

Metal Casting

Metal casting is the process of pouring a molten metal in to a mould and allowing it to solidify to produce a desired object.

Most commonly used method of metal casting is sand casting in which a sand mould is used. It is a very old method. Improved methods such as shell moulding, investment casting, die casting, centrifugal casting etc. now find wider application. Various step in casting are

1. Pattern making
2. Mould and core making
3. Melting and pouring
4. Fettling after solidification
5. Inspection and testing

Pattern Making

Pattern is the replica or full size model of the casting to be made. It is used to give shape to the mould cavity where the poured molten solidifies to the desired form and size.

Pattern is generally made using the following materials.

1. Wood
2. Metals
3. Plastics
4. Plasters
5. Wax

Each material has its own advantages and limitations. The required accuracy, strength and life of a pattern depend on the quantity of casting to be produced.

Generally for short run production wood is used as pattern material. For mass production metal patterns are used. Plastics may be used for batch production.

Pattern Allowances

A pattern is generally larger size compared to the casting due to the various allowances to be provided.

Various allowances are :

1. Shrinkage or contraction allowance
2. Machining or finishing allowance
3. Draft or taper allowance
4. Shaking or rapping allowance
5. Distortion or camber allowance

Shrinkage Allowance

Almost all metals shrink or contract on solidification. So to compensate the reduction in size of the casting, size of pattern is to be increased. The allowance provided for this is called shrinkage allowance. Following is the typical values of shrinkage allowances for some of the commonly used metals.

| | |
|---------------------------|-----------|
| Cast iron/ Malleable iron | : 10 mm/m |
| Brass, Cu, Al | : 15 mm/m |
| Steel | : 20 mm/m |
| Zn, Lead | : 25 mm/m |

A 'shrink scale' is a pattern maker's rule using which pattern dimensions, are laid out. Shrink scale is longer than a standard scale by the shrinkage value for the appropriate metal.

Machining or Finishing Allowance

To remove surface roughness and other imperfections and to achieve exact dimensions, a casting has to be machined. Therefore to account for this the pattern is to be made sufficiently larger. The allowance provided for this is called machining or finishing allowance.

Draft or Taper Allowance

Draft is the taper provided on the vertical surfaces of pattern for the easy removal of the pattern from the mould without damaging the edges of the mould around the pattern. Draft is expressed in mm per meter on a side or in degrees. The amount of taper depends on method of moulding, shape and size of pattern and the moulding material.

Shaking or Rapping Allowance

The pattern is to be shaken or rapped for easy withdrawal from the mould. The cavity of the mould is slightly increased by the shaking action. To compensate this the pattern is made slightly smaller than the required size.

Distortion or Camber Allowance

A casting will distort or warp during cooling due to uneven shrinkages due to irregular shape, uneven metal thickness or difference in exposures of the metal surfaces. To allow for this, the shape of the pattern is modified in such a way it bends in the opposite direction of distortion.

Types of Patterns

The type of pattern to be used depends up on the following points

1. Quantity of casting to be produced.

2. Size and complexity of the shape of casting to be produced.
3. Moulding method used.
4. Surface finish and accuracy required etc.

The most common type of patterns are :

1. Solid or single piece pattern.
2. Split pattern.
3. Loose piece pattern.
4. Cope and drag pattern
5. Match plate pattern
6. Gated pattern
7. Sweep pattern
8. Segmental pattern
9. Skeleton pattern
10. Built up pattern
11. Follow board pattern

Solid or single piece pattern is used either in the drag or in the cope. It is generally used for large castings of simple shape.

All castings, for example spherical shaped, cannot be mould using single piece patterns. So split patterns are used. Split patterns are made in two parts. So that one part will come in the dag and the other part will come in the cope. This facilitates easily removal of the pattern from the mould without damage to the mould.

In loose piece patterns projections or overhanging parts are made as loose pieces which are attached to the main part using wooden dowel pins. After making the mould, the main part of pattern is withdrawn first and then the loose pieces.

Cope and drag pattern is another type of split pattern. The split halves of the pattern are mounted on different plates. The two halves are made separately and then assembeled. These are used for very large castings.

Match plate patterns are mostly used in machine moulding and for producing large number of small castings by hand moulding. The pattern halves with gating and runner systems are mounted on opposite sides of one single wooden or metal plate called match plate.

Gated pattern is one or more loose patterns having attached gates and runners. Time required to cut gating system by hand is eliminated. These are used for mass production of small castings.

Sweep patterns are used for symmetrically shaped large castings. A section

or wooden board of proper contour is rotated about one edge so that a cavity is made in the moulding material such as loam sand with the desired contour.

Segmental patterns are also known as part patterns. These are used for producing large circular castings such as rings, gears etc. The part pattern is moved about the centre. After ramming one section it is moved to the adjacent section and this is continued to complete the mould.

Skeleton patterns are used for very large castings of simple geometrical shapes. If no. of castings required is small it is not economical to construct solid patterns. Pattern is made of wooden frame and ribs. the frame work is filled with loam sand and rammed. A strike off board known as strickle board is used to give the pattern the desired shape.

Built up patterns are composed of two or more segments made by cutting strips of wood. Pattern for special pulleys are built up type.

Follow board pattern is a wooden board and is used for supporting a pattern which is very thin and fragile. It also helps to establish a parting plane with ease in a pattern that has an irregular shape.

Stop Off

Stop offs are wooden pieces used to reinforce some portion of the pattern which are structurally weak. The cavities formed after moulding due to the stop offs are refilled with sand before pouring molten metal.

Pattern Colour Codes

Colour codes are used in patterns for indicating different surfaces. There is no universally accepted standard colour code. the colour code adopted by most of the foundries are as follows.

| Part of the pattern | Colour |
|---|---------------------------------|
| 1. Surface to be left unmachined | Black |
| 2. Surface to be machined | Red |
| 3. Coreprints and seats for loose core prints | Yellow |
| 4. Seats for loose pieces | Red strips on yellow background |
| 5. Stop offs or supports | Black strips on yellow |

Pattern Design Considerations

A pattern not properly designed will produce only bad castings. The following are some of the factors that must be taken into account while designing a pattern.

1. The pattern should be dimensionally accurate and should have very good

surface finish.

2. Metallic pattern give good surface finish but are cost compared to wood castings.
3. All the pattern allowances should be taken into account.
4. In the case of split pattern the parting surface should be such that the larger part of the pattern should be in the drag.
5. All sharp corners and edges should be rounded.
6. Change in section thickness should be smooth, gradual and uniform.
7. Match plate are preferred for machine moulding.
8. Jointed cores should be avoided.

In expendable mould casting a refractory material is used as mould material. The mould is to be destroyed for taking out the solidified casting. Sand mould casting is an example. the main draw back of sand mould casting is the poor surface finish of the casting.

Sand Mould Casting

About 80% of the cast products are made using sand mould casting method. Sand moulds are single casting moulds and are completely destroyed for taking out the casting. The moulding material is sand mixed with small quantities of binding materials and additives and water to improve the cohesive strength and mouldability of sand.

Sand moulds are prepared in wooden or metallic boxes called flasks. Depending up on the type of casting there can be one flask or more than one flasks. Two flask system is the most commonly used. In the assembled position, the upper flask is called 'cope' and bottom flask is called 'Drag'. In three flask system, the intermediate or central flask is called the 'Cheak'.

One flask design is used in 'full mould process' or in pit moulding where it is used as cope, the pit acting as 'drag'.

Cores

Cores are the materials used for making cavities and hollow projections, which cannot normally be produced by pattern alone. Cores are generally made of sand. During casting, cores are surrounded by molten metal and are subjected to severe thermal and mechanical conditions. There fore core sand should be of higher strength than the moulding sand. Core is set in the mould cavity of the prepared ,ould before closing and pouring. Through holes, recesses, projections, undercuts and internal cavities can be formed using cores.

Types of Cores

Cores can be classified according to the state of the material as

1. Green sand core
2. Dry sand core

Green sand core is formed by the patterns it self when it is being rammed while preparing a green sand mould (Greensand means sand containing moisture). The core is made of the same sand as the moulding sand. Green sand core is weak and can be used only for light castings.

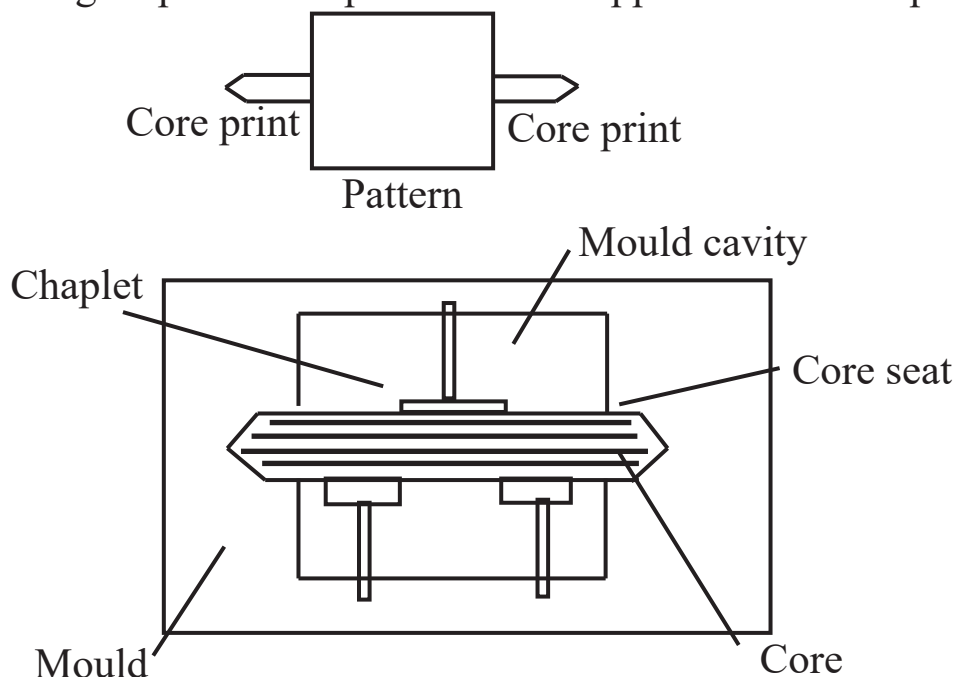
Dry sand core is made seperately by core making process of moulding a green core, drying, baking, finishing, coating etc. They are positioned in the mould, after the pattern is taken out before the mould is closed. These are the most commonly used cores.

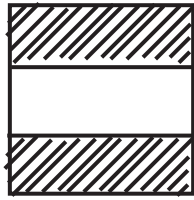
According to the position of the core in the mould, core can be classified as

1. Horizontal core
2. Vertical core
3. Balanced core
4. Hanging core
5. Drop core etc

Coreprints and Coreseats

Coreprints are extra projections provided on the pattern for making depressions in the mould for the placement of the core. The depression made by the coreprint in the mould is called core seat. Cores are placed in the core seats. Coreseats support the core against buoyancy of molten metal. Core prints, though a part of the pattern do not appear on the cast part.





Section of the cast part

Chaplets

Chaplets are metallic supports often kept inside the mould cavity to support the cores. They are made of the same material of the pouring metal. They melt and fuse with the pouring metal during solidification. There are various types of chaplets such as radiator chaplets, rivaled chaplets, double head chaplets, cast chaplets, sheet metal chaplets etc.

Moulding materials

Moulding materials may be classified into two groups basic and auxiliary.

Basic materials include silica sands and binders. Auxiliary materials include various additives which impart desired properties to the moulding and core sands.

A moulding sand consists silica sand grains, binder, additives and water. Silica sand grains form the base of the moulding sand. Binder is the bonding agent in a green sand. Most commonly used binder is clay. clay imparts cohesiveness and plasticity to the moulding sand in the moist state and increase its strength after drying. When moulding sand has proper amount of water added to it to give a high strength with sufficient plasticity it is said to be 'tempered'.

According to the amount of clay present, the moulding sand may be classified as

1. Silica sand : upto 2% clay
2. Lean or weak sand : 2 to 10% clay
3. Moderately strong sand : 10 to 20% clay
4. Strong sand : upto 30% clay
5. Extra strong or loam sand : upto 50% clay

According to the initial conditions and use moulding sand may be classified as

1. Green sand
2. Dry sand
3. Loam sand
4. Facing sand
5. Parting sand

6. Backing sand

Foundry sand containing moisture is known as green sand. Green sand may contain 20 to 30% clay and 6 to 8% water.

Another classification of moulding sand is

1. Natural sand
2. Synthetic sand
3. Chemically coated sand

Natural sand is available from natural deposits. It contains sufficient or slightly more clay content that is required for moulding. So only additives and water need to be added.

Relatively clay free sand having specified grain size is mixed with suitable type of clay additives and water to form synthetic sand.

Clean silica grain are coated with a non thermosetting hydrocarbon resin, which acts as a binder to form chemically coated sand.

Binders

Binders used in a foundry may be organic or inorganic. The most common is inorganic binders. Fire clay, Kaolinite, Illite and Bentonite are the clays used in moulding. The basic constituent which gives refractoriness to a clay is alumina, Al_2O_3 . Bentonite is the most commonly used clay. As it needs only smaller quantity of water to get sufficient plasticity. therefore steam generation during casting is less and moulding sand of low porosity or permeability can be used. Other inorganic binders are Portland cement, sodium silicate etc.

Organic binders are most commonly used in core making. Examples are

1. Cereal binders obtained from wheat, corn etc.
2. Drying oils such as linseed oil, fish oil, soyabean oils and some mineral oils
3. Pitch and molasses

Additives

Additives are small quantities of special materials added to a moulding sand in order to enhance its existing properties and to impart some special properties.

Sea coal, cereals, sand dust, wood flour, silica flour, fuel oil, Iron oxide, dextrin etc are some of the additives used.

Properties of Moulding Sand

The choice of moulding materials is based on their processing properties. The properties that are required in moulding materials are

- 1. Permeability or porosity**

The ability of the sand to allow gases from molten metal and steam and water vapours generated in the mould to pass through it is called permeability. It depends on the size and shape of grains, moisture content, degree of ramming etc.

2. Plasticity or flowability

It is the property of the moulding sand by which it is able to flow around and over a pattern during ramming and to uniformly fill the flask. Plasticity can be increased by adding clay and water.

3. Adhesiveness

The property to adhere with other materials is called adhesiveness.

Adhesiveness between moulding sand and the moulding flasks are required during handling of the rammed boxes.

4. Cohesiveness or strength

The ability of the sand particles to stick to each other is called cohesiveness. In the absence of this property the mould will break when molten metal is poured. This depends upon grain size of sand and clay content.

Green strength is the strength of the sand in green or moist state.

Dry strength is the strength of moulding sand in dry condition.

Hot strength is the strength required to hold the shape of the mould cavity in hot condition. It is above 100°C and the molten metal in the mould is still in liquid state.

5. Refractoriness

The capability of the moulding sand to withstand high temperatures of the molten metal without fusing is known as refractoriness.

6. Collapsibility

It is the ability of the moulding sand to decrease in volume under compressive forces developed by the shrinkage of metal during freezing and subsequent cooling. This is very important for cores. It permits the moulding sand to break easily during its knock out from casting.

7. Fineness

Finer mould sand resists metal penetration and produces smooth surface for the casting. But permeability is reduced by fineness.

8. Coefficient of expansion of the moulding sands should be less.

Forces Acting on the Moulds

When the mould cavity is filled with molten metal it experiences high metallostatic pressures and buoyant forces. As a result moulds may be distorted or cores may be displaced. The effects of these forces can be eliminated by

various methods such as placing weights on cope, clamping cope and drag properly by reinforcing sand mass etc.

The metallostatic force is due to the head acting by the molten metal in the mould cavity

Metallostatic force is given by

$$F_m = Awh$$

Where A = Projected area

w = sp. weight of molten metal

h = head of the molten metal

Upward force on core = displaced volume \times difference in sp.wt

Moulding Process

According to the method used moulding processes can be classified as

1. Bench moulding
2. Floor moulding
3. Machine moulding

Bench moulding is used for preparing small moulds. It is carried out on a bench of convenient height.

In floor moulding, the mould is made in the foundry floor. It is used for making medium and large size castings.

Machine moulding is used in batch and mass production. The moulding production becomes faster and labour is minimised. Moulding machines are classified according to

1. Method of compacting moulding sand and
2. The method of removing the pattern

Squeezer machines, jolt machine and sand slinger comes in the first group.

Straight draw moulding machine and turn over moulding machine are example of second group.

According to the mould materials used moulding process can be classified as

1. Green sand moulding
2. dry sand moulding
3. Loam sand moulding
4. Metallic moulding or permanent moulding
5. Carbondioxide moulding

Green sand moulding is used for small and medium castings. It is simplest and least expensive and requires less time to prepare.

In dry sand moulding the green sand mould is dried before pouring molten metal. Drying or baking is carried out in ovens. Time for baking depends upon the binders used.

Loam sand moulding is used for large castings. Approximate contour of the casting is made by bricks and other materials and a thick coating of loam sand is given inside. Using a sweep pattern, correct contour of the casting is produced.

In carbondioxide moulding, sand is thoroughly mixed with 3 to 5% sodium silicate liquid base binder (water glass $\text{SiO}_2 \text{Na}_2\text{O}$) in a muller. Mould is prepared using the sand mixture by machine or hand moulding. Then CO_2 is forced in to mould at a pressure of about 1.5 Kg/cm^2 for 10 to 30 seconds.

Sodium silicate reacts with CO_2 to form silica gel



Carbon dioxide is expected to form a weak acid, which hydrolises the sodium silicate resulting in amorphous silica, which form the bond. The introduction of CO_2 gas starts the reaction by forming hydrated sodium carbonate. This gelling action increases the viscosity of the binder till it becomes solid. The compressive strength of the bond increases due to dehydration.

Melting and Pouring

After the preparation of moulds, molten metal is poured in to the mould to get the casting. Various type of melting furnances are available for melting metals and alloys. Most commonly used furnances are,

1. Cupola furnance - for melting cast iron
2. Crucible furnance - for melting non-ferrous metals
3. Electric furnance - for melting steel and special alloy steels

Molten metal is poured into the mould through the gating system.

Gating System

All the passages through which molten metal passes before entering the mould cavity is referred as gating system.

Various elements of the gating system are

1. Pouring basin
2. Sprue
3. Sprue base or well
4. Runner
5. Runner extension
6. Choke

- 7. Skim bob
- 8. Gates and / or ingates
- 9. Riser

Pouring Basin

A pouring basin or cup is a reservoir at the top of the vertical passage (sprue) in the cope, where the molten metal is poured. It is used for maintaining the required flow rate, minimize turbulence and to aid in separating dross and slag from the molten metal before it enter the runner system.

Sprue

It is a vertical passage through the cope and connects the pouring basin to the runner or gate. A straight sprue with sharp corners will cause severe aspiration (air sucking) thereby causing turbulence in the molten metal. If a tapered sprue with round corners and dam type pouring basin are used aspiration and turbulence are negligible.

The molten metal when moving from the top of the cope to parting plane gains in velocity and as a consequence requires smaller area of cross section for the same amount of metal to flow. If straight sprue is used metal flow would not be full at the bottom leading to aspiration.

Equations of continuity can be used to find the exact tapering required. Denoting top and choke by 't' and 'c'.

$$A_t V_t = A_c V_c$$

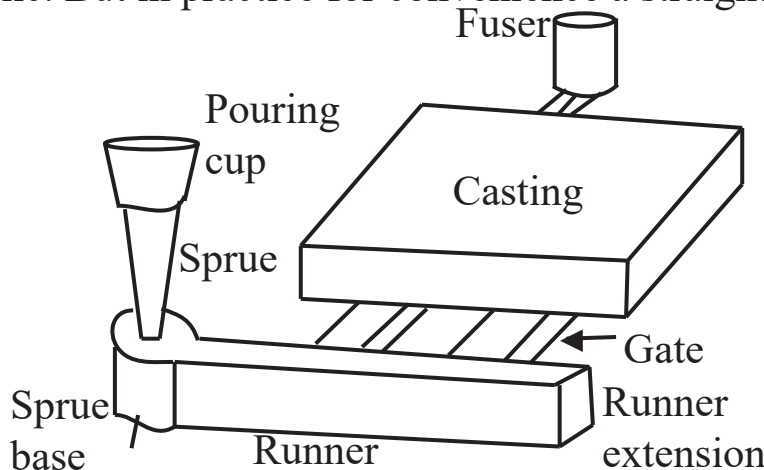
$$\text{or } A_t = A_c \frac{V_c}{V_t}$$

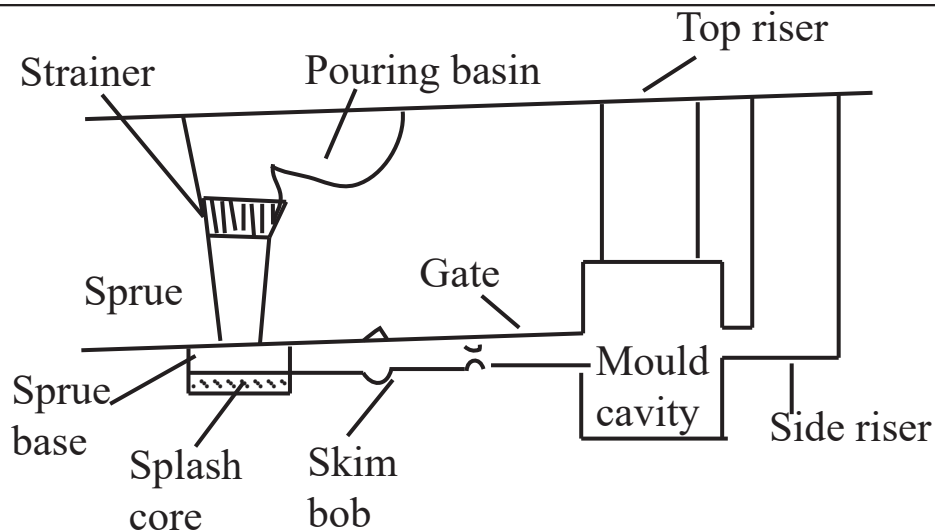
$$\text{But } V = \sqrt{2gh}$$

$$\text{Or } V \propto \sqrt{h}$$

$$\therefore A_t = A_c \sqrt{\frac{h_c}{h_t}}$$

From the above equation it can be seen that the profile of an ideal sprue is parabolic. But in practice for convenience a straight tapered sprue is used.





Sprue Base or Well

Where the sprue joins the runner an enlargement called sprue base or sprue well is provided. The molten metal pool formed at the sprue base prevents excessive sand erosion where the molten metal impinges.

Runners

A runner is a horizontal channel which connects the sprue with the gates. It is generally located in the horizontal, parting plane. Generally these are constructed in a trapezoidal cross section. For ferrous metals, generally runner is provided in the cope portion and in gates in the drag portion. This helps to trap the lighter slag and dross flowing with the molten metal.

Runner Extension

The runner is extended a little further after it meets the ingate. The slag flowing with the molten metal is trapped at the runner extension without going to the ingates.

Skim bob

Skimbob is an enlargement provided in the runner. Its function is to trap impurities such as dross or eroded sand from going in to the mould cavity.

Gates

Gate is a channel which connects runner with the mould cavity. Ingate is the end of the gate where it joins the mould cavity and through which the molten metal is introduced to the mould cavity.

Choke

Choke is that part of the gating system which has the smallest cross sectional area. It helps to lower the flow velocity in the runner, to hold back slag and foreign materials in the runner also minimise the sand erosion.

Gating Ratio

It describes the relative cross sectional area of sprue : total runner area : total gate area.

Depending upon the position of choke, the gating system may be described as

1. Pressurised or choked system
2. Unpressurised or free system

In pressurised system, ingates serve as choke. The total gate area is smaller than the sprue area. So a back pressure is maintained in the system. A gating ratio 2 : 2 : 3 indicates a unpressurised gating system.

Types of Gates

Gates may be classified as

1. Parting line gate
2. Bottom gate
3. Top gate

In parting line gate, metal enters the mould cavity at the parting line. The gate may contain skim bob, skimming gate, shrink bob and whirl gate. Skimming gate is a vertical passage through the cope : Lighter foreign material is trapped in skimming gate. Shrink bob may be provided if there is a tendency for shrinkage defect near the ingate.

Whirlgate employs centrifugal force to aid the slag come to the centre where it rises up in the skimming gate. A bottom gate is provided in the drag portion of the mould. Metal fills in the bottom first and then rises up steady in the mould.

In top gate, metal is poured down directly, into the mould cavity. In this molten metal at the top of the casting is always hot.

Riser

Due to the shrinkage of metal during solidification voids are likely to form in the casting unless additional molten metal is fed in to these places. A reservoir of molten metal is to be maintained from which the metal can flow readily in to the casting when the need arises. These reservoirs are called riser. Riser is a hole cut in cope to prevent the molten metal to rise above the highest point in the casting.

Other functions of the risers are

1. The pourer can see the metal in the mould cavity. If the metal is not seen it indicates that metal is not sufficient or there is some obstruction.

2. It gives passage of steam, gas, air etc.

Directional Solidification

In a casting all parts do not cool at same rate. Some parts solidify more quickly than others. Due to this cavities are formed at certain regions. This cavities should be filled with the molten metal from the risers. For this to happen, the riser should be the last to solidify. So solidification should progress towards the risers from the filled areas. this is known as dirrectional solidification.

Directional solidification can be achieved by the following methods.

1. Proper designing ans positioning of risers
2. Use of padding to increase thickness of certain sections.
3. Use of exothermic materials in risers
4. Use of chills in moulds.

Gating System Design

Bernoulli's theorem can be applied to the molten metal that flows through the gating system. Ignoring frictional loss, law states that

$$h + \frac{p}{w} + \frac{v^2}{2g} = \text{constant}$$

Where h = potential head, m

p = pressure, Pa

v = liquid velocity, m/s

w = specific weight, N/m³

g = acceleration due to gravity, 9.81 m/s²

As the metal enters the pouring basin, it has the highest potential energy with no kinetic or pressure energies. But as the flow proceeds there is frictional head loss and heat loss (heat loss is not represented in the Bernoulli's equation).

The continuity equation which states that

$Q = AV = \text{constant}$ can also be applied

(Q = rate of flow m³/s

A = area of cross section, m²

V = velocity, m/s)

Pouring Time

The duration of time required for complete filling of a mould with molten metal is termed as pouring time. It depends on the casting material, complexity of casting, section thickness and casting size.

High pouring rate means turbulent flow in the mould and mould erosion.

Low pouring rate requires higher pouring temperature. Otherwise the mould cavity may not be filled completely.

Empirical formulae for pouring time for different casting materials are given below :

1. Grey cast iron, mass less than 450 kg

Pouring time,

$$t = k \left[1.41 + \frac{T}{14.59} \right] \sqrt{w} \text{ seconds}$$

Where $k = \frac{\text{Fluidity of iron inches}}{40}$

T = average section thickness, mm

W = mass of casting, Kg

2. Grey cast iron, mass greater than 450 Kg

$$t = k \left[1.236 + \frac{T}{16.65} \right] 2\sqrt{w} \text{ seconds}$$

3. Steel castings

$$t = (2.4335 - 0.3953 \text{ Log } w) \sqrt{w} \text{ secs}$$

Choke Area

It is the area at sprue exit. Choke area can be calculated using Bernoullis equation as

$$A = \frac{W}{d \cdot t \cdot c \cdot \sqrt{2gH}}$$

Where A = choke area, mm²

W = casting mass, Kg

t = pouring time, s

d = density of molten metal Kg/mm³

g = acceleration due to gravity, mm/s²

H = effective metal head (sprue height)

C = efficiency factor - a function of gating system used.

H depends on the casting dimensions and the type of gating used. The following relations can be used.

Top gate , H = h

Bottom gate, $H = h - \frac{c}{2}$

Parting gate, $H = h - \frac{p^2}{2c}$

Where h = height of sprue

p = height of mould cavity in cope

c = total height of mould cavity

Risering Design

Riser is used to feed the casting during solidification so that no shrinkage cavities are formed. The requirement of risers depends to a great extent up on the type of metal poured and the complexity of casting. Various metals have various volumetric shrinkages.

Grey cast iron some times may have a negative shrinkage. This is because with higher carbon and silicon contents, graphitisation occurs which increases the volume and counter acts the metal shrinkage. Risering is not very critical in these situations. But for metals such as aluminium and steel volumetric contraction is very high and risering is very important.

Riser is also called feed heads. Molten metal rises in the riser after the mould cavity is filled up. They are used in heavy section casting or for high shrinkage alloys.

During casting metal shrinkage occur in three stages,

- i) Liquid contraction or shrinkage
- ii) Solidification shrinkage
- iii) Solid shrinkage

First two are classified for risering purposes.

Riser Location

A riser should be located close to each heavier section. It should be located in such a manner that it is the last portion of the casting to solidify.

Types of Risers

Depending upon the location, a riser can be side riser, top riser and end riser. If it is located between runner and casting it is also called live or hot riser as this contains the hottest metal. Top risers and end risers are also called dead risers as these risers fill up with coldest metal and are likely to solidify before casting. A riser can also be an open riser or blind riser.

Blind Risers

A riser which does not break to the top of the cope and is entirely surrounded by moulding sand is known as blind riser. As the rate of cooling is slower it helps directional solidification. Also the rate of cooling is slower it helps directional solidification. Also only a smaller size is required. It's main drawback is the formation vacuum due to the formation of metal skin on the walls. This hinders the metal feeding. To avoid this a permeable dry sand core is used connecting it to the mould sand layers.

Shape and Size of Riser

To help directional solidification the risers should loss heat at a slower rate. Amount of heat content is proportional to the volume and rate of heat dissipation depends upon the surface area. Therefore a riser should be designed for a high V/A (Volume/Surface Area) ratio for a given size. From this point of view a spherical shape is ideal one as it is having the lowest surface area for same volume. But risers of spherical shape is difficult to mould. therefore, a cylindrical shape is preferred. Height of a cylindrical riser is generally taken as $1.5 \times$ diameter of riser.

Riser Size

The solidification time of a casting depends up on the heat in the casting and its dissipation. So it is directly proportional to the volume. And indirectly proportional to the surface area. Based on these facts many relations are available for determining the riser size.

Chvorinov's Rule

Solidification or Freezing Time

$$T = C \left(\frac{V}{SA} \right)$$

Where V = volume of casting

SA = Surface area of casting

C = Constant of proportionality

To achieve directional solidification,

$$\left(\frac{V}{SA} \right)_{\text{Riser}} > \left(\frac{V}{SA} \right)_{\text{Casting}}$$

In practice

$$\left(\frac{V}{SA} \right)_{\text{Riser}} = 1.10 \text{ to } 1.15 \left(\frac{V}{SA} \right)_{\text{Casting}}$$

$\left(\frac{V}{SA} \right)$ for the casting is known.

So $\left(\frac{V}{SA} \right)$ for the riser can be calculated. Assuming height to diameter ratio for a cylindrical riser, its size can be determined.

Caine's Formula

Caine's method of determining the size of a riser is based on the experimentally determined hyperbolic relationship between relative freezing times and relative volumes of the casting and the riser.

Relative freezing time or freezing ratio,

$$X = \frac{\text{Cooling characteristics of casting}}{\text{Cooling characteristics of riser}}$$

$$= \frac{(SA/V)_{\text{Casting}}}{(SA/V)_{\text{Riser}}}$$

Volume ratio,

$$Y = \frac{\text{Volume of riser}}{\text{Volume of casting}}$$

Caine's formula is given as,

$$X = \frac{a}{Y - b} + c$$

Where a = freezing characteristic constant

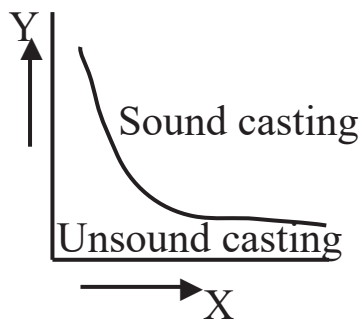
b = Liquid - solid solidification contraction constant

c = Relative freezing rate of riser and casting

Typical values a, b, c for commonly used cast metals are given below.

| Cast metals | a | b | c |
|-------------------|------|-------|------|
| Steel | 0.12 | 0.5 | 1.00 |
| Aluminium | 0.10 | 0.06 | 1.08 |
| Graycast Iron | 0.33 | 0.03 | 1.00 |
| Cast iron, Brass | 0.04 | 0.017 | 1.00 |
| Aluminium, Bronze | 0.24 | 0.017 | 1.00 |
| Silicon Bronze | 0.24 | 0.017 | 1.00 |

A typical Caine's hyperbolic curve is as shown in figure



Caine's curves for different cast metals are available in hand books. To find the riser size for a given casting, the riser diameter and height are assumed. Knowing values of a, b and c the values of X and Y are calculated. Values of X and Y are plotted on the hyperbolic curve. If the values meet above the curve the assumed size is satisfactory.

Modulus Method

Modulus is the inverse of cooling characteristic

$$\text{i.e, modulus} = \frac{V}{SA}$$

It has been empirically established that if the modulus of the riser exceeds the modulus of casting by a factor 1.2, the feeding solidification would be satisfactory.

It is generally preferable to choose a riser with height to diameter ratio = 1

$$\text{In such cases, Volume} = \frac{\pi D^3}{4}$$

$$\begin{aligned} \text{Surface area} &= \frac{\pi D^2}{4} + \pi D^2 \\ &= \frac{5}{4} \pi D^2 \end{aligned}$$

$$\text{Modulus of riser, } M_R = \frac{\pi D^3}{4} / \frac{5\pi D^2}{4} = 0.2D$$

$$\text{Since } M_R = 1.2 M_C$$

$$D = 6 M_C$$

Thus in this method, calculation of riser is very much simplified.

Cooling and Solidification

When a molten metal starts to cool and solidify crystals will begin to form independent of one another, at different locations in different orientations within molten mass. The formation of the first tiny particle is called nucleation. With passage of time these tiny particles (crystals) grow in size or grain growth takes place. When the cooling is rapid the pattern of grain/crystal growth is in the shape of radial arms which begin to develop from the various nuclei. As time progresses secondary arms develop at right angles to the radial arm and the process continues. This type of tree like crystals are called 'dendrites'. When cooling is slow equiaxed crystals grow uniformly in all directions. Crystal grows until it comes into contact with adjacent crystal of proper geometrical form and different orientations. The boundary formed between two adjacent crystal line growth because of different orientations of the grains is known as grain boundary.

Solidification in a Casting Mould

When molten metal is poured in to a mould solidification will be rapid along the mould walls. In this chill zone, a layer of fine, polly crystalline, equiaxed grains will be produced. As the solidification progress the grains growth will be inwards, towards the centre, their lateral growth reduced due to the early

contact made with the adjacent crystals. Here columnar, dendrite crystals are formed leading to the formation of a mushy zone. The width of the mushy zone depends upon the mould material, cooling rate and temperature gradient. As the heat extraction continues through out the mass, simultaneous freezing of the metal at the centre of the mould takes place. Here equiaxed coarse grain can be extended throughout, without formation of dendrites, by the addition of inoculants (nucleating agents) to the liquid alloy. Ferro-silicon, Ferro-manganese, ferro-Chromium, Ferro-silicon-chromium etc are the inoculants used.

Types of Solidification

i) Skin forming

Skin forming takes place when molten metal is solidified in moulds, in the case of pure metals or alloys having eutectic compositions. Since the mould walls are at room temperature, solidification first starts near the mould walls. The solidification front will move towards the centre, and layer by layer solidification takes place.

ii) Dendritic growth

Dendritic growth will happen if a mushy zone appears during solidifications. Initially solid is nucleated near the boundary and the solidification front moves towards the centre. Solid is also nucleated in the liquid region and the solidification front movement in this case is towards the centre and to the primary dendrite. In this case unidirectional solidification does not take place. Micro voids are formed at the meeting point of primary and secondary dendrites. These voids cannot be compensated by the riser. This results in defective casting.

Segregation

When a liquid alloy metal cools and solidifies the separating out of the constituent elements of different freezing points is called segregation. Various types of segregation are, micro segregation, macro segregation, normal segregation and gravity segregation.

Casting Defects

In a casting various defects may occur due to various reasons. It may be due to improper pattern design, improper mould construction, improper melting practice, improper pouring etc. The defects may be broadly classified as

1. Gas defects
2. Shrinkage cavities

3. Moulding material defects
4. Pouring metal defects
5. Metallurgical defects
6. Moulding and corebox defects

Gas Defects

These are due to lower permeability of the mould. Blow holes and open blows, air inclusions and pinhole porosity etc. come under gas defects.

Blow holes and open blows spherical, flattened or elongated cavities present inside the casting or on the surface. If they are on the surface they are called open blows. Moisture in the mould will be converted into steam due to the heat of the molten metal. A part of the steam may be entrapped in the casting. This leads to the formation of blow holes. Lower venting and lower permeability of mould also causes formation of blow holes and open blows.

Air Inclusion

Atmospheric and other gases are absorbed by the molten metal at high temperatures in the furnace, during pouring or in the mould. If they are not allowed to escape, they will be trapped inside the casting.

Pinhole Porosity

This is due to the presence of hydrogen in molten metal. During solidification of the molten metal hydrogen leaves the metal causing small diameter and long pinholes.

Shrinkage Cavities

Shrinkage cavities are formed during solidification of the molten metal, if feeding by risers are not proper or if the casting design is not proper.

Moulding Material Defects

Lack of the required properties of moulding materials improper ramming etc will lead to defects such as scabs, swell, runout and drop.

Scab

Scabs are projection formed on the casting. This occurs when a portion of the mould face lifts and metal flows underneath in a thin layer. If it happens due to the expansion of surface layer of sand it is called expansion scab. Scabs occur due to uneven ramming, excess moisture in sand etc.

Run Out

Runout is the escape of molten metal from mould cavity. Faulty moulding

flask or faulty mould making may lead to this.

Drop

Drop occurs when cope surface cracks and breaks. Pieces of sand fall into molten metal. Low green strength of sand, improper ramming of cope etc are the causes.

Cuts or Washes

Cuts or washes appear as low projections and areas of excess metal caused by erosion of moulding sand by the flowing molten metal. It usually occurs with bottom gating castings, when too much metal is made to flow and the moulding sand has insufficient hot strength.

Pouring Metal Defects

Misrun, cold sheet, poured etc are pouring metal defects.

Misrun

This happens when the metal is unable to fill the mould cavity completely leaving unfilled cavities. This may happen due to lack of fluidity or due to obstruction in flow.

Cold Shut

This is caused when two metal streams coming from different directions while meeting in the mould cavity do not fuse together properly. Due to this, continuity or weak spot in the casting is formed.

In these sections, improper gating system, slow and intermittent pouring, poor fluidity of metal etc may cause misrun or cold shut.

Poured Short

If the mould cavity is not completely filled due to insufficient metal, this happens.

Metallurgical Defects

Hot Tears

Occur due to hindered contraction of casting parts immediately after the metal solidification. Main reason is poor casting design.

Hardspots

This happens in metals such as gray cast iron with sufficient silicon. Such metals may become hardened by the chilling effect of moulding sand. Hardspots make machining of the metal difficult.

Mismatch or Mould Shift

This is due to mismatch of cope and drag flasks at the parting line. The worn out or loose dowels in the pattern halves, inexact assembly of mould halves etc are reasons. Core shift occurs due to the misalignment of core halves during assembly.

Flashes or Fins

Flashes or fins appear at the mould joints where gaps are formed. This may be due to wear or wrapping or improper fastening of the cope and drag.

Buckles and Rat Tails

Buckle is a broad vee shaped depression appearing on the face of casting. It extends in a fairly straight line across the entire flat surface. It results from the sand expansion carried by the high temperature molten metal, when sand has insufficient hot deformation. It also happens in the design with too large flat surfaces in the mould cavity. Rat tail is a defect similar to buckle, happening due to same reasons, but the shape of the defect is different. Rat tail is not shaped as a broad vee. Buckles are the rat tails which are severe.

Swell

Swell is a slight, smooth bulge appearing on vertical walls of a casting. This is caused by liquid metal pressure at areas of low mould strength, due to improper ramming or too high water content.

Design of Castings

The design of a cast part should be such that the design should ensure high level of its working characteristics such as strength, rigidity, stiffness, lightness and corrosion resistance. Proper attention to design aspects will minimize casting problems and lower the costs.

The design of the casting should be such that it allows directional solidification. Product design should be studied under the following categories.

1. design for economical moulding
2. Design for elimination of defects
3. Design for features to help handling of castings.

The following factors should be taken into account while designing a casting.

1. Function of the casting
2. Selection and optimum use of the casting alloy
3. Strength of the casting

4. Simplification of foundry practices
5. Consideration of safety aspects
6. Economy of production

A few of the rules in design are

1. Stress concentration should be avoided. For thin, sharp corners and frequent use of fillets etc should be avoided.
2. All members should have uniform sections as far as possible. Abrupt changes in sections should be avoided.
3. Large flat surfaces should be avoided because it is difficult to get true surfaces on large castings.
4. Pattern allowances should be provided.
5. By providing curved shapes, contraction stresses should be minimized (example - arm of pulleys and wheel).
6. Stiffening members such as webs and ribs should be minimum as these give rise to defects like hot tears and shrinkage.
7. Deep and narrow pockets in the casting should be avoided to minimize cleaning costs.
8. Vertical walls should be as smooth as possible for easy withdrawals of patterns (markings such as names or numbers etc on vertical walls should be avoided).
9. Tolerance should be provided depending up on the dimensional accuracy desired.

Special Casting Processes

Sand casting processes give fairly good results at lowest cost. Main drawback of sand casting is that the moulds are single use types. If in its place a permanent mould could be used there is considerable saving in time and labour cost. Also surface finish and accuracy is poor in the case of sand casting. To overcome this a number of special casting processes are developed. Some of the widely used casting processes are,

- i) Shell moulding
- ii) precision investment casting
- iii) Permanent mould casting
- iv) Die casting
- v) Centrifugal casting
- vi) Squeeze casting

Shell Moulding

It is a modification of sand moulding process. In this process thin, shell type half moulds are made using a mixture of dry silica sand and phenolic resin.

The sand is mixed with either urea or phenol formaldehyde in a muller and transferred to a dump box. Pattern made of metal is heated to 205 to 230°C and placed over the dump box and clamped. When the dump box is inverted the sand resin mixture falls over the hot patterns. The resin melts and acts as bond between sand grains at the surface of the pattern. After 30 seconds a hard and thin layer sand is formed over the pattern. Then the dump box is brought to the original position. The excess sand falls back. Pattern with thin shells is cured at 315°C for 2 minutes. The shell is then ejected by ejector pins and removed. Similarly shell is made for the other half also. These shells are assembled in a flask with backing sand to form the mould.

High dimensional accuracy and good surface finish are the main advantages. The shells can be stored for a long time.

High cost and requirement of specialized equipments are the main disadvantages.

Precision Investment Casting (Low Wax Method)

The term 'investment' refers to the layer of refractory material with which the pattern is covered to make the mould. Like sand casting method mould is destroyed every time a casting is made.

Shell moulding also is a precision investment casting method, through lost wax method is generally referred as precision investment casting.

In lost wax method a wax pattern is used. Wax pattern is melted from the mould, leaving the cavity.

In this method a master pattern is prepared using steel or brass. Using this pattern split mould is made with bismuth alloy or lead alloy. This mould is used for making wax pattern. Several wax patterns are assembled with necessary gates and risers. This assembly is dipped in a refractory slurry and refractory fine sand is sprinkled over it to ensure smooth surface for the casting. After the primary casting has dried sufficiently a final investment layer consisting of coarser and less expensive slurry is applied. The common refractory used is silica. The binder is of gypsum or water based sodium silicate. After the investment material is set the mould is placed upside down and heated to melt out the wax. The shell produced is used as mould for

casting. The final moulds can be made as solid type or shell type. In solid type, the shell is placed in a flask and a hard setting moulding material is poured. For shell type moulding dipping in slurry is continued till sufficient thickness is obtained.

Permanent Mould Casting

In permanent mould casting the mould can be used repeatedly. Permanent moulds are also called dies. In this method gravity feeding of molten metal is used. So this method is also known as gravity diecasting. This method is generally used for non-ferrous metals and alloys such as Al, Mg, Zn, Cu-alloys, Sn, Pb etc. A permanent mould is made up of two parts-one stationary and the other moving. Two common designs are

- i) Hinged type or book type
- ii) Straight line retractable type

For making hollow portions, cores are to be used. Cores can be made of metal or sand. Metal cores can be used repeatedly. But complex shapes cannot be used. When sand cores are used, the process is called semi-permanent moulding.

Die Casting

Die casting involves the preparation of components by injecting molten metal at high pressure into metallic die. Unlike in permanent mould casting or gravity die casting, metal is fed under pressure. So this process is also called pressure die casting. Narrow sections complex shapes and fine surface details can easily be produced as high pressure is used in this method. The stationary part of the die is called the cover die and moving part is called the ejector die. Lubricant is sprayed on the diecavity manually or by auto lubrication system to avoid sticking of the casting in the die.

Die casting machines are of two types :

1. Hot chamber die casting
2. Cold chamber die casting

In hot chamber die casting machine the melting unit of metal forms an integral part of the machine.

In cold chamber machine metal is melted in a furnace outside and transferred to the cylinder of the machine from where it is forced into the mould by means of the plunger.

Advantages of die casting are,

1. Very high production rates are possible

2. Thin complex section can be cast
3. Close dimensional control can be maintained.

Vacuum Die Casting

Air trapped in the dies when they are closed is a major problem die casting. This also causes a back pressure when molten metal is injected in to the mould. This problem is solved in vacuum die casting. As air is evacuated after closing the die, metal enters in to the die much faster. As a result fill time is reduced and blisters are avoided.

Low Pressure Die Casting

In low pressure die casting molten metal in a crucible rises to the mould through a riser tube dipped in the molten metal when low pressure in the range of 0.3 to 1.5 bar is applied to the molten metal. Since metal enters the mould slowly compared to die casting with less turbulence the casting quality is improved eliminating the defects.

Centrifugal Casting

In centrifugal casting process, the mould is rotated and the molten metal in the mould is acted up on by the centrifugal force. Due to this molten metal is distributed to the periphery of the mould cavity. Centrifugal casting process is classified as

1. True centrifugal casting
2. Semi-centrifugal casting
3. Centrifuging process

In true centrifugal casting process, the axis of rotation of the mould coincides with the axis of casting and due to the centrifugal force molten metal is thrown out uniformly to the periphery of the mould cavity. In this case no core is required for making a concentric hole. Centrifugal casting can be used for the production of cast iron pipes. The finished flask rammed with sand inside, with the required contour and end details, is rotated on rollers. The amount of molten metal poured determines the thickness of the pipe to be cast.

The mechanical properties of centrifugally cast objects are better compared to the other processes because impurities such as slag and oxides get segregated towards the centre. This can be removed easily by machining.

In semi-centrifugal casting the mould is rotated about the vertical axis and metal is poured in to central sprue where it first enters the hub and then

moves outwards to the periphery by centrifugal force. If central hole is required, a core is to be provided. Rotating speed is lesser than that is true centrifugal casting. For high rates of production, moulds can be stacked one over the other and molten metal can be fed through a common central sprue.

Centrifuging process is similar to semi-centrifugal casting process. Metal is fed through a central sprue and the moulds rotated. The main difference is that in the case of centrifuging the axis of the mould is not same as axis of rotation. Here identical small moulds are arranged in a circle which are connected through radial gates from the central sprue.

Continuous Casting

Continuous casting process consists of pouring into a short vertical metal die or mould at a controlled rate, cooling the melt rapidly and withdrawing the solidified product in a continuous length from the bottom at a rate consistent with the pouring rate. Using continuous casting process, slabs, billets and blooms can be directly cast with going through the rolling of ingot in various stages to obtain the products. The skin formed in the water cooled mould is further solidified by intensive cooling with water sprays as the casting moves forward.

Squeeze Casting

In squeeze casting the casting is solidified under high pressure. The product quality is greatly improved. Shrinkage cavities, dissolved gases etc eliminated at high pressures. It is a combination of casting and forging. Molten metal is poured in to a die. pressure is applied on this metal with a punch which is having the inner contour of the product.

Metal Forming processes

metal forming processes or mechanical working processes are based on permanent changes in the shape of body or plastic deformation under the action of external forces. Mechanical working processes include rolling, forging, extrusion, drawing and sheet metal working. Sheet metal working is also known as press working. The stresses induced in the part are greater than the yield strength but less than the fracture strength expect in sheet metal operations. In sheet metal operations such as shearing, piercing, blanking etc stress induced are greater than or equal to the fracture strength.

Machining or metal cutting operations are not included in the forming processes. In machining operations material is removed from the part in the form of chips. But in mechanical forming processes there is no material loss.

Recrystallisation Temperature

During deformation, metal flows plastically and the shapes of grains are changed. If the deformation is carried out at high temperature, new grains are formed in the metal. The process of formation of new grains is known as recrystallisation. The temperature at which formation of new grains is complete is known as recrystallisation temperature. Plastic deformations of a metal above the recrystallisation temperature but below the melting temperature is known as **hot working**. And plastic deformation below the recrystallisation temperature is known as **cold working**.

Under the action of heat and force, atoms reach high energy level, new crystals start forming during the recrystallisation. Recrystallisation destroys old grain structure deformed by mechanical working and entirely new crystals, which are strain free are formed. Recrystallisation temperature is defined as the approximate minimum temperature at which complete recrystallisation of a cold worked metal occurs within a specified time.

Recrystallisation temperature generally varies between one third and half the melting point for most of the metals.

For lead and tin minimum recrystallisation is below the room temperature. For Cadmium and Zinc it is at the room temperature. For iron it is 450°C.

Cold Working

Advantages

1. Strength and hardness of the metal is increased due to strain hardening.
2. As no oxides are formed on the surface, good surface finish is obtained.
3. Dimensional accuracy achieved is better.
4. It is easier to handle cold parts and is economical for smaller sizes.

Disadvantages

1. The amount of deformation that can be given is limited due to the higher yield strength and also due to strain hardening.
2. Brittle materials cannot be cold worked.
3. Possibility of crack formation and propagation is great.

Hot Working

Advantages

1. Since there is no strain hardening any amount of working can be imparted.
2. Even brittle materials can be hot worked.
3. Only lesser force is required for hot working.

4. A favourable grain size can be attained at controlled working conditions. So better mechanical properties can be achieved.

5. Blow holes and porosities are eliminated by welding action at high temperature and pressure.

Disadvantages

1. Some metals cannot be hot worked because of their brittleness at high temperature.
2. Poor surface finish due to scaling.
3. because of thermal expansion dimensional accuracy is hard to achieve.
4. Handling and maintaining of hot metal is difficult and troublesome.
5. Surface decarbonisation in steels reduces strength and hardness of the surface.

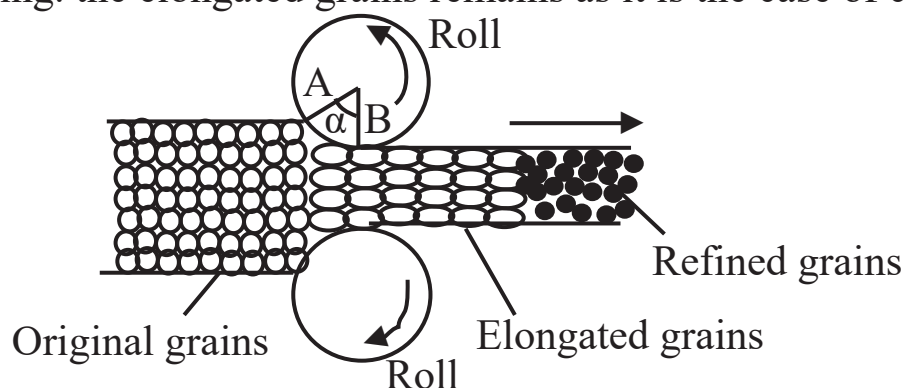
Rolling

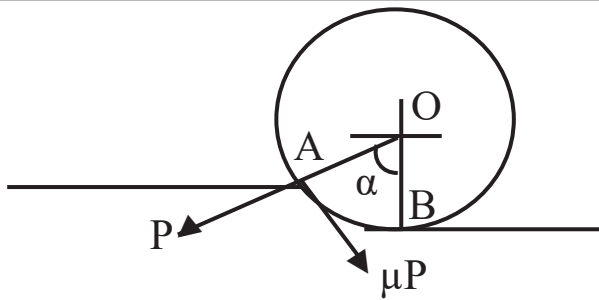
The process of shaping metals and alloys into finished or semi finished conditions passing between circular or contoured rotating cylinders (rolls) is called rolling. The metal is drawn in to the opening between rolls by frictional forces between metal and roll surface. The work piece is subjected to high compressive forces and is partially deformed.

Rolling is done in both hot and cold. the starting material is cast ingots. These are rolled to blooms, billets and slabs initially and then hot rolled to plates, sheets, rods etc.

In the rolling process the metal is passed through two rolls rotating in opposite directions at a uniform peripheral speed. The space between the rolls can be adjusted to obtain the desired thickness of the rolled product. The work piece comes out of the rolls with reduced thickness, but its width and length is increased.

In the rolling process, because of the squeezing, the grains are elongated in the direction of rolling and the velocity of metal is higher than that at the entry. After the stress zone, the elongated grains start refining in the case of hot rolling. the elongated grains remains as it is the case of cold rolling.





The metal contacts each of the rolls along the AB. The angle (α) made by the arc at the centre of the roll is called angle of bite or angle of contact. At the moment of bite two forces act on the metal, normal force P and tangential force μP , where μ is the coeff of friction. If the horizontal component of the resultant normal force P and frictional force μP is directed in the direction of rotation, the work piece will be dragged in the same direction. In the limiting case,

$$P \sin \alpha = \mu P \cos \alpha$$

$$\text{Or } \mu = \tan \alpha$$

$$\text{Or } \alpha = \tan^{-1} \mu$$

If α is greater than $\tan^{-1} \mu$, the work piece will not be passing through the rolls, without aid of external forces.

In hot rolling the primary purpose is to reduce the section. So the value α and hence μ will be maximum. The roll surface can be roughened to increase the value of μ . This process is called ‘ragging’. In the case of cold rolling, rolling loads are high and value of μ will be smaller.

During the plastic deformation of metal it can be assumed that the volume passing per unit time constant. So it can be stated that

$$V_0 h_0 b_0 = V_1 h_1 \text{ and } b_1$$

Where V , h and b are velocity, height and breadth respectively.

But $b_0 \approx b_1$

$$\text{So } V_1 = V_0 \frac{h_0}{h_1}$$

As $h_0 > h_1$, $V_1 > V_0$

If V_r is the velocity of the roll $V_1 > V_r > V_0$

$\frac{V_1 - V_r}{V_r} \times 100$ is called forward slip.

and $\frac{V_r - V_0}{V_r} \times 100$ is called backward slip

In the deforming area between the rolls velocity of metal is changing from V_0 to V_1 . At a particular section this equal to V_r , the velocity of roll. This section is called neutral or no slip section.

Other parameters are

Absolute draught $\Delta h = h_0 - h_1$ mm

Relative draught $\frac{\Delta h}{h_0} \times 100$

Absolute elongation $\Delta l = L_1 - L_0$ mm

Coefficient of elongation $= \frac{L_1}{L_0}$

Absolute spread $= b_1 - b_0$ mm

% of cold work $= \frac{A_0 - A_1}{A_0} \times 100$

where A = area of cross section

It can be shown that $\cos \alpha = - \frac{h_0 - h_1}{D}$

or $\cos \alpha = 1 - \frac{\Delta h}{D}$

where α = angle of contact

D = diameter of the roll

Maximum possible draught $\Delta h_{\max} = \mu^2 R$

Where $R = \frac{D}{2}$

Rolling Mills

A set of rolls assembled in a housing is called a rolling stand. A rolling mill may contain one or more rolling stands. A rolling mill is a place where metal rolling is done on rolls and other auxiliary operations are performed.

Classification of Rolling Mills

1. Classification based on number of rolls in the stand.
2. Based on products rolled.
3. Based on arrangement of rolling stands.

Based on no. of rolls in the roll stand it can be two high, three high, four high, multi roll universal rolling mill and planetary rolling mills.

Based on products, it can be blooming and slabbing mills, billet mills, rail and structural mills, rod mills, plate and sheet mills, seamless tube mills etc.

Based on arrangement of rolling stands, it can be looping mills cross country mills, continuous mills etc.

Roll Passes

Bars, rods and special purpose sections (I beam, channels, rails etc) are rolled between grooved rolls. The grooves cut on mating rolls will form passes through which the metal is passed to get the required cross section. Before

getting the final stage the work passes through many passes. Roll passes are classified as

1. Break down or roll down or roughing passes
2. Leader passes
3. Finishing passes

Break down passes are intended to reduce the cross sectional area.

Leader passes gradually brings the cross section near to the final shape.

Finishing pass is for the final or the required cross section.

Rolling Defects

Defects found in rolling process are

1. Wavy edges
2. Spread
3. Crocodile neck
4. Surface defects
5. Edge cracks

Wavy edges result from roll bending. the strip becomes thinner along edges corresponding to the centre thickness. As free expansion is restrained, buckling occurs. If the width to thickness ratio of plates and sheets are smaller, width increases considerably in the roll gap. This is called spreading.

If the plate is weak at the centre, sheet bifurcates into two causing neck formation. This is called crocodile neck. Presence of impurities such as scale, rust, dirt in hot bloom, billets or slabs causes surface defects in the rolled products. Limited ductility of the metal or uneven deformation at edges will cause edge cracks.

Example : A stock of thickness 30 mm is to be rolled to 10 mm in a single stage. Calculate the minimum diameter of the rolls, if the maximum angle of bite is 40° . Find also the required coefficient of friction.

Solution : $\Delta h = h_1 - h_2$

$$30 - 10 = 20 \text{ mmm}$$

$$\alpha = 40^\circ$$

Forging

Forging is the process of shaping a material under compressive forces in dies by plastic deformation normally after heating. The material is heated to a temperature at which its elastic properties entirely disappear and obeys the laws of plastic flow, following the directions of least resistance when

deformed under pressure.

Forging enhances mechanical properties of metals and improves the grain flow due to which strength and toughness of the forged component is increased.

Forging temperature of some common metals are given below.

| Material | Forging starting | Temperature finishing |
|-----------------------|------------------|-----------------------|
| Mild steel | 1300 | 800 |
| Wrought iron | 1275 | 900 |
| Medium carbon steel | 1250 | 750 |
| High carbon steel | 1150 | 825 |
| Copper, brass, bronze | 950 | 600 |
| Al and Mn Alloys | 500 | 350 |

Basic Forging Operations

- 1. Upsetting :**Upsetting is the process of increasing the cross sectional area of the stock at the expense of its length by application force in the direction of its length axis.
- 2. Drawing down :** Drawing down is the operation of reducing thickness of the stock to increase its length. Force is applied in a direction perpendicular to the length axis. Thickness is reduced at the end of the stock. Also known as cogging.
- 3. Fullering** is the operation reducing thickness of a stock between ends, at a central place. This is done with the help of tools called fullers.
- 4. Edging or rolling operation** is to distribute the metal longitudinally from a thick portion to a portion where material is deficient.
- 5. Heading** is an upsetting operation where thickness is increased only at on end.
- 6. Blocking :** It is a forging operation in which the work piece is obtained its general shape, prior to its final shape.
- 7. Piercing** is the operation done with the help of punch to obtain blind or through holes in the metal.
- 8. Punching** is the operation of shearing out a slug in a forging to produce a hole.
- 9. Swaging** is the operation of reducing the cross sectional area of a circular piece by rotating it and giving fast impact blows. Bending, flattening, cutoff coining etc are other forging operations.

Forging Processes

Forging processes can be classified in to two groups.

1. Open die forging
2. Closed die forging

Open Die Forging

In open die forging the work piece is struck or pressed between two flat surfaces. This process is used when the components to be forged are only a few. Flat-die forging is another name of open die forging. Open die forging can be further classified as

1. Hand forging
2. Power forging
3. Hammer forging
4. Press forging

Hand forging or Smith forging is usually done in a black smith's hearth with the help of small hammers and anvil, to produce small number of light forgings.

Power forging is used for producing large components which cannot be forged by hand. Machines which work on forging by blow are called hammers, while those working by pressure are called presses. Hammers can be mechanical, pneumatic, steam or air hammers.

Closed Die Forging

In closed die forging cavities or impressions are cut in the die block, where metal is forced to take the final shape. The dies can be single impression type or multi impression type.

Impression-die forging is used to make complex shapes of products with greater accuracy. After forging the product should be trimmed to remove flashes.

Types of Forging

The four types of forging methods generally used are

1. Smith forging
2. Drop forging
3. Press forging
4. Machine forging

In drop forging closed type dies and drop hammers are used. Using drop hammers repeated blows are given to the material in the die cavity.

In press forging the dies are similar to that of drop forging. But instead of repeated blows by hammer a single continuous squeezing action is given to the material by means of hydraulic presses. Because of the continuous action the material gets uniformly distributed through the cavity.

Machine forging is also known as upset forging as the operation involved is upsetting. Upsetting machines are also called upsetters. Upsetters were originally developed for making bolt heads in a continuous fashion. Now gear blanks, shafts, axles and similar parts are also produced using machine forging. Upsetting machines are generally horizontal acting.

Defects in Forged Parts

Defects may occur in forged parts due to various factors such as forging process, improper heating, incorrect die design, uneven cooling after forging etc. Defects are similar to those in casting. these are mismatch, scale pits, cold shunts or Laps, unfilled section, cracks, fins and rags etc.

Extrusion

Extrusion is the process by which a block of metal is reduced in cross section by forcing it to flow through a die orifice under high pressure. High pressure is applied by hydraulic press or mechanical press.

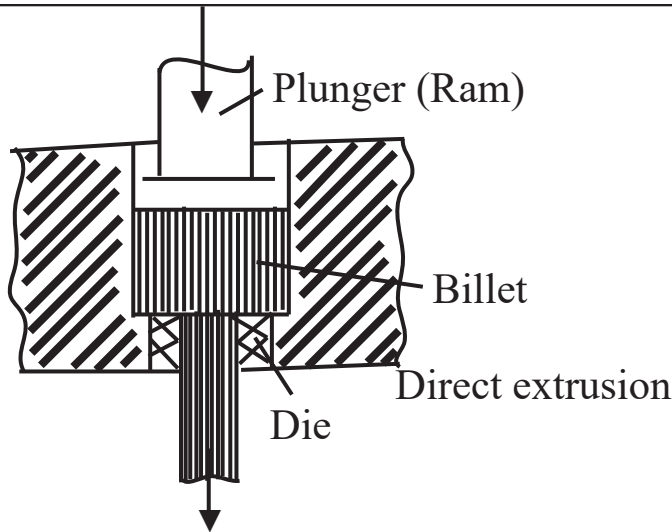
Extrusion process can be hot extrusion or cold extrusion depending up on the temperature at which the extrusion is done.

based on the direction of flow of metal and application of force extrusion can be classified as

1. Direct or forward extrusion
2. Indirect or backward extrusion
3. Impact extrusion
4. Side extrusion
5. Tube extrusion

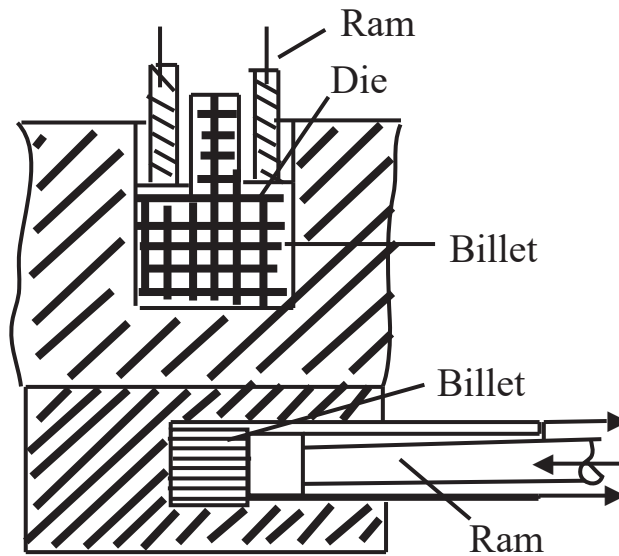
Direct or Forward Extrusion

In this case the billet is placed inside the container and force through the die with the help of pressure applied by a hydraulic driven ram.



Indirect or Backward Extrusion

It is similar to the direct extrusion except that the extruded part is forced through the ram stress. The deformed metal flows through the die opening in the direction opposite to that of ram motion.



In indirect extrusion, the billet inside the cylinder has no relative motion with the cylinder. So there is no friction between cylinder and billet. Therefore power required for indirect extrusion is less compared to direct extrusion. But the long hollow ram is required and this limits the loads that can be applied.

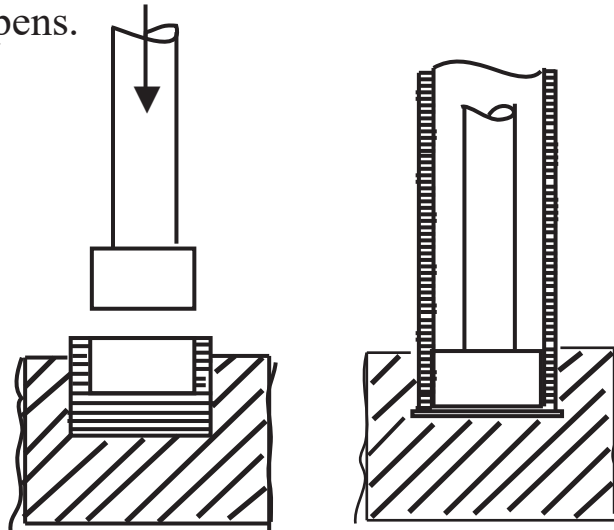
Impact Extrusion

It is a cold-chamber extrusion process used for soft metals (like aluminium). It can be backward or forward. In backward impact extrusion, metal flows in reverse direction of the plunger. The flowing metal is guided only initially. Afterwards it moves by its own inertia. Impact extrusion is carried out at higher speeds. The punch strikes a single blow with considerable force causing the metal to squirt up against the punch.

Application of impact extrusion process are in the manufacture of

collapsible tubes for tooth paste, ointments, shell cases, capsules etc.

Combined forward and backward extrusion can be used to produce complex shapes. In the same stroke of the plunger backward and forward extrusion happens.



Backward impact extrusion

Side Extrusion

In side extrusion the movement of the material is in a direction perpendicular to that of the ram motion. In this case the force required is very high and therefore mostly used for non-ferrous metals or highly plastic materials.

Tube Extrusion

Extrusion is one of the methods for producing seamless tubes. It is a form of direct extrusion but a mandrel is used to form the inside of the tube. After placing the billet inside the cylinder, die containing the mandrel is pushed through it. When force is applied on the press stem it advances extruding the metal through the die and around the mandrel forming the seamless tube.

Hydrostatic Extrusion

Hydrostatic extrusion is a cold extrusion process, in which billet is surrounded by a working fluid, which is pressurised by ram. To provide the extrusion force, friction between billet and container is eliminated in this case and this makes it possible to extrude very long billets.

Extrusion ratio is defined as the ratio of cross sectional area of the billet to the cross sectional area of the product.

Extrusion Pressure

Estimation of extrusion pressure in many cases is done with the help of empirical relationships. One such relation for calculating maximum pressure of backward extrusion of carbon steel is

$$P = T \left[3.45 \ln \frac{A_0}{A_b} + 1.15 \right] \text{ kW/mm}^2$$

Where T = upper yield point, kN/mm²

A₀ = cross sectional area of extruded component

A_b = cross sectional area of billet

The above expression is valid for extrusion ratios varying from 1.65 to 4.25 using billets with 0.6 length to diameter ratio.

Another expression for extrusion is

$$\text{Extrusion force} = kA_1 \ln \left(\frac{A_1}{A_f} \right)$$

Where k = extrusion constant

A₁ = initial area of cross section

A_f = final area of cross section

Drawing of Wire, Rod and Tube

Drawing is a cold working process, used to reduce the diameter of wires, rods and tubes by drawing through a tapered hole in a die.

Wire is made by cold drawing of hot rolled wire rod through one or more dies. Metals below 16 mm diameter are handled in coil form. The end of the rod or wire to be drawn is made pointed by swaging or hammering so that it freely enters the die orifice and sticks out behind the die. This end is gripped by jaws of a gripper and pulled. Under the tensile force material inside die undergoes deformation and its cross sectional area is reduced.

In rod drawing the product is to be straight. Maximum length of the rod that can be drawn depends upon the maximum travel of the carriage which pulls the rod through the die. Before drawing the rod is to be cleaned to remove scales etc. This is done by acid pickling. After pickling the metal is washed well and conditioned by sulling, coppering, phosphating, liming etc to have proper lubrication.

In sulling or yellowing the blank is given a thin coating of iron hydroxide Fe(OH)₃, which combines with lime to serve as a filler for the lubricant. Phosphating consists of applying coating of phosphates of Mn, Fe, Zn. Lubricant sticks to the phosphates coatings. In coppering the metal is dipped in a weakly acidified solution of copper sulphate. In liming the metal is dipped in a boiling lime solution. Acid remains are neutralized by liming and forms as a carrier for lubricant. Before drawing the metal is dried above 100°C. A suitable lubricant is applied on the dry surface. Drawing lubricants used are

mineral and vegetable oils, animal fats, graphite, certain emulsions etc. Considerable heat is generated during drawing. Water is circulated around the die to remove heat.

Tube drawing also is similar to the other drawing processes. The main difference is that a mandrel is used to form the internal hole.

Degree of Drawing

Degree of drawing is measured as the reduction of area (RA), which is the ratio of the difference in cross sectional area before and after drawing to the initial cross sectional area.

$$\text{i.e. RA} = \frac{D_i^2 - D_o^2}{D_i^2} = 1 - \left(\frac{D_o}{D_i}\right)^2$$

Defects in Wire Drawing

In wire drawing operations the following defects are observed

1. Bulge formation
2. Internal cracks
3. Surface defects
4. Seams

Bulge formation occurs in front of the die due to high die angle and low reduction.

Internal cracks or central burst occur due to increase in die angle or increase in the amount of impurities. It decreases with increasing drawing ratio and friction.

Surface defects occur due to inadequate lubrication and improper selection of drawing methods.

Longitudinal scratch or fold in materials is called seams.

Drawing Force

Force required for drawing under frictionless conditions is given by the following expression

$$F = Y_{av} A_f \ln \left(\frac{A_o}{A_f}\right)$$

where A_o = original area of cross section of the wire or rod

A_f = final area of cross section

Y_{av} = average true stress of the material in die gap

Maximum reduction in diameter

$$R = 1 - \left(\frac{D_f}{D_o}\right)^2 = 1 - \left(\frac{1}{1+B}\right)^{1/B}$$

Where D_f = final diameter

D_o = original diameter

$$B = \frac{\mu}{\tan\alpha}$$

Where μ = coefficient of friction

α = semi die angle

Hot Drawing and Cupping

This is another method of producing tubes and cylinders. A thick metal blank of circular shape is hot pierced by a hydraulically operated plunger to form a cup shaped product first. This is drawn through a series of dies by pushing with plungers to reduce diameter and increase the length. This method is generally used for producing thick walled cylindrical products.