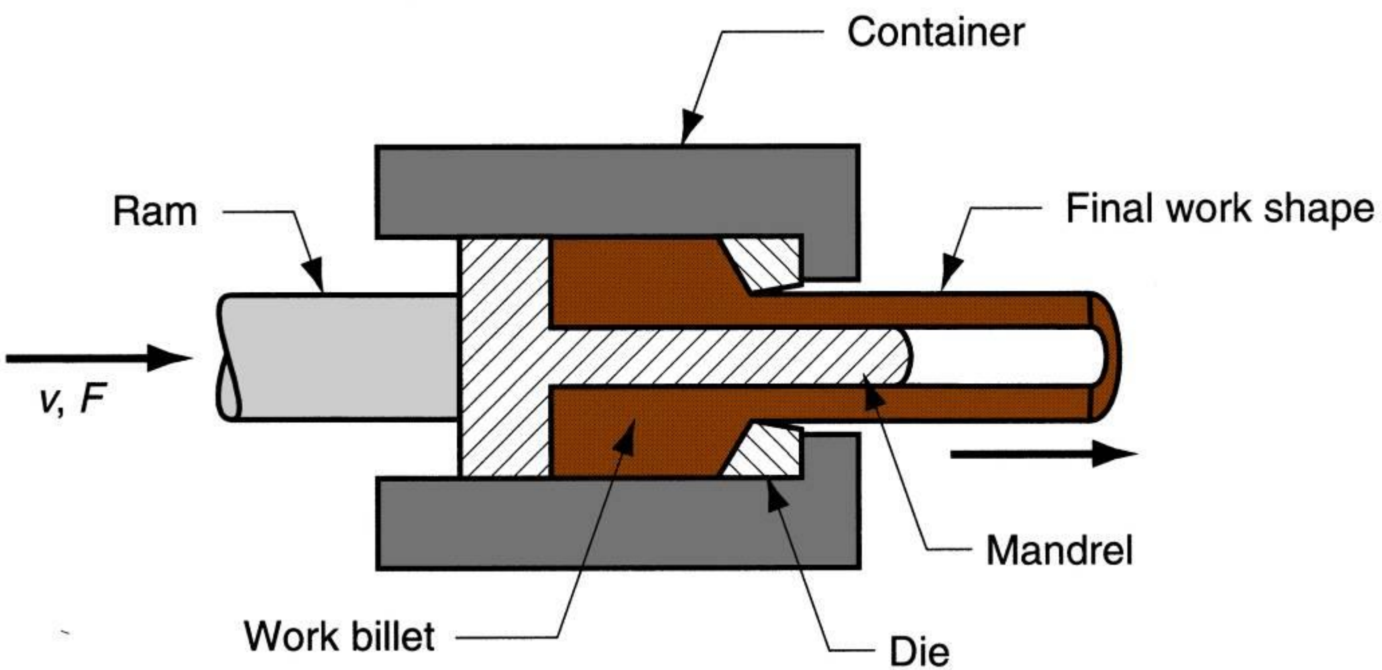
(3) TYPES OF EXTRUSION (DIRECT)

- This extra portion, called the ***butt*** ,is separated from the product by ***cutting*** it just ***beyond the exit of the die.***
- One of the problems in direct extrusion is the significant ***friction*** that exists between the ***work surface and the walls*** of the container as the billet is forced to slide to ward the die opening.
- This friction causes a substantial increase in the ram force required in direct extrusion.

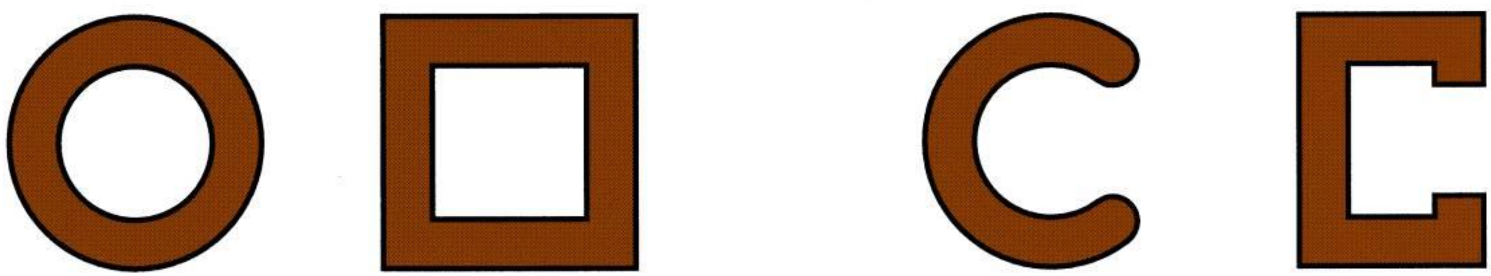
(3) TYPES OF EXTRUSION (DIRECT)

- Hollow sections (e.g., tubes) are possible in direct extrusion by the process setup in Figure.

(3) TYPES OF EXTRUSION (DIRECT)(hollow sections)



(a)



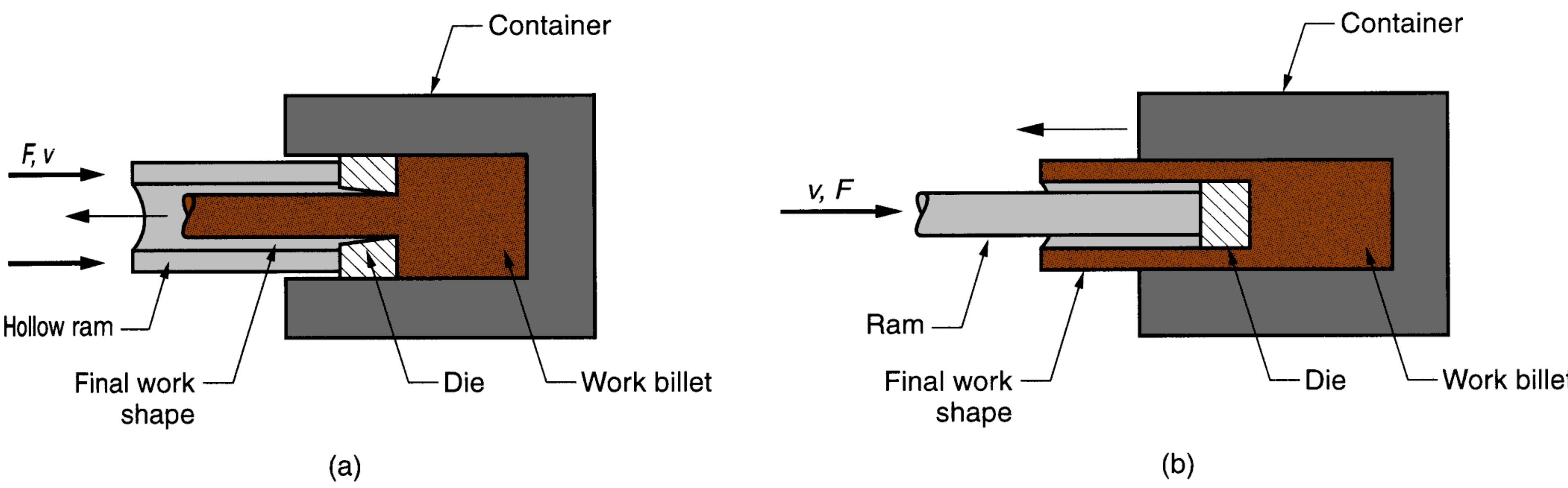
(3) TYPES OF EXTRUSION (INDIRECT)

- In ***indirect*** extrusion, also called ***backward*** extrusion and ***reverse*** extrusion, the ***die is mounted to the ram*** rather than at the opposite end of the container.
- As the ram penetrates into the work, the ***metal*** is forced to ***flow*** through the ***clearance*** in a ***direction opposite*** to the motion of the ram.

(3) TYPES OF EXTRUSION (INDIRECT)

- Since the billet is not forced to move relative to the container, there is ***no friction*** at the container walls, and the ram force is therefore lower than in direct extrusion.
- ***Limitations*** of indirect extrusion are imposed by the ***lower rigidity of the hollow ram*** and the ***difficulty in supporting*** the extruded product as it exits the die.
- Indirect extrusion can produce hollow (tubular) cross sections, as in Figure.

(3) TYPES OF EXTRUSION (INDIRECT)



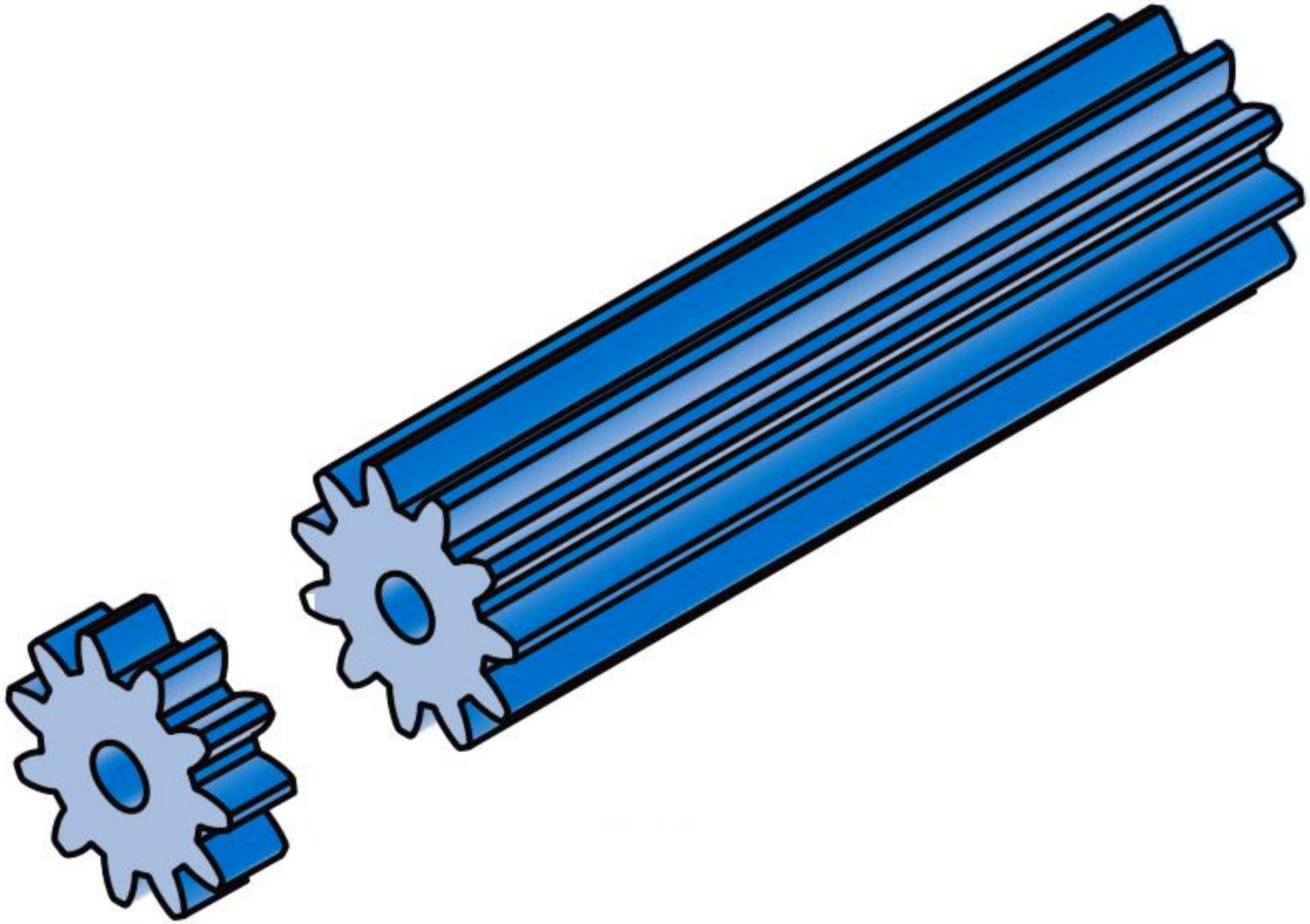
(3) TYPES OF EXTRUSION (HOT vs COLD)

- ***Hot extrusion*** - prior heating of billet to above its recrystallization temperature
  - Reduces strength and increases ductility of the metal, permitting more size reductions and more complex shapes
- ***Cold extrusion*** - generally used to produce discrete parts
  - The term impact extrusion is used to indicate high speed cold extrusion

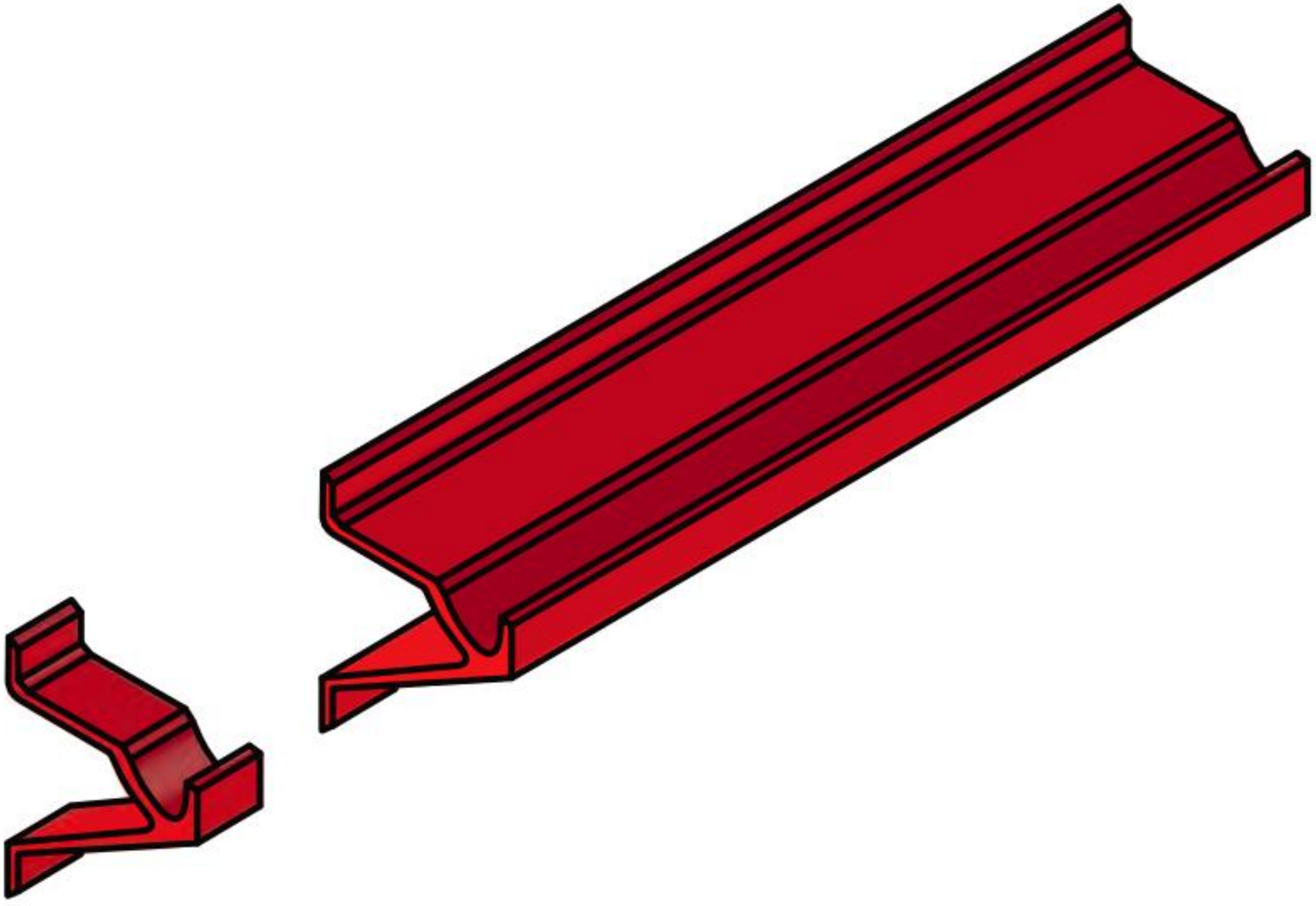
(3) TYPES OF EXTRUSION (HOT vs COLD))

- Variety of shapes possible, especially in ***hot extrusion***
  - ***Limitation***: part cross section must be uniform throughout length
- Grain structure and strength enhanced in cold and warm extrusion
- Close tolerances possible, especially in cold extrusion
- In some operations, little or no waste of material

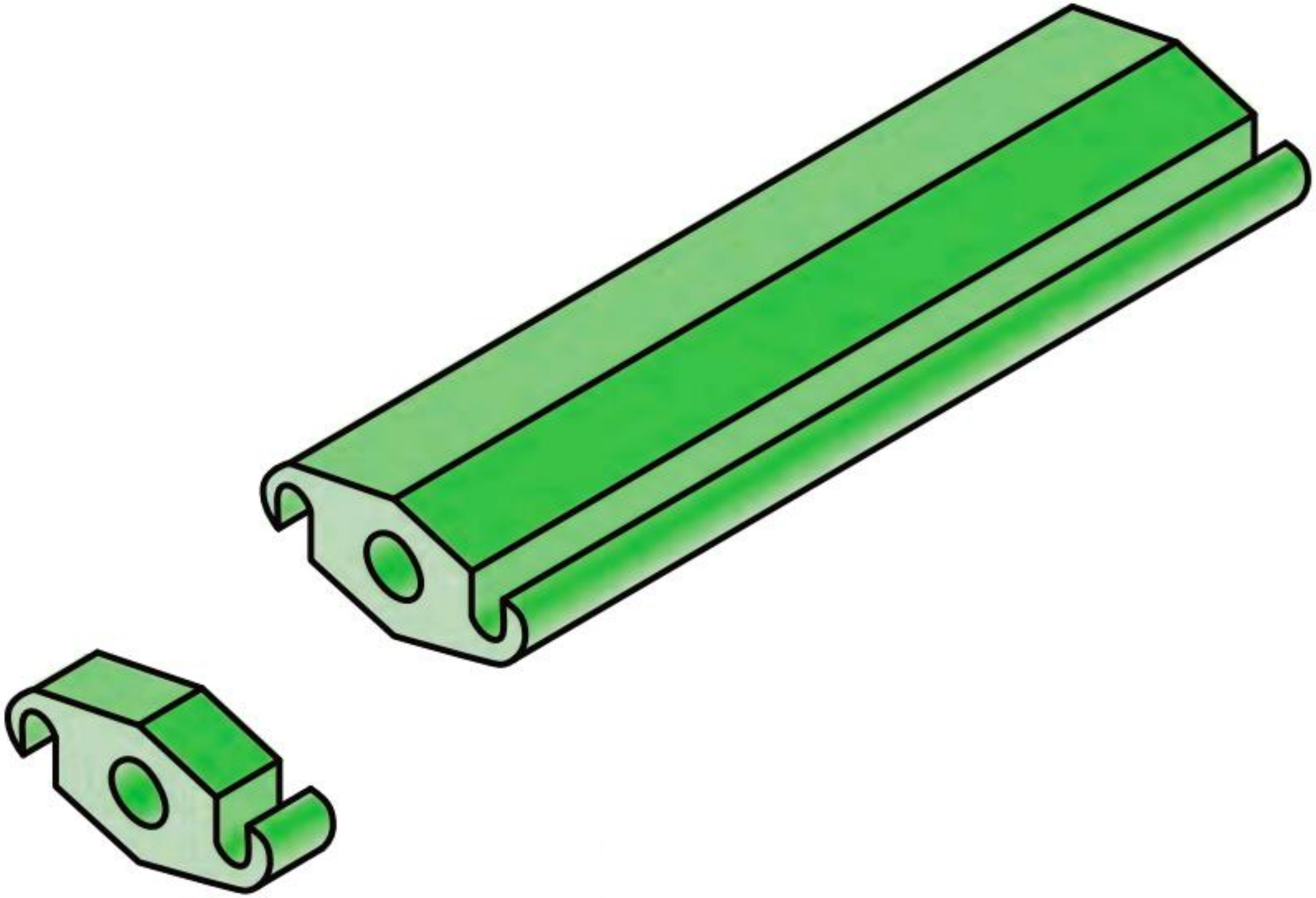
Types Of Extruded Products



Types Of Extruded Products



Types Of Extruded Products



Extrusion Force

Extrusion Force = $\sigma A_o \ln (A_o / A_f)$

σ = average flow stress of material during deformation

A_o = area of cross-section of billet

A_f = area of cross-section of extruded product

Extrusion Force

A_o / A_f is called extrusion ratio.

$$\varepsilon = \ln (A_o / A_f)$$

ε = true strain in extrusion

Extrusion Force - Numerical

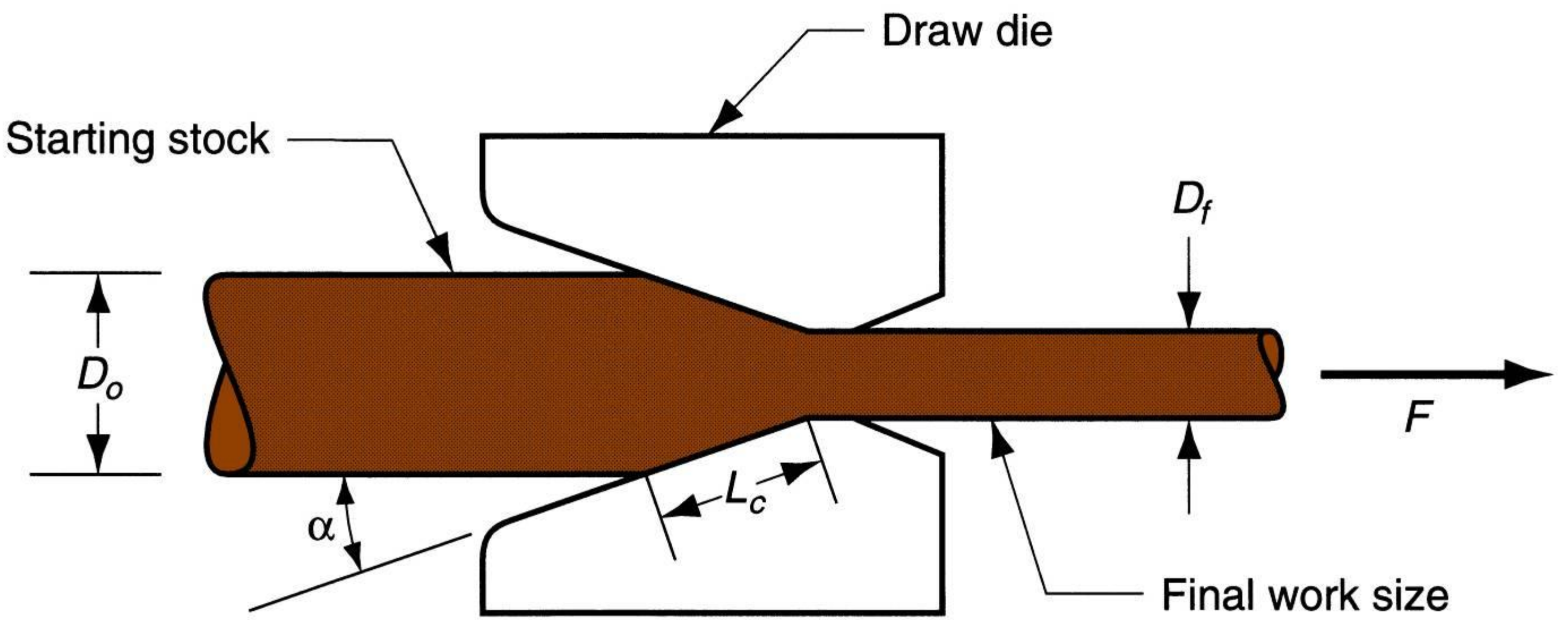
- A billet of metal **800 mm long X 150 mm dia** is to be extruded into a cylindrical component. Direct extrusion process is to be used. If the estimated **extrusion ratio is 40** and the average flow **stress** experienced by the metal during deformation is **100 Mpa**, calculate the true strain and the force required for the extrusion process.

WIRE AND BAR DRAWING

- Drawing is an operation in which the cross-section of a bar, rod, or wire is reduced by pulling it through a die opening, as in Figure .
- The general features of the process are similar to those of extrusion .
- The difference is that the work is pulled through the die in drawing, where as it is pushed through the die in extrusion.

WIRE AND BAR DRAWING

- Although drawing applies tensile stress, compression also plays a significant role since metal is squeezed as it passes through die opening.



WIRE AND BAR DRAWING

- Change in size of work is usually given by area reduction:

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

where r = area reduction in drawing; A_o = original area of work; and A_r = final work

- The draft is simply the difference between original and final stock diameters = D_o - D_f

WIRE AND BAR DRAWING

$$\text{Elongation} = \frac{L_f - L_o}{L_o}$$

Drawing Force = $\sigma_{avg} A_f \ln (A_o / A_f)$

σ_{avg} = average true stress of the material in the die gap

WIRE AND BAR DRAWING

Alternative Formula

Drawing Force = $c\,\sigma_t \ln\,(A_o - A_f)$

c = constant whose value ranges from 1.5 to 3.0 (lower value for higher percentage reduction)

σ_t = tensile strength of the material before drawing

Wire Drawing vs. Bar Drawing

- Difference between bar drawing and wire drawing is stock size
  - Bar drawing - large diameter bar and rod stock
  - Wire drawing - small diameter stock - wire sizes down to 0.03 mm are possible
- Although the mechanics are the same, the methods, equipment, and even terminology are different

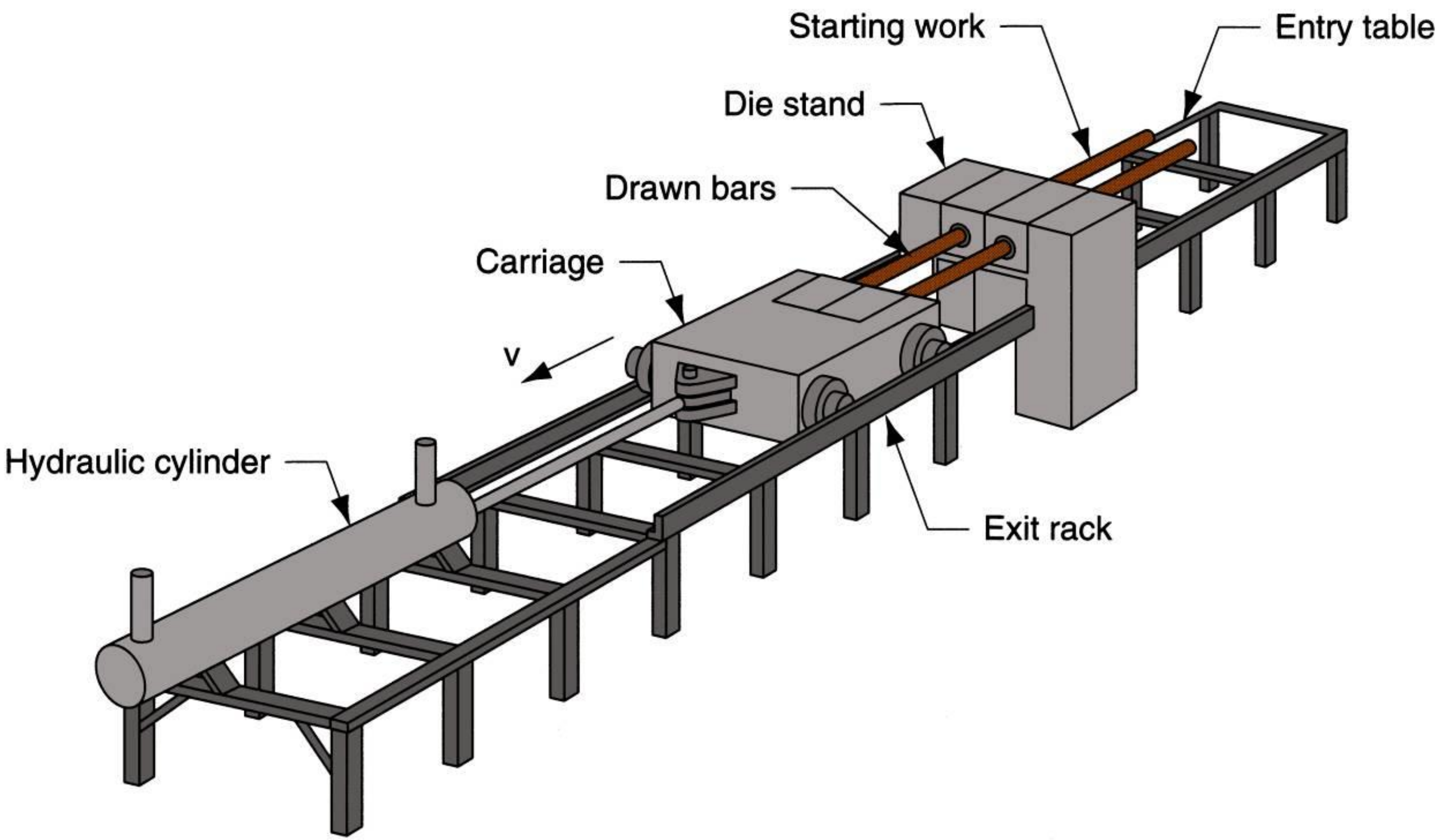
Drawing Practice and Products

- ***Drawing practice:***
  - Usually performed as cold working
  - Most frequently used for round cross sections
- ***Products:***
  - Wire: electrical wire; wire stock for fences, coat hangers, and shopping carts
  - Rod stock for nails, screws, rivets, and springs
  - Bar stock: metal bars for machining, forging, and other processes

Bar Drawing

- Accomplished as a *single-draft* operation - the stock is pulled through one die opening
- Beginning stock has large diameter and is a straight cylinder

Hydraulically operated draw bench for drawing metal bars.



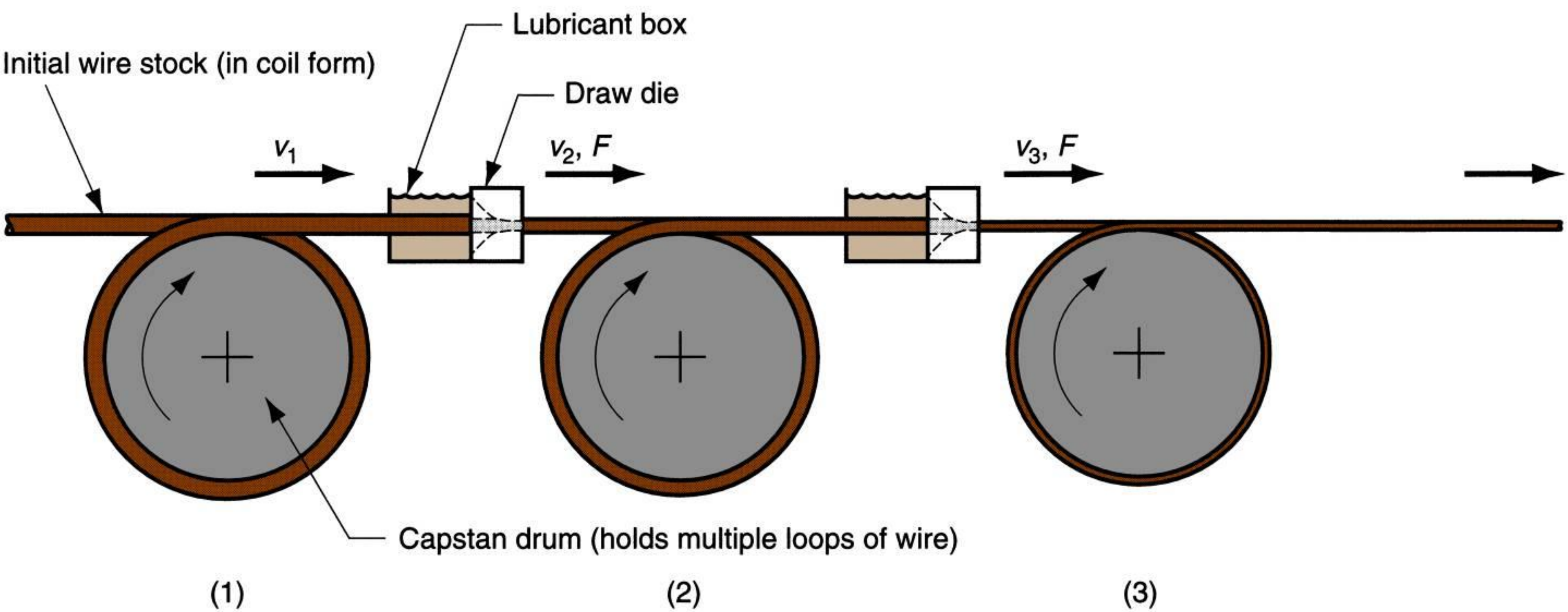
Bar Drawing

- Bar drawing is accomplished on a machine called a draw bench, consisting of an entry table, die stand (which contains the draw die), carriage, and exit rack.
- The carriage is used to pull the stock through the draw die. It is powered by hydraulic cylinders or motor-driven chains.
- The die stand is often designed to hold more than one die, so that several bars can be pulled simultaneously through their respective dies.

Wire Drawing

- Continuous drawing machines consisting of multiple draw dies (typically 4 to 12) separated by accumulating drums
  - Each drum (*capstan*) provides proper force to draw wire stock through upstream die
  - Each die provides a small reduction, so desired total reduction is achieved by the series
  - Annealing sometimes required between dies to relieve work hardening

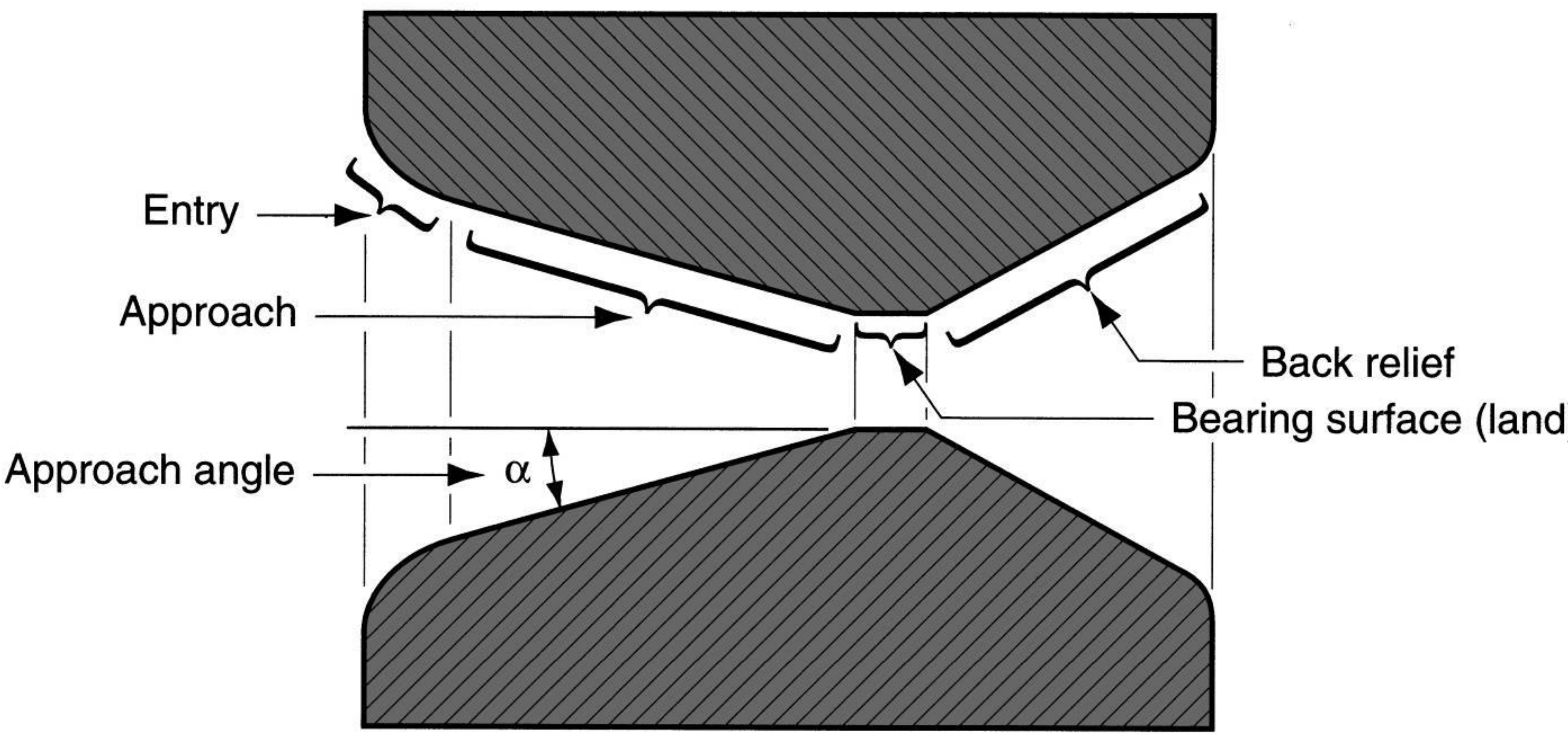
Wire Drawing



Features of a Draw Die

- Entry region - funnels lubricant into the die to prevent scoring of work and die
- Approach - cone-shaped region where drawing occurs
- Bearing surface - determines final stock size
- Back relief - exit zone - provided with a back relief angle (half-angle) of about 30°
- Die materials: tool steels or cemented carbides

Draw Die Details



Preparation of Work for Drawing

- Annealing – to increase ductility of stock
- Cleaning - to prevent damage to work surface and draw die
- Pointing – to reduce diameter of starting end to allow insertion through draw die

Sheet Metalworking

Sheet Metalworking

- Sheet metalworking includes cutting and forming operations performed on relatively thin sheets of metal.
- Typical sheet-metal thicknesses are between 0.4 mm and 6mm .
- When thickness exceeds about 6 mm, the stock is usually referred to as plate rather than sheet.
- The sheet or plate stock used in sheet metalworking is produced by flat rolling.

Sheet Metalworking

- The most commonly used sheet metal is low carbon steel (0.06%–0.15% C typical).
- Its low cost and good formability, combined with sufficient strength for most product applications, make it ideal as a starting material.
- Sheet-metal processing is usually performed at room temperature (cold working) .
- The exceptions are when the stock is thick, the metal is brittle, or the deformation is significant.

Sheet Metalworking

- These are usually cases of warm working rather than hot working.
- Most sheet-metal operations are performed on machine tools called presses.
- The term stamping press is used to distinguish these presses from forging and extrusion presses.
- The tooling that performs sheet metalwork is called a punch-and-die; the term stamping die is also used.
- The sheet-metal products are called stampings.

Sheet Metalworking

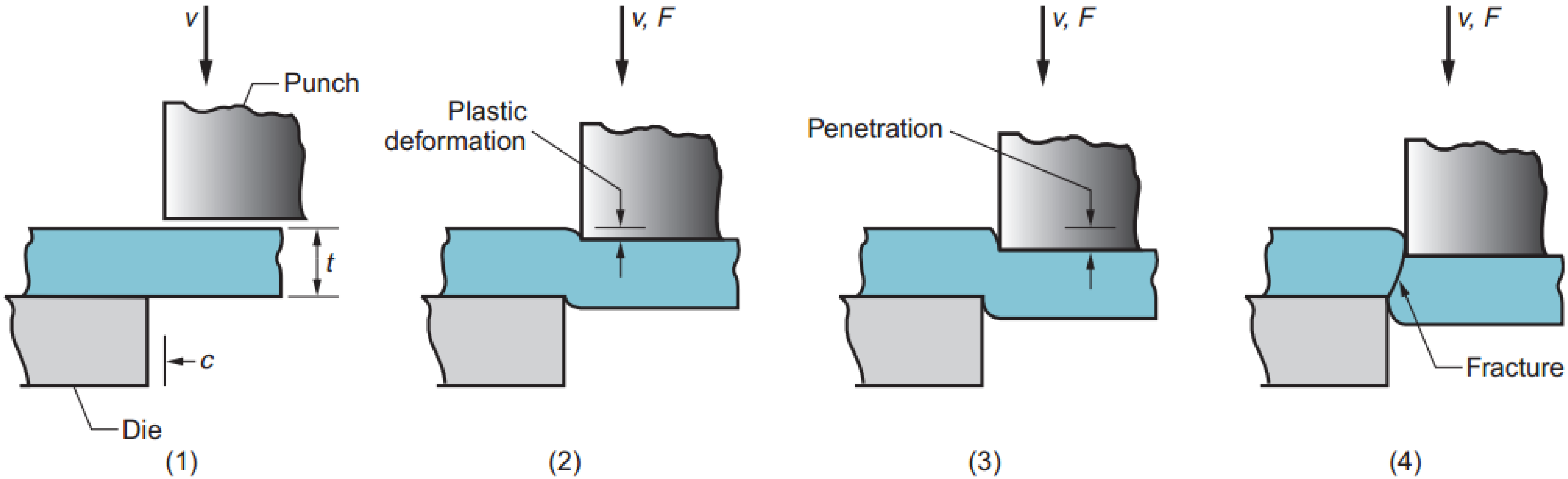
- To facilitate mass production, the sheet metal is often presented to the press as long strips or coils.
- The three major categories of sheet-metal processes are ***(1) cutting, (2) bending, and (3) drawing.***
- Cutting is used to separate large sheets into smaller pieces, to cut out part perimeters, and to make holes in parts.
- Bending and drawing are used to form sheet-metal parts into their required shapes

CUTTING OPERATIONS

- Cutting of sheet metal is accomplished by a shearing action between two sharp cutting edges.
- The shearing action is depicted in the four stop-action sketches of Figure, in which the upper cutting edge (the punch) sweeps down past a stationary lower cutting edge (the die).
- As the punch begins to push into the work, plastic deformation occurs in the surfaces of the sheet.

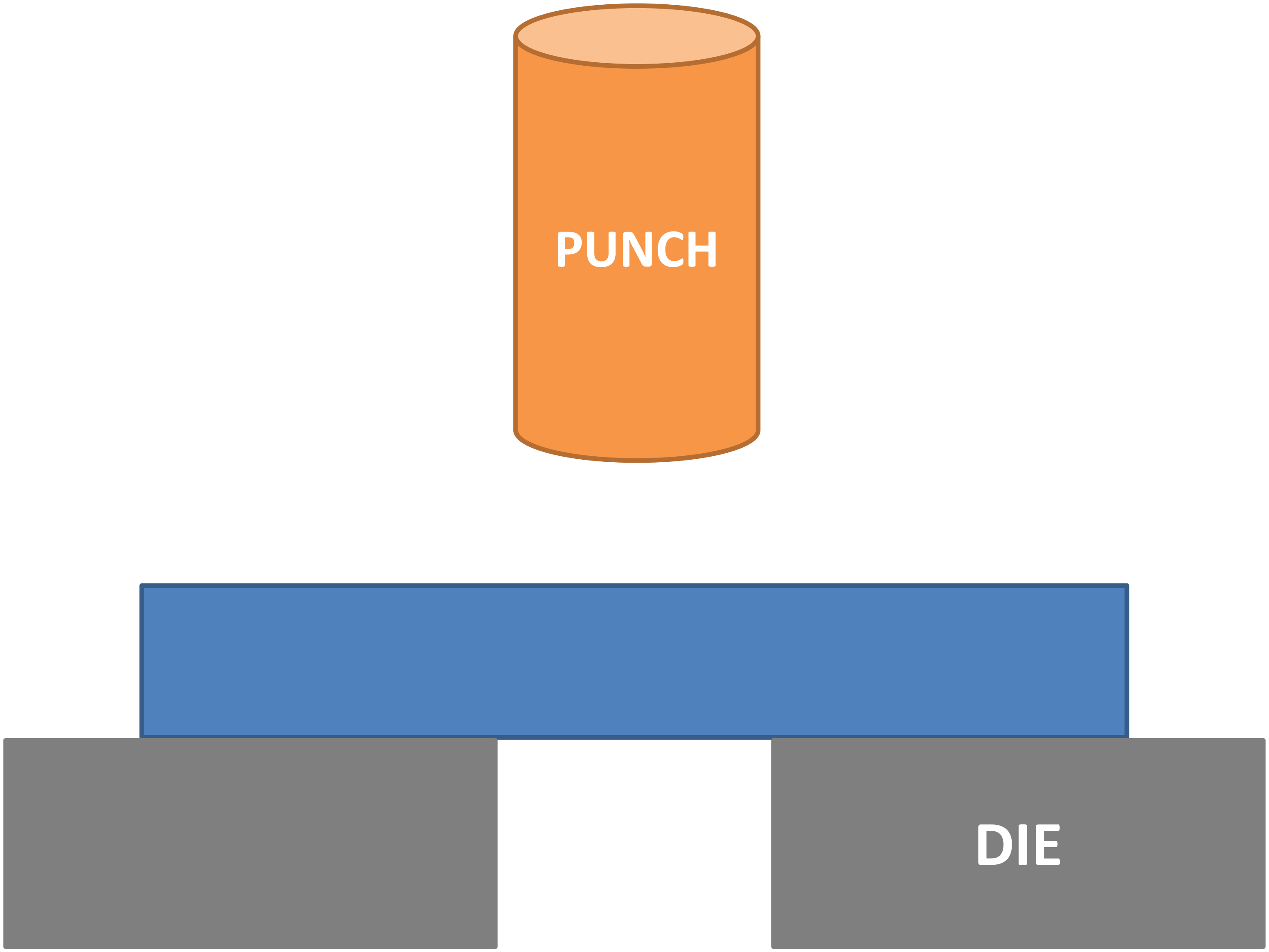
CUTTING OPERATIONS

- If the clearance between the punch and die is correct, the two fracture lines meet, resulting in a clean separation of the work into two pieces.



CUTTING OPERATIONS

- As the punch moves downward, penetration occurs in which the punch compresses the sheet and cuts into the metal.
- This penetration zone is generally about one-third to half the thickness of the sheet.
- As the punch continues to travel into the work, fracture is initiated in the work at the two cutting edges.


PUNCH
DIE

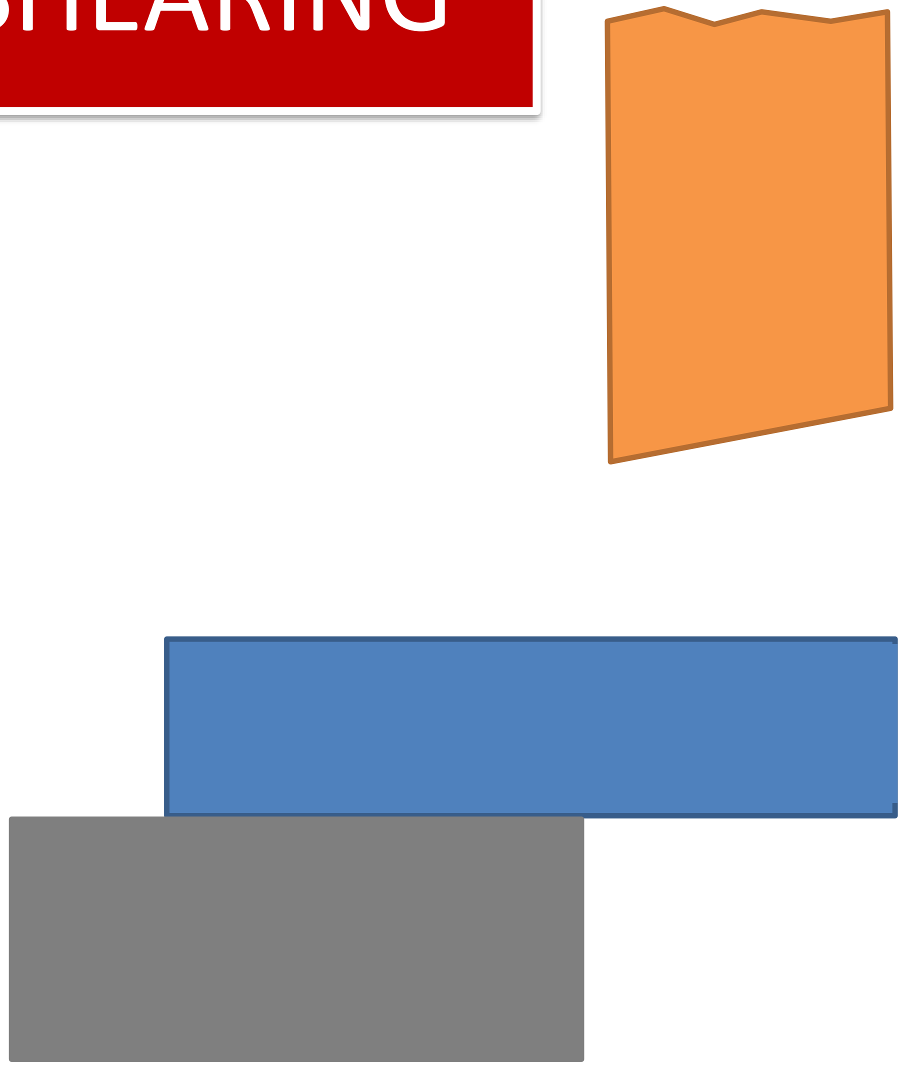
SHEARING , BLANKING, AND PUNCHING

- The three most important operations in pressworking that cut metal by the shearing mechanism just described are ***shearing, blanking, and punching.***

SHEARING

- Shearing is a sheet-metal cutting operation along a straight line between two cut tiny edges, as shown in Figure .
- Shearing is typically used to cut large sheets into smaller sections for subsequent pressworking operations.
- It is performed on a machine called a power shears , or squaring shears .
- The upper blade of the power shears is often inclined, to reduce the required cutting force.

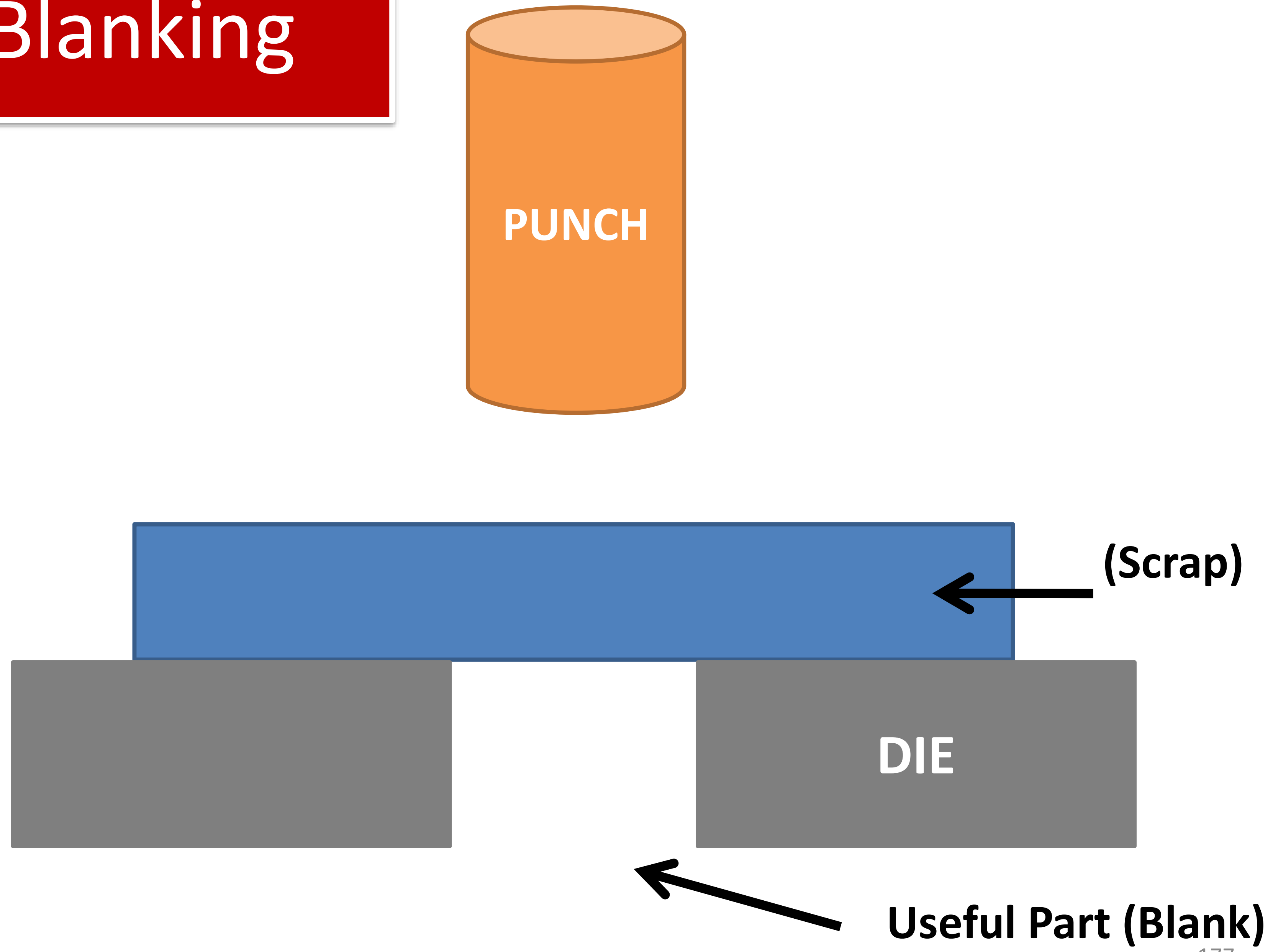
SHEARING



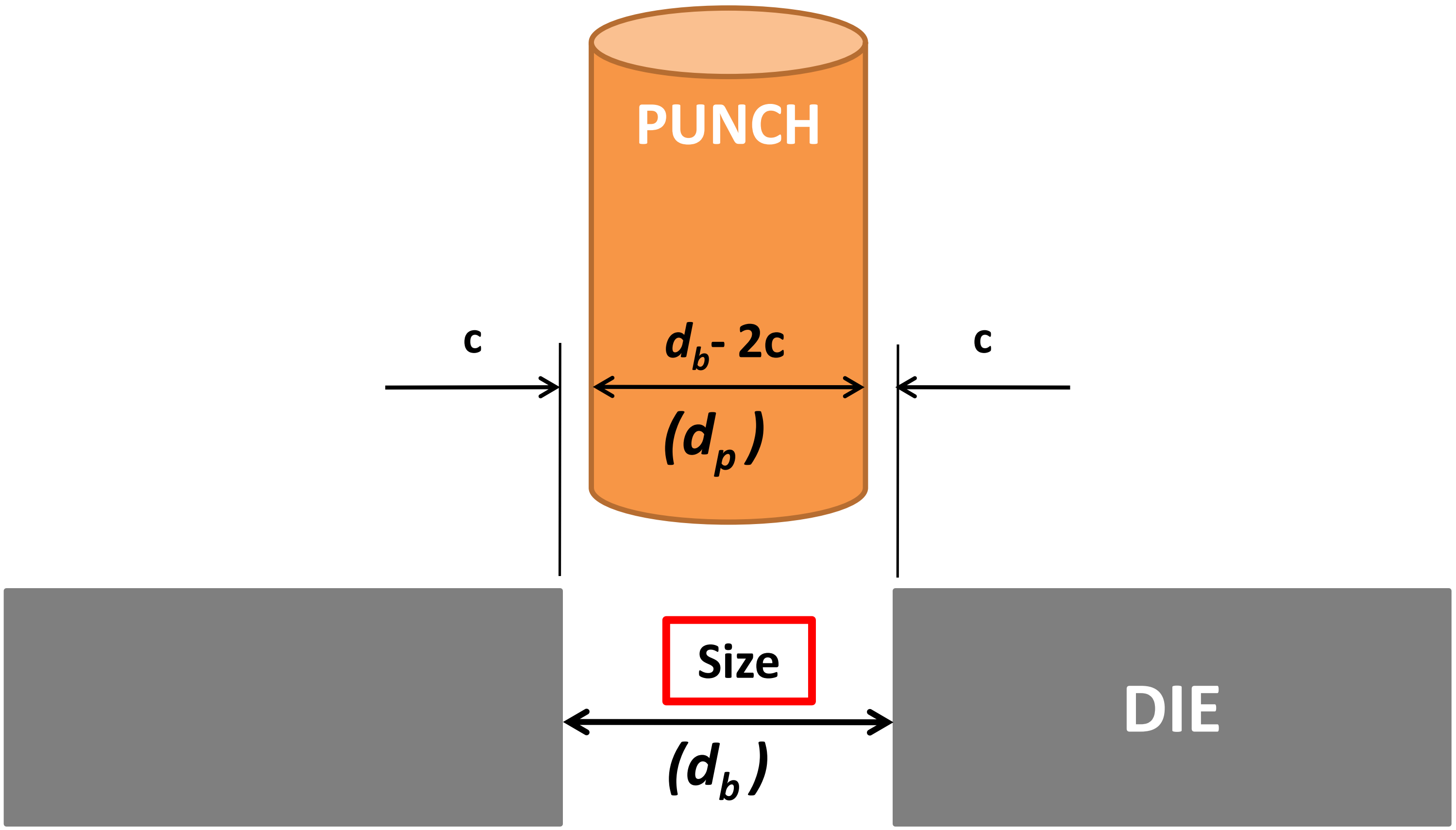
Blanking

- Blanking involves cutting of the sheet metal along a closed outline in a single step to separate the piece from the surrounding stock.
- The part that is cut out is the desired product in the operation and is called the blank.

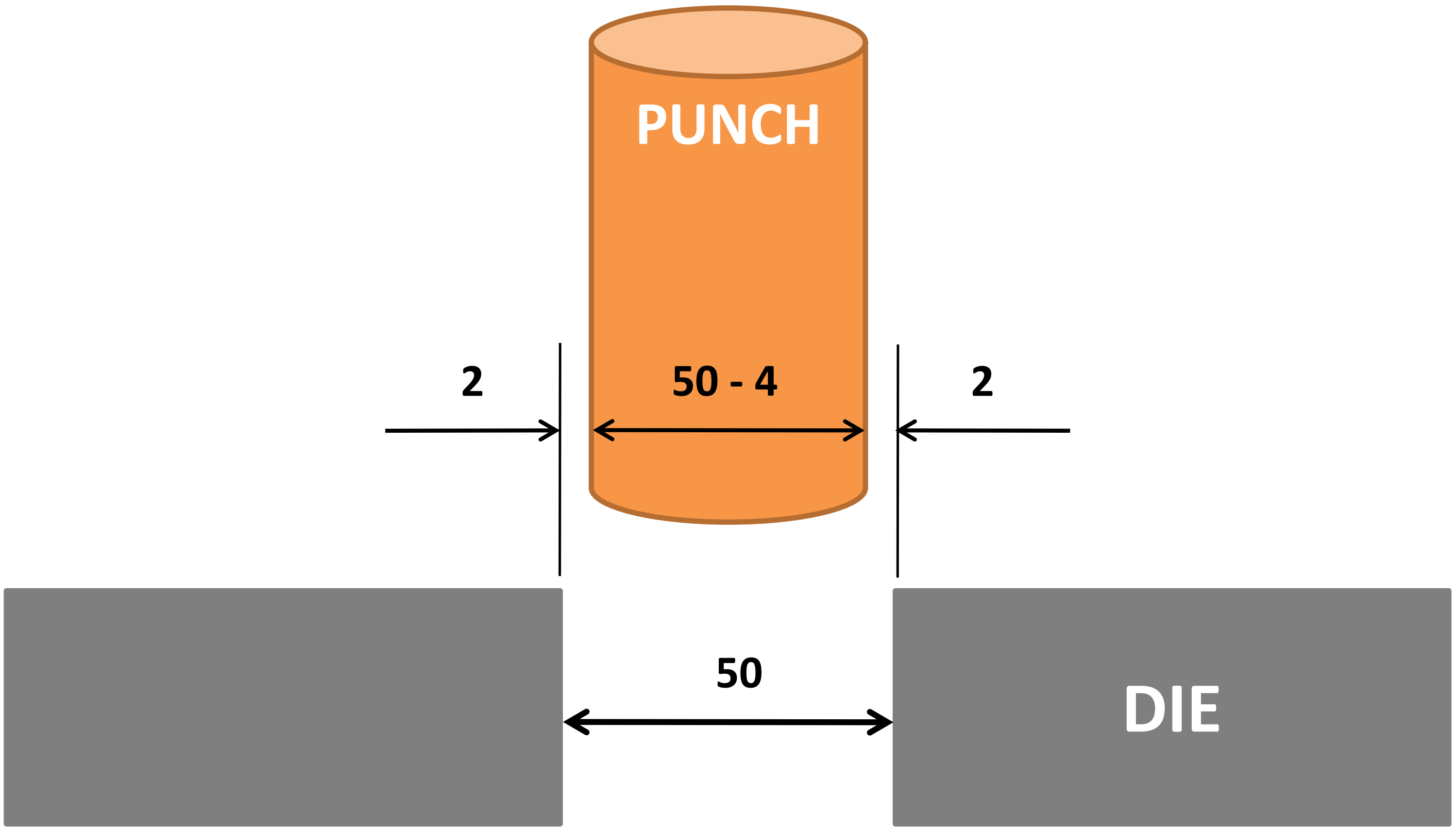
Blanking



Blanking



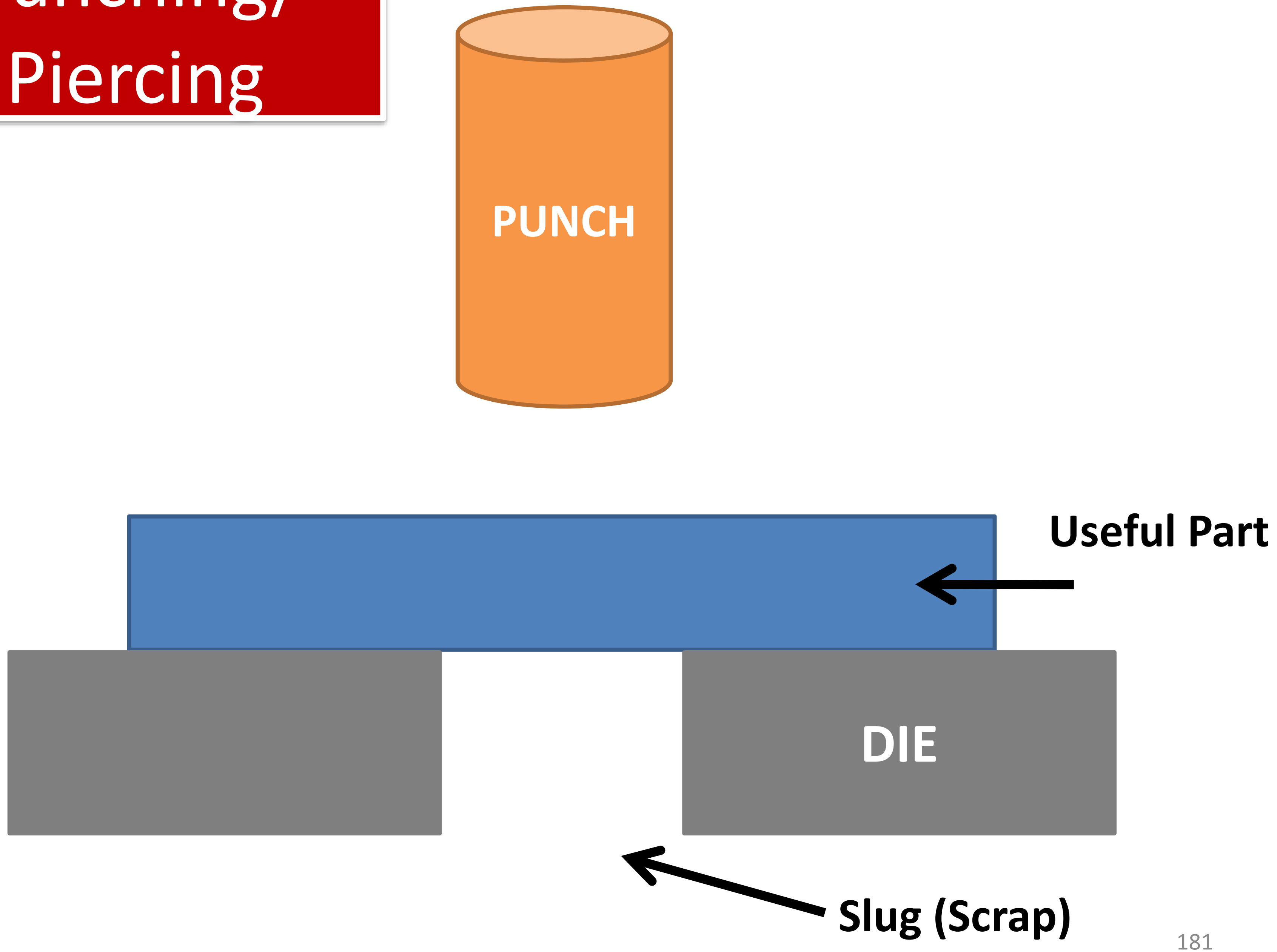
Blanking



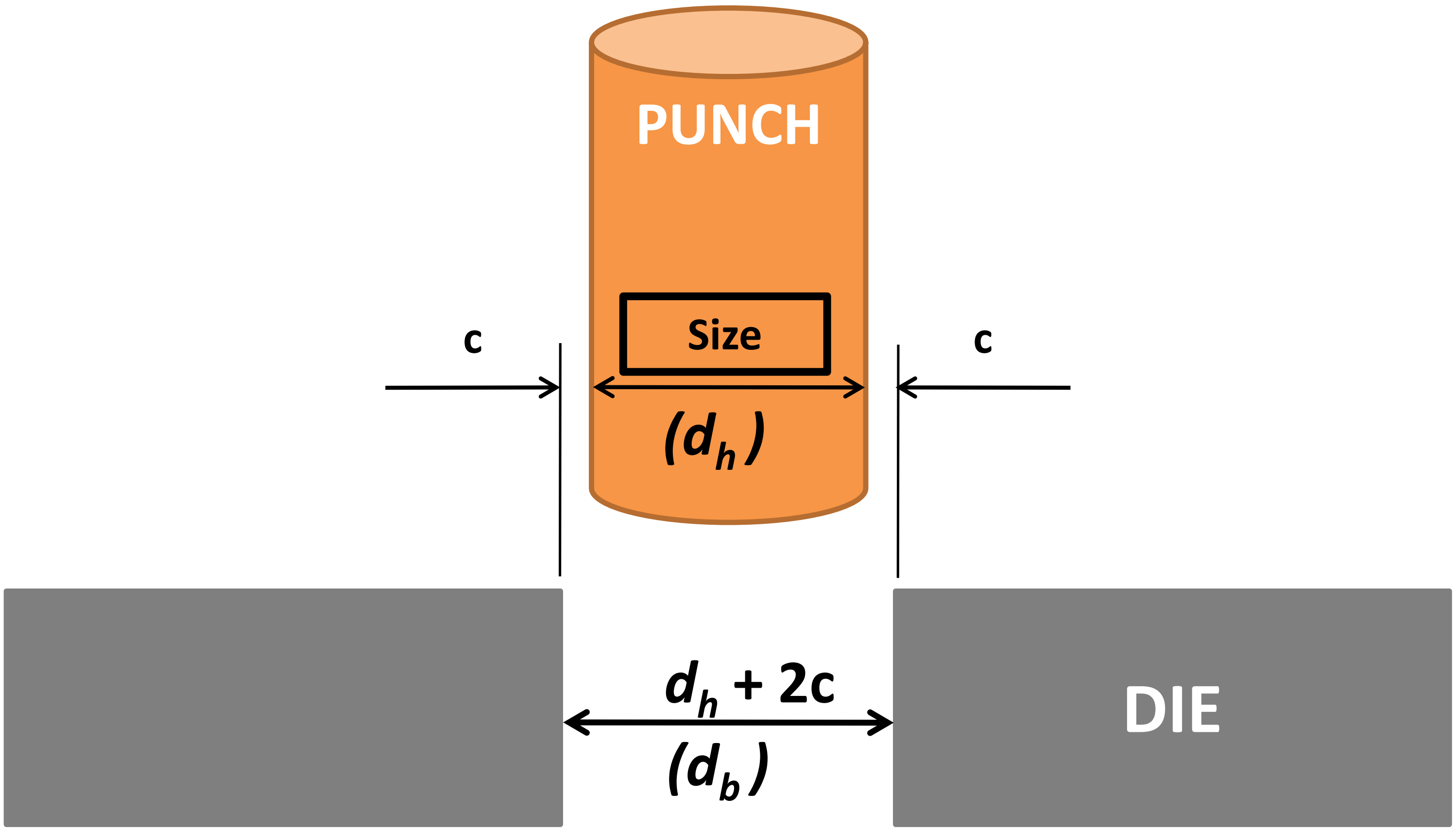
Punching/ Piercing

- Punching/Piercing is similar to blanking except that it produces a hole, and the separated piece is scrap, called the slug .
- The remaining stock is the desired part.

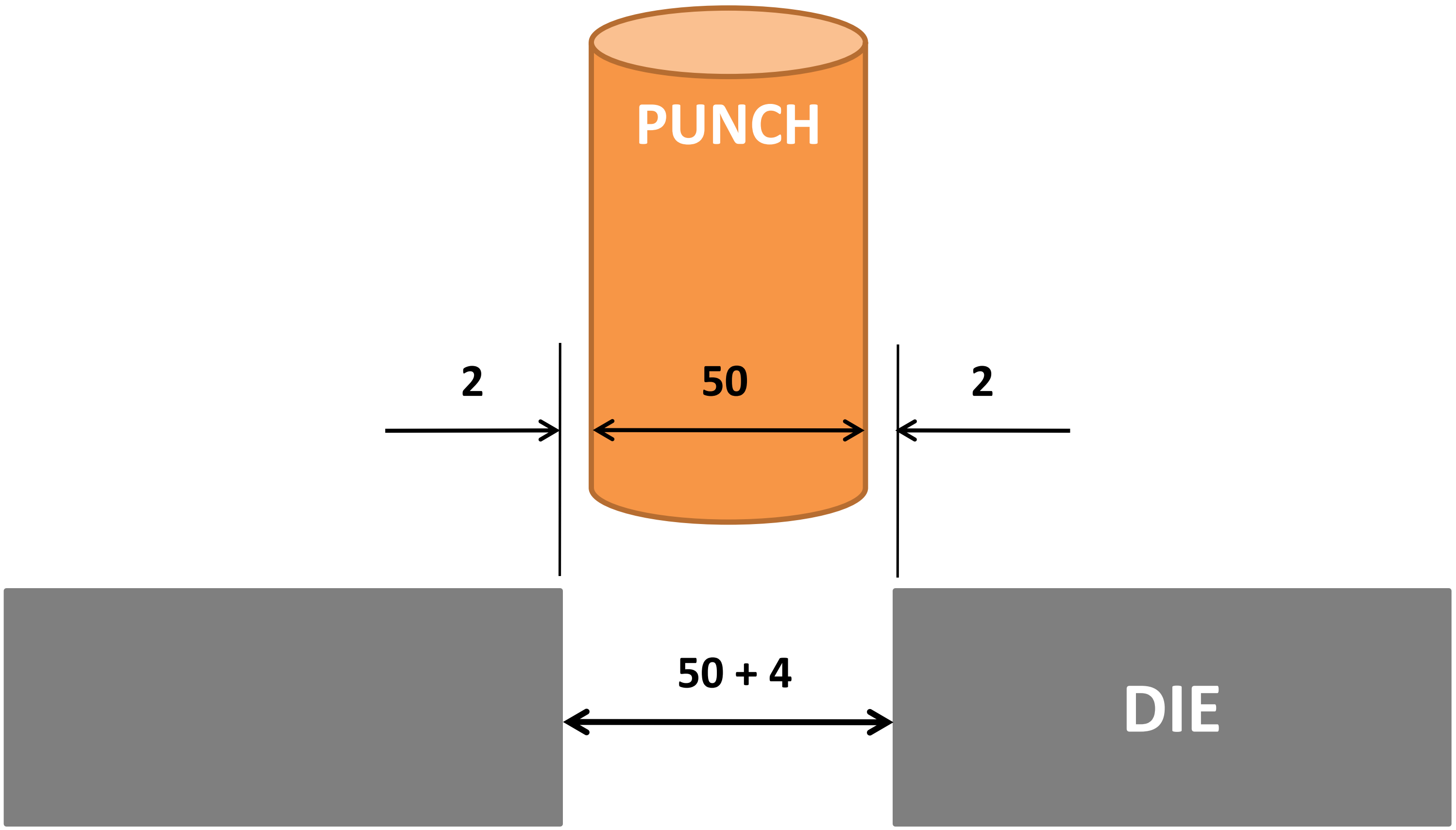
Punching/ Piercing



Punching/ Piercing



Punching/ Piercing



Clearance

- The clearance "c" in a shearing operation is the distance between the punch and die.
- Typical clearances in conventional pressworking range between ***4% to 8%*** of the sheet-metal thickness t.

$$c = a(t) \qquad (1)$$

Where a = *Allowance* = *4 to 8%*

Cutting Forces

- Cutting force " ***F*** " in sheet metalworking can be determined by

$$\boxed{F = StL} \quad \textit{(lb)} \qquad (2)$$

S = shear strength of the sheet metal, MPa ***(psi)***

t = stock thickness, mm ***(in)***

L = length of the cut edge, mm ***(in)***

Cutting Forces

- In blanking, punching, slotting, and similar operations, " L "is the ***perimeter length*** of the blank or hole being cut.

NUMERICAL 1

- A blanking operation is to be performed on ***2 mm*** thick cold rolled steel. The part is ***circular*** with ***diameter*** = ***75 mm***. Determine:

a) the appropriate punch and die sizes for this operation if the allowance for the cold rolled steel is ***a= 0.075***.

b) the blanking force required if the steel has a ***shear strength = 325 MPa*** and the tensile strength is 450 MPa

NUMERICAL 1

Solution:

(a) Since $a = 0.075$, the clearance is given by,

$$c = 0.075\,(2) = 0.15 \text{ mm.}$$

Thus the Punch diameter D_h is calculated as

$$\mathbf{D_h} = D_b - 2c = 75.0 - 2(0.15) = \mathbf{74.70\ mm}.$$

and the Die diameter is $\boldsymbol{D_b} = \mathbf{75\ mm.}$

NUMERICAL 1

(b) the blanking force is given by

$$F = StL$$

The thick of the metal stock t is given by the problem as t = 2 mm

The length of cut edge is calculated as:

$$L = \pi D = 75\pi = 235.65 \text{ mm}$$

Thus the blanking force is

$$\boldsymbol{F} = 325\ (2)\ (235.65) = \mathbf{153{,}200\ N}$$

ENERGY REQUIRED

- The energy E required for punching is calculated by an emperical formula

$$E = 1.16Fpt/12$$

E = Energy ***ft-lb***

p = penetration of punch into stock (%)

If the punch makes N strokes per minute the power in horsepower is

POWER (hp)

- If the punch makes N strokes per minute the power in horsepower is

$$P = EN/33000$$