

# **LECTURE-02 : BULK DEFORMATION PROCESSES – FORGING & EXTRUSION**



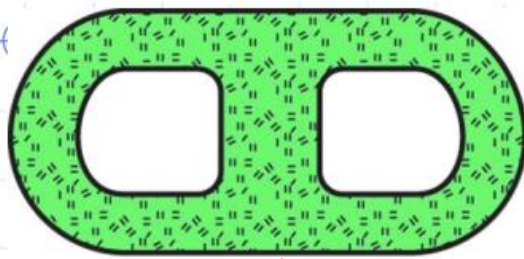
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**DR. NIKHIL R. DHAR**

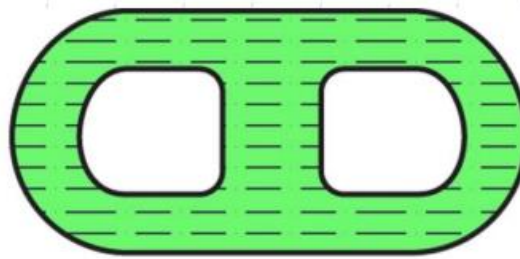
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# Forging

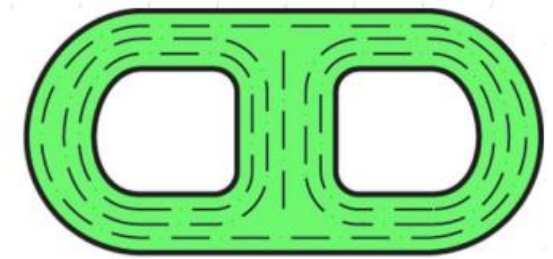
- Forging is a manufacturing process involving the shaping of a metal through **hammering**, **pressing**, or **rolling**. These compressive forces are delivered with a hammer or die. Forging is often categorized according to the temperature at which it is performed—**cold**, **warm**, or **hot forging**.
- A wide range of metals can be forged. Typical metals used in forging include **carbon steel**, alloy steel, and **stainless steel**. Very soft metals such as **aluminum**, **brass**, and **copper** can also be forged.
- There are several forging methods with different capabilities and benefits. The more commonly used forging methods include the **drop forging** methods, as well as **roll forging**.



Casting



Machining

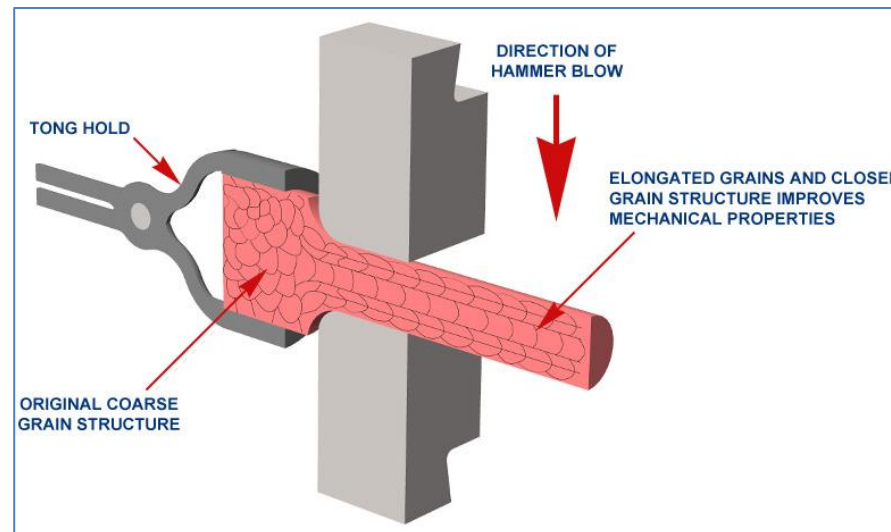


Forging



# Open-Die Forging

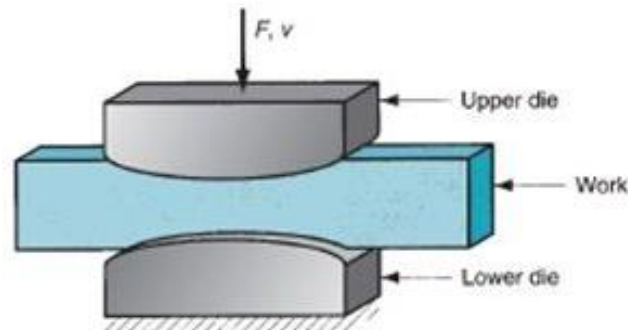
Open-die forging is also known as **smith forging**. A hammer strikes and deforms a metal on a stationary anvil. In this type of forging, the metal is never completely confined in the dies—allowing it to flow except for the areas where it is in contact with the dies. It is the operator's responsibility to orient and position the metal to achieve the desired final shape. Flat dies are used, with some having specially shaped surfaces for specialized operations. Open-die forging is **suitable for simple and large parts**, as well as customized metal components.



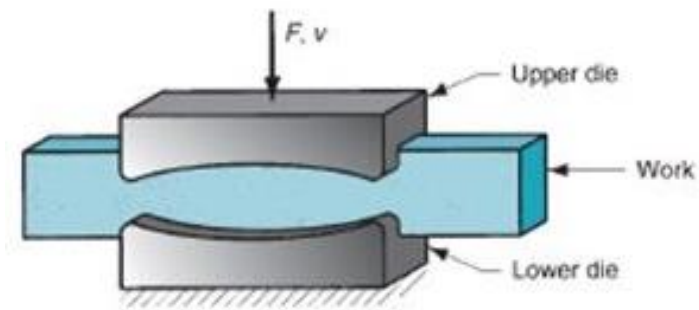
The skill of the human operator is a factor in the success of these operations.

Operations classified as open-die forging or related operations include:

- Fullering: Reducing workpiece cross section to prepare for subsequent shaping action. Dies with **convex surface** cavity are used.
- Edging: Similar to Fullering, but the dies have **concave surface** cavity.

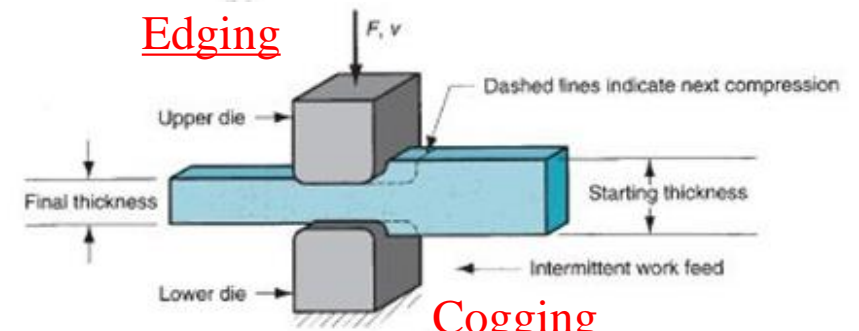


Fullering



Edging

- Cogging: Open dies with flat or slightly contoured surfaces to reduce cross-section and to increase length.



Cogging



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- Advantages of open-die forging

- Simplest type of forging
- Dies are inexpensive
- Wide range of part sizes, ranging from 30-1000lbs
- Good strength qualities
- Generally good for small quantities

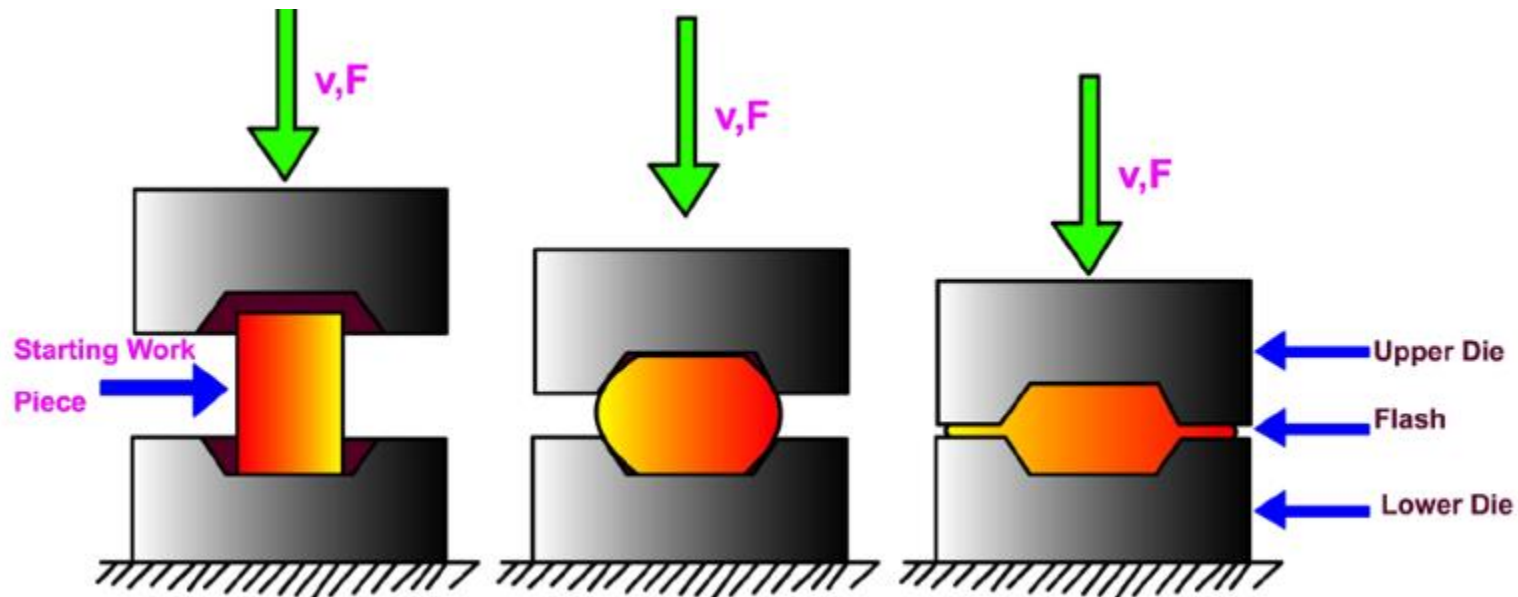
- Limitations of open-die forging

- Simple shapes only
- difficult to hold close tolerances
- machining necessary
- low production rate
- poor utilization of material
- high skill required



# Impression or Closed Die Forging

In impression-die forging, sometimes called closed 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 as shown in following Figure. In this type of operation, a portion of the work metal flows beyond the die impression to form **flash** and must be **trimmed off** later.



Stages of closed die forging process



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## ■ Advantages of closed die forging

- Good utilization of material
- Better properties than open die forgings
- Dies can be made of several pieces and inserts to create advanced parts
- Presses can go up to 50,000 ton capacities
- Good dimensional accuracy
- High production rates
- Good reproducibility

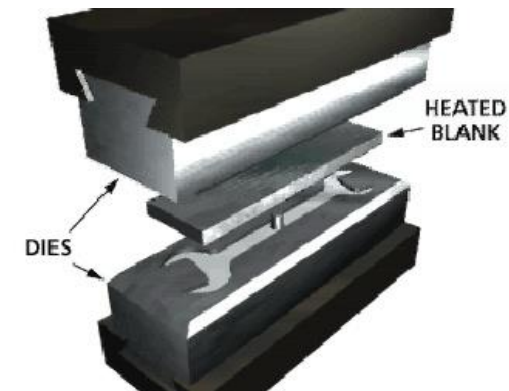
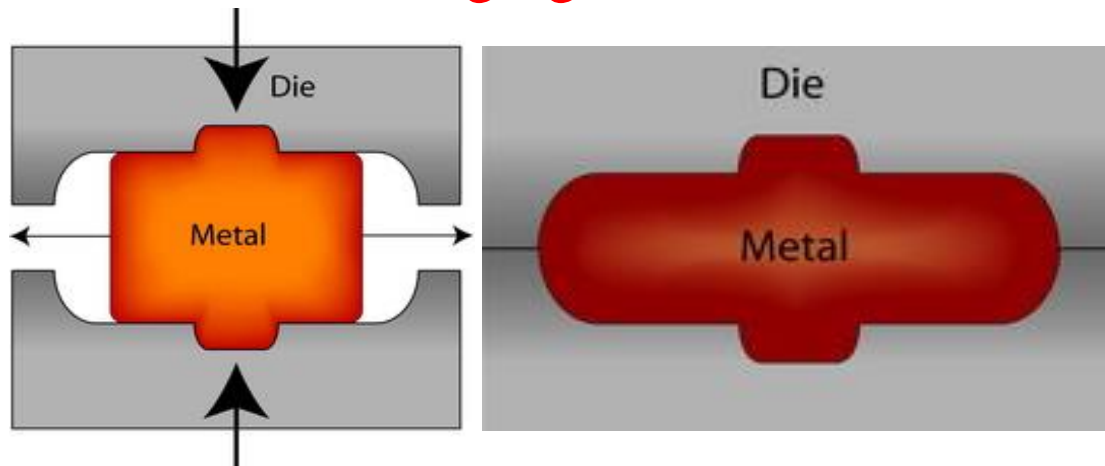
## ■ Limitations of closed die forging

- High die cost
- Machining is often necessary
- Economical for large quantities but not for small quantities



# Flashless Forging

- Impression die forging is sometimes performed in totally enclosed impressions. The process is used to produce a near-net or net shape forging. The dies make no provision for flash because the process does not depend on the formation of flash to achieve complete filling. Actually, a thin fin or ring of flash may form in the clearance between the upper punch and die, but it is easily removed by blasting or tumbling operations, and does not require a trim die. The process is therefore called flashless forging, and is sometimes called enclosed die forging.



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- Advantages of flashless forging

- Close dimensional tolerances
- Very thin webs and flanges are possible
- Very little or no machining is required
- Little or no scrap after part is produced
- Cheaper to produce from less finishing operations and faster production
- Typical applications are gears, connecting rods, and turbine blades

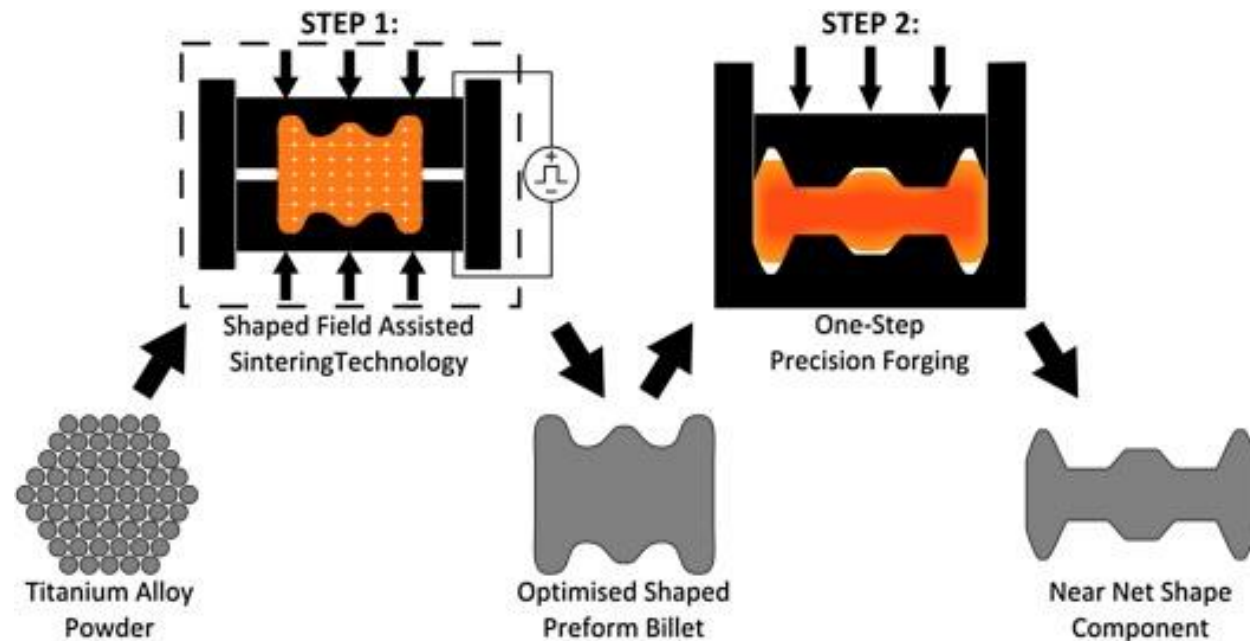
- Limitations of flashless forging

- High forging forces
- Thus higher capacity equipment is required
- Intricate dies leading to increased die cost
- Precise control over the Blank's volume and shape
- Accurate positioning of the Blank in the die cavity



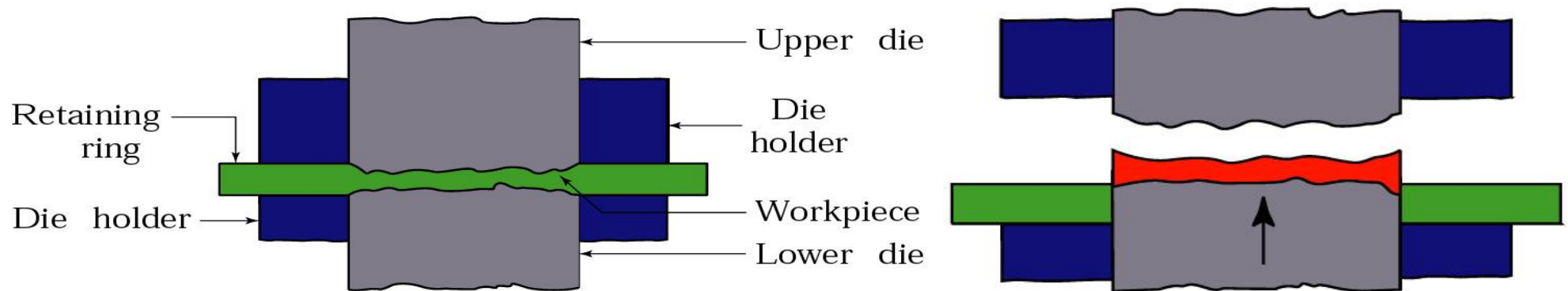
# Net and Shape Forging

- Net and near net shape forging represents some relatively recent developments of the conventional impression die forging process. Net and near net shape forgings are distinguished by geometric features that are thinner and more detailed, varying parting line locations, virtual elimination of draft, closer dimensional tolerances and with many as-forged surfaces. The resulting product benefits are much fewer machining operations, reduced weight and lower costs for raw materials and energy.



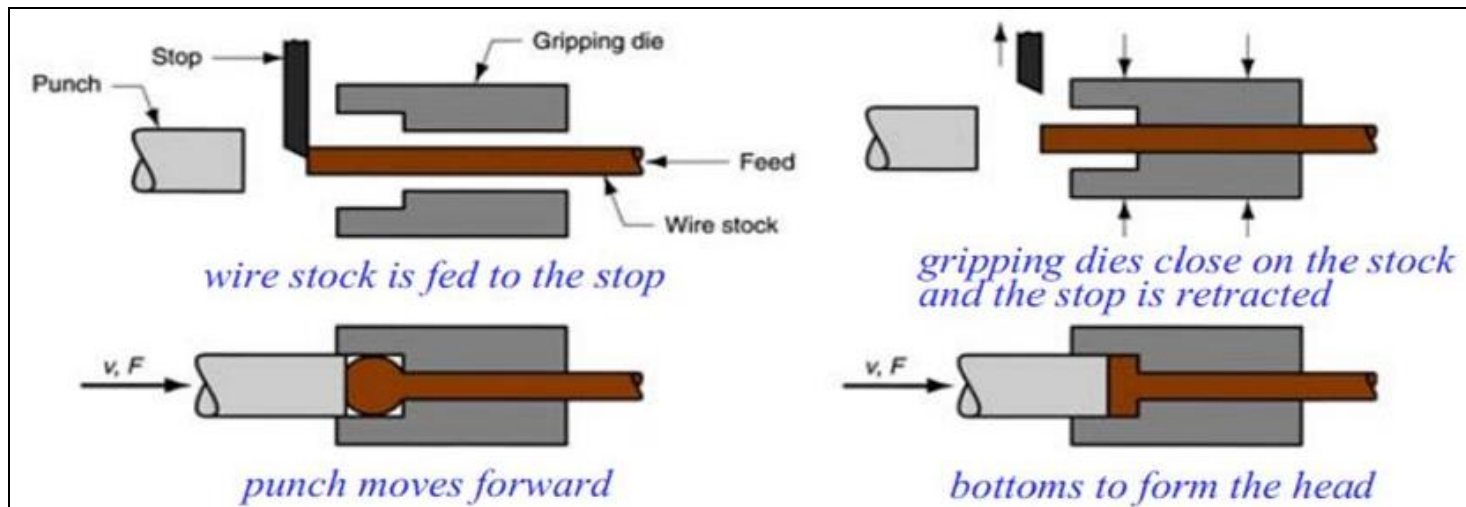
# Coining

- Coining is a **closed die forging process**, in which pressure is applied on the surface of the forging in order to obtain closer tolerances, smoother surfaces and eliminate draft. Closed die forging is a process in which forging is done by placing the work piece between two shaped dies. This is a **flashless, precision forging operation**, that due to the required accuracy of the process, is performed cold. In the coining process, a large amount of force is exerted on the forging, over a short distance. **Mechanical presses** are often used for these operations.



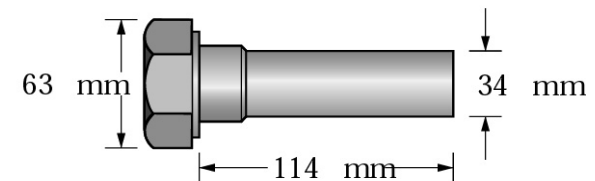
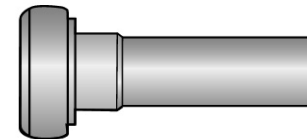
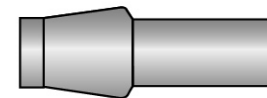
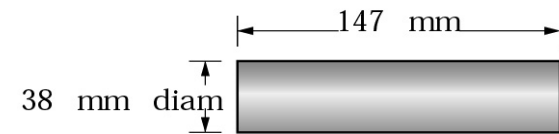
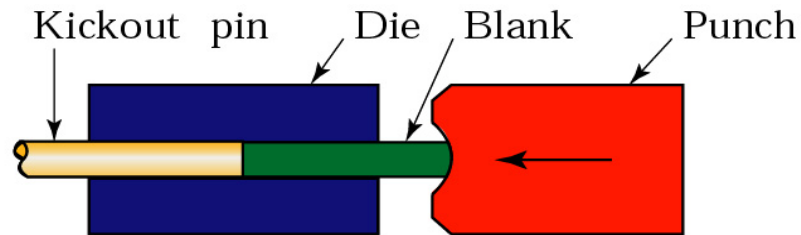
# Upsetting

- Upset forging, also known as heading, is a manufacturing process which decreases the length of a workpiece in order to increase the diameter of the material in this area. Upset forging is usually performed in presses. The most common components, produced using this technique are fasteners as engine valves, couplings and others. Since a finished part can be manufactured with every move cycle of the presses, upset forging is one of the most advantageous methods for mass production.



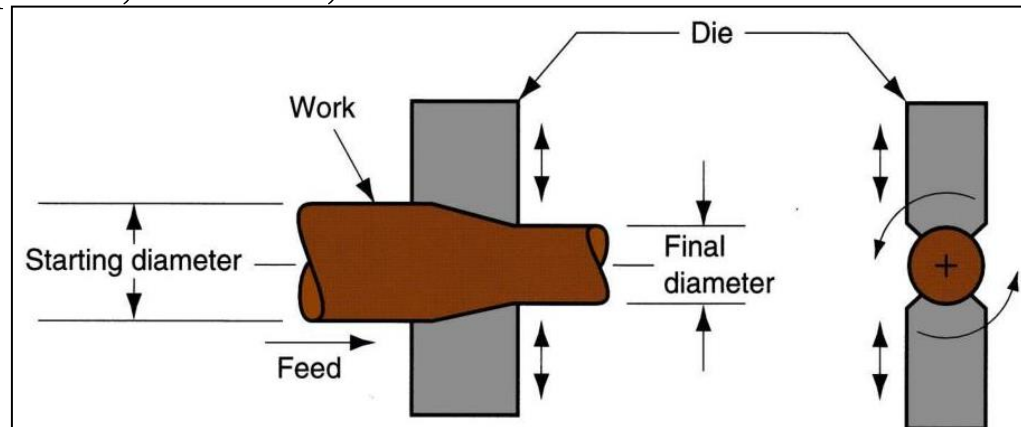
# Heading

- The following Figure illustrates a variety of heading applications, indicating various possible die configurations. Owing to these types of applications, more parts are produced by upsetting than any other forging operation. It is performed as a mass production operation—cold, warm, or hot—on special upset forging machines, called headers or formers.



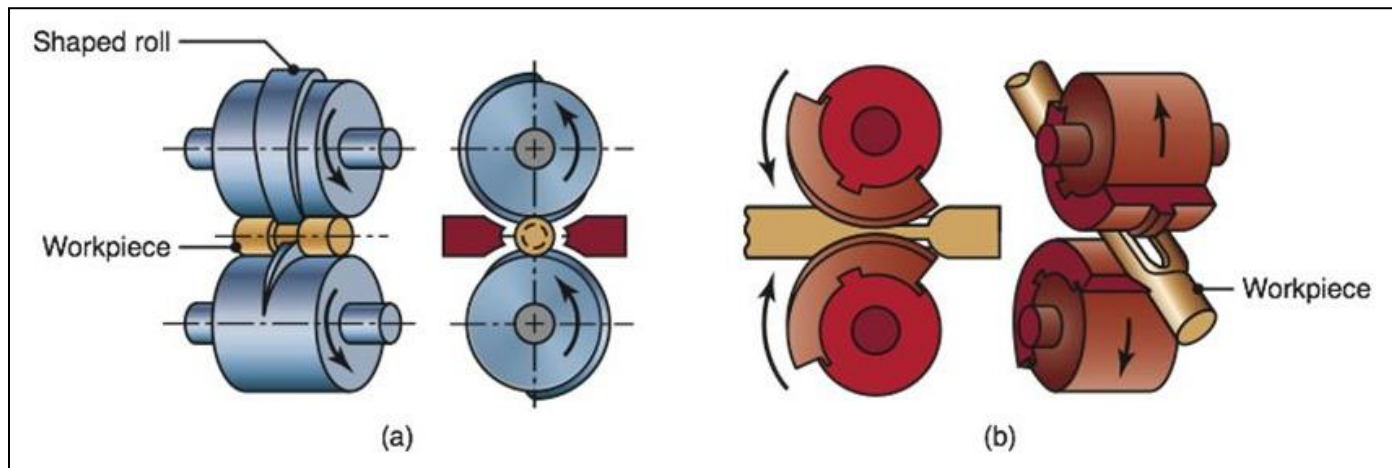
# Swaging and Radial Forging

- Swaging and radial forging are forging processes used to reduce the diameter of a tube or solid rod. **Swaging** is often performed on the end of a workpiece to create a tapered section. 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. A **mandrel** is sometimes required to control the **shape and size of the internal diameter of tubular** parts that are swaged. **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



# Roll Forging

- Roll forging is a deformation process used to reduce the cross section of a cylindrical (or rectangular) workpiece by passing it through a set of opposing rolls that have grooves matching the desired shape of the final part. Roll forging is generally classified as a forging process even though it utilizes rolls. The rolls do not turn continuously in roll forging, but rotate through only a portion of one revolution corresponding to the desired deformation to be accomplished on the part

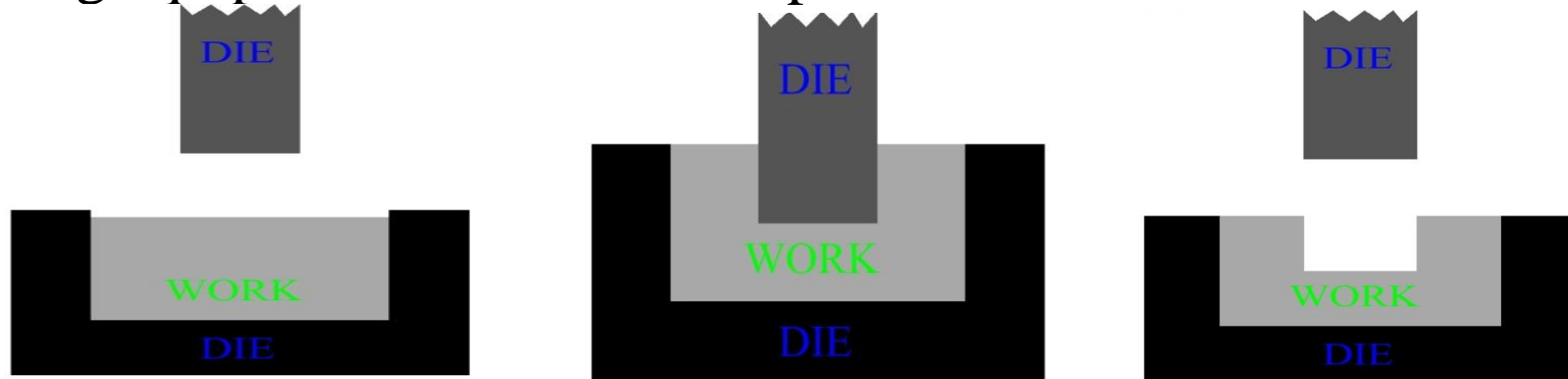


Tapered leaf springs and knives can be made by this process using specially designed rolls



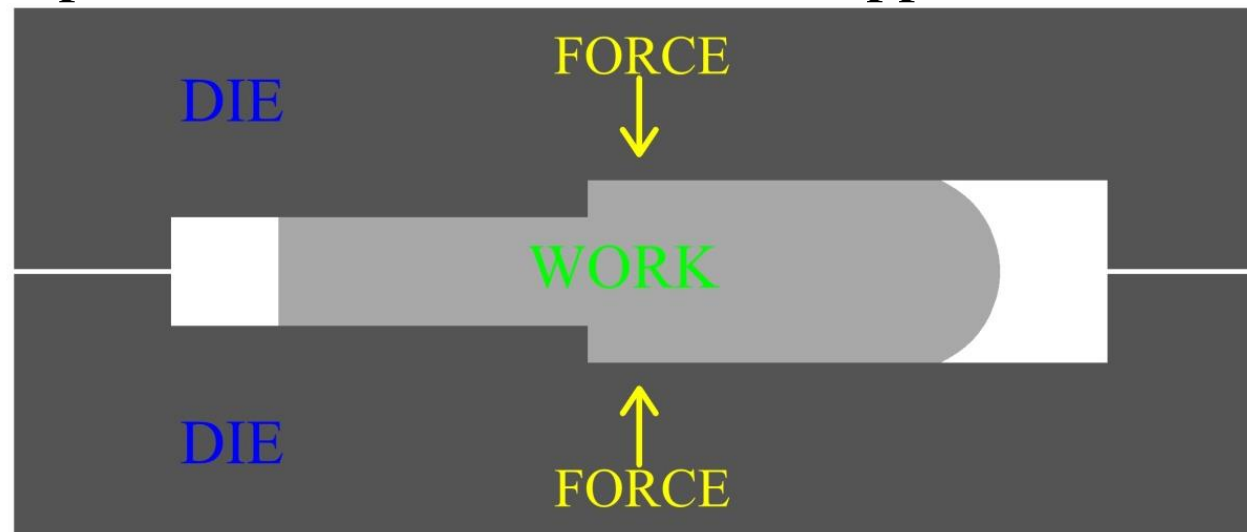
# Metal Piercing

- Piercing is a metal forging technique that is often performed as an auxiliary process in conjunction with other forging processes, in the manufacture of a part. It can be used to create a cavity or hole in the work piece. Piercing does not break through the metal's surface, like a drilling operation. Instead, the cavity is pressed into the work, hence it is a forging operation. Similar to other metal forging processes, piercing will change the properties of the work material, and affect the grain structure of the part. Often in manufacturing practice, more **complex cavities** can be further forged using side acting equipment attached to the punch.



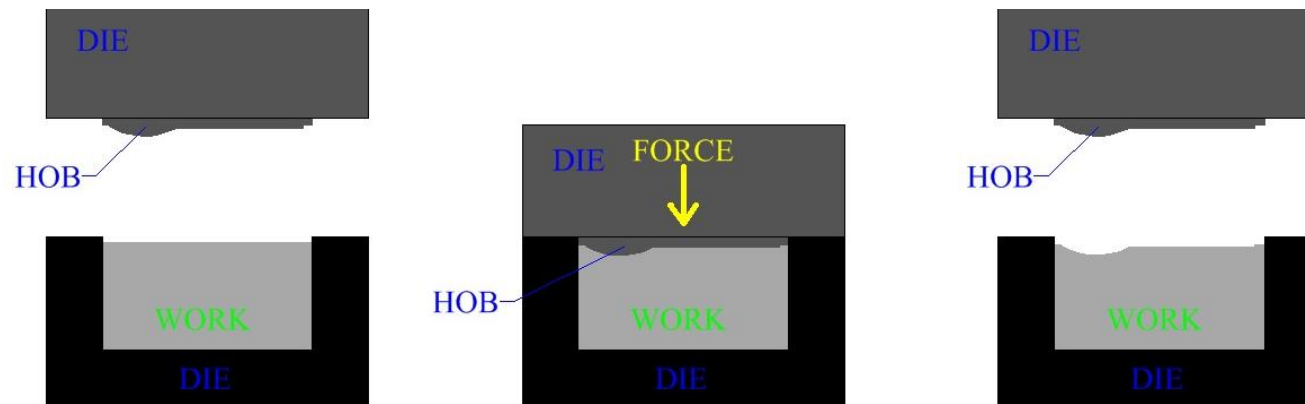
# Metal Sizing

- Sizing is a metal forging process that is used mainly to finish work that has already been manufactured. It is a cold forming process. Metal sizing uses a lot of force over a short distance, producing very accurate dimensions in the finishing of these parts. This manufacturing technique can also be used to create work with excellent surface quality. Sizing is characteristic in that during the operation, the flow of work material is unrestricted in all directions except that over which the force is applied.



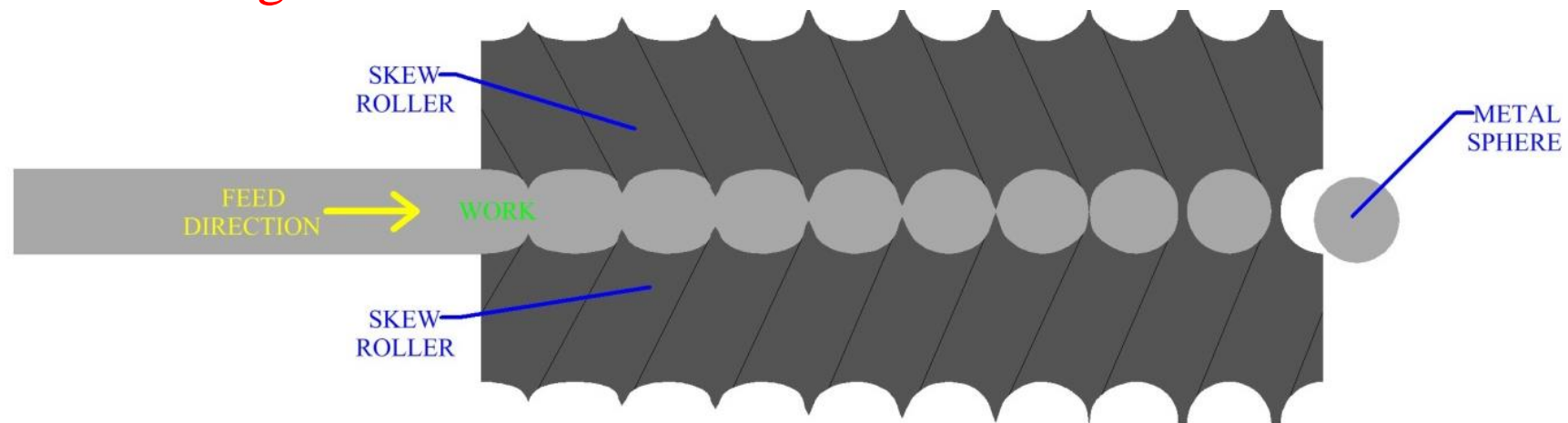
# Metal Hobbing

- Hobbing is a cold working, metal forging process in which a punch, with an exact geometry at its end, is pressed into a work piece. The special punch, called a hob, will create a cavity with the precise dimensions desired. Due to the high tolerances of the hob, the high pressures applied during the manufacturing process, and the fact that the operation is performed cold, very accurate dimensions and surface quality are obtained within the cavity. The hob is most often machined from hardened steel. A common application of hobbing in modern industry is to produce molds or die cavities for other manufacturing processes such as plastic molding, die casting, and other metal forging processes.



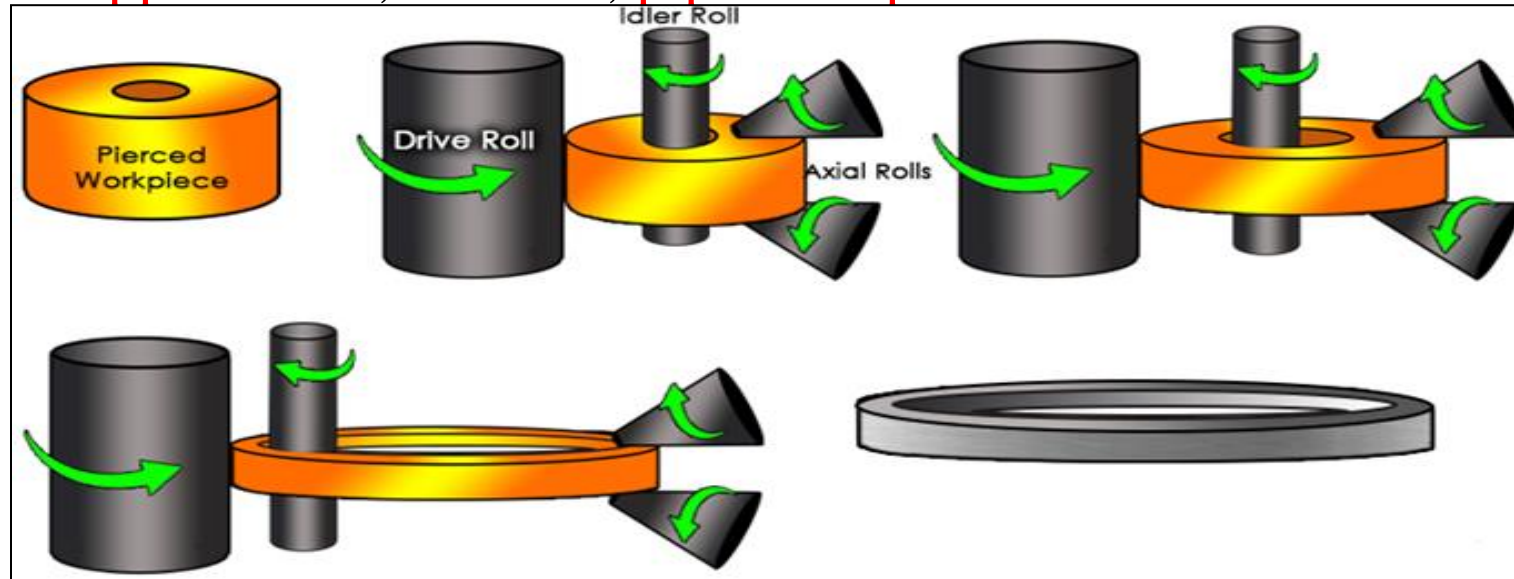
# Metal Ball Forging

- One of the main ways that these metal spheres are manufactured is by **skew rolling**. Skew rolling is a metal forging process that uses two specially designed opposing rolls, that rotate continuously. Round stock is fed into the rolls, the material is forged by each of the grooves in the rolls and emerges from the end as a metal ball. The stock is fed through the rolls continuously, but each ball is produced separately, thus it is a discrete process and not a continuous one. One of the main applications of these metal balls is for use as **ball bearings**.



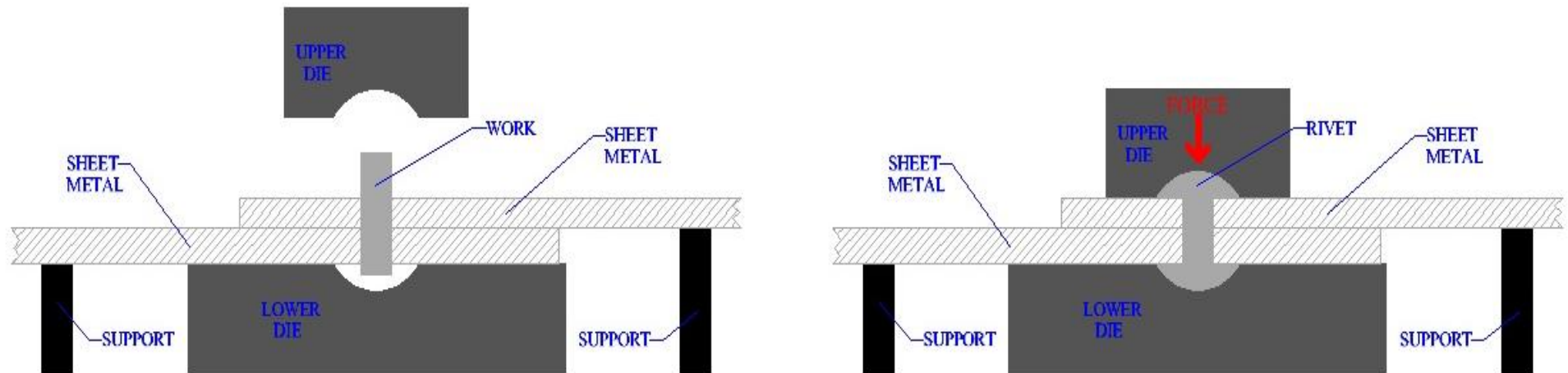
# Ring Forging

- Once the work piece is **pierced** all the way through, it is ready to be **ring forged**. The work is placed on a **mandrel** or **saddle**. The ring is then formed by the up and down motion of a forging die that hammers the material from above, as the work is incrementally rotated in a series of steps that will forge the ring to its final size. Seamless metal rings, of different sizes, are commonly manufactured in modern industry for various applications, such as **parts for machine tools**, **aerospace applications**, **turbines**, **pipes** and **pressure vessels**.



# Riveting

- Riveting is a forging process that may be used to **join parts together** by way of a metal part called a rivet. The rivet acts to join the parts through adjacent surfaces. A straight metal piece is connected through the parts. Then both ends are formed over the connection, joining the parts securely. The metal work piece used to form the connection may be hollow or it may be solid. Rivets have many uses, such as in the **construction** and **sheet metal industries**.



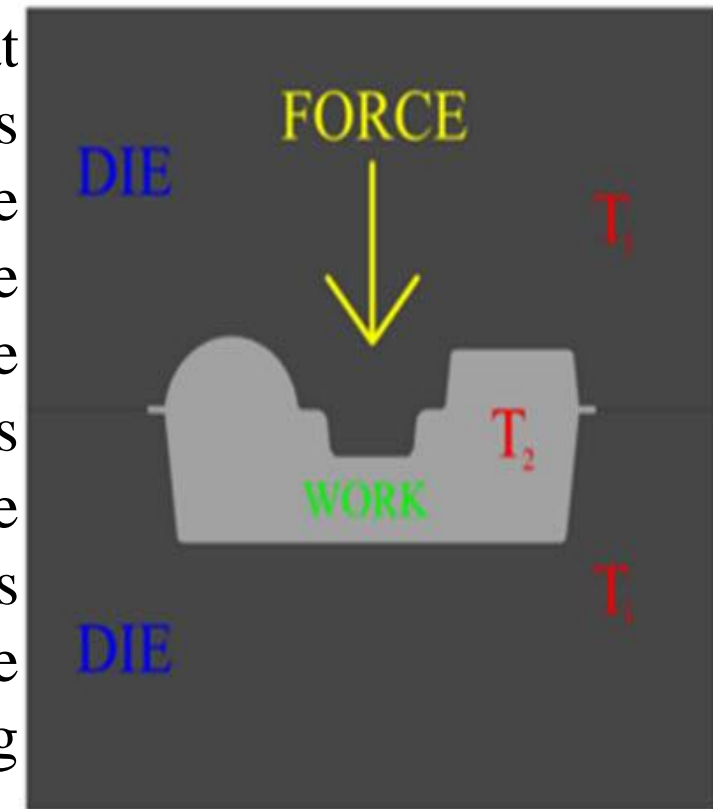
WORK IS SET IN PRE MADE HOLES

ENERGY FROM DIE COMPRESSION FORMS RIVET



# Isothermal Forging

- Isothermal forging is a hot working process that attempts to maintain the work piece at its maximum elevated temperature throughout the entire operation. This is achieved by heating the die to the temperature of, or slightly below the temperature of the starting work piece. As forces exerted by the die form the work, cooling of the work piece between the mold work interface is eliminated, and thus flow characteristics of the metal are greatly improved. Isothermal forging may or may not be performed in a vacuum. Equipment costs for this process are high, and the added expense of this type of operation should be justified on a case by case basis.



$T_1 =$  Temperature of the mold

$T_2 =$  Temperature of the work

$$T_1 = T_2$$



# Forging Machines

- Equipment used in forging consists of **forging machines**, classified as forging hammers and presses, and forging dies, which are the special tooling used in these machines. 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: Forging hammers operate by applying an **impact load** against the work. Drop hammers are most frequently used in impression-die forging. The upper portion of the forging die is attached to the ram, and the lower portion to the anvil. In the operation, 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.
- **Hammers are classified** according to the way in which the ram is raised and whether it falls freely or is driven. The different hammers are as (i) **Board hammer**, (ii) **Air-lift hammer**, (iii) **Steam hammer** and (iv) **Impacters**.

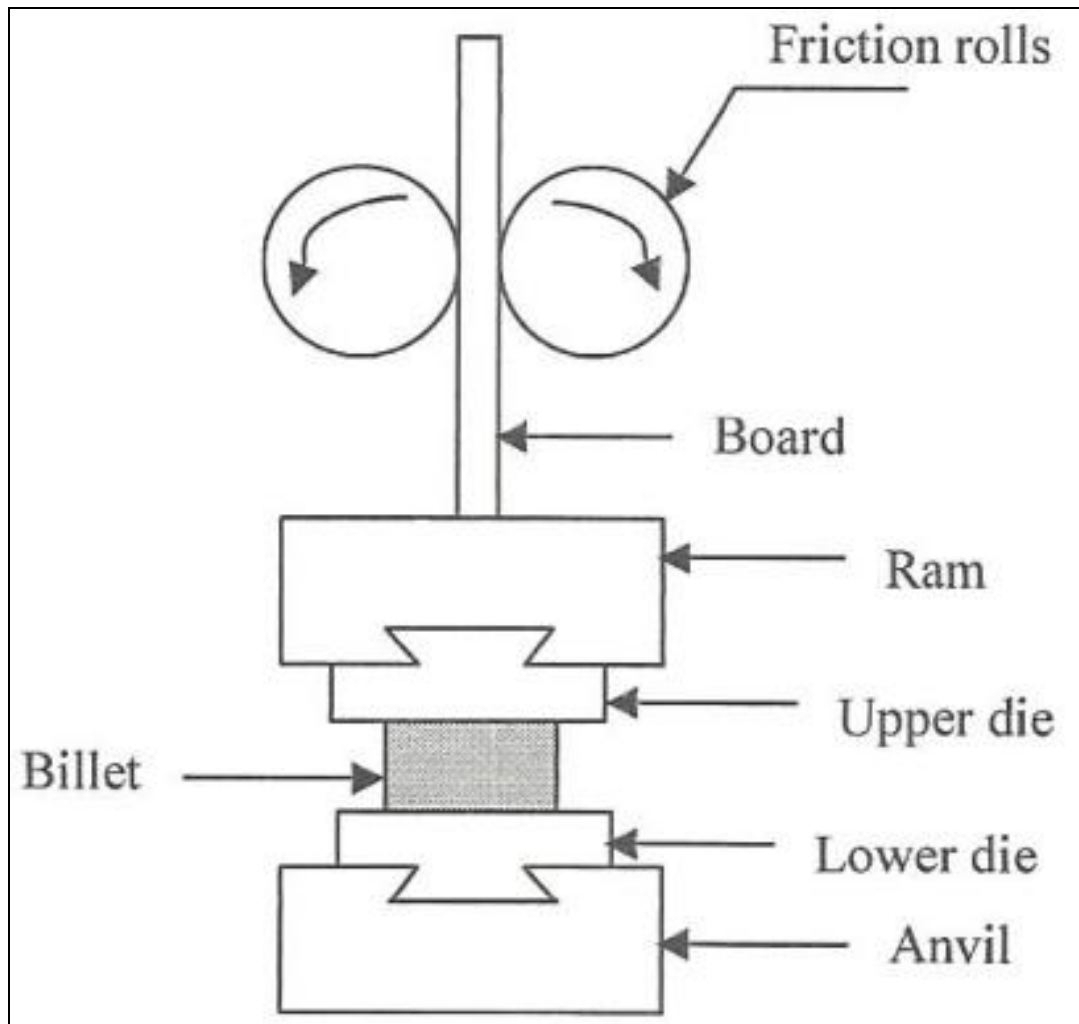


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- **Board Hammers**: Board hammers, or board drop hammers, which gave rise to the term drop forging, operate by gravity only. The ram is raised mechanically to a predetermined height, which cannot be varied between blows, but can be reset between jobs. Cycle rates are high, as many as seventy per minute, and the energy imparted to the workpiece is the same on each blow. The workpiece is typically struck several times in impression die forging.
  - **Air-lift Hammers**: Air-lift hammers are similar to board hammers except that the ram is raised by action of air cylinders. On some hammers, the height can be varied on each stroke, either by the operator or by pre-programmed blow control. Air-lift hammers range in size from 500 to 10,000 pounds falling weight. Many air operated hammers are conversions from steam hammers and operate with power down as well as power up operation.

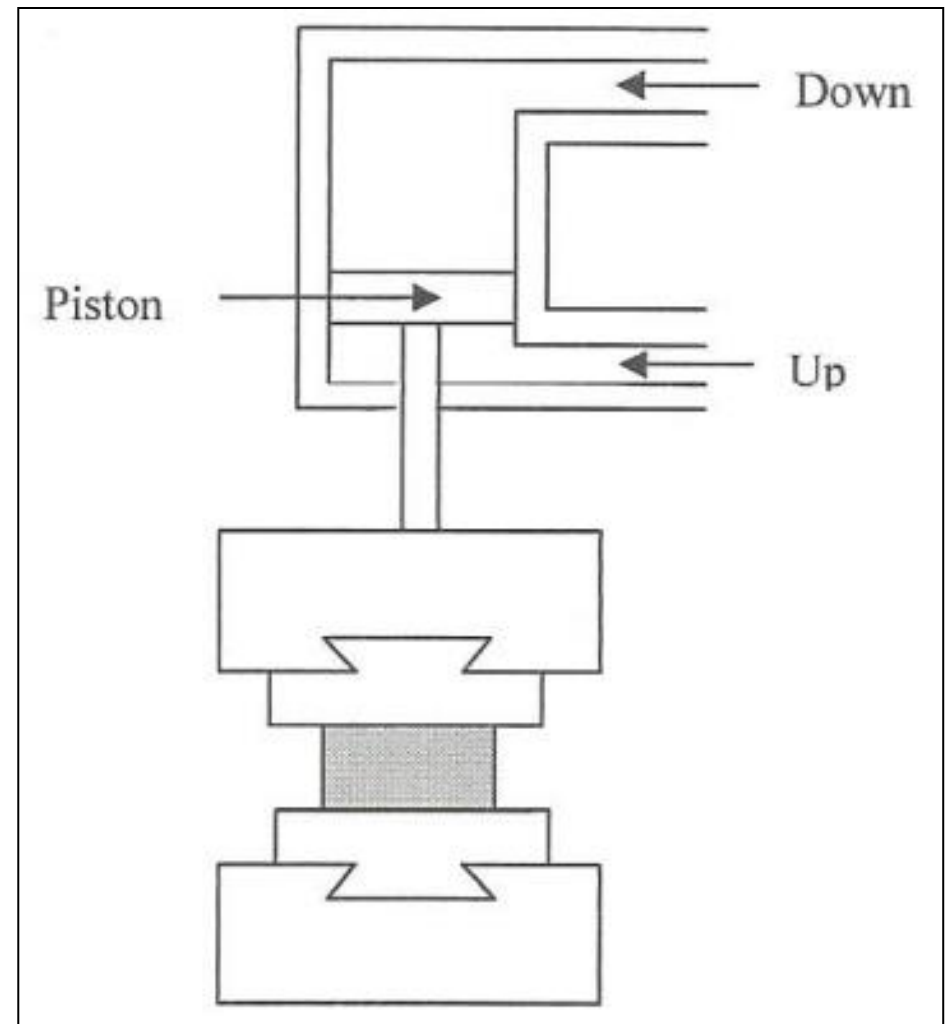


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- **Steam or Air-Powered Hammers**: Steam or air-powered hammers are similar to air-lift hammers except that the hammer is **raised either by steam or air**, and is powered down onto the workpiece by pressurized steam or air, adding controlled energy and speed beyond gravity. Striking force can be varied on each stroke over the entire range from a light tap to full power. The complete control of each work stroke places higher requirements on operator skills than for other types of hammer. In a growing number of cases, they are being controlled by programmable systems.
  - **Impacters**: A modification of air-driven hammers is the impacter, where two rams of equal weight are propelled horizontally toward each other and impact in a central location. Impacters can be automated to forge several hundred parts per hour, and generally are not designed for manual operation as are vertical air-powered hammers.





**Board Drop Hammers**

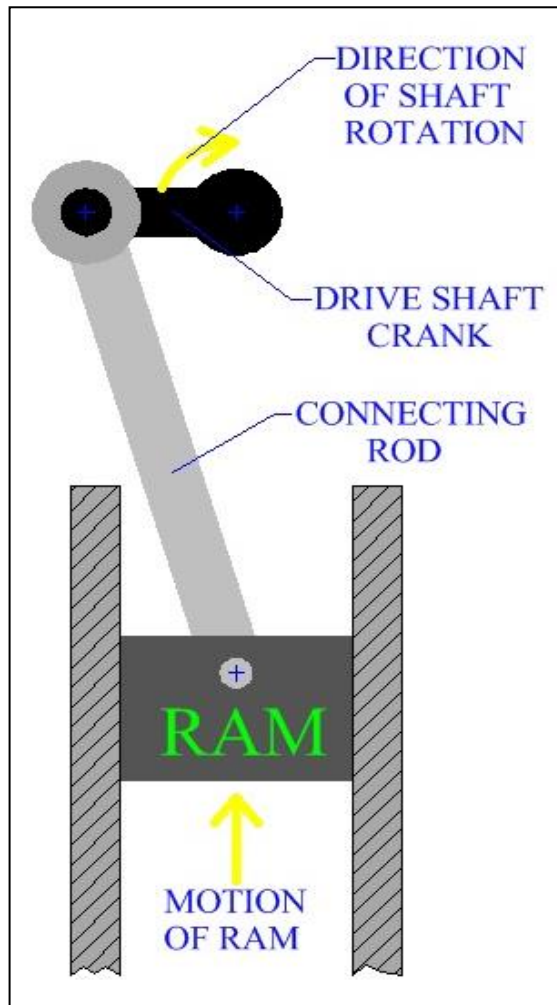


**Steam or Air-Powered Hammers**

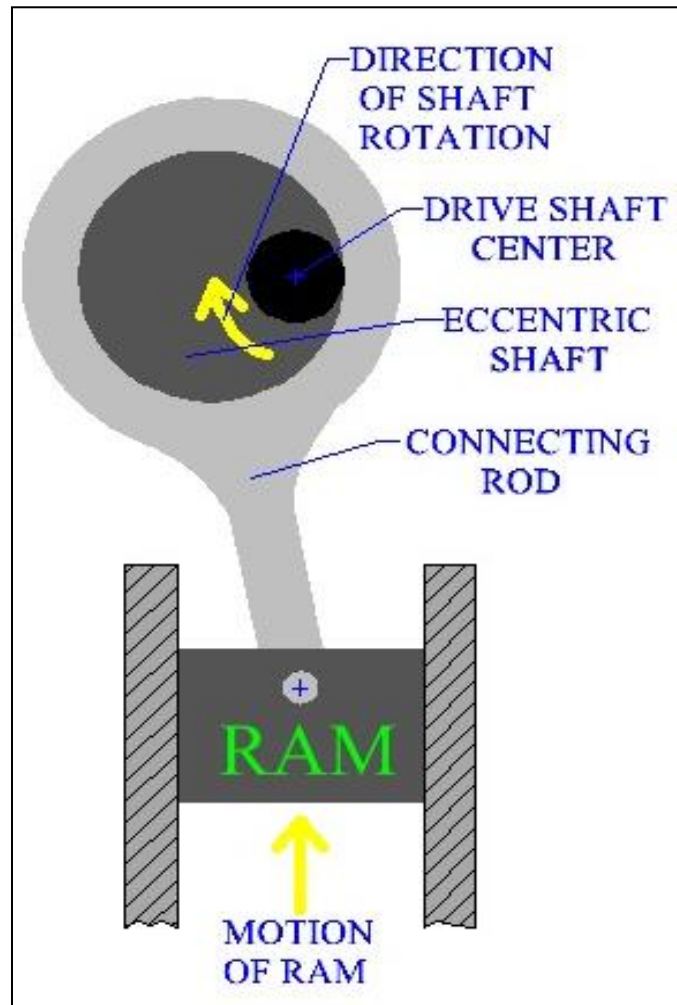


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- **Forging Presses**: Presses apply gradual pressure, rather than sudden impact, to accomplish the forging operation. Forging presses include **Mechanical presses**, **Hydraulic presses** and **Screw presses**.
  - **Mechanical Presses**: Mechanical presses typically store energy in a rotating flywheel, which is driven by an electric motor. The flywheel is engaged and disengaged to a mechanical drive such as a **crankshaft**, **eccentric shaft**, or **knuckle joints**, which convert flywheel rotation to vertical motion. The stroke is of set speed, length and duration. Mechanical presses are not suitable for open die forging, where the length of stroke must be varied between strokes.
  - Recent developments in mechanical presses are focusing on increased stiffness of the press structure to improve forging accuracy, automation, and high speed. They are increasingly replacing hammers because of greater environmental compatibility, ease of automation and lower operating costs.

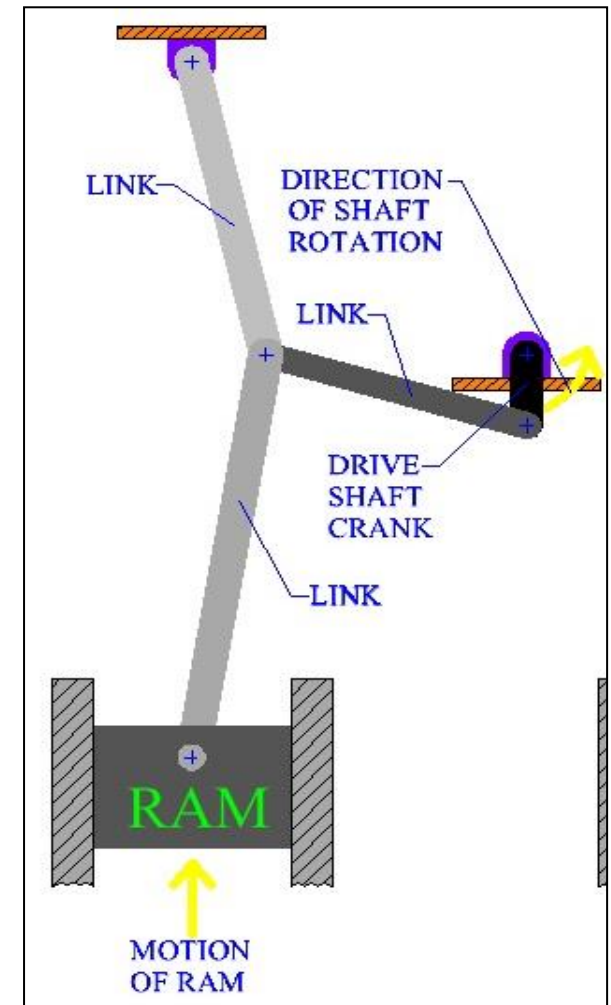




**Crank Press**



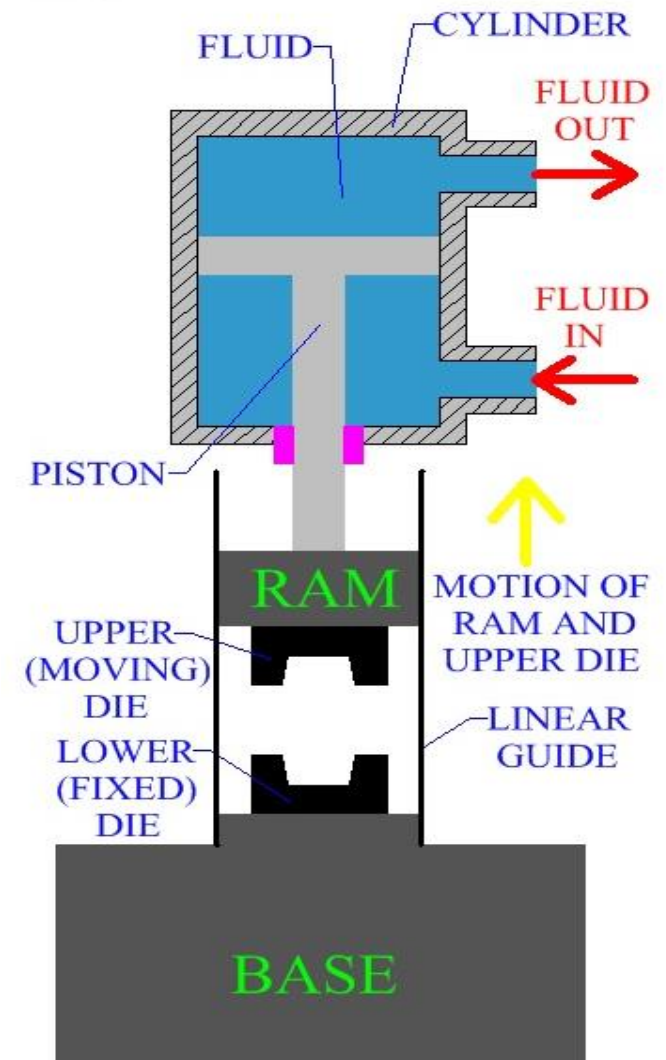
**Eccentric Press**



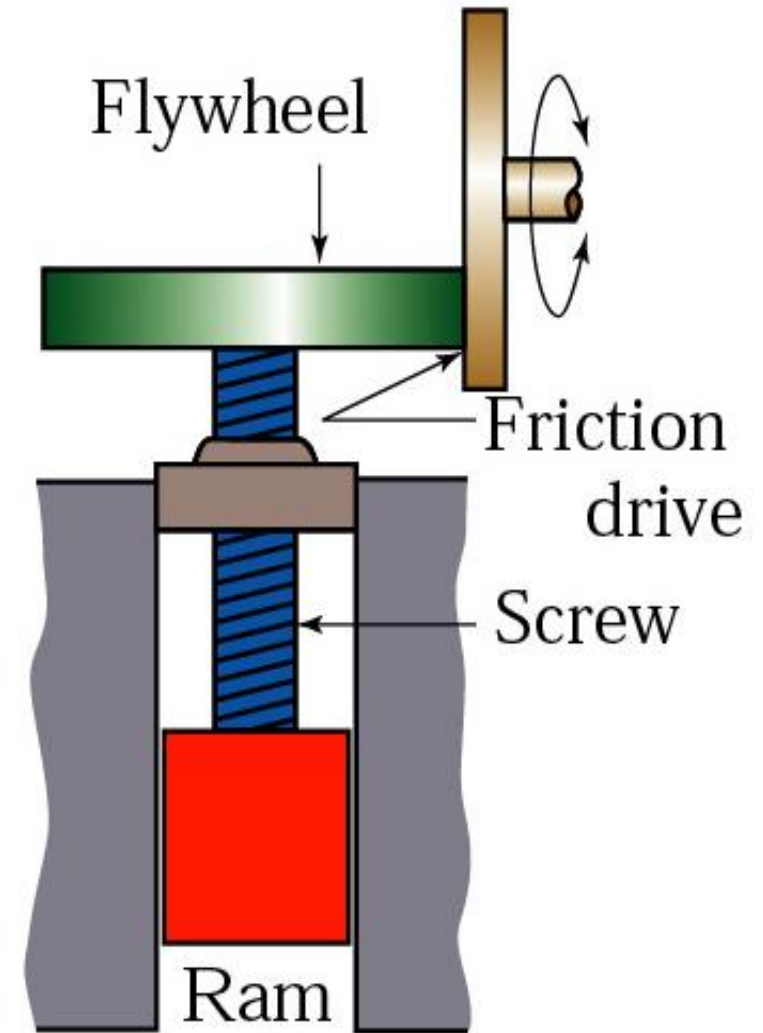
**Knuckle Joint Press**



- **Hydraulic Presses:** Hydraulic presses are operated by large pistons driven by high-pressure hydraulic or hydro-pneumatic systems. They are slow moving compared with mechanical and screw presses, and squeeze rather than impact the workpiece. In operation, hydraulic pressure is applied to the top of the piston, moving the ram downward. When the stroke is complete, pressure is applied to the opposite side of the piston to raise the ram. In many cases, hydraulic presses used for open and some closed die forging presses use microprocessors or computers to control the press operation, for parameters such as ram

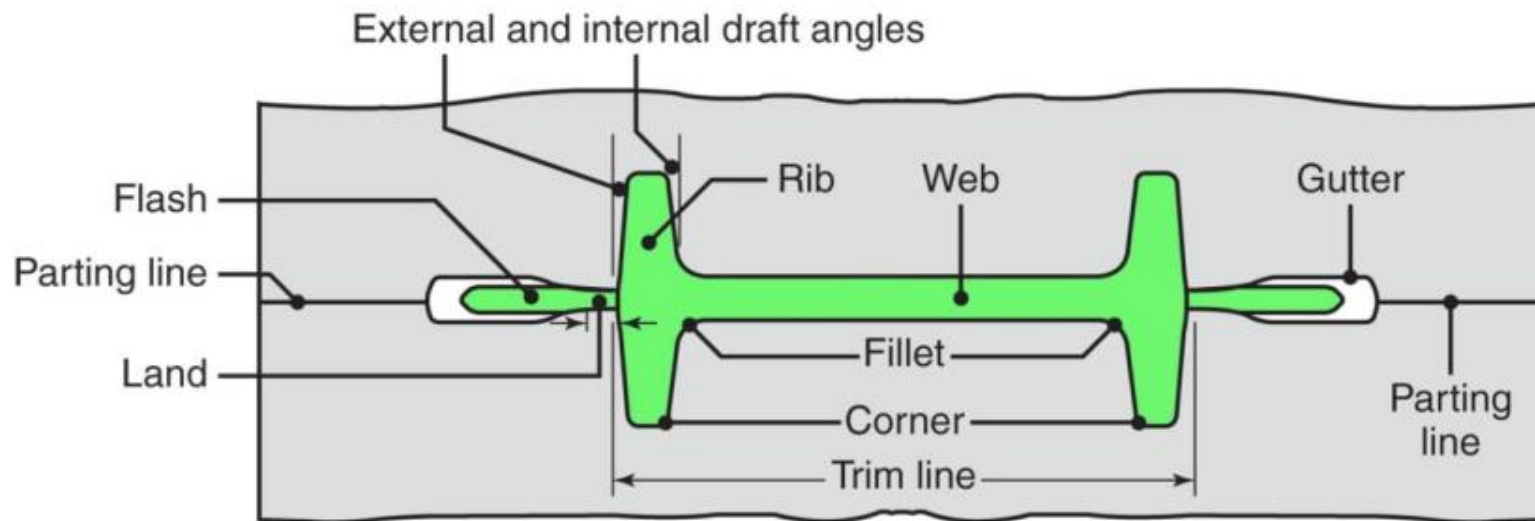


- **Screw Presses**: Forging screw presses use the rotational energy of a motor to turn a large screw. Typically a friction disk is used to translate the force from the drive shaft to the screw's head. The screw pushes a ram with great mechanical advantage. Screw presses are similar to hydraulic presses in that they are relatively slow and require a longer contact with the work. Screw presses are also similar to hydraulic presses in that they can produce a constant amount of force over a long stroke. Some screw press machines in modern industry can produce 31,000 tons of force.

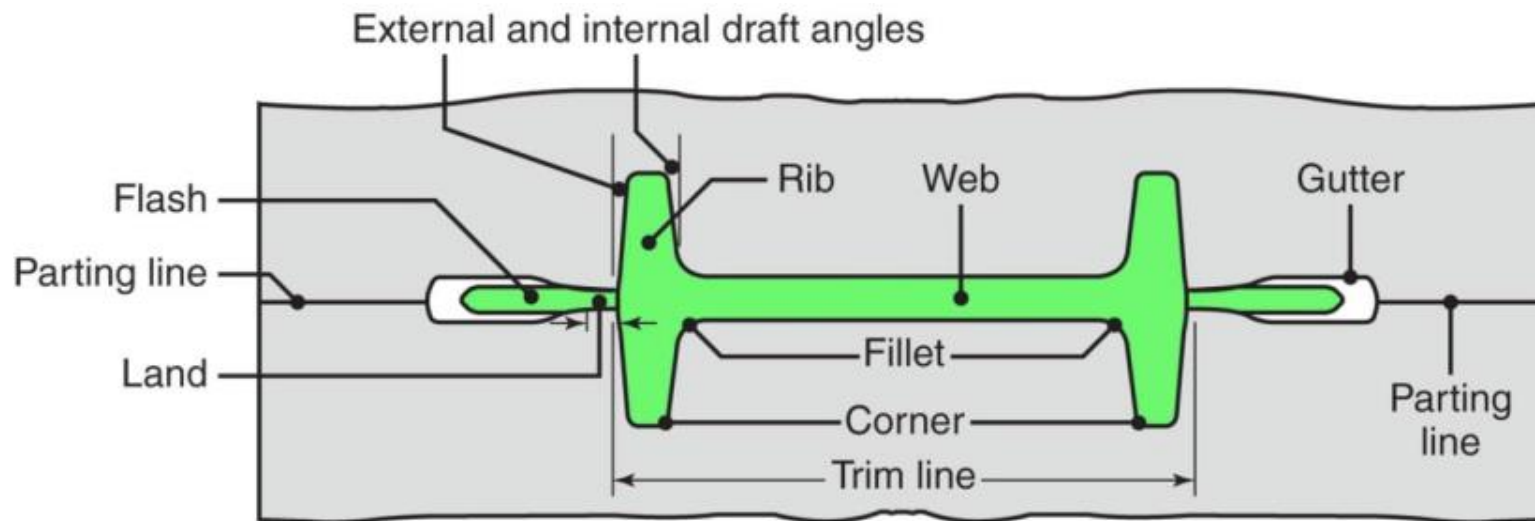


# Forging Dies

- **Parting line**: The parting line divides the upper die from the lower die. In other words, it is the plane where the two die halves meet. The selection of parting line affects grain flow in the part, required load, and flash formation.
- **Draft**: It is the amount of taper given on the sides of the part required to remove it from the die.
- **Draft Angles**: It is meant for easy removal of part after operation is completed.  $3^\circ$  for Al and Mg parts;  $5^\circ$  to  $7^\circ$  for steel parts.



- **Webs and Ribs**: They are thin portions of the forging that is parallel and perpendicular to the parting line. More difficulty is witnessed in forming the part as they become thinner.
- **Fillet and Corner Radii**: Small radii limits the metal flow and increase stresses on die surfaces during forging.
- **Flash**: The pressure build up because of flash formation is controlled proper design of gutter and flash land.

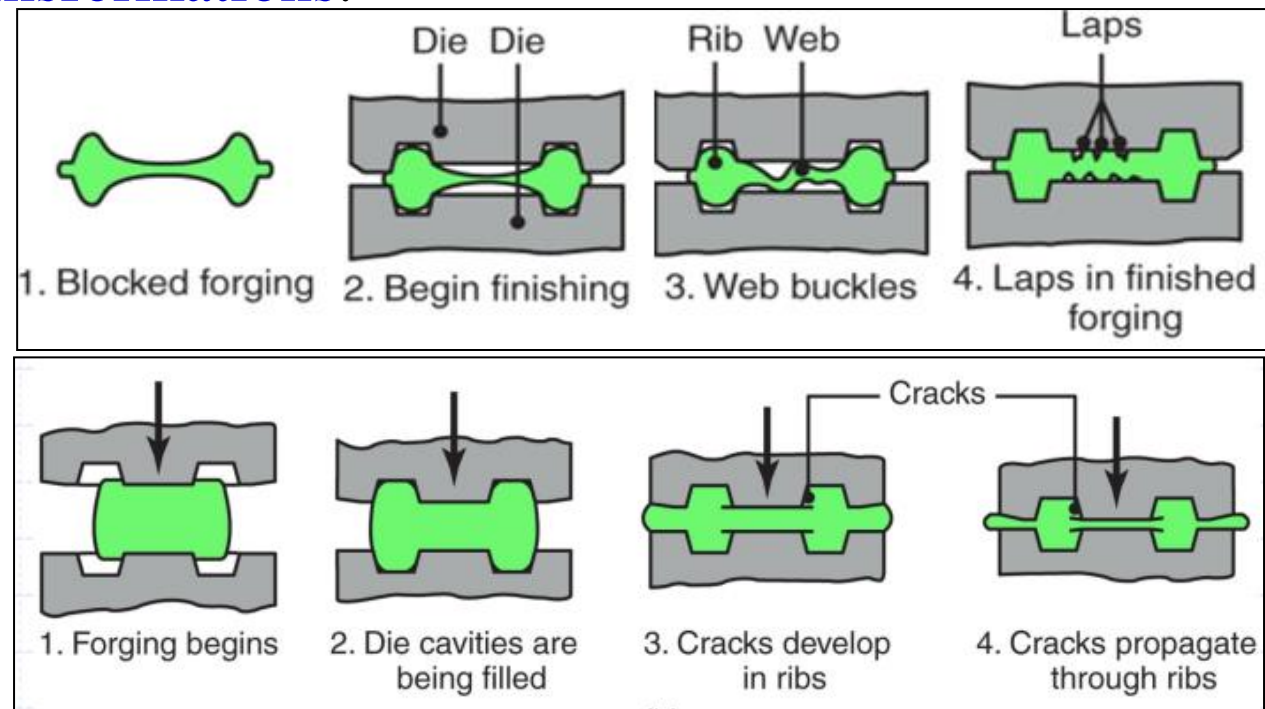


# Forging Defects

- The various radii in the forging-die cavity can significantly influence the formation of such defects. Internal defects also may develop from (i) **non-uniform deformation** of the material in the die cavity, (ii) **temperature gradients** throughout the workpiece during forging and (iii) **microstructural changes** caused by phase transformations.

Laps formed by web buckling during forging; web thickness should be increased to avoid this problem.

Internal defects caused by an oversized billet. Die cavities are filled prematurely, and the material at the center flows past the filled regions as the dies close.



# Forging Problems

## ■ Open Die (Cold upsetting a Cylinder)

Assumptions are:

- Metal is cold formed, platen workpiece interface is frictionless
- As the deformation proceeds the cylinder becomes shorter and the diameter increases.

$$A_0 h_0 = A_1 h_1$$

$A_0$  is the initial cross-sectional area

$h_0$  is the original cylinder height

$A_1$  is the deformed area

$h_1$  is the deformed height.

true strain associated with the upsetting operation is

$$\varepsilon = \ln \left( \frac{A_0}{A_1} \right)$$

true stress required for upsetting (often called the flow stress in forming situations) can be calculated using the Hollomon equation as

$$\begin{aligned} \sigma_1 &= K \varepsilon_1^n \\ &= K \left[ \ln \left( \frac{A_0}{A_1} \right) \right]^n \end{aligned}$$

The forming force is given by  $F = K \left[ \ln \left( \frac{A_0}{A_1} \right) \right]^n A$

The material strength constant,  $K$ , and strain hardening exponent,  $n$ , are listed for some common engineering materials in Table

The ideal work for deformation is given by equation

$$W_i = \frac{KV\varepsilon_1^{n+1}}{n+1}$$

$V$  is the volume of the cylinder, and  $\varepsilon_1$  is the total true strain due to upsetting

Power is the time rate of doing work, and therefore equation can be used to calculate the average power consumed per cycle as

$$p_{av} = \frac{1}{t_{av}} \left( \frac{KV\varepsilon_1^{n+1}}{n+1} \right)$$

$p_{av}$  is the average power per cycle  
 $t_{av}$  is the average time per cycle.



## ■ Open Die (Hot upsetting a Cylinder)

- If the cylinder is hot upset, then strain hardening effects are minimal, but strain rate effects become important.
- Assuming the deformation to be homogeneous, uniaxial and frictionless,  
When the deformation is homogeneous, the **strain rate** is defined as

$$\dot{\epsilon} = \frac{1}{h} \times \frac{dh}{dt} \quad \begin{array}{l} \dot{\epsilon} \text{ is the strain rate} \\ v \text{ is the platen velocity} \\ h \text{ is the instantaneous height of the cylinder} \end{array}$$

$$= \frac{v}{h}$$

The true stress during hot working as a function of strain rate was given as

$$\sigma_t = C\dot{\epsilon}^m$$

where C is the strain rate strength constant, and m is the strain rate sensitivity exponent

Deformation force is obtained  $F = C\left(\frac{v}{h_1}\right)^m A_1$

The work done can be defined as  $W = \int_{h_0}^h F dh$

To obtain an estimate of the magnitude of the work and power, most hot forging operations can be approximated as constant strain rate processes

$$W = CV\dot{\epsilon}^m \int_{h_0}^{h_1} \frac{dh}{h} = CV\dot{\epsilon}^m \epsilon_1$$

Average power necessary to upset a cylinder is the time rate of doing work,

$$P_{av} = \frac{1}{t_{av}} \times CV\dot{\epsilon}^m \epsilon_1$$



## ■ Upsetting a cylinder with friction

- Friction is almost certain to develop between the die and workpiece.
- Horizontal platen friction causes the cylinder to assume the barreled shape
- The barreling causes secondary horizontal stresses, and the associated redundant work increases the vertical stress required for deformation.
- The **amount of barreling**, and the consequent **redundant work**, depends upon the **friction coefficient**

This factor is combined with the true stress for deformation (the flow stress) to give an estimate for the actual stress required for deformation according to

$$\sigma_a = Q_a \sigma_t$$

$\sigma_a$  is the stress required for deformation including friction

$\sigma_t$  is the uniaxial flow stress in the absence of friction

$Q_a$  is the multiplying factor (Fig. 4.7).

The deforming force in this case is then  $F = Q_a \sigma_t A_m$

where  $A_m$  is the mean cross-sectional area of the workpiece

Using the friction coefficient, the average vertical flow stress is estimated with the aid of Fig. 4.7, which gives a friction multiplying factor  $Q_a$

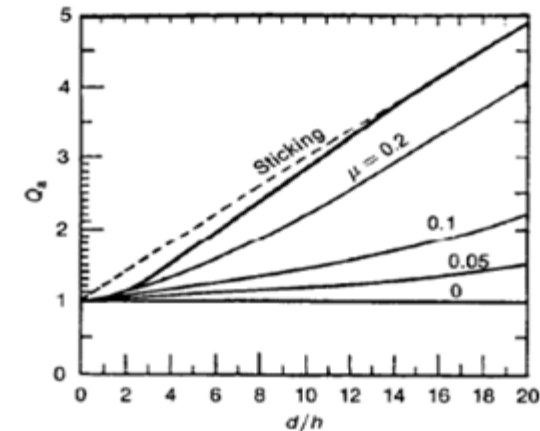


Fig 4.7

Plot giving multiplying factors for forging as a function of friction coefficient and geometry.



- Problem-1**: A 302 stainless steel cylinder of height 12 cm and diameter 7 cm at room temperature is compressed to a height of 2 cm between large platens. Mineral oil is used as a lubricant between the cylinder and platens. Calculate the **force necessary** and **stress** on the platens.

$$F = Q_a \sigma_t A_m$$

for 302 stainless steel:  $\sigma_t = 1300 \epsilon^{0.3}$  MPa

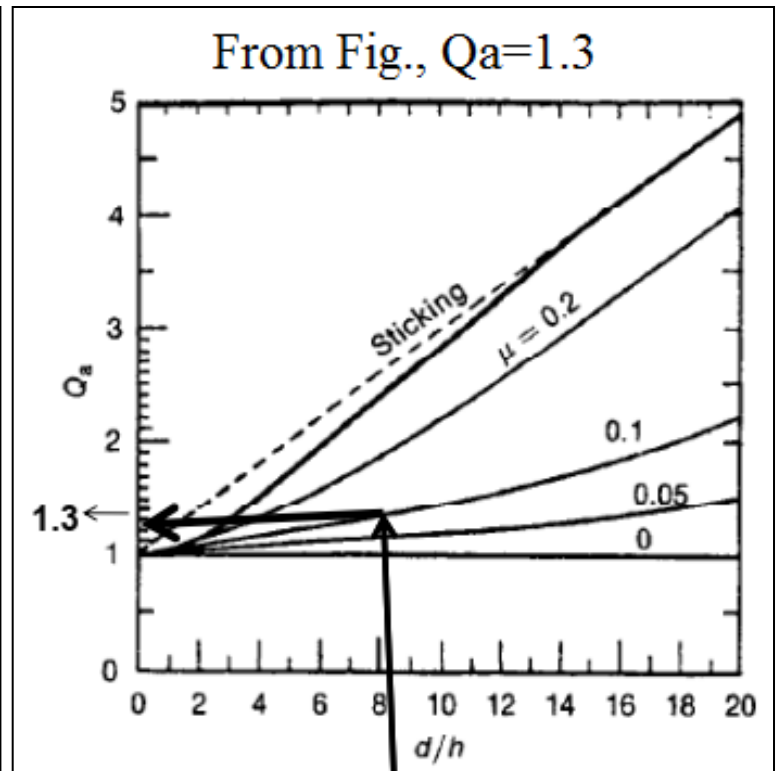
with mineral oil,  $\mu = 0.1$  (Table 4.1)

From volume constancy,  $A_o h_o = A_m h$  so that

$$A_m = \frac{A_o h_o}{h}$$

$$d_m^2 = d_o^2 \frac{h_o}{h} = 7^2 \frac{12}{2}; \quad d_m = 17.2 \text{ cm}$$

$$\frac{d_m}{h} = \frac{17.2}{2} = 8.57$$



$$\sigma_a = Q_a \sigma_t = Q_a K \left[ \ln \frac{A_o}{A} \right]^n$$

$$= 1.3(1300 \times 10^6) \left( \ln \left[ \frac{7^2}{17.2^2} \right] \right)^{0.3} = 2015 \text{ MPa}$$

$$F = \sigma_a A_m = 2015 \text{ MPa} \times \frac{\pi(0.172 \text{ m})^2}{4} \approx 46500 \text{ kN} \quad (\approx 4740 \text{ t})$$

- **Problem-2:** The 302 stainless steel cylinder of the previous example is hot upset at 1000°C to a height of 2 cm by a platen moving at 2 cm/s. Graphite is used as the lubricant between platen and workpiece. Calculate the forging force necessary.

$$F = \sigma_t Q_a A_m; \text{ for 302 stainless steel at } 1000^\circ\text{C: } \sigma_t = 170 \dot{\epsilon}^{0.1} \text{ MPa}$$

$$\text{coefficient of friction } \mu = 0.2 \quad d_m = 17.2 \text{ cm}, \quad d_m/h = 8.57$$

Example 4.2;  $Q_a \approx 1.9$  from Fig. 4.7

$$F = Q_a \sigma_t A_m = 1.9 \left[ 170 \times 10^6 \left( \frac{2}{2} \right)^{0.1} \right] \pi \frac{(0.172^2)}{4} \quad \left( \text{recall } \dot{\epsilon} = \frac{v}{h} \right) = 7500 \text{ kN} \quad (\approx 765 \text{ t})$$

Increasing the forging temperature reduces the power required by about a factor of nearly 3

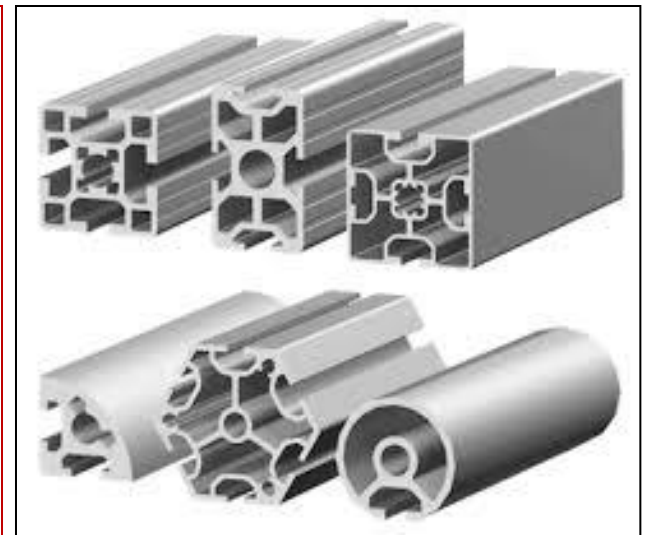
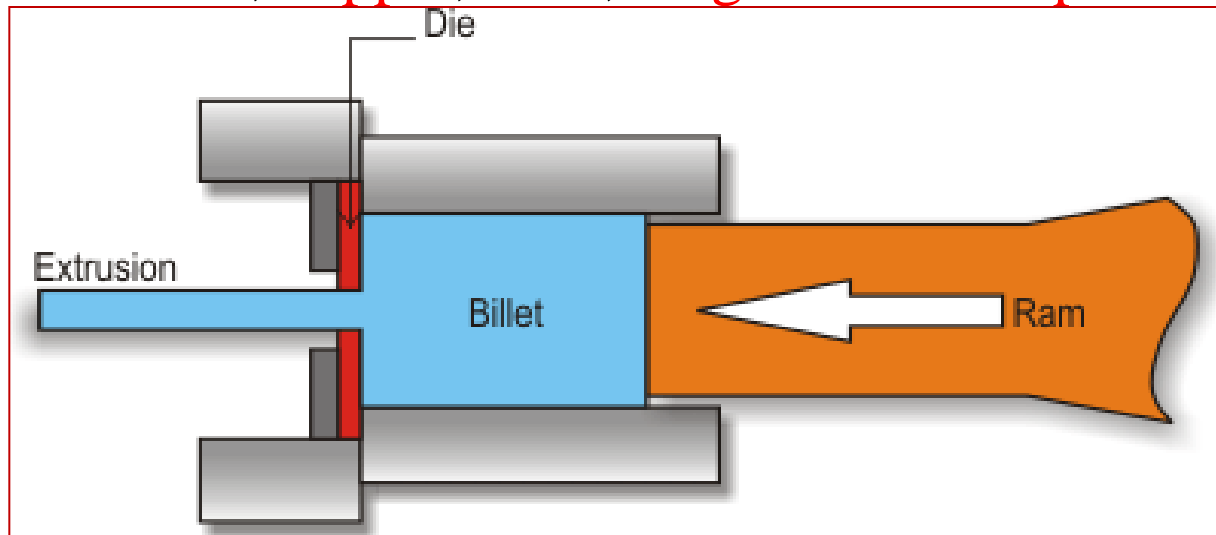


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- **Problem-3**: A solid cylindrical slug made of 304 stainless steel is 150 mm in diameter and 100 mm high. It is reduced in height by 50% at room temperature by open die forging with flat dies. Assuming that the coefficient of friction is 0.2 and the flow stress of this material is 1000 MPa, calculate the forging force at the end of the stroke.
  - **Problem-4**: Calculate the forging force for the cylindrical workpiece made of 1020 steel that is 90 mm high and 125 mm in diameter and is reduced in height by 40%. Assuming that it is a complex forging and that the projected area of the flash is 30% greater than the projected area of the forged workpiece.



# Extrusion Process

- **Extrusion** is a process that forces metal or plastic to flow through a shaped opening die. The material is plastically deformed under the compression in the die cavity. The process can be carried out hot or cold depending on the ductility of the material. The **tooling cost** and **setup** is expensive for the extrusion process, but the actual manufactured part cost is inexpensive when produced in significant quantities. **Materials** that can be extruded are **aluminum, copper, steel, magnesium** and **plastics**.



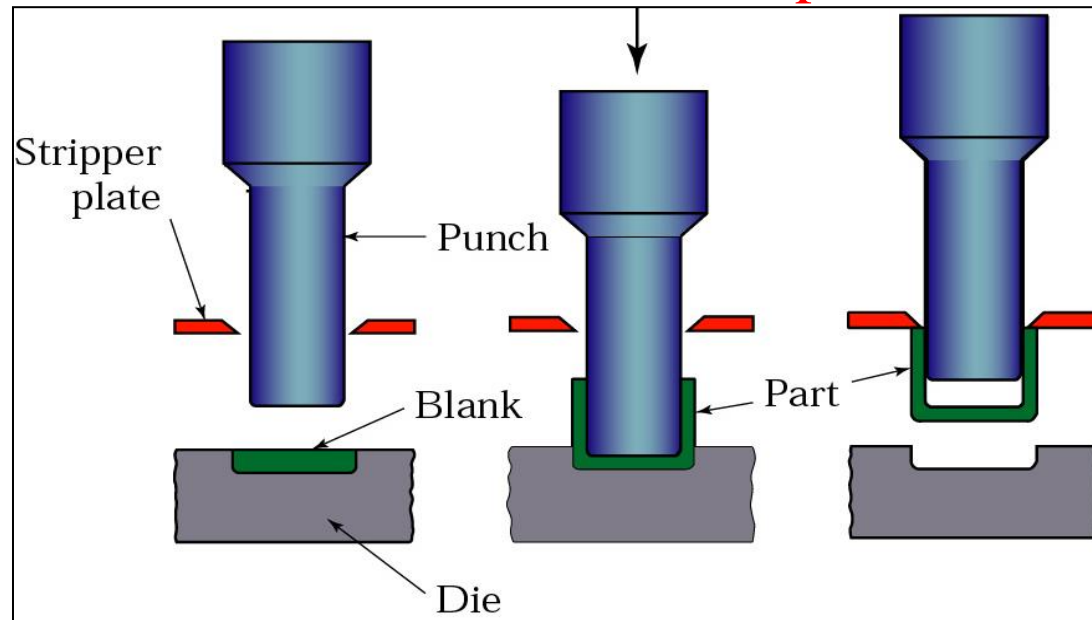
# Extrusion Processes

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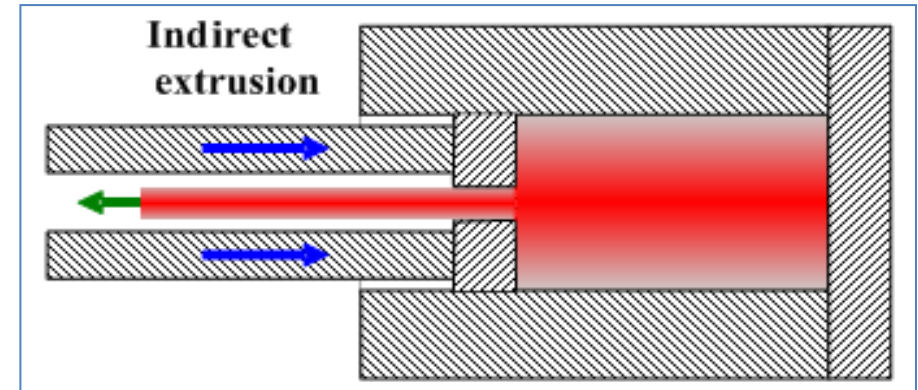
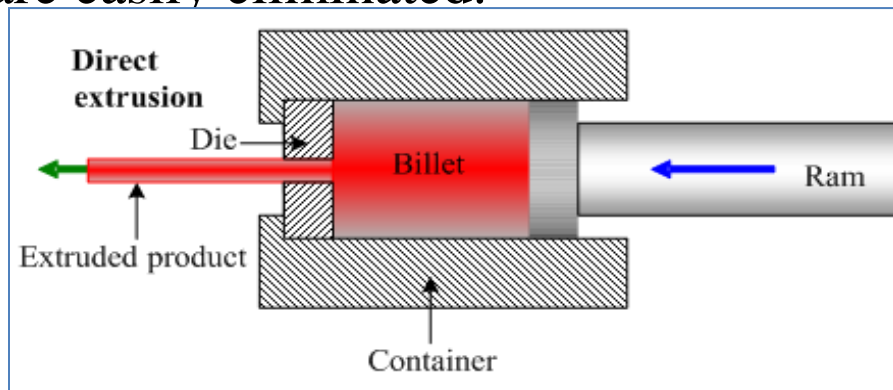
- **Hot Extrusion:** Hot extrusion is one of the most popular method to develop objects having a fixed cross-sectional profile. This extrusion process is done at increased temperature, which keeps the materials from work hardening along with making the procedure of pushing the material through the die simpler. In general, a large amount of hot extrusions are done using horizontal hydraulic presses.
- This lubrication can be done by glass powder in case of higher temperature extrusions and graphite or oil for all the lower temperature extrusions. Though the hot extruded materials are highly preferred, hot extrusion has couple of disadvantages associated with it that are the cost of extrusion machines and their upkeep.
- The hot extrusion process is widely used to manufacture products from Aluminum, Copper along with their alloys. Some of the products that are developed using this process are Electrical Wires, Bars and Tubes



- **Cold Extrusion**: This process is similar to hot extrusion except that the metals worked possess the plasticity necessary for successful forming without heating them. Cold extrusion is also done to improve the physical properties of a metal and to produce a finished part. Cold extrusion is done mostly on vertical mechanical presses because they are fast and simple. The widely employed cold extrusion method is impact extrusion.

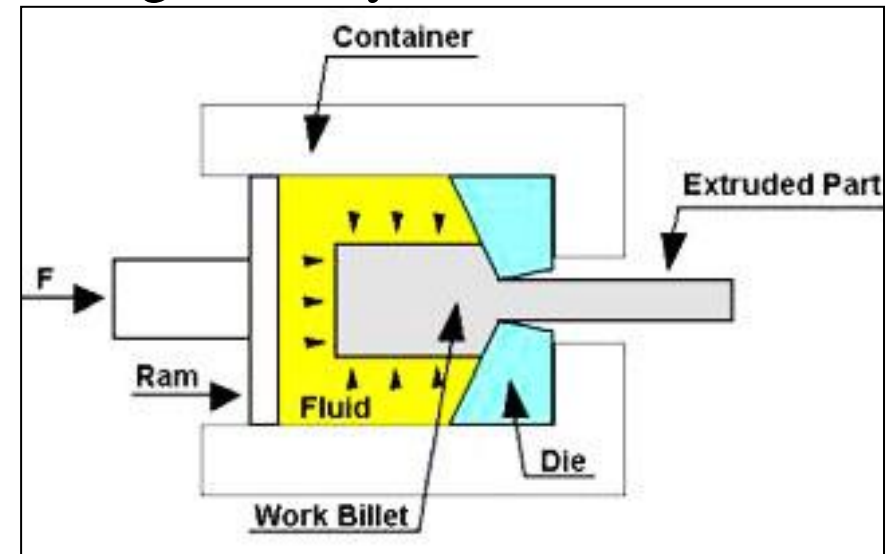


- **Direct Extrusion**: **Direct extrusion**, also known as forward **extrusion**, is the most common **extrusion process**. It works by placing the billet in a heavy walled container. The billet is pushed through the die by a ram or screw. There is a reusable dummy block between the ram and the billet to keep them separated.
- **Indirect Extrusion**: Indirect extrusion is also called backwards extrusion and in this process, the die is constant whereas the billet & container move together. To keep the die stationary, a “stem” is used which must be longer than the length of container. The final and maximum extrusion length is decided by the stem's column strength. As the billet movement is along with the container, all the frictional forces are easily eliminated.



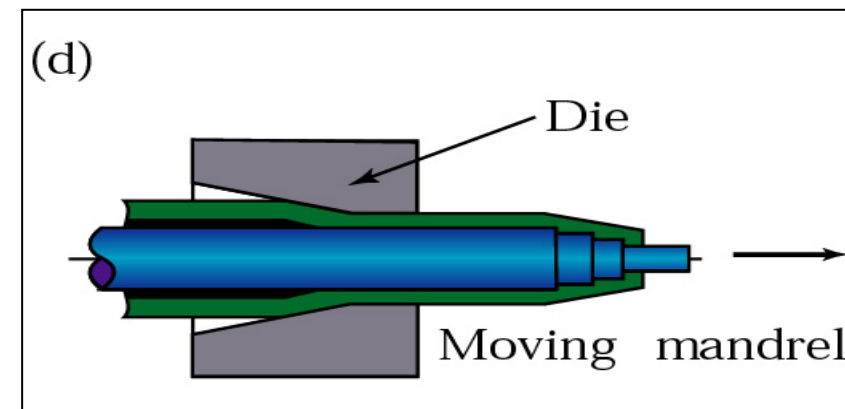
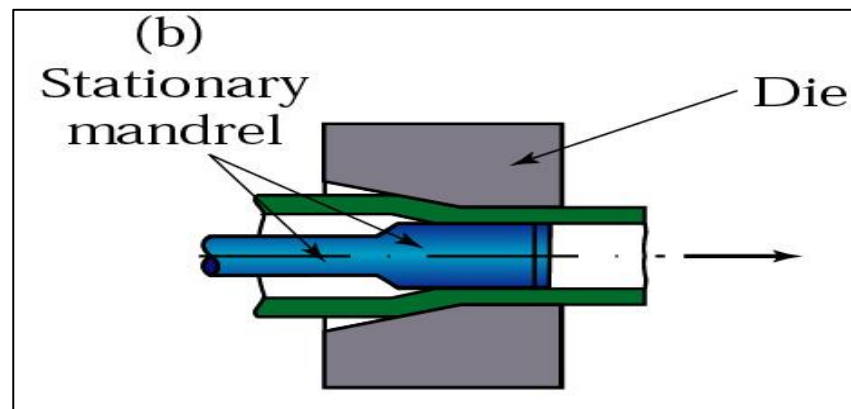
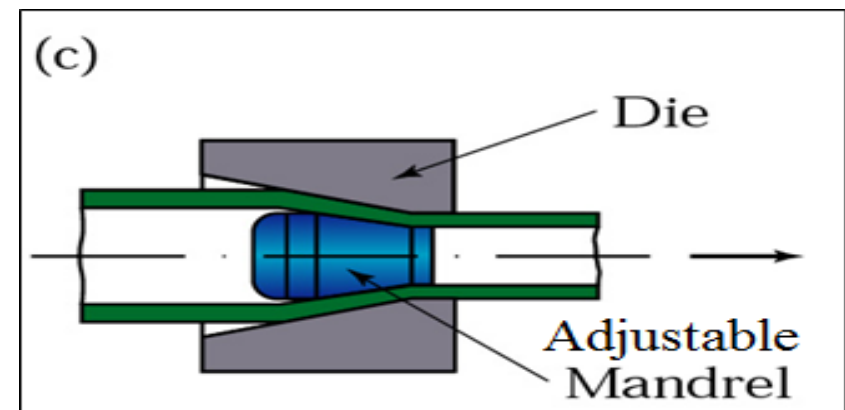
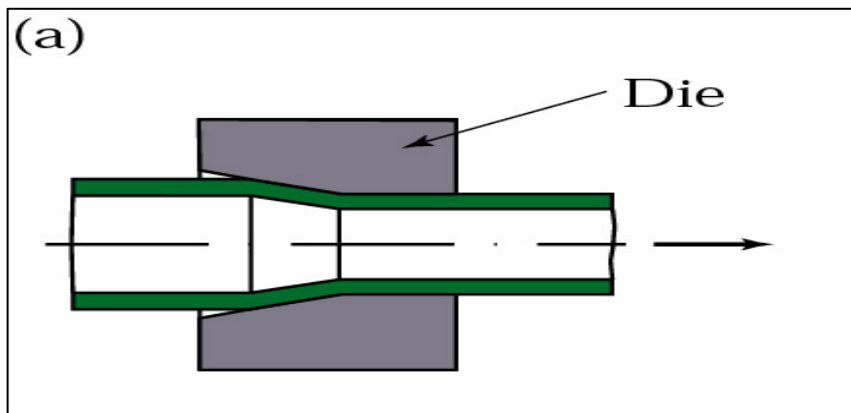
- **Hydrostatic Extrusion**: Hydrostatic extrusion is a process in which the billet is completely circumscribed by a pressurized liquid in all the cases, with the exception being the case where billet is in the contact with die. This process can be carried out in many ways including warm, cold or hot but due to the stability of the used fluid, the temperature is limited. Hydrostatic extrusion has to be carried out in a completely sealed cylinder for containing the hydrostatic medium. The fluid may be pressurized in following two ways:

- **Constant-Rate Extrusion**: A ram or plunger is used for pressurizing the fluid in the container
- **Constant-Pressure Extrusion**: A pump with a pressure intensifier is used for pressurizing the fluid, which is then pumped into the container



# Tube-Drawing

- Tube-drawing operations, with and without an internal mandrel. Note that a variety of diameters and wall thicknesses can be produced from the same initial tube stock.



# Extrusion Defects

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- **Surface Cracking:** Cracking on billet materials occurs due to temperature, friction, punch speed.
  - High Temperatures: Crack from along the grain boundaries. Typically occur in aluminum, magnesium, zinc alloys
  - Cold Temperatures: Caused by sticking of billet material at the die land. Known has the “Bamboo Defect” because of its similar appearance to bamboo
- **Pipe:** The metal-flow pattern tends to draw oxides and impurities toward the center of the billet
- **Internal Cracking:** Center of extruded product develops cracks.
  - Attributed to a state of hydrostatic tinsel stress
  - Cracks increase with increasing die angle, impurities, and decreasing extrusion ratio and friction



# Advantages, Disadvantages and Applications

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## ■ Advantages:

- The range of extruded items is very wide.
- No time is lost when changing shapes as the dies may be readily removed and replaced.
- Dimensional accuracy of extruded parts is generally superior to that of rolled ones.
- Very large reductions are possible as compared to rolling
- Small parts in large quantities can be made.
- It does not need flash to trim and needless machining as it is more accurate

## ■ Disadvantages:

- Process waste in extrusion is higher than in rolling, where it is only 1 to 3%



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- Service life of extrusion tooling is shorter because of high contact stresses & slip rates.
  - Relatively high tooling costs, being made from costly alloy steel.
  - In productivity, extrusion is much inferior to rolling.
  - Cost of extrusion are generally greater as compared to other techniques
  - **Applications:**
    - Extrusion is more widely used in the manufacture of solid and hollow sections etc.
    - Steel and other ferrous alloys can also be successfully processed
    - Manufacture of sections and pipes of complex configuration.
    - Medium and small batch production
    - Manufacture of parts of high dimensional accuracy

