Metal Forming Processes (ME5807)

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Module 03

Bulk Metal Forming Processes

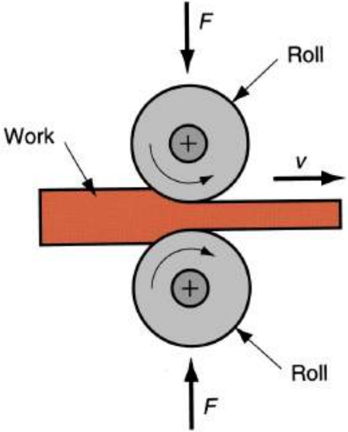
Bulk Metal Forming Processes

- Characterised by significant deformations and massive shape changes
- ”Bulk” refers to workparts with relatively low surface area-to-volume ratios.
- Starting work shapes include cylindrical billets and rectangular bars.

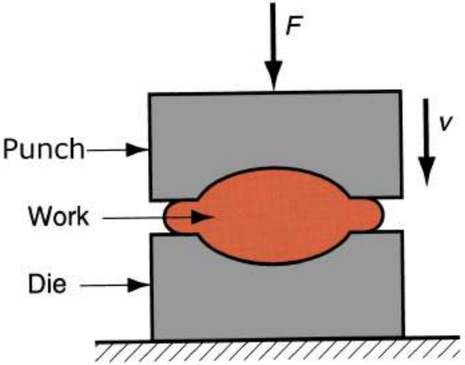
Bulk Metal Forming Processes

- Rolling
- Forging
- Extrusion
- Wire and bar drawing

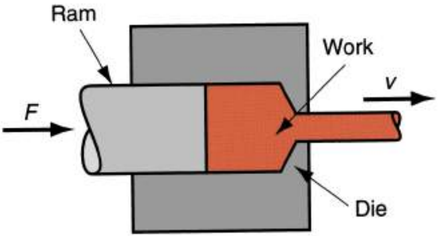
Rolling



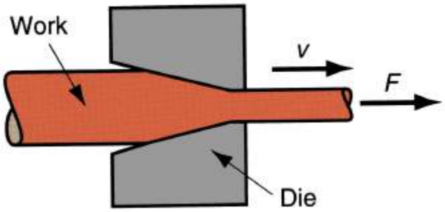
Forging



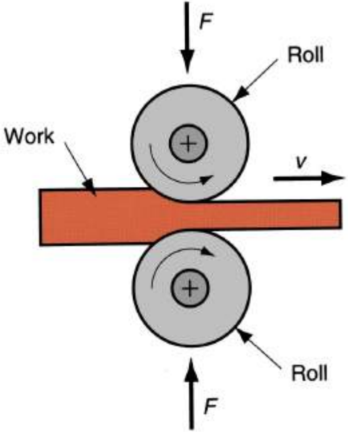
Extrusion



Wire and Bar Drawing



Rolling



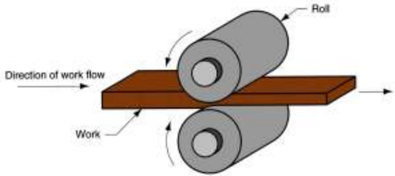
Rolling

- The Process of plastically deforming metal / alloy by passing it between rolls is known as Rolling.
- Rolling done either at Hot or cold.
- The metal is drawn into the opening between the rolls by frictional forces.
- Work piece is subjected to high compressive forces due to squeezing action of rolls, resulting in reduced area of cross-section and increased length.

Rolling-Terminology

- **Ingot**: An ingot is a mass of metal cast into a size and shape convenient to store, transport, and work into a semifinished or finished product.
  - **Bloom** has a square cross-section of 150*mm* x 150*mm* (6*inch* x 6*inch*) or larger.
  - **Billet** has a square cross-section of 38*mm* x 38*mm* (1.5*inch* x 1.5*inch*) or larger.
  - **Slab** has a rectangular width cross-section of 250*mm* (10*inch*) and a thickness of 38*mm* (1.5*inch*) or larger.

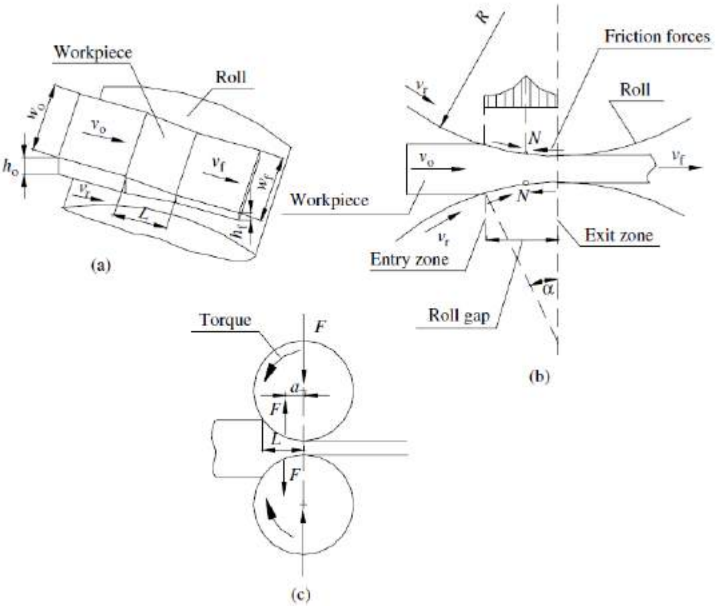
Flat Rolling



- Metal strip enters the roll gap
- The strip is reduced in size by the metal rolls
- The velocity of the strip is increased the metal strip is reduced in size

- Factors affecting Rolling Process
  - Frictional Forces
  - Roll Force and Power Requirement

Analysis of Flat Rolling



(a) Draft: The maximum possible draft is defined as the difference between the initial and final thicknesses of the strip.

$$\Delta = h_o - h_f = \mu^2 R$$

Where,

$\Delta =$ draft, mm (in.)
$h_o =$ starting thickness, mm (in.)
$h_f =$ final thickness, mm (in.)
$\mu =$ coefficient of friction between roll and material
$R =$ roll radius, mm (in.)

The draft is sometimes defined as a function of the starting thickness of rolling material, called relative reduction:

$$r = \frac{h_o - h_f}{h_o} = \frac{\Delta}{h_o}$$

(b) Lateral Spread: The elongation in the transverse direction results in an increase in the width of the workpiece by an amount called lateral spread.

$$\Delta w = w_f - w_o$$

Where,

Δw = lateral spread, mm (in.)
w_o = starting thickness, mm (in.)
w_f = final thickness, mm (in.)

Lateral spread is often expressed by the width spread factor.

$$s = \frac{w_f}{w_o}$$

(c) Forward Slip in Rolling: On either side of neutral point N, slipping and friction occur between rolls and workpiece. The amount of slip between the rolls and the workpiece can be measured by mean forward slip

$$S = \frac{v_f - v_r}{v_r}$$

Where,

$S =$ forward slip
$v_f =$ final (exiting) workpiece velocity, m/s (ft/s)
$v_r =$ roll speed, m/s (ft/s).

(d) Average Flow Stress: Average flow stress applied to the workpiece in flat rolling can be expressed by

$$\sigma_{f(m)} = \frac{K\epsilon^n}{1+n}$$

Where,

$\epsilon = ln(\frac{h_o}{h_f}) =$ true strain on the workpiece in rolling.

(e) Pressure in the roll gap: There is often significant variation in the roll pressure along the contact length in flat rolling.

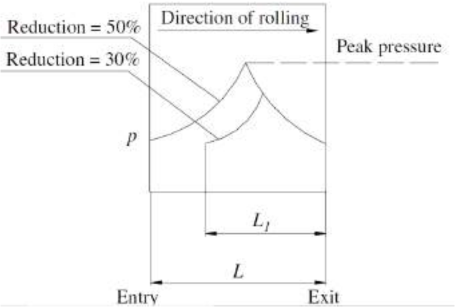


Figure: Typical variation in pressure along the contact length in flat rolling

- Maximum pressure is at the neutral point N and trails off on either side of the entry and exit points
- Pressure in the roll gap is calculated as average pressure:

  $p = \frac{F}{A_a}$

  Where,

  $F =$ roll separating force, N

  $A_a =$ projected area on the surface plane of contact between roll and workpiece, MPa

Roll Force, Torque, and Power

The roll force, roll torque, and drive power necessary to form the workpiece are some of the important parameters of process information.

(a) Roll Force The roll separating force can be determined if the distribution of normal pressure in the deformation zone is known by the following equation:

$$F = \int_0^L wpdL = w \int_0^L pdL \quad (1)$$

Where,
F = rolling force, N (lb)
w = width of workpiece, mm
p = roll pressure
L = projected arc of contact between roll and workpiece, *mm*

Roll Force

Because, in practice, the arc of contact between the roll and the workpiece is very small compared with the roll radius, So it can be assumed that the force is perpendicular to the plane of the workpiece without causing significant errors in the calculations. Thus, the roll force can be calculated based on the average flow stress experienced by the material in the roll gap from the formula:

$$F = Lw\sigma_{f(m)} \tag{2}$$

Where,

$\sigma_{f(m)}$ = average flow stress, MPa

Lw = roll workpiece contact area, mm^2

Roll Force

L is projected arc of contact between roll and workpiece, *mm* (in.).

$$L = \sqrt{R(h_o - h_f)} = \sqrt{R(\Delta)}$$

Where,

$R =$ roll radius, *mm*.

Torque

The torque M in flat rolling in the case of the rolls being of equal diameter can be calculated by

$$M = Fa \tag{3}$$

Where,

$a =$ length of lever arm, mm.

If length of lever arm is $a = 0.5L$, then the torque for each roll is

$$M = 05.LF \tag{4}$$

Power

The total power for two rolls in SI units can be calculated by

$$P = \frac{2\pi FLN}{60,000} \tag{5}$$

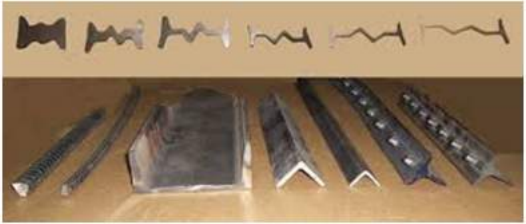
Where,

$P =$ power, kW,
$F =$ rolling force, N,
$L =$ contact length, m,
$N =$ rotation speed, rev/min.

Shape Rolling

- In shape rolling, the work is deformed into a contoured cross section.
- Products 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.
- Most of the principles that apply in flat rolling are also applicable to shape rolling.
- Shaping rolls are more complicated; and the work, usually starting as a square shape, requires a gradual transformation through several rolls in order to achieve the final cross section.

Shape Rolling Products



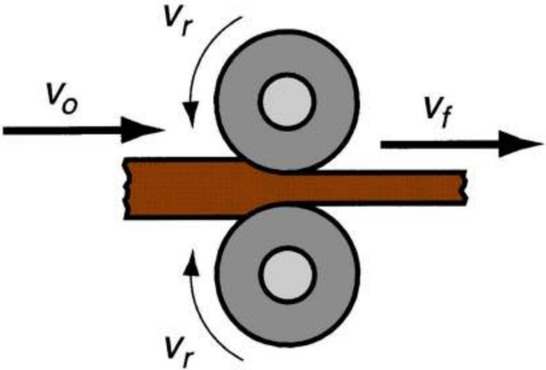
L- beam

U- beam

I- beam

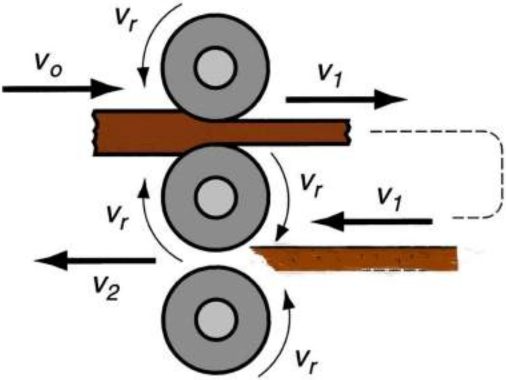
Rolling mill configurations

(a) Two-high consists of two opposing rolls, and the configuration can be either reversing or nonreversing.



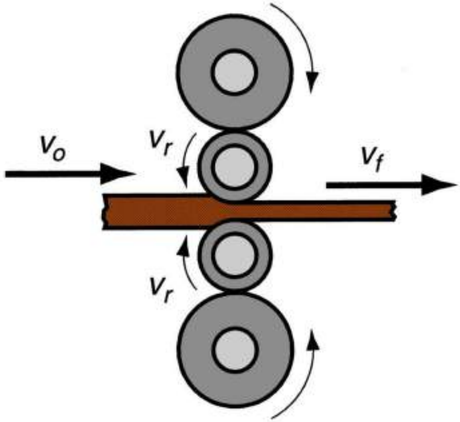
Rolling mill configurations

(b) Three-high three rolls in a vertical column, and the direction of rotation of each roll remains unchanged.



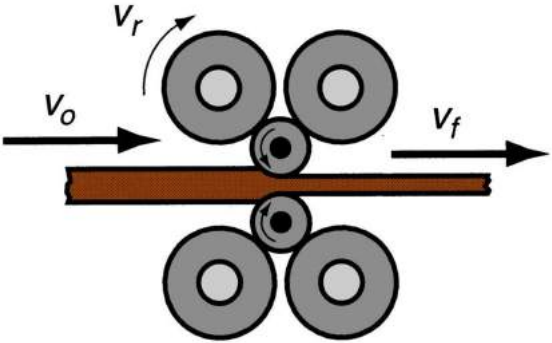
Rolling mill configurations

(c) Four-high uses two smaller-diameter rolls to contact the work and two backing rolls behind them.



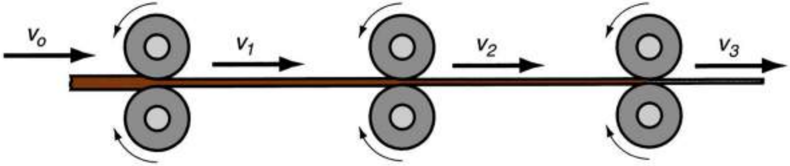
Rolling mill configurations

(d) Cluster mill roll configuration that allows smaller working rolls against the work (smaller than in four-high mills).



Rolling mill configurations

(e) Tandem rolling mill consists of a series of rolling stands, aimed at higher throughput rates.



Thread Rolling

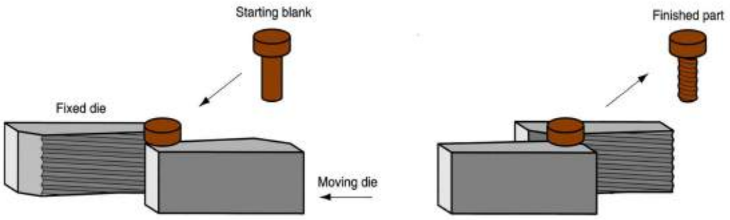


Figure: Thread rolling with flat dies: (1) start, and (2) end of cycle.

Thread Rolling

- Used to form threads on cylindrical parts by rolling them between two dies.
- The most important commercial process for mass producing external threaded components.
- Performed by cold working in thread rolling machines. These are equipped with special dies that determine the size and form of the thread.
- Advantages of thread rolling over thread cutting and rolling include:
  - Higher production rates.
  - Better material utilization.
  - Smoother surface.
  - Stronger threads and better fatigue resistance due to work hardening.

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

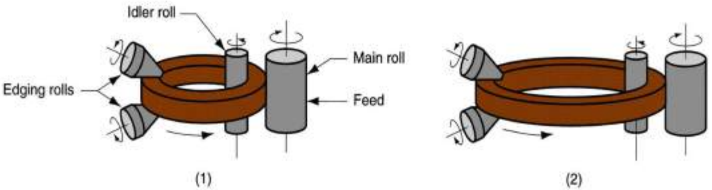


Figure: Ring Rolling

Ring Rolling

- Usually performed as a hot-working process for large rings and as a cold-working process for smaller rings.
- Applications include ball and roller bearing races, steel tires for railroad wheels, and rings for pipes, pressure vessels, and rotating machinery.
- Advantages over processes producing similar products include:
  (1) raw material savings,
  (2) ideal grain orientation for the application, and
  (3) strengthening through cold working.

Roll Piercing

Roll Piercing: a specialized hot working process for making seamless thick-walled tubes.

- Based on the principle that when a solid cylindrical part is compressed on its circumference, high tensile stresses are developed at its center. If compression is high enough, an internal crack is formed.
- Compressive stresses on a solid cylindrical billet are applied by two rolls, whose axes are oriented at slight angles (6^o) from the axis of the billet, so that their rotation tends to pull the billet through the rolls. A mandrel is used to control the size and finish of the hole created by the action.

Roll Piercing

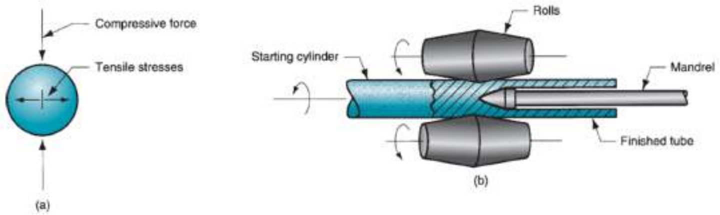


Figure: Roll piercing: (a) formation of internal stresses and cavity by compression of cylindrical part; and (b) setup of Mannesmann roll mill for producing seamless tubing.

Forging

- **Forging:** a deformation process in which the work is compressed between two dies, using either impact or gradual pressure to form the part.
  - Dates back to perhaps 5000 BCE.
  - Today, forging is an important industrial process used to make a variety of high-strength components for automotive, aerospace, and other applications.
  - These components include engine crankshafts and connecting rods, gears, aircraft structural components, and jet engine turbine parts.
  - In addition, steel and other basic metals industries use forging to establish the basic form of large components that are subsequently machined to final shape and dimensions.

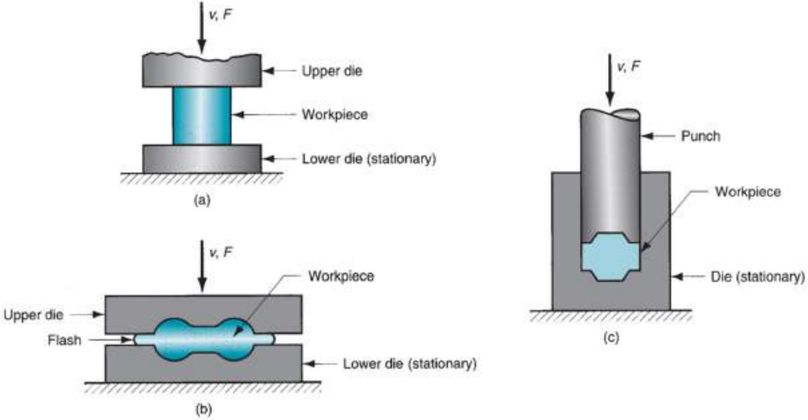
Forging

- **Forging** can be classified in many ways, one is working temperature.
    - **Hot or warm forging:** done when significant deformation is demanded by the process and when strength reduction and increase of ductility is required.
    - **Cold forging:** its advantage is the increased strength that results from strain hardening of the component.
- The other way is by the way the forging is carried out:
    - **Forging hammer:** a forging machine that applies an impact load.
    - **Forging press:** a forging machine that applies gradual load.

Forging

- **Forging** can be also classified according to the degree to which the flow of the work metal is constrained by the dies.
  - **Open-die forging:** the work is compressed between two flat dies, thus allowing the metal to flow without constraint in a lateral direction relative to the die surfaces.
  - **Impression-die forging:** the die surfaces contain a shape or impression that is imparted to the work during compression, thus constraining metal flow to a significant degree. Here, flash will form.
  - **Flashless forging:** the work is completely constrained within the die and no excess flash is produced.

Forging


v, F
Upper die
Workpiece
Lower die (stationary)
(a)
v, F
Workpiece
Upper die
Flash
Lower die (stationary)
(b)
v, F
Punch
Workpiece
Die (stationary)
(c)

Open-Die Forging

- Known as upsetting or upset forging.
- Involves compression of a workpart of cylindrical cross section between two flat dies, much in the manner of a compression test.
- It reduces the height of the work and increases the diameter.

Analysis of Open-Die Forging

If carried out under ideal conditions of no friction between work and die surfaces, then homogeneous deformation occurs, and the flow of the material is uniform throughout its height.

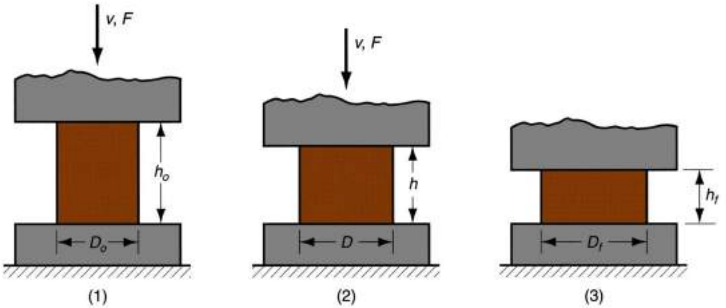


Figure: Homogeneous deformation of a cylindrical workpart under ideal conditions in an open-die forging operation: (1) start of process with workpiece at its original length and diameter, (2) partial compression, and (3) final size.

Analysis of Open-Die Forging

- Under these ideal conditions, the true strain experienced by the work during the process can be determined by:

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

- The force to perform upsetting at any height is given by:

$$F = Y_f A$$

Where,
$F =$ Force, N;
$A =$ cross-sectional area, mm^2; and
$Y_f =$flow stress, MPa.

Analysis of Open-Die Forging

If carried out under conditions where friction between work and die surfaces is accounted for, a barreling effect is created.

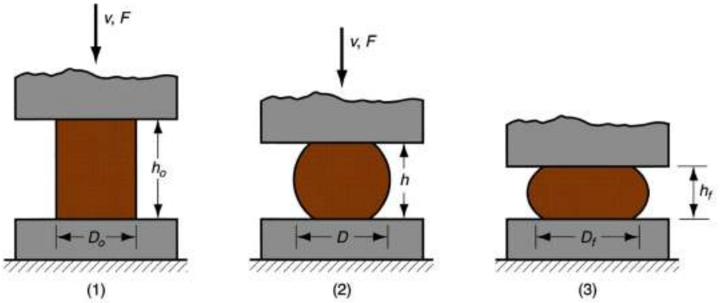


Figure: Actual deformation of a cylindrical workpart in open-die forging, showing pronounced barreling: (1) start of process, (2) partial deformation, and (3) final shape.

Analysis of Open-Die Forging

- Friction causes the actual upsetting force to be greater than what is predicted the previous equation:

$$F = K_f Y_f A$$

Where, K_f is the forging shape factor, defined as:

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

Where, μ = coefficient of friction; D = workpart diameter or other dimension representing contact length with die surface, mm; and h = workpart height, mm.

Open-Die Forging

In practice, open-die forging can be classified into:

- Fullering: a forging operation performed to reduce the cross section and redistribute the metal in a workpart in preparation for subsequent shape forging (dies have convex surfaces).
- Edging: similar to fullering, except that the dies have concave surfaces.
- Cogging: consists of a sequence of forging compressions along the length of a workpiece to reduce cross section and increase length.

Open-Die Forging

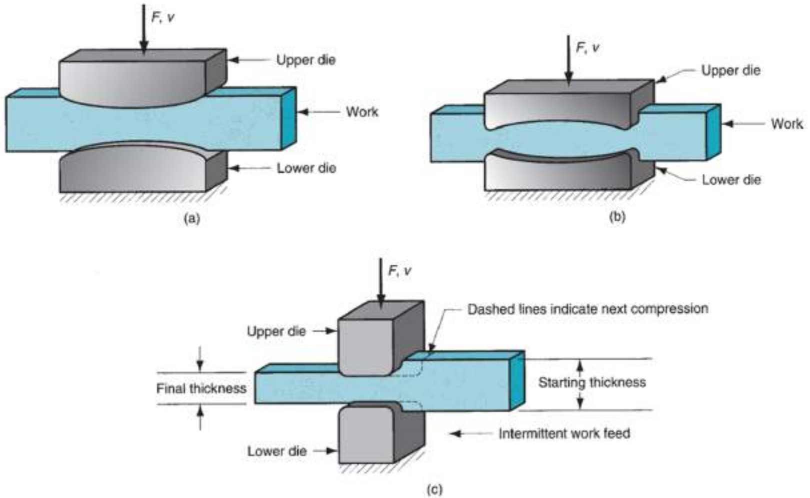


Figure: Several open-die forging operations: (a) fullering, (b) edging, and (c) cogging.

Impression-Die Forging

- Impression-die forging (sometimes called closed-die forging): performed with dies that contain the inverse of the desired shape of the part.
  - As the die closes to its final position, flash is formed by metal that flows beyond the die cavity and into the small gap between the die plates.
  - Although this flash must be finally cut away, it serves an important function during impression-die forging.
    - As the flash begins to form, friction resists continued flow of metal into the gap, thus constraining the bulk of the work material to remain in the die cavity.
    - In hot forging, metal flow is further restricted because the thin flash cools quickly against the die plates, thereby increasing its resistance to deformation.
    - Accordingly, compression pressure is increased, thus forcing the material to fill the whole cavity.

Impression-Die Forging

- Sequence in impression-die forging:

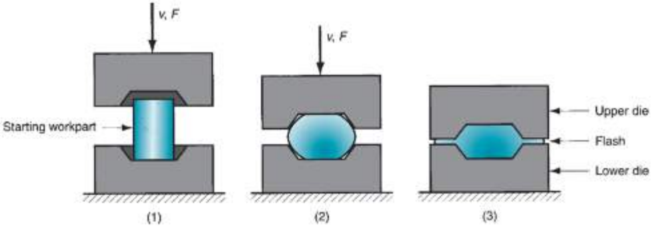


Figure: Sequence in impression-die forging: (1) just prior to initial contact with raw workpiece, (2) partial compression, and (3) final die closure, causing flash to form in gap between die plates.

Impression-Die Forging

- **Advantages**:
  - higher production rates,
  - less waste of metal,
  - greater strength and
  - favorable grain orientation in the metal.

- **Limitations:**
  - incapability of close tolerances and
  - machining is required to achieve accuracies and features needed.

Flashless Forging

- **Flashless Forging:** the raw workpiece is completely contained within the die cavity during compression, and no flash is formed.
- **Several requirements**:
  - The work volume must equal the space in the die cavity within 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.
  - Simple geometries required.
  - Best for soft metals, such as aluminum and cupper and their alloys.
  - Sometimes classified as Precision Forging.

Flashless Forging

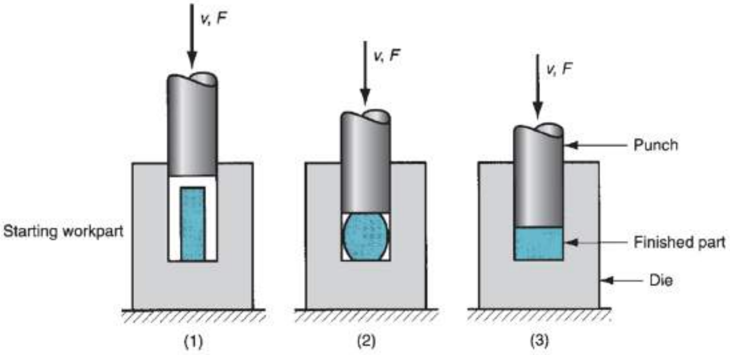


Figure: Flashless forging: (1) just before initial contact with workpiece, (2) partial compression, and (3) final punch and die closure

Flashless Forging

- **Coining:** is a type of flashless forging, in which fine details in the die are impressed into the top and bottom surfaces of the workpart. There is little flow of metal in coining.

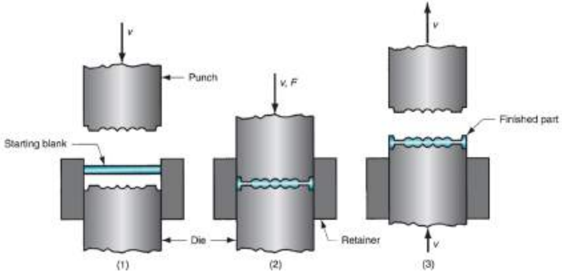


Figure: Coining operation: (1) start of cycle, (2) compression stroke, and (3) ejection of finished part.

Forging Hammers and Presses

- Equipment used in forging consists of forging machines, classified as hammers or presses, and forging dies.
- In addition, auxiliary equipment is needed, such as furnaces to heat the work, mechanical devices to load and unload the work, and trimming stations to cut away the flash in impression-die forging.

Forging Hammers and Presses

(1) **Forging Hammers:** operate by applying an impact loading against the work. They deliver impact energy to the workpiece.

- Used for impression-die forging.
- The upper portion of the forging die is attached to the ram, and the lower portion is attached to the anvil.
- The work is placed on the lower die, and the ram is lifted and then dropped.
- When the upper die strikes the work, the impact energy causes the part to assume the form of the die cavity.
- Several blows of the hammer are often required to achieve the desired change in shape.

Forging Hammers and Presses

- Forging hammers are classified into:
  1. **Gravity drop hammers:** achieve their energy by the falling weight of a heavy ram, and the force of the blow is determined by the height of the drop and the weight of the ram.
  2. **Power drop hammers:** accelerate the ram by pressurized air or steam.
     - **Disadvantage:** a large amount of the impact energy is transmitted through the anvil and into the floor of the building.

Forging Hammers and Presses

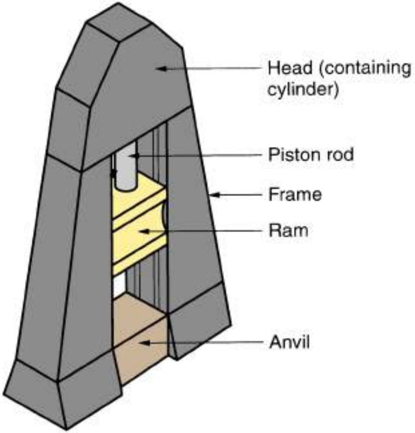


Figure: Diagram showing details of a drop hammer for impression-die forging.

Forging Hammers and Presses

(2) **Forging Presses:** apply gradual pressure, rather than sudden impact, to accomplish the forging operation.

- Include mechanical presses, hydraulic presses, and screw presses.
- Mechanical presses convert the rotating motion of a drive motor into the translation motion of the ram.
- Hydraulic presses use a hydraulically driven piston to drive the ram.
- Screw presses apply force by a screw mechanism that drives the vertical ram.

Other Deformation Processes Related to Forging

- **Upsetting** and **Heading**: a deformation operation in which a cylindrical workpart is increased in diameter and reduced in length.
  - Used in the fastener industry to form heads on nails, bolts, etc (in these applications, it is referred to as heading).
  - More parts produced by upsetting than any other forging operation.
  - Performed cold, hot or warm on special upset forging machines, called headers or formers.
  - Long wire is fed into the machines, the end of the stock is upset forged, and then the piece is cut to length to make the desired hardware item.

Other Deformation Processes Related to Forging

- **Upsetting** and **Heading**: a deformation operation in which a cylindrical workpart is increased in diameter and reduced in length.

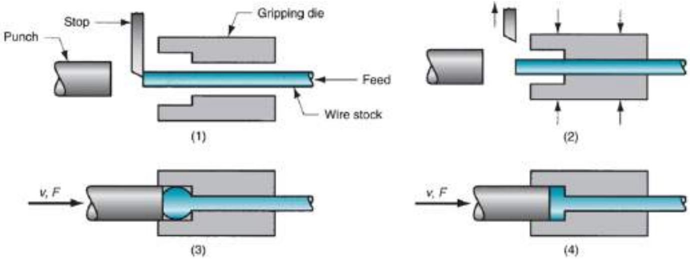


Figure: An upset forging operation to form a head on a bolt. (1) wire stock is fed to the stop; (2) gripping dies close on the stock and the stop is retracted; (3) punch moves forward; and (4) bottoms to form the head.

Other Deformation Processes Related to Forging

- **Upsetting** and **Heading**: a deformation operation in which a cylindrical workpart is increased in diameter and reduced in length.

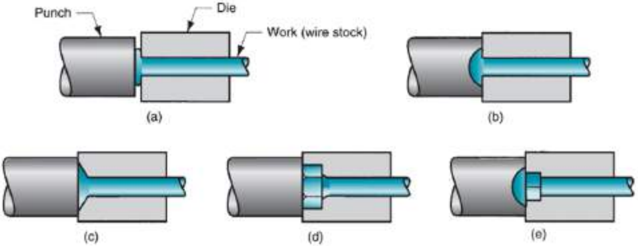


Figure: Examples of heading (upset forging) operations: (a) heading a nail using open dies, (b) round head formed by punch, (c) and (d) heads formed by die, and (e) carriage bolt head formed by punch and die.

Other Deformation Processes Related to Forging

- **Swaging** and **Radial Forging:** forging processes used to reduce the diameter of a tube or solid rod.
  - The **Swaging** process is accomplished by means of rotating dies that hammer a workpiece radially inward to taper it as the piece is fed into the dies.
  - **Radial Forging** is similar to swaging in its action against the work and is used to create similar part shapes. The difference is that in radial forging the dies do not rotate around the workpiece; instead, the work is rotated as it feeds into the hammering dies.

Other Deformation Processes Related to Forging

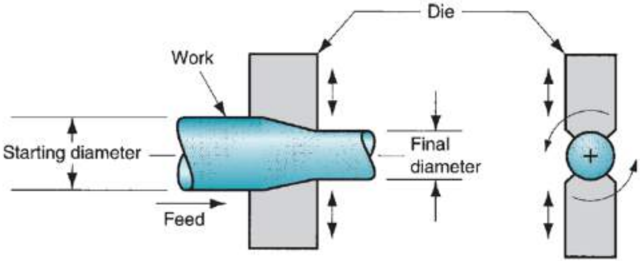


Figure: Swaging process to reduce solid rod stock; the dies rotate as they hammer the work. In radial forging, the workpiece rotates while the dies remain in a fixed orientation as they hammer the work.

Other Deformation Processes Related to Forging

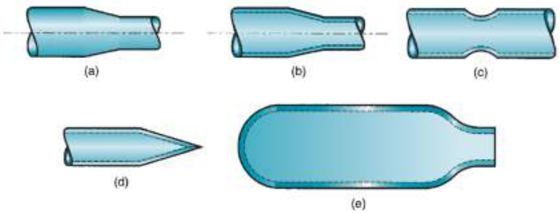


Figure: Examples of parts made by swaging: (a) reduction of solid stock, (b) tapering a tube, (c) swaging to form a groove on a tube, (d) pointing of a tube, and (e) swaging of neck on a gas cylinder.

Other Deformation Processes Related to Forging

- **Trimming:** an operation used to remove flash on the workpart in impression-die forging.
  - In most cases, **Trimming** is accomplished by shearing.
  - **Trimming** is usually done while the work is still hot.
  - In cases where the work might be damaged by the cutting process, **Trimming** may be done by alternative methods, such as grinding or sawing.

Other Deformation Processes Related to Forging

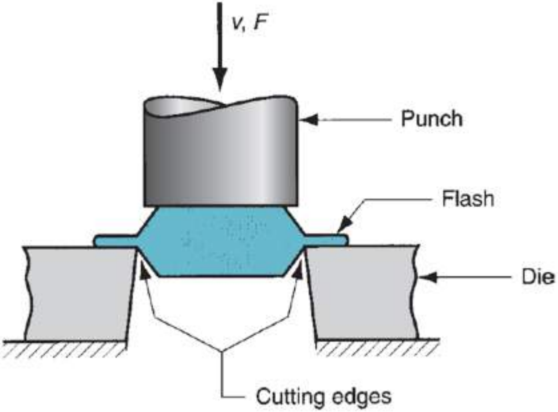


Figure: Trimming operation (shearing process) to remove the flash after impression-die forging.

Extrusion

- **Extrusion:** a compression process in which the work metal is forced to flow through a die opening to produce a desired cross-sectional shape.
- Imagine squeezing toothpaste out of toothpaste tube.
- Advantages include:
  - A variety of shapes are possible (especially in hot extrusion).
  - Microstructure and strength are enhanced in cold and warm extrusion.
  - Close tolerances are possible, especially in cold extrusion.
  - in some extrusion operations, little or no wasted material is created.

Types of Extrusion

- Extrusion can be classified in various ways:
  - By physical configuration: **Direct Extrusion** and **Indirect Extrusion**.
  - By working temperature: **Cold**, **Warm**, or **Hot Extrusion**.
  - Finally, it is performed as either a **Continuous** or **Discrete process**.

Direct Extrusion

- **Direct extrusion** (also called **forward extrusion**)

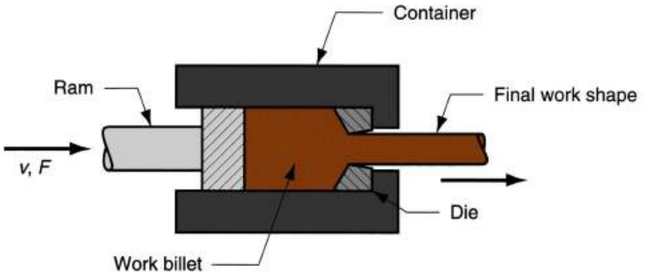


Figure: Direct extrusion

Direct Extrusion

- 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.
- This extra portion, called the butt, is separated from the product by cutting it just beyond the exit of the die.
- Friction between container's walls and workpiece is one big problem in extrusion (so higher forces are needed to accomplish the process).
- The problem is aggravated in hot extrusion due to formation of oxide layer.

Direct Extrusion

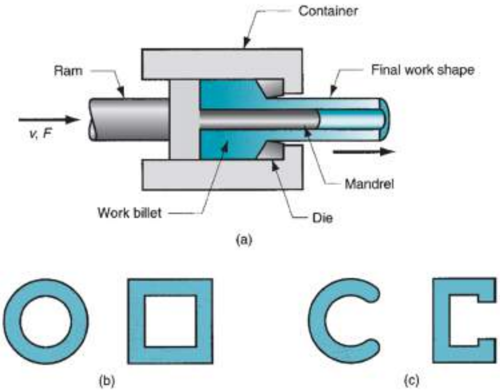


Figure: (a) Direct extrusion to produce a hollow or semi-hollow cross section; (b) hollow and (c) semi-hollow cross sections.

Indirect Extrusion

- **Indirect extrusion** (also called **backward extrusion**)

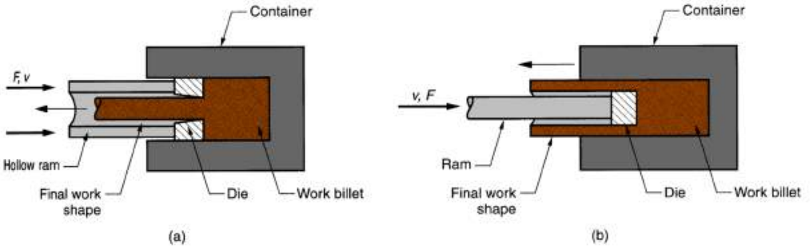


Figure: Indirect extrusion to produce (a) a solid cross section and (b) a hollow cross section.

Indirect 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.
- 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.

Types of Extrusion

- **Hot** versus **Cold** Extrusion:
  - Extrusion can be performed either hot or cold, depending on work metal and amount of strain to which it is subjected during deformation.
  - Hot extruded metals include: Al, Cu, Mg, Zn, Sn, and their alloys (sometimes extruded cold as well).
  - Steel alloys are usually extruded hot, although the softer, more ductile grades are sometimes cold extruded (e.g. low C-steels).
  - Al is probably the most ideal metal for extrusion (hot and cold).
  - Products include: doors and window frames.

Hot Extrusion

- Involves prior heating of the billet to a temperature above its recrystallization temperature.
- This reduces strength and increases ductility.
- Additional advantages include reduction of ram force, and increased ram speed.

Cold Extrusion

- Used to produce discrete parts, in finished (or near finished) form.
- Impact Extrusion: indicates high-speed cold extrusion.
- Advantages: increased strength due to strain hardening, close tolerances, improved surface finish, absence of oxide layers, and high production rates.

Types of Extrusion

- **Continuous** versus **Discrete** Extrusion:
  - **Continuous Extrusion:** producing very long sections in one cycle, but these operations are limited by the size of the starting billet that can be loaded into the extrusion container. In nearly all cases, the long section is cut into smaller lengths in a subsequent sawing or shearing operation.
  - **Discrete Extrusion:** a single part is produced in each extrusion cycle. Impact extrusion is an example of the discrete processing case.

Analysis of Extrusion (Ideal Case – No Friction considered)

Extrusion Ratio: $r_x = \frac{A_o}{A_f}$.

True Strain: $\epsilon = ln\frac{A_o}{A_f}$.

Idea (no friction) case, pressure $p = \overline{Y}_f ln(r_x)$

Average flow stress (MPa) $\overline{Y}_f = \frac{K\epsilon^n}{1+n}$

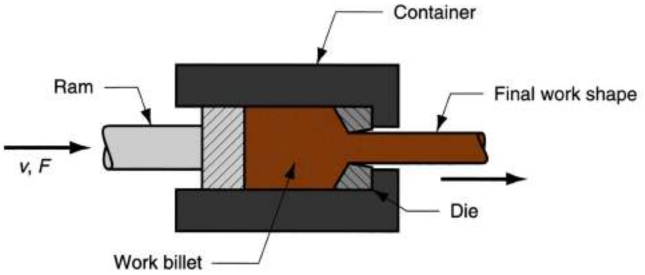


Figure: Direct extrusion ideal case

Analysis of Extrusion (Friction considered)

Extrusion strain: $\epsilon_x = a + b.ln.(r_x)$.
Where a & b are constants for a given die angle: a = 0.8 & b = 1.2 to 1.5.

For indirect extrusion: $p = \overline{Y}_f \epsilon_x$
For direct extrusion, friction is higher, so: $p = \overline{Y}_f(\epsilon_x + \frac{2L}{D_o})$

Ram forces in indirect or direct extrusion, $F = pA_o$
Power required $P = Fv$
Where, v is velocity in m/s

Extrusion Dies and Presses

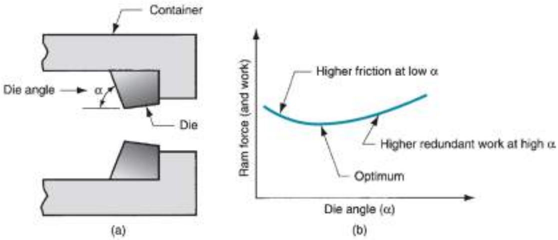


Figure: (a) Definition of die angle in direct extrusion; (b) effect of die angle on ram force.

- Low die angles (α): high friction so high ram force.
- High die angles (α): more turbulence, so increased ram force.
- An optimum die angle exists.

The effect of the die orifice shape can be assessed by the die shape factor, can be expressed as follows:

$$K_x = 0.98 + 0.02\left(\frac{C_x}{C_c}\right)^{2.25}$$

Where $K_x =$ die shape factor in extrusion; $C_x =$ perimeter of the extruded cross section, mm; and $C_c =$ perimeter of a circle of the same area as the extruded shape, mm

K_x for circular shape = 1

K_x for hollow, thin-walled sections is higher.

For shapes other than round

For indirect extrusion: $p = K_x(\overline{Y}_f)\epsilon_x$

For direct extrusion: $p = K_x\overline{Y}_f(\epsilon_x + \frac{2L}{D_o})$

Extrusion Dies and Presses

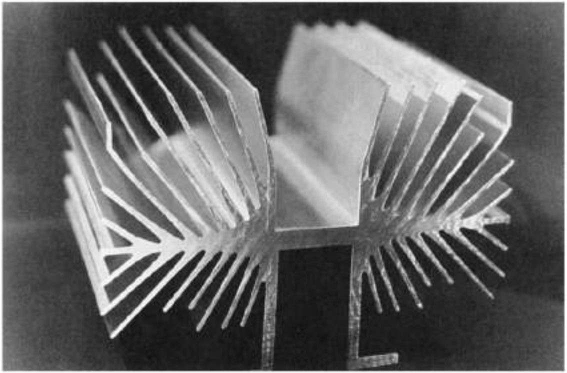


Figure: A complex extruded cross section for a heat sink.

Extrusion Dies and Presses

- Extrusion presses: either horizontal or vertical, depending on orientation of the work axis.
- Usually hydraulically driven.
- This drive is especially suited to semi-continuous production of long sections, as in direct extrusion.
- Mechanical drives are often used for cold extrusion of individual parts, such as in impact extrusion.

Defects in Extrusion

- **Centerburst:** an internal crack that develops as a result of tensile stresses along the centerline of the workpart during extrusion. Conditions that promote centerburst are high die angles, low extrusion ratios, and impurities.
- **Piping:** a defect associated with direct extrusion. It is the formation of a sink hole in the end of the billet. The use of a dummy block whose diameter is slightly less than that of the billet helps to avoid piping.
- **Surface cracking:** results from high workpart temperatures that cause cracks to develop at the surface. They often occur when extrusion speed is too high, leading to high strain rates and associated heat generation.

Defects in Extrusion

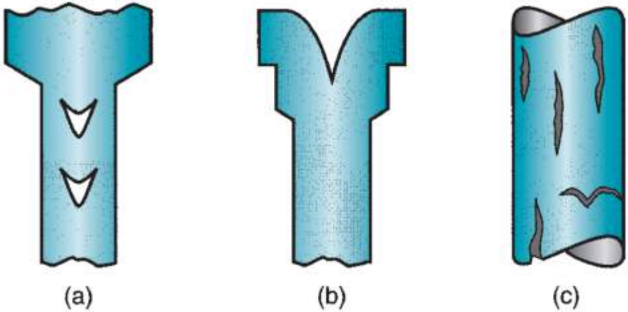


Figure: Some common defects in extrusion: (a) centerburst, (b) piping, and (c) surface cracking

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.
- The difference between drawing and extrusion: the work is pulled through the die in drawing, whereas it is pushed through the die in extrusion.

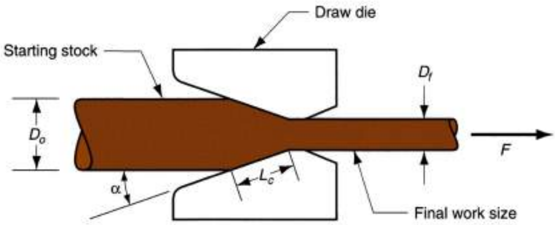


Figure: Drawing of bar, rod, or wire

Wire and Bar Drawing

- **Bar drawing:** the term used for large diameter bars.
- **Wire drawing:** applies to small diameter bars (wire sizes down to 0.03 mm are possible in wire drawing).
- Two stress components are present is drawing; **tensile stresses** due to the pulling action and **compressive stresses** because the metal is squeezed down as it passes through the die opening.
- Change in size of work (given by area reduction): $r = \frac{A_o - A_f}{A_o}$
- Draft: difference between original and final diameter: $d = D_o - D_f$

Analysis of Drawing

- **Mechanics of Drawing:** assume no friction
- True strain: $\epsilon = ln\frac{A_o}{A_f} = ln\frac{1}{1-r}$
- Stress: $\sigma = \overline{Y}_{f\epsilon} = \overline{Y}_f ln\frac{A_o}{A_f}$

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

- **Mechanics of Drawing:** assuming friction
  $\sigma_d = \overline{Y}_f\phi(1 + \frac{\mu}{tan\alpha})ln\frac{A_o}{A_f}$
  where, $\sigma_d =$ draw stress, MPa; μ = die-work coefficient of friction; $\alpha =$ die angle; and ϕ is a factor that accounts for inhomogeneous deformation.

  $\phi = 0.88 + 0.12\frac{D}{L_c}$
  where $D =$ average diameter of work during drawing, mm; and $L_c =$ contact length of the work with the draw die.

  $D = \frac{D_o+D_f}{2}$ and $L_c = \frac{D_o-D_f}{2sin\alpha}$

  Accordingly $F = A_f\sigma_d$
  where $F =$ drawing force, N

Analysis of Drawing

- **Maximum Reduction per Pass:** why entire reduction is not taken in one pass?
  - As the reduction increases, draw stress increases.
  - If the reduction is large enough, draw stress will exceed the yield strength of the exiting metal.
  - When that happens, the drawn wire will simply elongate instead of new material being squeezed through the die opening.
  - For wire drawing to be successful, maximum draw stress must be less than the yield strength of the exiting metal.

Analysis of Drawing

- **Maximum Reduction per Pass:** assuming perfectly plastic material; then ($n = 0$ hence $\overline{Y}_f = Y$), and no friction:
  $\sigma_d = \overline{Y}_f ln\frac{A_o}{A_f} = Yln\frac{A_o}{A_f} = Yln\frac{1}{1-r} = Y$
- This means that $ln\frac{A_o}{A_f} = ln\frac{1}{1-r} = 1$. Hence, $\frac{A_o}{A_f} = \frac{1}{1-r}$ must equal the natural logarithm base e. that is, the maximum possible strain is 1.0:
  $\epsilon_x = 1.0$
- The maximum possible area ratio is: $\frac{A_o}{A_f} = e = 2.7183$
- The maximum possible reduction is: $r_x = \frac{e-1}{e} = .632$

Drawing Practice

- Drawing is usually performed as a cold working operation.
- Most frequently used to produce round cross sections, but other shapes are also drawn.
- Drawn products include:
  - Electrical wire and cable; wire stock for fences, coat hangers, and shopping carts.
  - Rod stock to produce nails, screws, rivets, springs, and other hardware items.
  - Bar drawing is used to produce metal bars for machining, forging, and other processes.

Drawing Practice

- **Advantages include:**
    - Close dimensional control.
    - Good surface finish.
    - Improved mechanical properties such as strength and hardness.
    - Adaptability to mass production.

Drawing Practice

- **Drawing Equipment:** (Bar Drawing)
  - Draw bench: consists of an entry table, die stand, carriage, and exit rack.
  - The carriage is used to pull the stock through the draw die.
  - Powered by hydraulic cylinders or motor-driven chains.

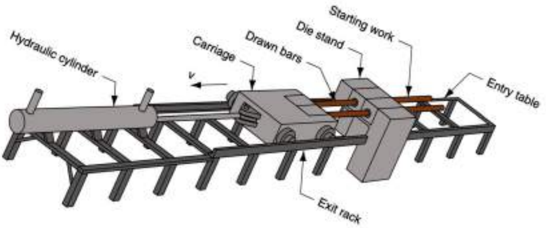


Figure: Hydraulically operated draw bench for drawing metal bars.

Drawing Practice

- **Drawing Equipment:** (Wire Drawing)
  - 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.

Drawing Practice

- **Drawing Equipment:** (Wire Drawing)

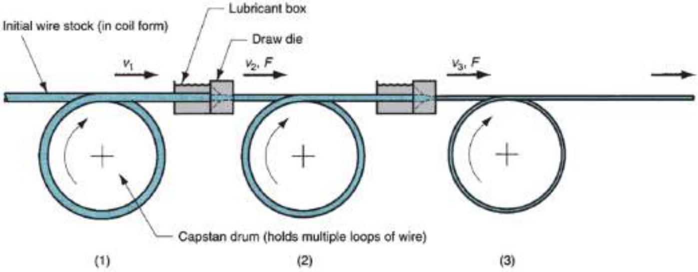


Figure: Continuous drawing of wire

Drawing Practice

- **Drawing Dies** are made of tool steel, cemented carbides or diamond and they consist of 4 regions:
    1. **Entry Region:** usually a bell-shaped mouth that does not contact the work. Its purpose is to funnel the lubricant into the die and prevent scoring of work and die surfaces.
    2. **The Approach Region:** is where the drawing process occurs. It is cone-shaped with an angle (half-angle) normally ranging from about 6 to 20^o.
    3. **The Bearing Surface (Land):** determines the size of the final drawn stock.
    4. **The Back Relief:** is the exit zone. It is provided with a back relief angle (half-angle) of about 30^o

Drawing Practice

- **Drawing Dies**

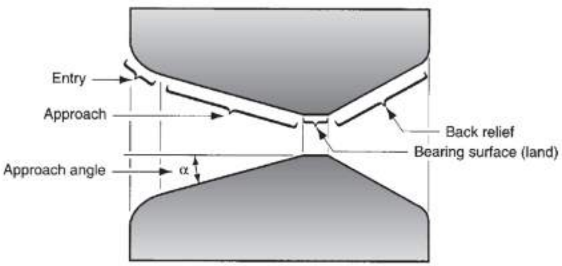


Figure: Draw die for drawing of round rod or wire.

Drawing Practice

- **Preparation of work:** involves three steps: (1) annealing, (2) cleaning, and (3) pointing.

    1. **Annealing:** done to increase the ductility of the stock.
    2. **Cleaning:** required to prevent damage of the work surface and draw die.
    3. **Pointing:** involves the reduction in diameter of the starting end of the stock so that it can be inserted through the draw die to start the process. This is usually accomplished by swaging, rolling, or turning.