UNIT – III

METAL FORMING PROCESSES

Hot working and cold working of metals – Forging processes – Open, impression and closed die forging – forging operations. Rolling of metals– Types of Rolling – Flat strip rolling – shape rolling operations – Defects in rolled parts. Principle of rod and wire drawing – Tube drawing – Principles of Extrusion – Types – Hot and Cold extrusion.

FUNDAMENTALS OF METAL FORMING

There are four basic production processes for producing desired shape of a product. These are casting, machining, joining (welding, mechanical fasteners, epoxy, etc.), and deformation processes.

- Casting process
- Machining processes
- Joining processes
- Deformation processes

To understand the forming (by deformation process) of metal, it is important to know the structure of metals. Metals are crystalline in nature and consist of irregularly shaped grains of various sizes. Each grain is made up of atoms in an orderly arrangement, known as a lattice. When a force is applied to deform it or change its shape, a lot of changes occur in the grain structure. These include grain fragmentation, movement of atoms, and lattice distortion.

To deform the metal permanently, the stress must exceed the elastic limit. At room temperature, the metal is in a more rigid state than when at higher temperature. Thus, to deform the metal greater pressures are needed when it is in cold state than when in hot state.

The amount of deformation that a metal can undergo at room temperature depends on its ductility. The higher the ductility of a metal, the more the deformation it can undergo. Metals having large grains are more ductile than those having smaller grains.

The deformation of metal can be achieved by following methods, namely

- Cold working
- Warm working
- Hot working

Cold Working:

Plastic deformation of metals below the recrystallization temperature is known as cold working. It is generally performed at room temperature. In some cases, slightly elevated temperatures may be used to provide increased ductility and reduced strength.

Benefits of cold working are

1. No heating is required
2. Better surface finish is obtained
3. Better dimensional control is achieved; therefore no secondary machining is generally needed.
4. Products possess better reproducibility and interchangeability.
5. Better strength, fatigue, and wear properties of material.
6. Directional properties can be imparted.
7. Contamination problems are almost negligible

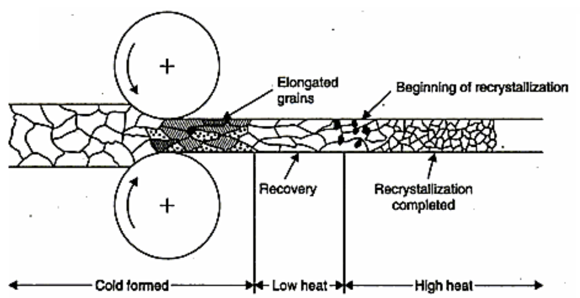


Fig. 3.1: Cold working Processes

Drawbacks of cold-working processes are:

1. Higher forces are required for deformation.
2. Heavier and more powerful equipment is required.
3. Less ductility is available.
4. Metal surfaces must be clean and scale-free.
5. Strain hardening occurs (may require intermediate annealing).
6. Undesirable residual stresses may be produced

Cold forming processes, in general, are better suited to large-scale production of parts because of the cost of the required equipment and tooling.

Warm Working:

Metal deformation carried out at temperatures intermediate to hot and cold forming is called Warm Forming. Compared to cold forming, warm forming offers several advantages. These include:

- Lesser loads on tooling and equipment

- Greater metal ductility
- Fewer number of annealing operation (because of less strain hardening)

Advantages.

1. Lesser amount of heat energy requirement
2. Better precision of components
3. Lesser scaling on parts
4. Lesser decarburization of parts
5. Better dimensional control
6. Better surface finish
7. Lesser thermal shock on tooling
8. Lesser thermal fatigue to tooling, and so greater life of tooling.

Hot Working:

Plastic deformation of metal carried out at temperature above the recrystallization temperature, is called hot working. Under the action of heat and force, when the atoms of metal reach a certain higher energy level, the new crystals start forming. This is called recrystallization. When this happens, the old grain structure deformed by previously carried out mechanical working no longer exist, instead new crystals which are strain-free are formed.

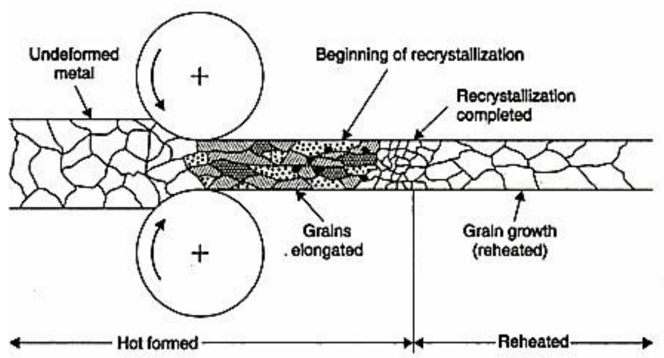


Fig. 3.2 : Hot working Processes

In hot working, the temperature at which the working is completed is critical since any extra heat left in the material after working will promote grain growth, leading to poor mechanical properties of material.

The advantages of hot working are

1. No strain hardening
2. Lesser forces are required for deformation
3. Greater ductility of material is available, and therefore more deformation is possible.

4. Favorable grain size is obtained leading to better mechanical properties of material
5. Equipment of lesser power is needed
6. No residual stresses in the material.

Disadvantages of hot-working of metals are:

1. Heat energy is needed
2. Poor surface finish of material due to scaling of surface
3. Poor accuracy and dimensional control of parts
4. Poor reproducibility and interchangeability of parts
5. Handling and maintaining of hot metal is di
6. fficult and troublesome
7. Lower life of tooling and equipment.

Recrystallization temperature

Recrystallization temperature can be defined as the process, the temperature in which grains of a crystal structure are come in new structure or new crystal shape. Recrystallization is usually accompanied by a reduction in the strength and hardness of a material and a simultaneously increase in the ductility.

Comparison of hot working and cold working

Sl.No.	Hot working	Cold working
1	Working temperature is above the re crystallization temperature. Therefore, it can be regarded as a simultaneous process of deformation and recovery.	Cold working temperature is below the crystallization temperature. So no appreciable recovery can take place during deformation.
2	Coefficient of friction in hot forming is as high as 0.6.	The coefficient of friction in cold forming i generally of the order of 0.1.

3	Hardening due to plastic deformation is completely eliminated by recovery and re crystallization, only if the rate of recrystallization is higher than deformation.	Harding is not eliminated in this case. This is always accompanied by work hardening.
4	Refinement of crystal occurs.	Grains are only elongated and distorted.
5	Internal and residual stresses are not developing in the metal.	Internal and residual stresses are developed.
6	Surface finishing is not good.	Better surface finishing is obtained.
7	It promotes uniformity of materials.	Uniformity of material is lost.
8	Cracks and blow holes are welded up.	Possibility of crack formation and its propagation is great.
9	Mechanical properties such as elongation, reduction of area, and impact value are improved	Cold working decreases elongation, reduction of area, and impact value.

Classification of hot working and cold working processes

Hot working processes

- Rolling
- Forging
- Drawing
- Spinning
- Piercing
- Extruding

Cold working processes

- Drawing
- Squeezing
- Bending
- Shearing
- Hobbing
- Shot peening
- Extruding

Forging

Forging is a manufacturing process involving the shaping of metal using localized compressive force. The blows are delivered with a hammer (often a power hammer) or a die. Forging is often classified according to the temperature at which it is performed:

- Cold forging (performed at room temperature)
- Warm forging (performed at elevated room temperature)
- Hot forging (a type of hot working)

Application:

- Crankshaft and Connecting rod for I.C. Engines
- Turbine disc, gear wheel, bold head, hand tools
- Many types of structural components

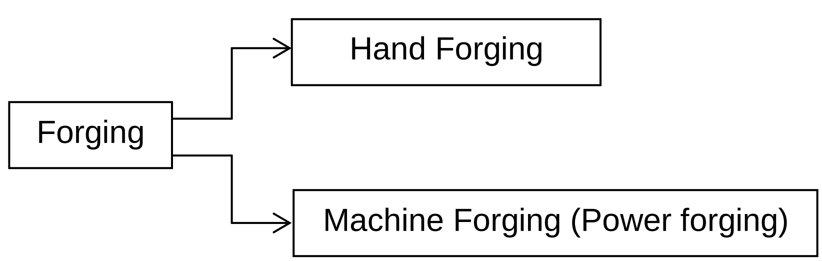
Benefits of forging:

1. It improves the structure as well as mechanical properties of the metallic parts.
2. Forged components can withstand unpredictable load.
3. Forged parts are consistent in shape with the minimum presence of voids and porosities.
4. Forging can produce parts with high strength to weight ratio.
5. Forging processes are very economical for moderate to high volume productions.

Drawbacks of forging:

1. Initial cost of dies and the maintenance cost are high
2. In hot forging, due to high temperature, there is rapid oxidation on the surface resulting poor finish
3. Forging are usually costlier than casting
4. Forging operations are limited to simple shape

Classification of forging



- Drop forging
- Press forging
- Open – die forging
- Closed – die forging
- Impression die forging
- Flashless forging
- Upset forging
- Roll forging

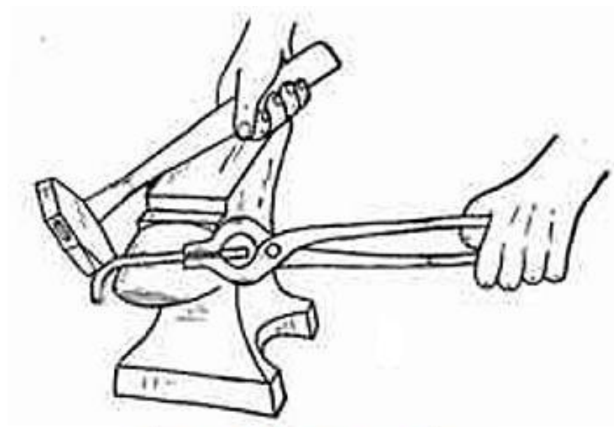


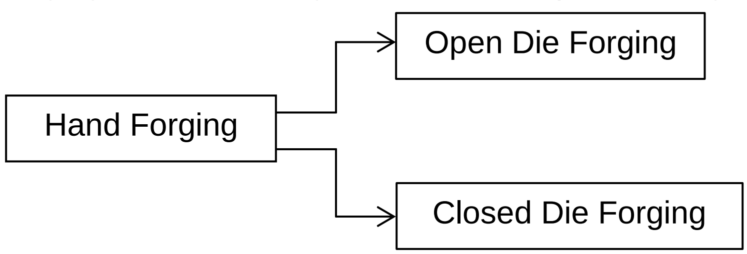
Fig. 3.3 : Hand Forging

Hand forging

The hand forging process is an ancient one that has been utilized for many centuries by professionals who are generally referred to as blacksmiths. Basically, they shape the metal by heating and hammering with varying pressure to the metal in order to manipulate it into a desired to achieve. This method of forging metal requires a lot of labour and strength.

Benefits of hand forging are the fact the metal produced through this method is usually stronger than metal produced by other techniques, such as casting or welding. The main reason is that the repeated blows from the blacksmith and the careful monitoring of the process results in a less porous material that is better refined than most tactics.

Hand forging can be done by two methods: open die forging and closed die forging



Drop forging

Hammer forging (drop forging) is forming a preheated work piece by using impact energy of the falling hammer by a mechanical force, forcing the metal to fill the space between the punch (a part attached to the hammer) and the forging die (a part attached to the anvil).

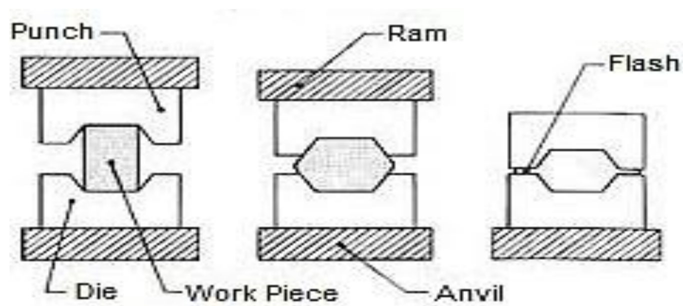


Fig. 3.4 Drop Forging (Closed - Die - Forging)

Press Forging (closed die

forging)

Press forging, which is mostly used for forging of large sections of metal, uses hydraulic press to obtain slow and squeezing action instead of a series of blows as in drop forging. The continuous action of the hydraulic press helps to obtain uniform deformation throughout the entire depth of the work piece. Therefore, the impressions obtained in press forging are cleaner.

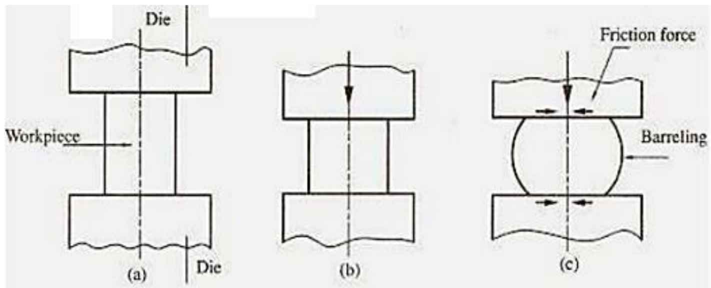


Fig. 3.5 Drop Forging
(Open - Die - Forging)

Press forgings generally need smaller draft than drop forgings and have greater dimensional accuracy. Dies are generally heated during press forging to reduce heat loss, promote more uniform metal flow and production of finer details.

Hydraulic presses are available in the capacity range of 5 MN to 500 MN but 10 MN to 100MN capacity presses are more common.

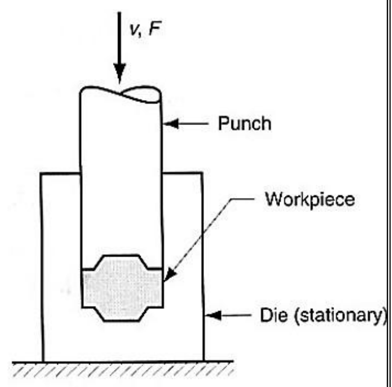


Fig. 3.4 Flashless forging

Upset Forging

Upset forging involves increasing the cross – section of a material at the expense of its corresponding length. Upset – forging was initially developed for making bolt heads in a continuous manner, but presently it is the most widely used of all forging processes. Parts can be upset – forged from bars or rods upto 200 mm in diameter in both hot and cold condition. Examples of upset forged parts are fasteners, valves, nails, and couplings.

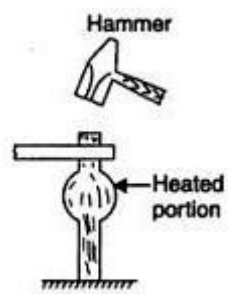


Fig. 3.6 Upset forging

The process uses split dies with one or several cavities in the die. Upon separation of split die, the heated bar is moved from one cavity to the next. The split dies are then forced together to grip the and a heading tool (or ram) advances axially against the bar, upsetting it to completely fill the die cavity. Upon completion of upsetting process the heading tool comes back and the movable split die releases the stock.

Upsetting machines, called up setters, are generally horizontal acting.

When designing parts for upset – forging, the following three rules must be followed.

- The length of unsupported bar that can be upset in one blow of heading tool should not exceed 3 times the diameter of bar. Otherwise bucking will occur.
- For upsetting length of stock greater than 3 times the diameter the cavity diameter must not exceed 1.5 times the diameter of bar.
- For upsetting length of stock greater than 3 times the diameter and when the diameter of the upset is less than 1.5 times the diameter of the bar, the length of un – supported stock beyond the face of die must not exceed diameter of the stock.

Roll Forging

This process is used to reduce the thickness of round or flat bar with the corresponding increase in length. Examples of products produced by this process include leaf springs, axles, and levers.

The process is carried out on a rolling mill that has two semi cylindrical rolls that are slightly eccentric to the axis of rotation. Each roll has a series of shaped grooves on it. When the rolls are in open position, the heated bar stock is placed between the rolls. With the rotation of rolls through half a revolution, the bar is progressively squeezed and shaped. The bar is then inserted between the next set of smaller grooves and the process is repeated till the desired shape and size are achieved.

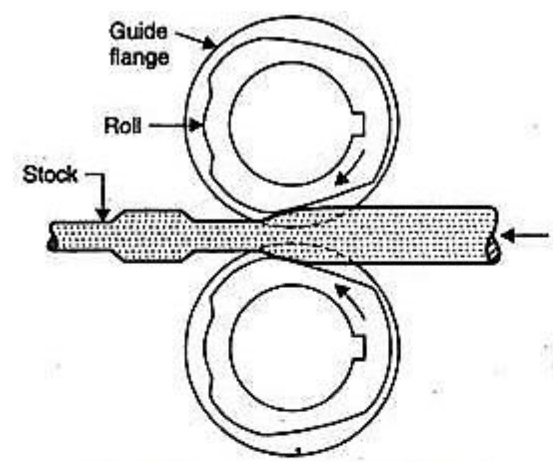


Fig. 3.7 : Roll Forging

Forging operation

- Upsetting
- Drawing down
- Heading
- Fullering
- Edging

Upsetting

The process of shortening the length of the work piece or increasing the thickness and width (if the work piece is circular, then its diameter) on either side is named as upsetting

Heading

Heading operation is similar to upsetting operation, but the stock dimension is increased only on one end of the stock.

Fullering

It is the operation of reducing the stock between the two ends of the stock at a central place, so as to increase its length. The inclined surface of the die prevents material movement in the width direction, because there is a pressure component acting in the direction of material flow. Repeated strokes with the stock rotated around its axis between strokes, allow substantial material redistribution.

Edging

The process (edging or rolling operation) of distribute the metal longitudinally by moving the metal from the portion of the stock where it is in excess to the portion which is deficient in metal.

Drawing down or cogging

It is an operation similar to fullering with the difference that the stock is reduced at only one end (and its length increased) instead of at a central place as in fullering.

Bending

Bending operation makes the longitudinal axis of the stock in two or more places. This operation is done after the stock has been edged or fullered, so that the stock is brought into a proper relation with the shape of the finishing impression.

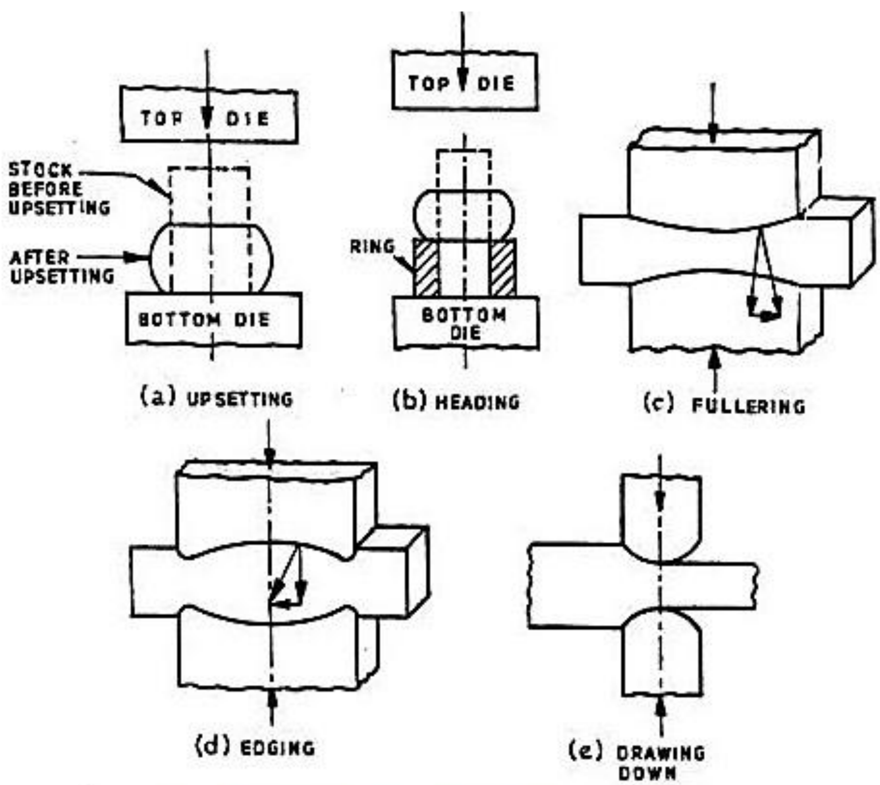


Fig. 3.8 Various forging operations

Flattening

This operation is used to flatten the stock so that it fits properly into the finishing impression of a closed die.

Blocking

This operation which imparts to the forging its general but not exact or final shape. This is done just prior to finishing operation.

Cut-off

A pair of blade, either milled in the corner of a pair of forging dies, or inserted in the dies, used to cut away a forging from the bar after the finishing blow.

Piercing

It is the operation done with the help of a punch to obtain blind or through holes in the metal. The pierced billet is further processed.

Punching

This is the operation of shearing out a slug in a forging to produce a hole.

Swaging

It is the operation of reducing or changing the cross-section area of diameter by revolving the stock under fast impact blows.

Coining

It is a cold closed die forging operation (no flash) to obtain closer tolerances and smoother surfaces.

Hot Forging Vs. Cold Forging

Hot forging and **cold forging** are two different metal forming processes that deliver similar results. Forging is the process of deforming metal into a predetermined shape using certain tools and equipment—deformation is accomplished using hot, cold, or even warm forging processes. Ultimately, the manufacturer will look at a number of criteria before choosing which type of forging is best for a particular application.

Hot Forging Process

When a piece of metal is hot forged it must be heated significantly. The average temperatures necessary for hot forging are:

- Up to 1150 degrees Celsius for Steel
- 360 to 520 degrees Celsius for Al-Alloys
- 700 to 800 degrees Celsius for Cu-Alloys

During hot forging, the temperature reaches above the recrystallization point of the metal. This kind of extreme heat is necessary in avoiding strain hardening of the metal during deformation. In order to prevent the oxidation of certain metals, like super alloys, a type of hot forging called isothermal forging is a good choice. In isothermal forging, the metal deformation occurs within a highly controlled atmosphere, similar to that of a vacuum.

Factor to be consider for hot Forging

- Production of discrete parts
- Low to medium accuracy
- Scale Formation

- Low stresses or low work hardening
- Homogenized grain structure
- Increased ductility
- Elimination of chemical incongruities

Possible disadvantages of hot forging include:

- Less precise tolerances
- Possible warping of the material during the cooling process
- Varying metal grain structure
- Possible reactions between the surrounding atmosphere and the metal

Cold Forging

Cold forging deforms metal while it is below its recrystallization point. Cold forging is generally preferred when the metal is already a soft metal, like aluminum. This process is usually less expensive than hot forging and the end product requires little, if any, finishing work. Sometimes, when aluminum is cold forged into a desired shape, it is heat treated to strengthen the piece. This is called "tempering."

Cold Forging Process

Despite the word "cold," cold forging actually occurs at or near room temperature. The most common metals in cold forging applications are usually standard or carbon alloy steels. One of the most common types of cold forging is a process called impression-die forging, where the metal is placed into a die that is attached to an anvil. The metal is then hit by a descending hammer and forced into the die. Depending on the product, the hammer may actually be dropped on the metal numerous times in a very rapid sequence.

Advantages:

- Easier to impart directional properties
- Improved interchangeability
- Improved reproducibility
- Increased dimensional control
- Handles high stress and high die loads
- Produces net shape or near-net shape parts

Disadvantages:

- Easier to impart directional properties
- Improved interchangeability
- Improved reproducibility
- Increased dimensional control

- Handles high stress and high die loads
- Produces net shape or near-net shape parts
- The metal surfaces must be clean and free of scale before forging occurs
- The metal is less ductile
- Residual stress may occur
- Heavier and more powerful equipment is needed
- Stronger tooling is required

Comparison of press forging and drop forging

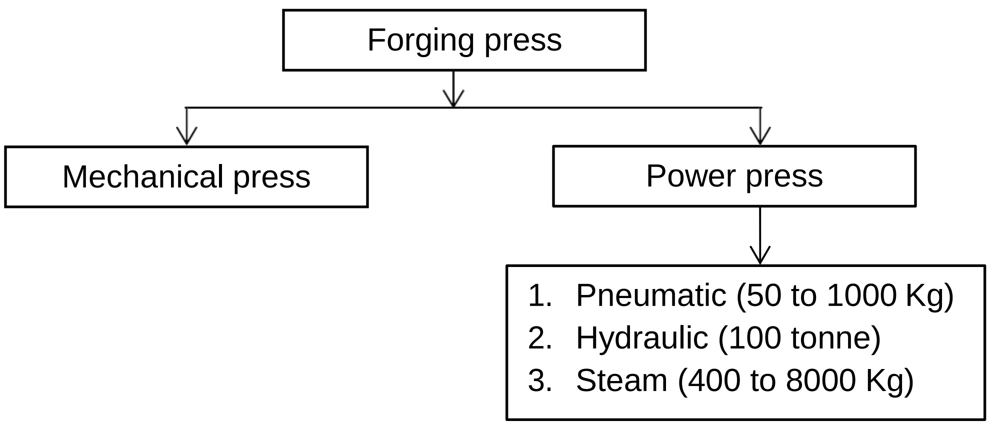
Sl. No.	Press forging	Drop forging
1	Faster process	Slow process
2	Alignment of dies is easier	Alignment of dies is difficult
3	Quite operation	Noisy operation
4	Structural quality of the product is superior	Structural quality is fair
5	Easy to maintenance	Difficult to maintenance
6	High productivity	Moderate productivity
7	No need for skilled operator	Required skilled operator
8	One stroke is enough to complete an operation	More than one stroke is needed to complete an operation
9	Stroke and ram speed is high	Slow speed is recommended

Comparison of open die forging and closed die forging

Sl. No.	Open forging	Closed forging
1	The process is completed in between the flat surface of the two die.	The upper die fitted with ram and the lower die is fitted with anvil and the process is completed.

2	The process is finished by repeated blowing	The process is finished by single blowing
3	It is simple and flexible	This is complex and rigid
4	Pressure is limited	Pressure can be varies depends on the material
5	‘U’ Bolt, chisels, polygonal shaped components are example of the product.	Spanner, automobile parts and machine parts are made by closed die forging process.

Types of forging (hammer) machines or press



Board Drop Hammer

This type is commonly used type. The ram carrying the upper die is fastened to the hardwood board which passes between a pair of steel roll which rotate continuously. These rolls are moving together, pressure of the rolls against the board raise the ram. The ram is continuously lifted until the release lever is actuated by a pin on the ram. This cause the roll to move outward, releasing the board and allowing the ram to fall freely by gravity. The blowing force is depends on the weight of falling ram and the height to which it is lifted. The size of drop hammer is varies from 900Kn to 45000KN. The height range is 0.75m to 1.5m.

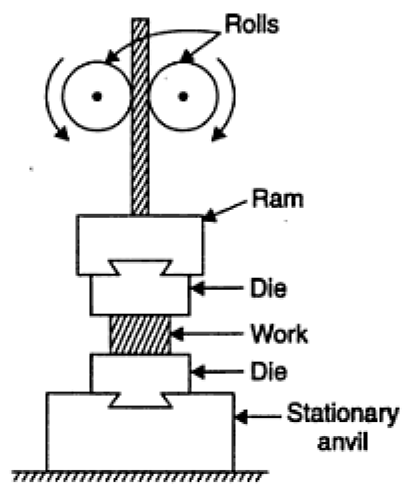


Fig. 3.9 Board Hammer

Mechanical Press

Mechanical presses belong to a class of machine tools that encompass a wide range of different machine types. Primarily, the mechanical press transforms the rotational force of a motor into a translational force vector that performs the pressing action. Therefore, the energy in a mechanical press comes from the motor. These types of presses are generally faster than hydraulic or screw presses, (actually the screw press may also be classified as a mechanical press). Unlike some presses, in a mechanical press, the application of force varies in both speed and magnitude throughout the distance of the stroke. When performing a manufacturing operation using a mechanical press, the correct range of the stroke is essential.

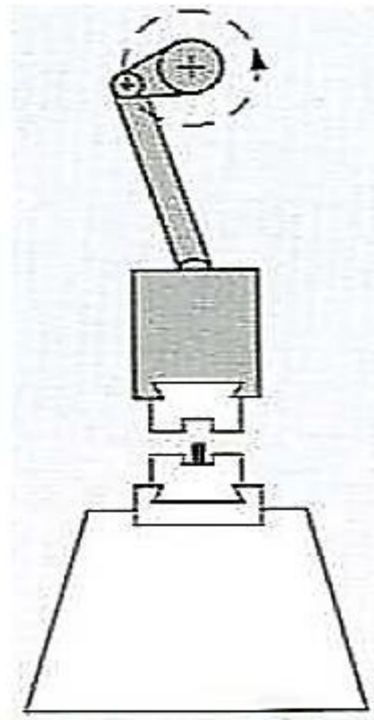


Fig. 3.10: Crank Press

These presses are basically of either crank, knuckle, screw or the eccentric type. The energy in a mechanical press is generated by a large flywheel powered by an electric motor. The clutch engaged the flywheel to an eccentric shaft. A connecting rod translates the rotary motion to reciprocating motion. The capacity range of the mechanical press varies from 900KN to 110MN.

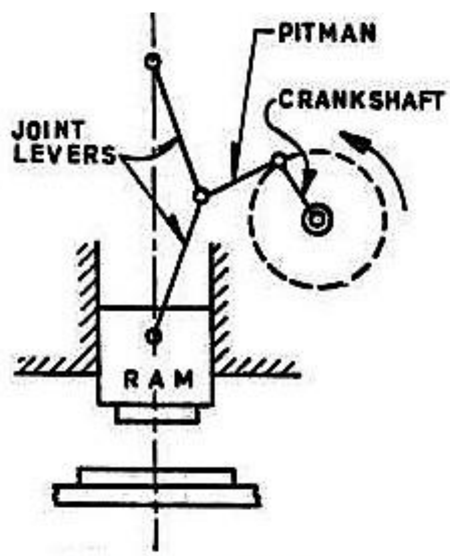


Fig.3.11: Knuckle Press

Presses are chosen based on the characteristics of the manufacturing process. Mechanical press machine tools are commonly used in metal forging manufacture, and sheet metal working. The desired application of force will dictate the type of machine required.

Crank press:

The crank press uses a crank link attached to a drive shaft. The crank link rotates with the drive shaft and is attached to a connecting rod by a rotational joint. The connecting rod rocks back and forth during the motion of the crank. The connecting rod is, in turn, attached to a ram by a rotational joint. The ram operates in a slider joint and travels a one dimensional path in both directions. It is through this path that the crank press delivers its force. The crank press does allow for a stoke of a relatively long distance.

Knuckle press:

The knuckle joint press translates the energy of a motor through a powerful linkage design, and is capable of delivering a tremendous amount of force. The drive shaft crank rotates completely. The links are well grounded to support such pressure.

Eccentric press

The eccentric press uses a motor to drive an eccentric shaft, rotating in a connecting rod. The connecting rod moves a ram in a slider joint one dimensionally. The eccentric shaft itself is round; therefore it may completely rotate within the connecting rod. The center of the drive is not the center of the overall shaft. As the motor rotates, the center of the drive remains stable but the overall center of the shaft changes. This causes the shaft to change position, providing motion. The actual principle of an eccentric press is very similar to a crank press.

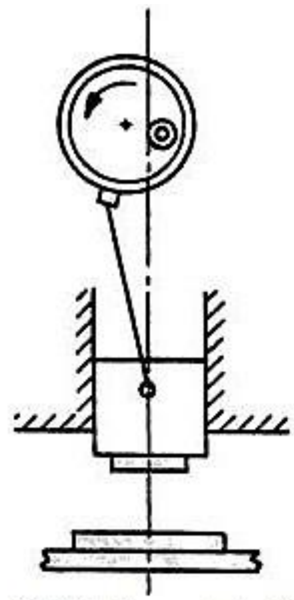


Fig. 3.12 Eccentric Press

Screw Press

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.

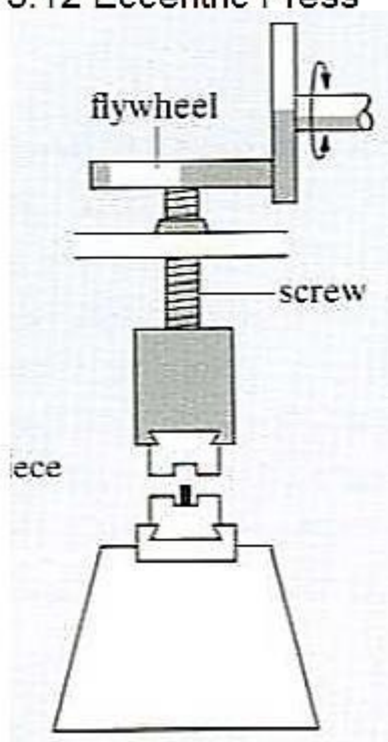


Fig. 3.13 Screw Press

Some screw press machine tools in modern industry can produce 31,000 tons of force.

Rack and Pinion Press

The rack and pinion press delivers the motors energy from a gear directly connected to the drive shaft. The rack is actually a round gear of infinite radius. A rotating gear (pinion) provides force through the rack. This gives the one dimensional, translational motion desired of press machines.

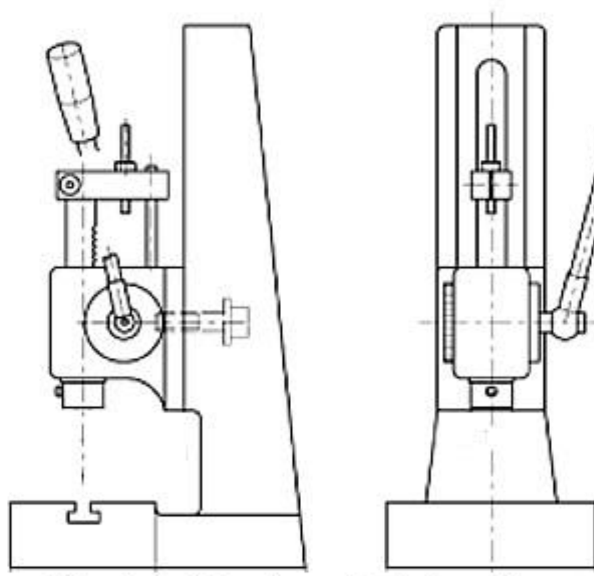


Fig. 3.14 Rack and Pinion Press

Hydraulic presses

Hydraulic presses are a powerful class of machine tools, they derive the energy they deliver through hydraulic pressure. Fluid pressure, in a particular chamber, can be increased or decreased by the use of pumps, and valves. Sometimes devices and systems may be used to increase the capacity of the pumps in more powerful presses. These presses can operate over a long distance and at a constant speed. Hydraulic presses are generally slower relative to other press machine types. This involves longer contact with the work, therefore the cooling of the work can be an issue when hot forming a part with hydraulic force. Hydraulic presses are capable of being the most powerful class of presses. Some may be as large as buildings, and can deliver awesome pressure. The largest hydraulic presses are capable of applying 75,000 tons of force. The hydraulic press shown is being used to manufacture a metal forging.

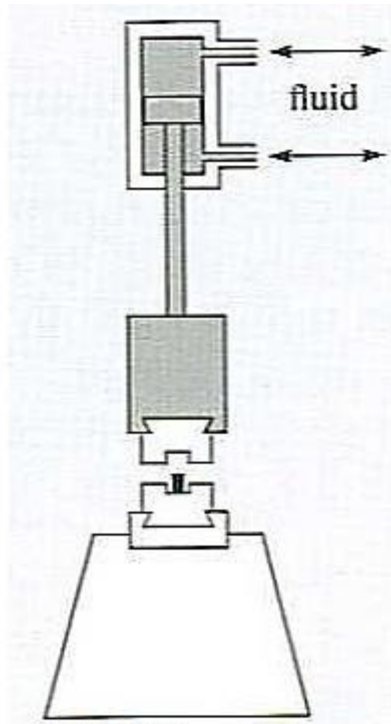


Fig. 3.15 Hydraulic Press

The basic working principles of the hydraulic press are simple, and trust on differences in fluid pressure. Fluid is pumped into the cylinder below the piston; this causes the fluid pressure under the piston to increase. Simultaneously, fluid is pumped out of the top channel, causing the fluid pressure above the piston to decrease. A higher pressure of the fluid below the piston than the fluid above it causes the piston to rise. In the next step, fluid is pumped out from below the piston, causing the pressure under the piston to decrease. Simultaneously, fluid is pumped into the cylinder from the top; this increases the fluid pressure above the piston. A higher pressure of the fluid above the piston, than the fluid below it, moves the piston downward.

Pneumatic press

Pneumatic presses are used to forge small parts. In this press, the weight of anvil is equal to 15 to 20 times of falling weight. The operating principle is similar to hydraulic press. There are two cylinder namely; compressor cylinder and ram cylinder. The air is compressed in a compressor cylinder for the upward stroke and downward stroke and is delivering to the ram cylinder, where it actuates the ram, delivering the forging blow to the work. The reciprocation of the compressor piston is obtained from a crank drive which is powered from an electric motor through reducing gear. The distribution of air between compressor cylinder and ram cylinder is controlled by means of two valves with port through which air passes in to the ram cylinder, up and down the ram alternately. The valves are actuated by depressing foot treadle or operating by a hand lever.

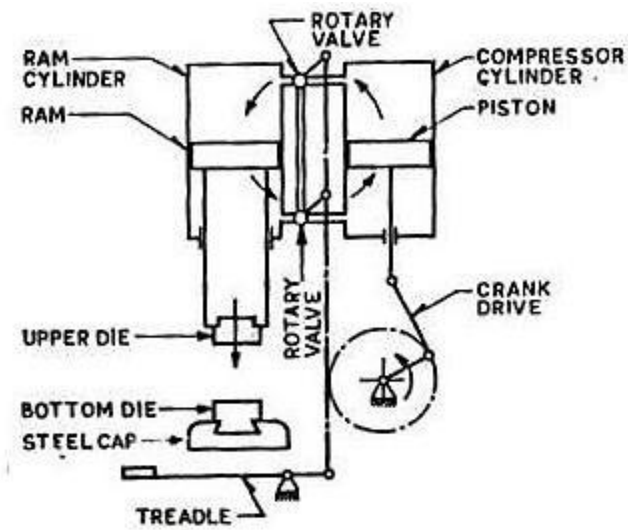


Fig. 3.16 Pneumatic Press

By controlling the air distribution, the required ram movement can be attained: either continuous blow or to hold the ram in upper or lower position.

The size of pneumatic press varies from 0.5 to 10KN. The operating speed is 80 to 200 blows per minute.

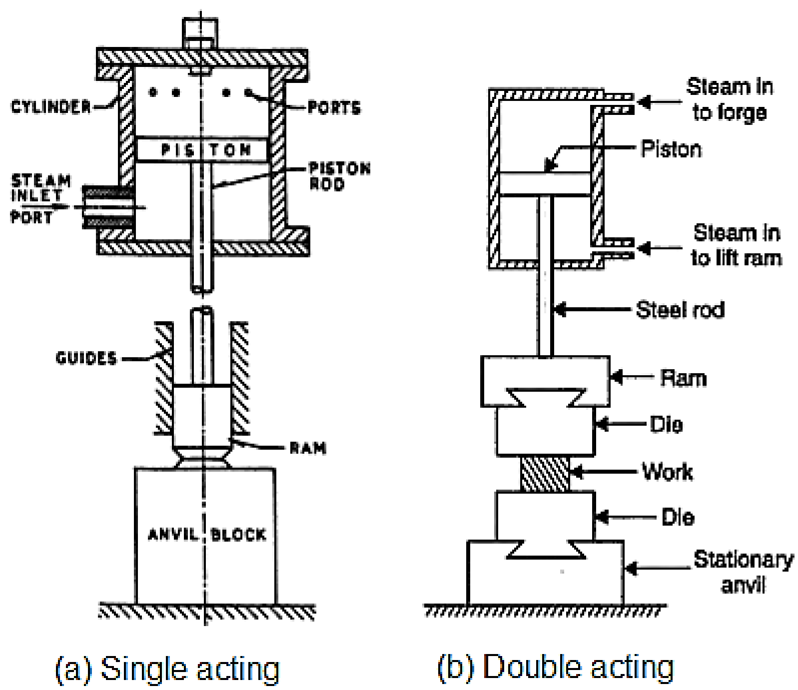


Fig. 3.17 Steam Hammer

Steam hammer

In this type of hammer, there is no in-built air compressor. Separate high pressure steam is required. There are two types of steam hammer are employed namely (1) single acting (2) double acting.

In single acting steam hammer, the high pressure steam enters in to the cylinder port employed at lower portion of the cylinder. Due to this, the ram fitted with upper die allow to move up, meanwhile the steam or air present in the upper portion of the cylinder is exhaust through port provided at top most portion of the cylinder. The ram will move downward by self-weight of ram and also due to gravitational force. Now the compressive action is happen and the forging process is completed.

Similarly, the double acting steam hammer also have same working principle, but the lowering movement of ram is occurred due to steam inlet through the port provided in the upper portion of the cylinder. The capacity of this type of hammer is in the range of 400Kg to 8000Kg.

Forging defects

Sl.No.	Types of crack		Causes
1	Cold shuts or laps	:	Short crack occur at corner
2	Pitting	:	Due to scale formation
3	Die shift	:	Misalignment of die
4	Dents	:	Result of careless work
5	Burnt and overheated metal	:	Improper heating condition
6	Cracks	:	Improper heating
7	Hair crack	:	Too rapid cooling
8	Internal crack	:	Drastic changes in material properties
9	Fins and rags	:	Loose metal is driven in to the surface.
10	Ruptured fiber structure	:	Due to inadequate stock size

Rolling

Rolling is a forming operation where cylindrical rolls are used to reduce the cross sectional area of a bar or plate with a corresponding increase in the length. Rolling process is widely used because of high productivity. **Figure 3.3.2 depicts schematic set-up of rolling process**. Rolling processes are broadly classified by the geometry of the final rolled shape of the work piece material such as flat rolling that is used to reduce thickness of a rectangular cross-section, and shape rolling that is used to produce shaped sections such as I-Beam from a square or rectangular cross-section

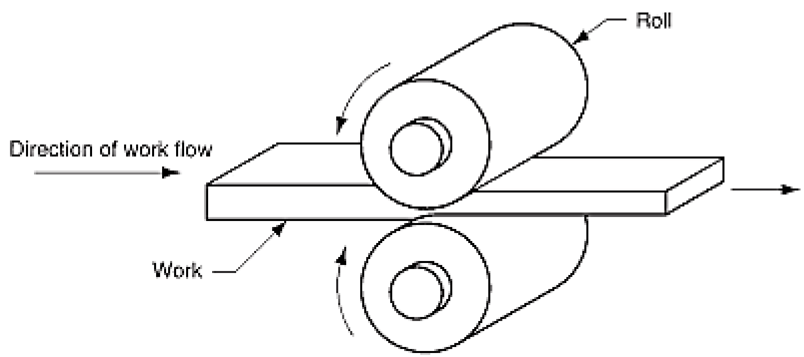


Fig. 3.18 : Rolling of metal

Rolling processes are performed both at high temperature (above the recrystallization temperature), which is referred to as Hot Rolling, as well as at room temperature that is referred to as Cold Rolling. Hot Rolling is usually performed when large amount of deformation is required while Cold Rolling is performed for finished sheet and plate stock. Various structural members, plates and sheets as well as pipes are produced by rolling at very high productivity although due to high tooling cost, it is economical for large batch size only

Comparison of hot rolling and cold rolling

Sl.No.	Hot Rolling	Cold Rolling
1	Metal is fed to the rolls after being heated above the recrystallization temperature.	Metal is fed to the rolls when it is below the recrystallization temperature.
2	In general rolled metal does not show work hardening effect.	The metal shows the working hardening effect after being cold rolled.
3	Co-efficient of friction between two rolls and the stock is higher	Co-efficient of friction between two rolls and the stock is comparatively lower.

	Experiment measurements are difficult to make.	Experiment measurement can be carried out easily in cold rolling.
4	Heavy reduction in area of the work piece can be obtained.	Heavy reduction is not possible.
5	Mechanical properties are improved by breaking cast structure are refining grain sizes below holes and others,	Cold rolling increased the tensile strength and yield strength of the steel.
6	Rolls radius is generally larger in size	Rolls radius is smaller.
7	Very thin sections are not obtained.	Thin sections are obtained.
8	Hot roll surface has (metal oxide) on it, this surface finish is not good.	The cold rolled surface is smooth and oxide free.
9	Hot rolling is used for ferrous as well as non-ferrous metals such as industries for steel, aluminum, copper, brass, bronze, alloy to change ingot into slabs.	Cold rolling is equally applicable to both plain and alloys steels and non-ferrous metals and their alloys.
10	Hot rolling is the father of the cold rolling.	Cold rolling follows the hot rolling.

Classification of rolling mill

- Classification based on the mill product

  This classification is usually done in three ways.

  1. By the type of the product. These are:

     Flat mills – These mills rolls plates, sheets and strips.

Long product mills – These mills rolls rounds, rods and shapes.

2. Based on the nature of the product. These are

   Finishing mills – These mills produced saleable products.

   Semi finishing mills – These mills produce semi-finished products which need further rolling in the finishing mills.

3. based on products

   Blooming, cogging and slabbing mills – These are the preparatory mills to roll blooms and slabs from ingots. With the wide spread acceptance of slab and bloom continuous castings these mills are no more required.

   Billet mills – These mills produce billets from the blooms.

   Beam mills – These mills are used for the production of heavy beams and large channels.

   Rail mills – As the name suggest rails mills are used for rolling of rails from the blooms.

   Shape or structure mills – In these mills medium and smaller sizes of beams and channels and other structural shapes are rolled usually from billets.

   Merchant bar mills – These mills rolls merchant grades of rounds and reinforcement bars.

   SBQ mills – These mills are used for rolling special bar quality rounds.

   Wire rod mills – These mills produces wire rods from billets. Usually these mills are provided with no twist rolling in the blocks and controlled cooling of the rods after rolling.

   Plate mills – These are flat mills to produce heavy plates.

   Hot strip mill – These are also flat mills and rolls hot strips from slabs.

   Cold strip mills – These mills rolls cold strips from hot strips by cold rolling.

   Universal mills – These mills are for the production of various wide flanged shapes by a system of vertical and horizontal rolls.

Classification based on rolling process

Under this classification, the rolling mills can be classified as follows:

Reversing mills – In this type of mills the rolling direction changes after each pass. In these mills the rolls are stopped, reversed, and then brought back up to rolling speed after each pass. In these materials the material being rolled moves in to and fro directions.

Continuous mills – In this type of mills the material to be rolled moves only in one direction and all the mill rolls rotates only in single direction. There are number of stands provided in the mill for giving total reduction to the material being rolled and for giving final shape to the rolled product.

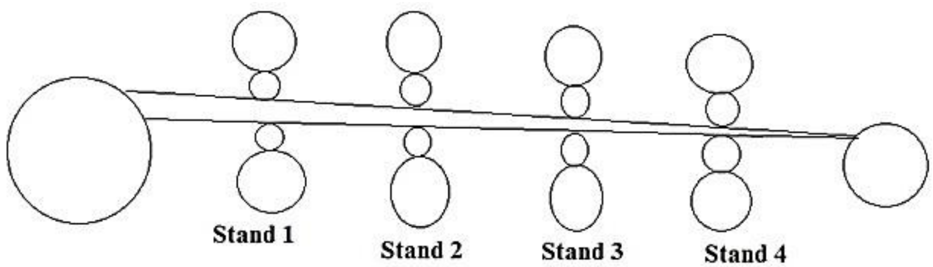


Fig. 3.19 Continuous rolling mill

Semi continuous mills – In this type of mills some roll stands (usually roughing stands) are reversing type while other rolling stands (usually finishing stands) constitutes continuous rolling.

Tandem mills – A tandem mill is a type of rolling mill where rolling is done in one pass. In a traditional rolling mill rolling is done in several passes, but in tandem mill there are several stands (>/=2 stands) and reductions take place successively. The number of stands ranges from 2 to 18. Tandem mills can be either of hot or cold rolling mill types.

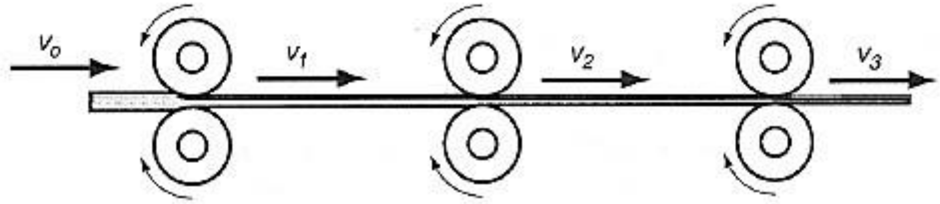


Fig. 3.20 Tandem Rolling Mill

Classification based on stand arrangements

Under this classification there are two types of rolling mills as given below.

Cross country mills – In these types of the mills the centre lines of initial rolling stands are parallel to each other and the material being rolled is shifted perpendicular to the rolling directions. Most of the cross country mills are reversing mills.

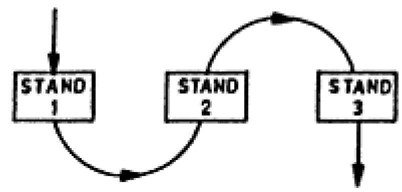


Fig. 3.21 Cross country Mill

Straight line mills – In these mills all the roll stands have a common centre line and material being rolled moves only in forward or forward/backward direction.

Classification based on roll configuration

Rolling mills are also classified based on the roll configurations. The types of mills based on roll configurations are given below.

Two high rolling mills may further classified as

- Reversing mill
- Non reversing mill

A two high rolling mill has two rolls only.

Two high reversing mill:

In two high reversing rolling mills the rolls rotate ist in one direction and then in the other, so that rolled metal may pass back and forth through the rolls several times. This type is used in pluming and slabing mills and for roughing work in plate , rail , structural and other mills.

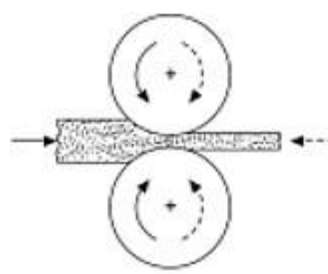


Fig. 3.22 Two roll Mill

Three high rolling mill:

It consists of a roll stand with three parallel rolls one above the other. Adjacent rolls rotates in opposite direction. So that the material may be passed between the top and the middle roll in one direction and the bottom and middle rolls in opposite one.In three high rolling mills the work piece is rolled on both the forward and return passes. First of all the work piece passes through the bottom and middle rolls and the returning between the middle and the top rolls.

So that thickness is reduced at each pass. Mechanically operated lifted tables are used which move vertically or either side of the stand. So that the work piece fed automatically into the roll gap.

Since the rolls run in one direction only a much less powerful motor and transmission system is required. The rolls of a three high rolling mills may be either plain or grooved to produce plate or sections respectively.

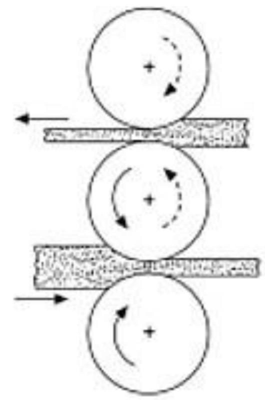


Fig. 3.23 Three roll mill

Four-High Rolling Mill

It is essentially a two-high rolling mill, but with small sized rolls. Practically, it consists of four horizontal rolls, the two middle rolls are smaller in size than the top and bottom rolls as shown in Figure 2(d). The smaller size rolls are known as working rolls which concentrate the total rolling pressure over the workpiece. The larger diameter rolls are called back-up rolls and their main function is to prevent the deflection of the smaller rolls, which otherwise would result in thickening of rolled plates or sheets at the centre. The common products of these mills are hot or cold rolled plates and sheets.

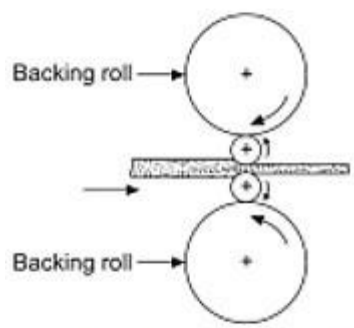


Fig. 3.24 Four roll mill

Cluster Mill

It is a special type of four-high rolling mill in which each of the two smaller working rolls are backed up by two or more of the larger back-up rolls as shown in Figure 2(e). For rolling hard thin materials, it may be necessary to employ work rolls of very small diameter but of considerable length. In such cases adequate support of the working rolls can be obtained by using a cluster-mill. This type of mill is generally used for cold rolling work.

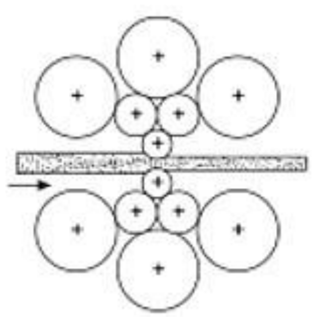


Fig. 3.25 Cluster mill

Planetary mill

This mill consists of a pair of heavy back up rolls surrounded by a large number of planetary rolls. Each planetary roll gives an almost constant reduction to the feed material as it sweeps out of a circular path between the backup roll and the feed material. As each pair of planetary rolls ceases to have contact with the work piece, another pair of rolls makes contact and repeat the reduction.

Flat strip rolling

Flat strip rolling utilizes a series of rolls to gradually change the shape of the metal. As the fast moving continuous strip passes between the rolls, the cross sectional shape is changed to the desired form.

The work is squeezed between two rolls so that it thickness is reduced by an amount called the draft. If the draft is expressed as a fraction of the starting block thickness, it is called reduction. Rolling increases the work width and this is called spreading.

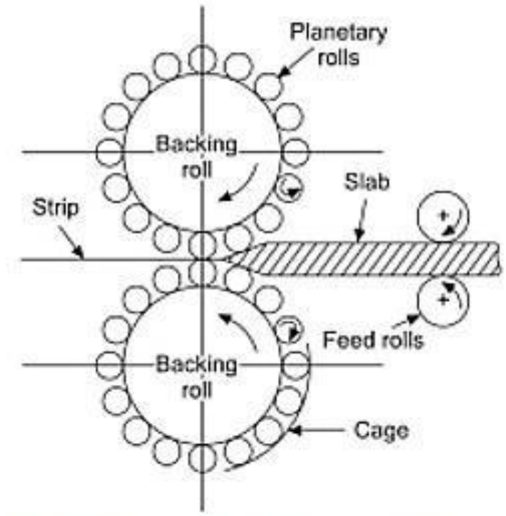


Fig. 3.26 Planetary rolling mill

The inlet and outlet volume rates of material flow must be the same

The entering and exiting velocities of the work. The point where roll velocity equals work velocity is known as the no-slip point or the neutral point.

The true strain and the mean flow stress are defined by true strain, and mean flow stress

Friction occurs with a certain coefficient of friction μ on either sides of no-slip point. Both friction forces act in opposite directions and are not equal. The entrance force is bigger so that the resulting

force pulls the work through the rolls. The maximum possible draft depends on μand roll radius R.

The rolling force F is estimated as

□ = □ □ □□□□

□ℎ □□□, □ = □□□□ □□□□□ □□□□□□□ □□□□□ℎ

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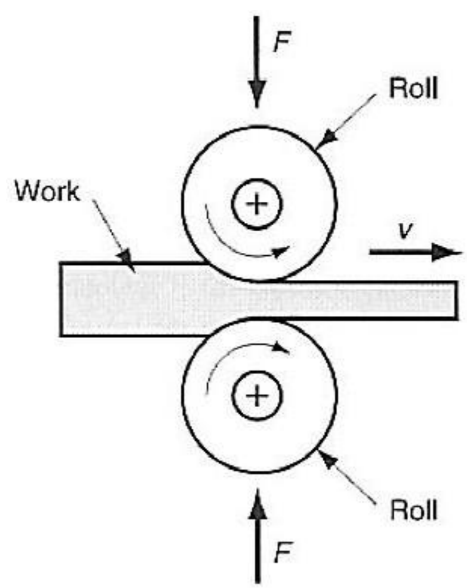

Fig. 3.27 Flat strip rolling

The power P required to drive each roll is □ = $\frac{2\square\square\ \square\square}{60\times1000}$ □□

Where N = speed of roll in rpm and F = Force in N.

Shape rolling is a broad term for a range of metal rolling operations that involve forming the work with rolls of certain geometry. The rolls form the part to a specific shape. Most shape rolling involves passing the material through several steps. Two very common examples of continuous shape rolled product are the I beam for structural purposes and the rail for railroad track.

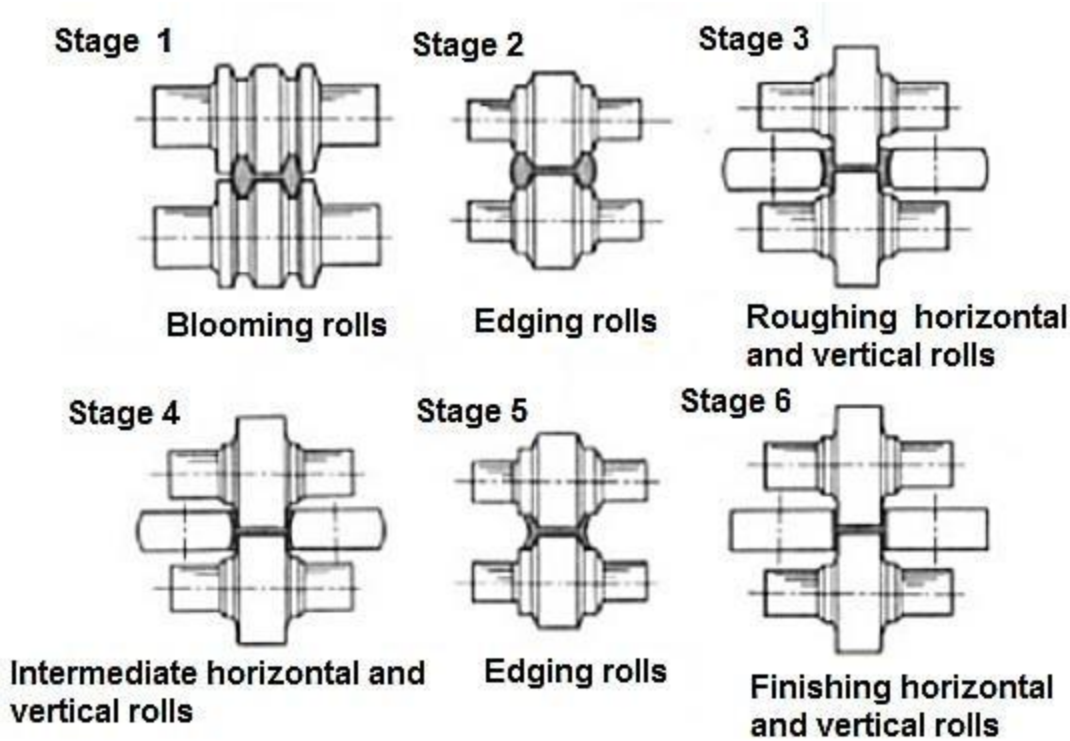

Fig. 3.28 Shape Rolling operation

Designing a proper series of shape changes in a work will involve more deformation in some areas than others. As mentioned earlier, excessive shape change in some parts of the cross section is a serious cause of defects in shape rolling production. The rolling engineer must design a system of passes in such a way as to achieve the shape change through several steps, mitigating any excessive deformations at any particular area of the work's cross section.

Many different shapes can be shape rolled in metal rolling industry today. Here is an example of a possible roll pass design for the production of a H- section roll shape rolling.

Ring rolling

Ring rolling is a particular category of metal rolling, in which a ring of smaller diameter is rolled into a precise ring of larger diameter and a reduced cross section. This is accomplished by the use of two rollers; one driven and one idle, acting on either side of the ring's cross section. Edging rollers are typically used during industrial metal rolling manufacture, to ensure that the part will maintain a constant width throughout the forming operation. The work will essentially retain the same volume; therefore the geometric reduction in thickness will be compensated for entirely by an increase in the ring's diameter. Rings manufactured by ring rolling are seamless. This forming process can be used to manufacture not only flat rings, but rings of differently shaped cross sections as well, producing very precise parts with little waste of material.

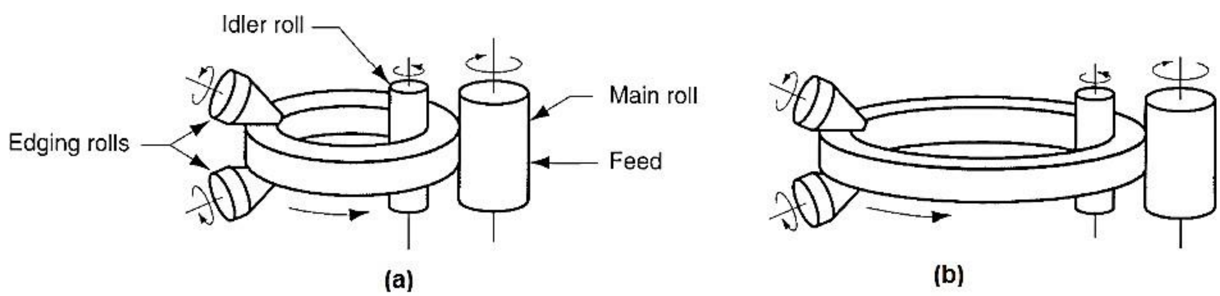

Fig. 3.29 Ring rolling process

A significant advantage of parts produced by this metal rolling process is that the forming of the material will impart the ring with a grain orientation that gives it enhanced strength relative to most applications. Common items produced by this process in manufacturing industry today include rings for machinery, aerospace applications, turbines, pipes, pressure vessels, roller and ball bearing races. The following shows the sequence of events of the ring rolling process, the part is commonly started as a metal bar cut to a certain length.

Thread rolling

Thread rolling is a metal rolling process used extensively in manufacturing industry to produce screws, bolts and other fasteners. A common thread rolling process, used in industry to manufacture threaded parts, involves forming the threads into the metal of a blank by a pressing and rolling action between two die. The die surfaces hold the shape and the force of the action forms the threads into the material. A similar metal forming process has been developed for the production of gears.

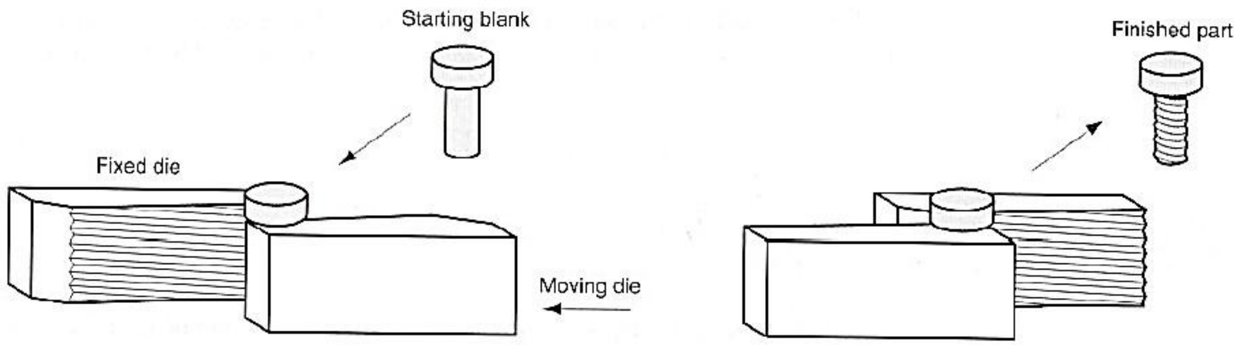

Fig. 3.30 Threading rolling with flat die

Thread rolling, in modern manufacturing, has an extremely high productivity rate, significantly higher than producing threaded parts by machining. Machining is the alternative method to industrial manufacturing of threaded parts. Producing threads by this method has several other benefits over machining. Forming will harden the metal through cold working, does not waste material by cutting, and produces a favorable grain structure to strengthen the part with respect to its function.

Rolling defects

There are two types of defects which can be observed in rolled products.

1) Surface defects
2) Internal surface defects.
    a) Wavy edges
    b) Zipper cracks
    c) Edge cracks
    d) Alligatoring
    e) Folds
    f) Laminations.

Defects due to bending on rolls:

Types of defects occur due to this reason

a) Wavy edges
b) Zipper cracks

Zipper crack also occur due to poor material ductility at the rolling temperature. The remedy is to provide a camber to the rolls, (i.e.) their diameter is made slightly larger at the centre than at the edges.

Inhomogeneous deformation of elements across the width.

During rolling process, the thickness of metal is reduced and the length is increase, due to this the elements near the edges will be under tension and the element near the centre will be under compression. Such a situation can lead to **edge cracks** (fig. (c)).

Another interesting defect that can occur in flat rolling is **alligatoring**, where the work being rolled actually splits in two during the process. The two parts of the work material travel in opposite directions relative to their respective rolls.

Folds: these defects are encountered during plate rolling if the reduction per pass is very small.

Laminations: during rolling process, due to incomplete welding, defects like longitudinal strings of non-metallic inclusions are introduced at the time of ingot productions. Under severe reduction, these defects can results in to small crack called laminations along the thickness direction. Due to this the strength along the thickness direction can get drastically reduced.

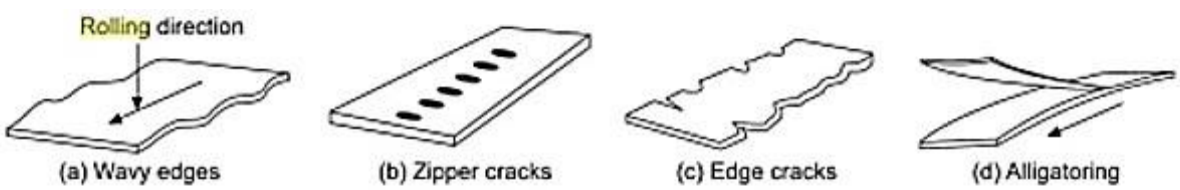

Fig. 3.31 Rolling defects

Process variable in rolling process are:

- Roll diameter
- Angel of bite
- Temperature
- Strength of work material
- Speed of rolling roll gap
- Coefficient of friction
- Dimensions of sheet

Metal Drawing

Metal drawing is a manufacturing process that forms metal work stock by reducing its cross section. This is accomplished by forcing the work through a mold, (die), of smaller cross sectional area than the work. This process is very similar to metal extrusion, the difference being in the application of force. In extrusion the work is pushed through the die opening, where in drawing it is pulled through.

- Rod (bar) drawing
- Wire drawing
- Tube drawing

Rod (bar) drawing

Rod or bar drawing is a term used to denote one of two categories of metal drawing. Rod or bar drawing refers to the drawing of work of larger cross sections, while wire drawing refers to the forming of work of a relatively smaller profile. Due to the size of the work, rod and bar drawing involves much more finite lengths of material than wire drawing. This type of process is carried out as a discrete manufacturing operation.

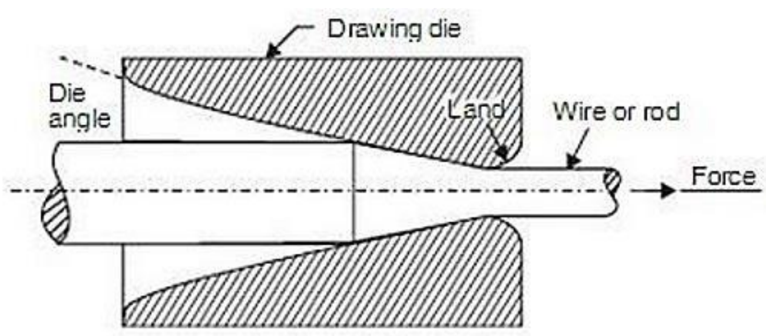

Fig. 3.32 Rod or bar drawing

It is usually performed on a draw bench. A draw bench consists of a long table, a die stand containing the mold and a carriage used to grip and draw the work. The die stand may contain two or more molds; multiple dies allow more than one part to be drawn with each operation. Draw benches vary in size and can be up to 100 feet in length. Force used to draw the metal is exerted through hydraulic or mechanical means. Pulling force as high as 150 tons has been used during industrial production.

Wire drawing

Wire drawing is the second major category of metal drawing operations. While rod and bar drawing refer to the drawing of larger cross sections, wire drawing refers to the drawing of relatively smaller cross sections. The enormous amount of electrical wire and cable produced by this manufacturing method makes wire drawing a major modern industrial process. Some wire must be manufactured to tremendously small cross sectional areas, such as those used in electromagnets. Wire may be drawn to diameters as low as .0001 inch. Diamond die inserts are often used in the production of extremely fine wire.

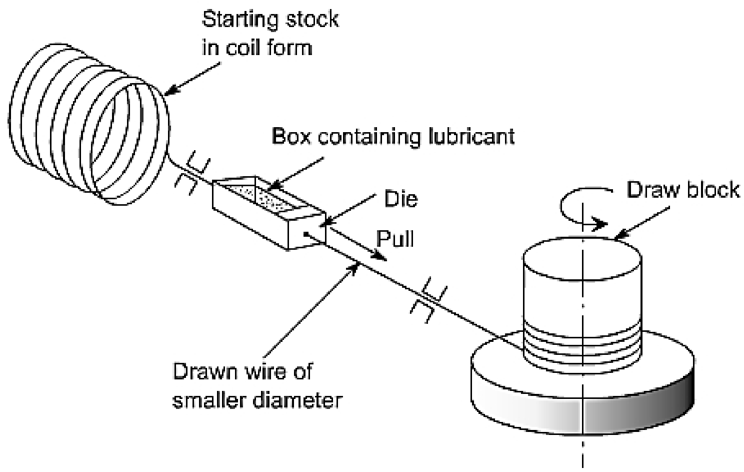

Fig. 3.33 Wire drawing

Metal work stock in wire drawing will usually undergo several reductions in diameter, since the mechanics of the process limit the amount of reduction in a single draw. This is accomplished by drawing the work through several die in series, each producing an incremental reduction in the work's diameter. Between dies the wire stock is wrapped several times around a motor driven rotating drum called a capstan, before proceeding to the next die in series. Annealing of the metal may be performed between groups of operations. The capstans provide the force for the manufacturing process. As the diameter is reduced, the speed of the wire is increased. Velocity of wire leaving the last mold in a series can be significantly higher than the velocity of the work entering the first mold. Typically drawing speeds may be 20-100 feet per minute, but in some cases wire may be drawn at 10,000 feet per minute. Pieces of stock can be end welded together as they are fed into the system of capstans and die so that the process will be completely continuous. Industrial wire drawing operations can manufacture miles of wire at a time.

TUBE DRAWING

Tubes and pipes are required in large quantities by industries all over the world. Tubes are basically of two types. They are either seamless (i.e., without any joint) or with joint all along the length of the tube. Seamless tubes are made by processes such as casting, extrusion or rolling. Tubes with joint are made by welding. Usually, the weld joint is made by electric resistance welding process; such tubes are referred to as ERW tubes. The size of a tube or pipe is indicated by the size of its bore in mm. Since the requirement of tubes is so large, a special rolling process called Mannesmann rotary piercing process has been developed. In this process, a heated round billet with its leading end, in the centre of which a short guide hole has been punched or drilled, is pushed longitudinally between two large tapered rolls as shown in Fig. 3.33.

The rolls revolve in the same direction and their axes are inclined at opposite angles of approx 6°from the axis of the billet. As the billet is caught by the rolls and is rotated, their inclination causes the material to be drawn forward. The small clearance between the rolls forces the material to deform into an elliptical shape. Due to compressive forces, secondary tensile stresses start acting in a direction perpendicular to the direction of the compressive stresses. The guide hole drilled/punched at centre of billet tears open. This action is assisted by a suitably placed mandrel. As the billet mores forward and keeps rotating the tearing action is propagated throughout the length of the billet. End result is a roughly formed seamless tube of elliptical cross-section. This roughly formed seamless tube is further rolled in a "plug rolling mill". The final operations of "reeling" and "sizing" are further conducted on cooled tube to improves size and finish of tube.

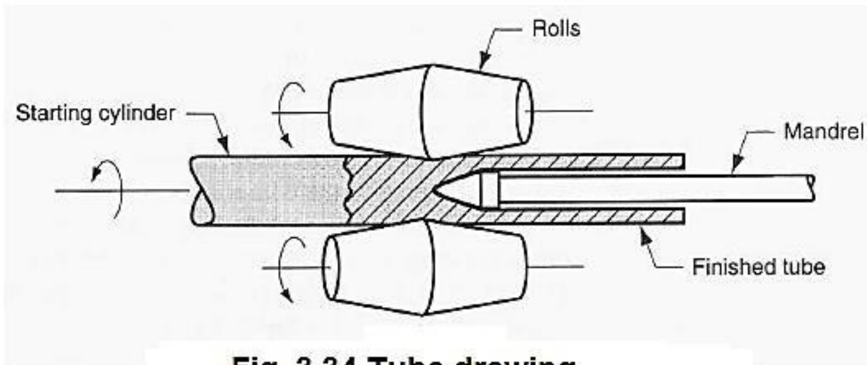

Fig. 3.34 Tube drawing (or) Tube Piercing (or) seemless tube drawing

TUBE DRAWING METHOD

- Tube drawing with fixed plug
- Tube drawing with floated plug
- Tube drawing with moving mandrel
- Tube sinking

The 'drawing' process can also be used for tube drawing. Tube drawing does not mean manufacturing a tube from solid raw material. It means lengthening a tube reducing its diameter. Various arrangements used for tube drawing are shown in Fig. 3.33

The method shown in Fig. 3.33 (a) is the most common method used for tube drawing. A conventional tube drawing bench is used. Method shown in Fig. 3.33 (b) employs a floating mandrel. Method shown in Fig. 3.33 (c) uses a long circular rod to control the size of tube-bore. Method shown inFig.3.33 (d) uses neither a mandrel nor a bar and controlling size of bore is difficult.

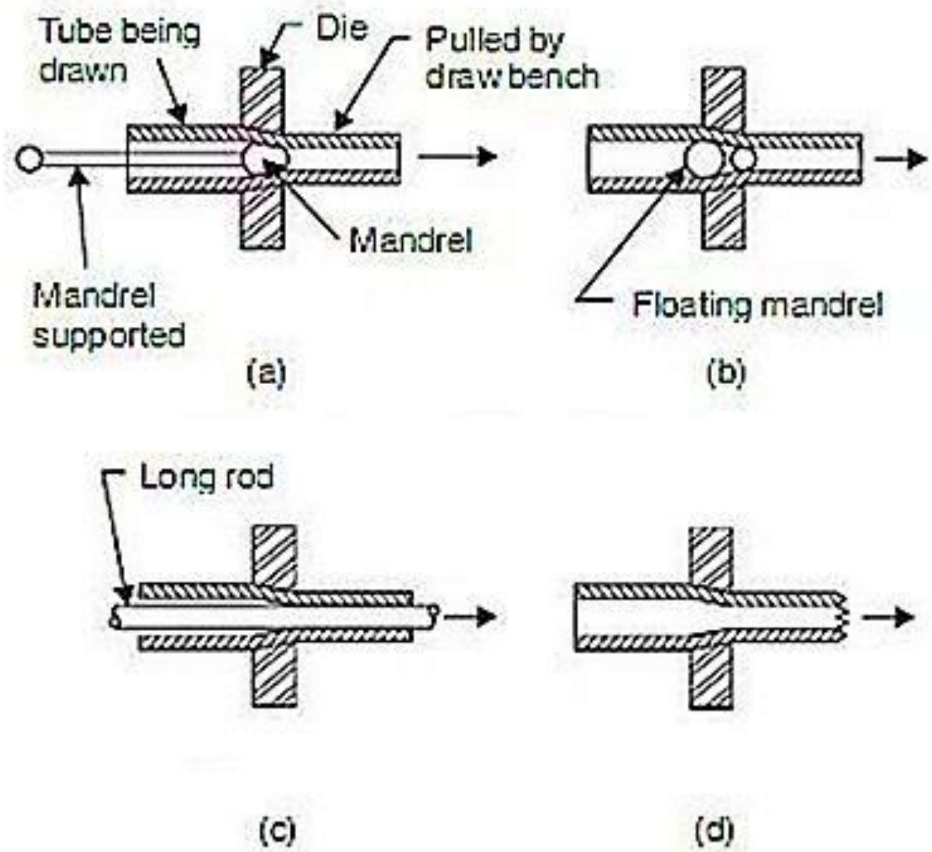

Fig. 3.35 Tube drawing method

EXTRUSION

"Extrusion is a process in which the metal is subjected to plastic flow by enclosing the metal in a closed chamber in which the only opening provided is through a die". The material is usually treated so that it can undergo plastic deformation at a sufficiently rapid rate and may be squeezed out of the hole in the die. In the process the metal assumes the opening provided in the die and comes out as a long strip with the same cross-section as the die-opening. Incidentally, the metal strip produced will have a longitudinal grain flow.

The process of extrusion is most commonly used for the manufacture of solid and hollow sections of nonferrous metals and alloys. Aluminum is an extremely good material for metal extrusion. Copper, magnesium, zinc, tin and some softer low carbon steels, can also be extruded with little complication due to the material. High carbon steels, titanium and various refractory alloys, can be difficult to extrude.

Advantages of extrusion processes.

- Extrusion can produce variety of shapes with uniform cross-section.
- The grain structure and mechanical strength of work piece material are improved in cold and warm extrusion processes.
- Cold extrusion can provide close tolerances.
- Wastage of material is the minimum in extrusion processes.
- Extrusion can be performed even for relatively brittle materials.

Type of extrusion

- Hot extrusion
- Cold extrusion
- Direct extrusion
- Indirect extrusion
- Hydrostatic extrusion
- Impact extrusion

Hot Extrusion

Hot extrusion is done at fairly high temperatures, approximately 50 to 75 % of the melting point of the metal. The pressures can range from 35-700 MPa. Due to the high temperatures and pressures and its detrimental effect on the die life as well as other components, good lubrication is necessary. Oil and graphite work at lower temperatures, whereas at higher temperatures glass powder is used.

Typical parts produced by extrusions are trim parts used in automotive and construction applications, window frame members, railings, aircraft structural parts.

Advantages of hot extrusion

- Improvement of the mechanical properties
- This ratio can be very large while still producing quality parts.
- Improved physical characteristics of the metal
- Easy to extrude for larger parts,
- It has more extreme changes in shape
- Possible for extruding more complex geometry.

Disadvantages

- Results in a layer of oxide scale build up on the external surfaces of the work piece.
- Scale can affect surface finish
- Affect the accuracy of the part

- wear at die metal interfaces.
- High maintenance cost
- decreased tolerances, and
- increased die wear

Cold Extrusion

Cold extrusion is the process done at room temperature or slightly elevated temperatures. This process can be used for most materials-subject to designing robust enough tooling that can withstand the stresses created by extrusion. Examples of the metals that can be extruded are lead, tin, aluminum alloys, copper, titanium, molybdenum, vanadium, steel. Examples of parts that are cold extruded are collapsible tubes, aluminum cans, cylinders, gear blanks.

Advantages of cold extrusion over hot extrusion include,

- Process not having to heat the work,
- Higher production rate,
- No oxidation and scale form on surfaces,
- Greater geometric accuracy,
- Better surface finish
- Ability to strengthen the part by way of strain hardening.

DIRECT or FORWARD EXTRUSION

In manufacturing industry, extrusion processes can be classified into two main categories, direct and indirect. Hollow extrusions, as well as cross sections, can be manufactured by both methods. Each method, however, differs in its application of force and is subject to different operational factors.

In Direct or forward extrusion, the work billet is contained in a chamber. The ram exerts force on one side of the work piece, while the forming die, through which the material is extruded, is located on the opposite side of the chamber. The length of extruded metal product flows in the same direction that the force is applied.

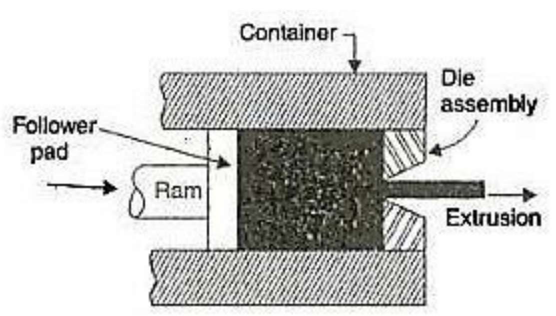

Fig. 3.36 Forward or Direct extrusion

During direct extrusion, metal flow and forces required are affected by the friction between the work piece and the chamber walls. Particularly in hot working, oxide scale build up on the outer surfaces of the work piece can negatively influence the operation.

For these reasons, it is common manufacturing practice to place a dummy block (follower pad) ahead of the ram. The dummy block is of slightly smaller diameter than the chamber and work piece. As the metal extrusion proceeds, the outermost surface of the work is not extruded and remains in the chamber. This material will form a thin shell, (called skull), that will later be removed. Much of the skull will be comprised on the surface layer of oxidized scale from the work metal.

BACKWARD or INDIRECT EXTRUSION

Indirect extrusion is a particular type of metal extrusion process in which the work piece is located in a chamber that is completely closed off at one side. The metal extrusion die are located on the ram, which exerts force from the open end of the chamber. As the manufacturing process proceeds, the extruded product flows in the opposite direction that the ram is moving. For this purpose the ram is made hollow, so that the extruded section travels through the ram itself. This manufacturing process is advantageous in that there are no frictional forces between the work piece and the chamber walls. Indirect extrusion does present limitations. Tooling and machine set up are more complicated, hollow rams are not as strong and less ridged and support of the length of the metal extrusion's profile, as it travels out of the mold, is more difficult.

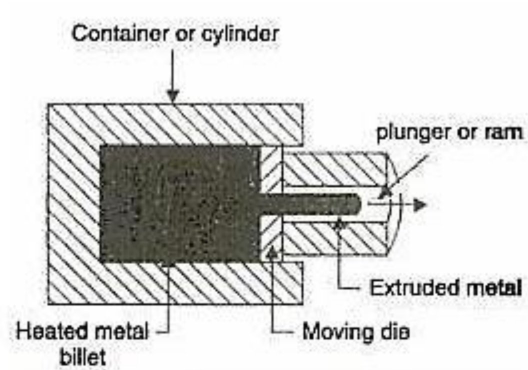

Fig. 3.37 Backward or Indirect extrusion

Indirect extrusion can also be used to produce hollow parts. In this process, a ram is forced into the work material. The ram gives the internal geometry to the tubular part, while the material is formed around it. Difficulties in supporting the ram limit this process and the length of tubular metal extrusions that may be manufactured.

IMPACT EXTRUSION

Impact extrusion is a discrete manufacturing process, in which a metal part is extruded through the impact of a die with the work stock. The part is formed at a high speed and over a relatively short stroke. In impact extrusions, mechanical presses are most often employed. The force used to form in standard extrusions is usually delivered over a horizontal vector, producing a long continuous product. But in this method, Force used to form is usually delivered over a vertical vector, producing a single part with each impact of the punch. Impact extrusion is most often performed cold. Occasionally with some metals and thicker walled structures, the work is heated before impact forming it.

This process is best suited for softer metals, aluminum is a great material for forming by impacting.

In manufacturing operation of impact extrusion, a work piece is placed in a mold and struck with great force, causing the metal to flow into position in an instant. The forces acting on the machinery are extreme, particularly on the punch and die. Tooling must have sufficient impact resistance, fatigue resistance and strength, for extruding metal by impact. There are three basic types of impact extrusion processes, forward, reverse and combination. The different categories are based on the kind of metal flow that occurs during the process. In forward impact extrusion, metal flows in the same direction that the force is delivered. In backward impact extrusion, the metal flows in the opposite direction that the force is delivered. In combination, the metal flows in both directions.

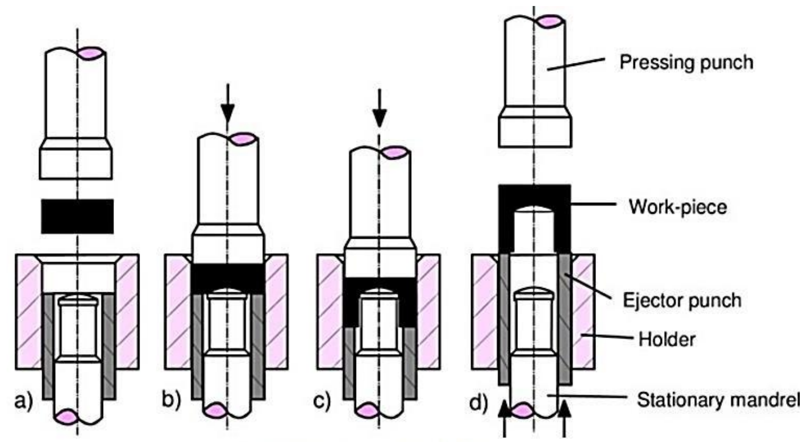

Fig. 3.38 Impact Extrusion (forward method)

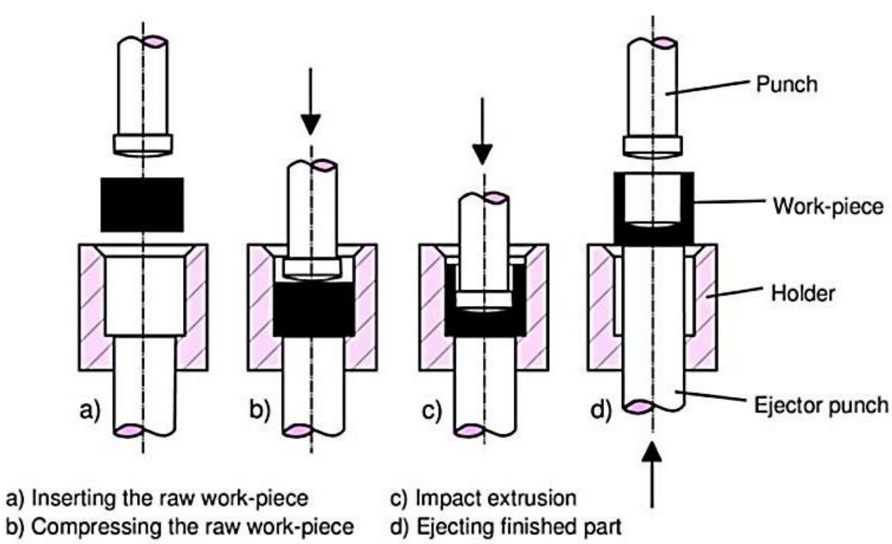

Fig. 3.39 Impact Extrusion (Backward method)

Benefits of impact extrusion compared to conventional extrusion

- Raw material savings of up to 90%
- Reduced machining times up to 75%
- Elimination of secondary machining operations
- Reduction in multi-part assemblies
- Improved mechanical properties for material strength and machining due to cold working of the material
- Significantly reduced total part costs up to 50%

HYDROSTATIC EXTRUSION

In hydrostatic extrusion the work piece is held in a sealed chamber surrounded by pressurized liquid. Hydrostatic extrusion is actually a form of direct extrusion. The force delivered through the ram is what pressurizes the liquid. The liquid applies pressure to all surfaces of the work billet. When the ram moves forward, it is the force from the incompressible fluid that pushes the work through the die, extruding the metal part.

A critical aspect of manufacturing by this process is setup. The metal work billet must first be tapered to fit through the die opening, thus creating a seal. This is done before adding the liquid, in order to prevent leaking. Since the liquid is under great pressure, this taper must be precise to create a robust bond. Many different shapes may be manufactured by this process, using a variety of materials.

Liquid pressure from all directions also greatly decreases the chances of buckling of the work.

Hydrostatic extrusion may be performed at room or elevated temperatures, depending upon the manufacturing process. When performed hot, the liquid will insulate the work from thermal gradients between the container and work material. An advanced variation of this process is called fluid to fluid extrusion. This process is basically the same, except that the part is extruded into a second chamber also containing pressurized liquid. The liquid in the second chamber is of a lower pressure than the first. Several different kinds of liquids are used when manufacturing by

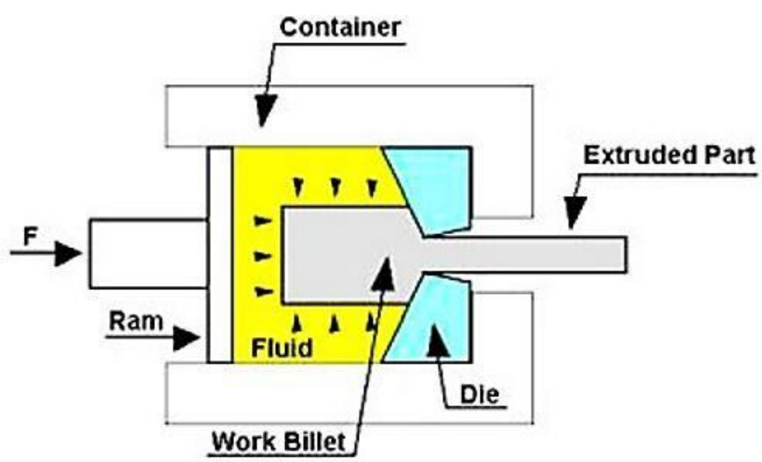

Fig. 3.40 Hydrostatic extrusion

hydrostatic extrusion, including oils, waxes, melted polymers and molten glass. Hydrostatic extrusion has not had much use in manufacturing industry, due to the complicated equipment and procedures, work preparation, long cycle times and dangers of working with hot, high pressure liquid.

Advantages of Hydrostatic Extrusion

- No friction amidst the container and billet. This minimizes the force requirements, allowing higher reduction ratios, faster speeds, & lower billet temperatures.
- Friction of the die can be largely reduced by a film of pressurized lubricant amidst the die surface and deforming metal.
- On applying high pressures, the ductility of material increases.
- Even flow of material.
- Large billets & large cross-sections are extruded.
- Uniform hydrostatic pressure inside the container eliminates the requirement of billets being straightened and extrusion of coiled wire.
- No billet residue is left on the walls of container.

Limitations of Hydrostatic Extrusion

There are a number of limitations in the hydrostatic extrusion, especially when a large volume of fluid is used in comparison with the billet volume, which is to be extruded. These limitations are as follows:

- Increased handling for the injection and removal of the fluid for every extrusion cycle
- Decreased control of speed of the billet & stopping because of potential stick-slip and enormous stored energy in the compressed fluid
- Decreased process efficiency in terms of billet-to-container volume ratio
- Enhanced complications, when extrusion is done at elevated temperatures

Defects in Extrusion

Surface cracking

Surface cracking occurs when the surface of an extrusion splits, which is often caused by the extrusion temperature, friction, or speed being too high. It can also happen at lower temperatures if the extruded product temporarily sticks to the die.

Internal cracking

Internal cracking occurs when the centre of the extrusion develops cracks or voids. These cracks are attributed to a state of hydrostatic tensile stress at the center line in the deformation zone in the die.

Pipe

It is the flow pattern that draws the surface oxides and impurities to the centre of the product. Such a pattern is often caused by high friction or cooling of the outer regions of the billet.

Surface lines

These are the lines visible on the surface of the extruded profile. This depends heavily on the quality of the die production and how well the die is maintained, as some residues of the material extruded can stick to the die surface and produce the embossed lines.