Module II
Metal Casting

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Casting:

- One of the oldest manufacturing process

- In this process, the material is first liquefied by properly heating it in a suitable furnace. Then the liquid is poured into a previously prepared mould cavity where it is allowed to solidify.

- Subsequently, product is taken out of the mould cavity , trimmed, and cleaned to shape.

- Whole process of producing casting may be classified into five stages:

✓ Pattern making: patterns are designed and prepared as per the drawing of the casting.

- Pattern materials:

1. selection depends on number of castings required
2. possibility of repeat orders
3. surface finish desired in the casting

✓ Moulding and Core making:

- Moulds are prepared in either sand or a similar material with the help of pattern to produce a cavity of desired shape.

- For obtaining hollow portions, cores are prepared separately in core boxes.

- Mould and core are then baked to impart strength and finally assembled for pouring.

✓ Melting and casting:

- Melted in a suitable furnace.
- Taken into ladles and poured into the mould.
- Castings are finally extracted by breaking the moulds and send to the cleaning section.

✓ Fettling:

- Direct castings are not fit for immediate use or for work in the machine shop as they carry unwanted metal (projections) attached in the form of gate, risers etc.

✓ Testing and Inspection:

- Before the casting is dispatched from the foundry it is tested and inspected to ensure that it is flawless and conform to the specifications desired.

Pattern and Mould

Pattern:

A pattern is the replica of the part to be cast and is used to prepare the mould cavity.

- Primary cavity (mould cavity):

The mould cavity holds the liquid material and essentially act as a negative of the desired product.

- Secondary cavities:

The mould also contains secondary cavities for pouring and channeling the liquid material into the primary cavity and to act as a reservoir, if necessary.

Patterns Materials:

- Wood: easily shaped, worked and joined to form any complex shape. Light in weight, easily available and less cost. But affected by moisture (swell or shrink), poor strength, low resistance to wear

- Metals and Alloys:

✓ where repetitive production of castings is required in large quantities. Metals commonly used are Aluminum alloys, cast iron, steel and copper based alloys such as brass and bronze.

✓ Prepared by master pattern: wood, plastic, plaster or metal. Double allowances have to be made for contraction and machining.

- Plastics and Rubber:

  Both thermosetting and thermoplastic materials are used

✓ Thermosetting: long lasting and durable patterns (epoxy, polyester resins).

✓ Thermoplastic type: for short runs or piece work (polystyrene).

In special cases Silicon rubbers have been used for making dies.

- Types of patterns:

1. Loose patterns (in one piece, from wood, casting number up to 100).
2. Gated patterns: one or more than one loose pattern with attached gate and runners and provide a channel though with the molten metal can flow.
3. Match plate patterns: pattern is made in two halves mounted on both sides of a match plate (of wood or metal).

4. Cope and drag pattern:
5. Sweep pattern: surface of revolution in large castings,
6. Skeleton pattern: simple wooden frame outlining the shape of the casting.

Pattern Allowances

- “Pattern allowances” is a vital feature in pattern design as it affects the dimensional characteristics of the casting.
- A pattern is always made somewhat larger than the final job to be produced.
- This excess in dimensions is referred to as the pattern allowance.
- The proper selection of correct allowances greatly helps to reduce machining cost and avoid rejections.

- The allowances usually considered on patterns and core boxes are as:

1. *Shrinkage or Contraction allowance.*
2. *Machining allowance.*
3. *Draft or Taper allowance.*
4. *Rapping and Shake allowance.*
5. *Distortion allowance.*

1. Shrinkage or Contraction allowance

- All metals used for casting contract after solidification in the mould.
- The shrinkage allowance is provided to take care of the contractions of the casting.
- Therefore, patterns must be made larger than the casting by an amount known as “ Patternmaker’s contraction”.
- The pattern maker is equipped with a special rule of scale, called the “patternmaker’s contraction” rule.
- One rule has 2 scales on each side (total 4 in number for 4 commonly cast metals, steel, C.I, brass and AL.)

- Total contraction of a casting takes place in three stages:

1). Contraction of liquid from the pouring temp. to the freezing temp.

2). Contraction associated with the change of phase from liquid to solid.

3). Contraction of the solid casting from the freezing temp. to the room temp.

Only the last stage is taken care by the shrinkage allowance

- The amount of shrinkage allowance depends on the linear coefficient of thermal expansion α_l of the material.
- The higher the value of this coefficient, the more the value of shrinkage allowance.
- For a dimension l of a casting the shrinkage allowance is given by

$$\alpha_l \, l \, (\theta_f - \theta_0)$$

where θ_f = *freezing point of the material.*

θ_0 = *room temp.*

Cast Metal	Dimension (mm)	Contraction (mm/m)	Remarks
Cast iron	Up to 600	10.5	
	600-1200	8.5	
	Over 1200	7.0	
Cast steel	Up to 600	21	
	600-1800	16	
	Over 1800	13	
Aluminum	Up to 1200	13	1.5 mm less for core construction
	1200-1800	12	
	Over 1800	10.5	
Magnesium	Up to 1200	14.5	1.5 mm less for core construction
	Over 1200	13.0	
Brass		16	
Bronze		10.5-21	Depend on composition
Malleable iron		11.8	6 mm section thickness
		10.5	9 mm section thickness
		9.2	12 mm section thickness
		7.9	15 mm section thickness
		6.6	18 mm section thickness
		4.0	22 mm section thickness
		2.6	25 mm section thickness

2. Machining allowance

- Machining or finishing allowance is the oversize allowance given to certain part of the casting to enable their finishing or machining to required size.
- For internal surface, the allowances provided should be negative.

Cast Metal	Machining allowance for dimensions	
	0-30 cm	30-60 cm
Cast iron	2.5 mm	4.0 mm
Cast steel (low carbon)	3.0 mm	4.5 mm
Aluminum	1.5 mm	3.0 mm
Bronze	1.5 mm	3.0 mm
Brass	1.5 mm	3.0 mm

3. Draft or Taper allowance

- It refers to a taper put on the surface parallel to the direction of withdrawal of the pattern from the mould cavity.
- A draft facilitates easy withdrawal of the pattern.
- The average value of the draft is between $1/2^0$ and 2^0

4. Rapping and Shake allowance

- When the pattern is rapped for easy withdrawal, the mould cavity gets slightly larger in size.
- To compensate for this growth, the pattern should initially be made slightly smaller than the required size.
- In small and medium-sized castings, this allowance may be ignored, but for large castings or where precision is desired, this allowance should be considered.

5. Distortion allowance

- Sometimes castings get distorted during cooling due to their typical shape.

  For example: if the casting has the form of the letter "U".
- This allowance is considered only for castings that tend to get distorted and have an irregular shape.
- It also happens due to internal stresses caused by unequal cooling rates.

Types of Moulds

- On the basis of mould material
  - Green sand mould
  - Plastic mould
  - Metal mould
- On the basis of mould making
  - Shell mould
  - Investment mould

Green sand mould

- The material for a green sand mould is a mixture of sand, clay, water, and some organic additives, e.g., wood flour, dextrin and sea coal.

- The percentage of these ingredients on wight basis is approximately:

✓ Sand (specific grain size distribution) = 70-80%

✓ Clay = 10-20%

✓ Water = 3-6%

✓ Additives= 1-6%

- Clay together with water, acts as a bonding agent and imparts tensile and shear strength to the moulding sand.
- Organic additives burn out at high temperatures and make room for the moulding sand to expand and thus save the mould from crumbling.
- The success of a casting depends greatly on the following sand properties:

i) Strength (compressive strength)

ii) Permeability (gas flow rate through the specimen)

iii) Deformation (change in length of a standard specimen)

iv) Flowability (ability of the sand to flow around and over the pattern).

v) Refractoriness (ability of sand to remain solid as a function of temperature)

Core Making

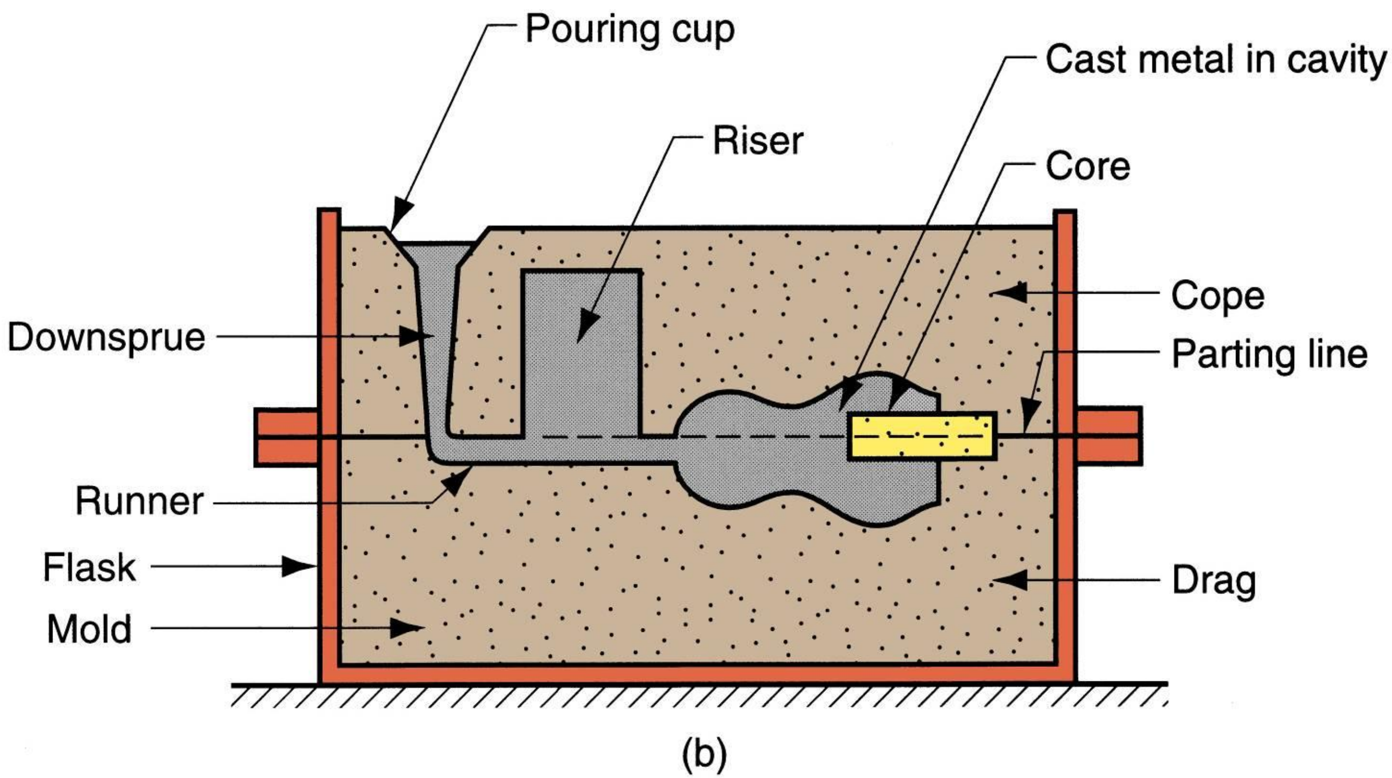
- A core is an obstruction which is placed in the mould in such a way that the molten metal, when poured through the gate, will by-pass the portion obstructed by the core and fill the cavity formed by the outline of the pattern.
- It is either integrated part of the mould or placed separately in the mould.
- When it is integrated part of the mould then it is made of green sand and when placed separately, it is made of dry sand after baking.

- Sand-mix used for core making consists of the sand together with a binder which is used to give strength after baking.

- A natural binder (sometimes called core-gum) is linseed oil, and a synthetic binder is a synthetic resin.

- In recent development sand is mixed with sodium silicate solution so that grains are coated and get the hardness after “ gassing” with carbon dioxide.

Sand Casting Mold



Sand casting mold.

Gating System

- *It is channel through which molten metal flows into cavity from outside of mold*

- Consists of a ***down-sprue*** through which metal enters a ***runner*** leading to the main cavity

- At the top of down-sprue, a ***pouring cup*** is often used to minimize splash and turbulence as the metal flows into down-sprue.

Riser

- *It is a reservoir in the mold which is a source of liquid metal to compensate for shrinkage of the part during solidification*

- Most metals are less dense as a liquid than as a solid so castings shrink upon cooling, which can leave a ***void*** at the last point to solidify. Risers prevent this by providing molten metal to the casting as it solidifies, so that the cavity forms in the riser and not in the casting

Pouring the Molten Metal

- For this step to be successful, metal must flow into all regions of the mold, most importantly the main cavity, *before solidifying*
- Factors that determine success
  - Pouring temperature
  - Pouring rate
  - Turbulence
- **Pouring temperature** should be sufficiently high in order to prevent the molten metal to start solidifying on its way to the cavity.

Pouring rate should neither be high (may stuck the runner – should match viscosity of the metal) nor very low that may start solidifying on its way to the cavity

Turbulence should be kept to a minimum in order to ensure smooth flow and to avoid mold damage and entrapment of foreign materials. Also, turbulence causes oxidation at the inner surface of cavity. This results in cavity damage and poor surface quality of casting.

Why Sprue cross-section is kept taper ??

- In order to keep volume flow rate ($Q=VA$) constant.
- In case, cross-section is fixed, increased fluid velocity due to gravity will increase flow rate. This can cause air entrapment into liquid metal.

Pouring, Gating design

- A good gating design should ensure proper distribution of molten metal in the mould cavity at the proper rate without excessive temperature loss, turbulence, gas entrapping gases and slags.
- If the molten metal is poured very slowly, since time taken to fill the mould cavity will become longer, solidification will start even before the mould is completely filled up. This can be avoided by using too much super heated metal, but in this case gas solubility will be a problem.
- On the other hand, If the molten metal is poured very faster, it can erode the mould cavity.

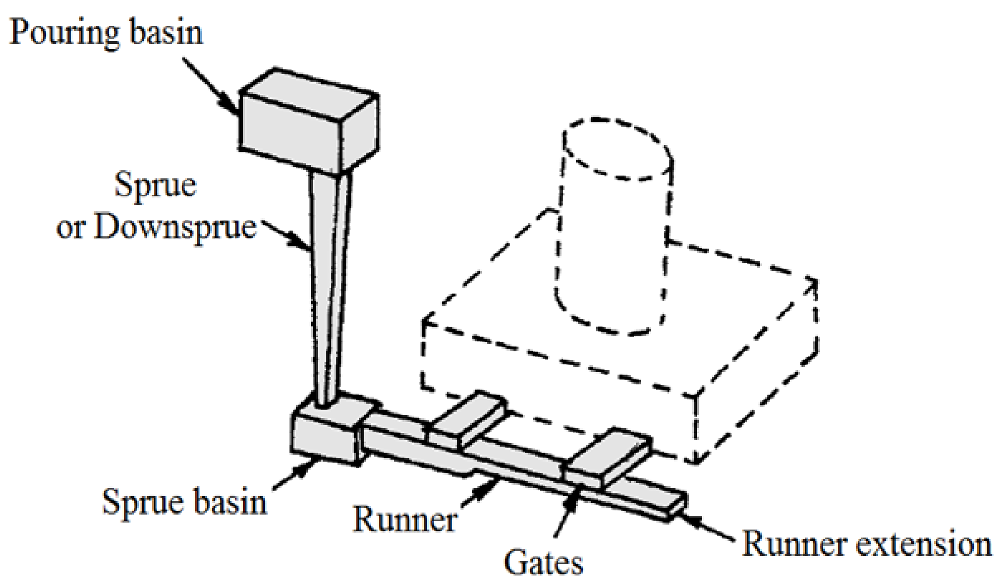
- So gating design is important and it depends on both the metal and mould composition.
- Gating design is classified mainly into three categories:

Vertical gating, bottom gating, parting line side gating.

Elements of a gating system

- The term gating system refers to all passageways through which the molten metal passes to enter the mould cavity.
- The gating system is composed of:

✓ Pouring basin
✓ Sprue
✓ Runner
✓ Gates
✓ Risers



Gates

- A gate is a channel which connects runner with the mould cavity and through which molten metal flows to fill the mould cavity.
- A small gate is used for a casting solidifies slowly and vice versa.
- A gate should not have sharp edges as they may break during pouring and sand pieces thus may be carried with the molten metal in the mould cavity.

Types

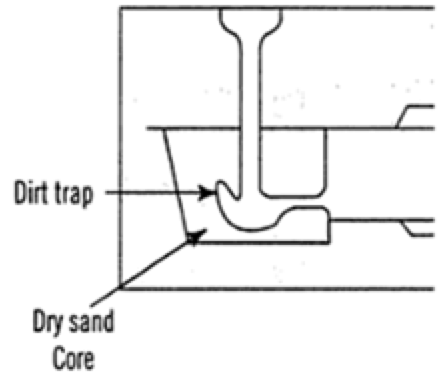
✓ Top gate

✓ Bottom gate

✓ Parting line side gate

Top Gate

- A top gate is made in the cope portion of the mould.
- In a top gate the molten metal enters the mould cavity from the top.
- Top gate involves high turbulence and sand erosion.
- Top gate produces poor casting surfaces.



Bottom Gate

- A bottom gate is made in the drag portion.
- In a bottom gate the liquid metal fills rapidly the bottom portion of the mould cavity and rises steadily and gently up the mould walls.
- As comparison to top gate, bottom gate involves little turbulence and sand erosion.
- Bottom gate produces good casting surfaces.
- If freezing takes place at the bottom, it could coke off the metal flow before the mould is full.
- Creates an unfavourable temperature gradient and makes it difficult to achieve directional solidification.

Parting line side gate

- Middle or side of parting gating system combines the characteristics of top and bottom gating systems.
- Gate is provided along the parting line such that some portion of the mould cavity will be below the parting line and some portion will be above it.
- The cavity below the parting line will be filled by assuming top gating and the cavity above the parting line will be filled by assuming bottom gating.

Analysis of pouring and filling up mould

(a) Vertical gating

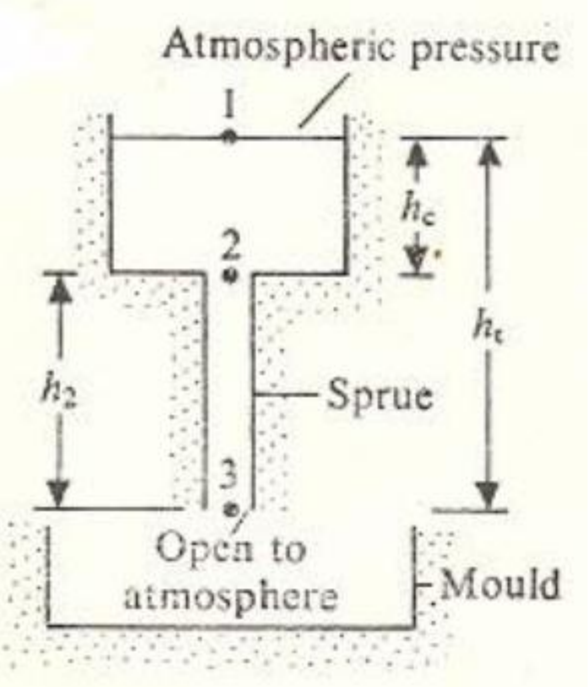
- For analysis we use energy balance equation like Bernoulli's equation

$$h_1 + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} + F_1 = h_3 + \frac{p_3}{\rho g} + \frac{v_3^2}{2g} + F_3$$

Assuming $p_1 = p_3$ and level at 1 is maintained constant, so $v_1 = 0$; frictional losses are neglected.

The energy balance between point 1 and 3 gives,

$$g h_t = v_3^2 / 2 \qquad v_3 = \sqrt{2 g h_t}$$



Simple vertical gating

Here v_3 can be referred as velocity at the sprue base or say gate, v_g

Continuity equation: Volumetric flow rate, $Q = A_1 v_1 = A_3 v_3$

Above two equations say that sprue should be tapered.

As the metal flows into the sprue opening, it increases in velocity and hence the cross-sectional area of the channel must be reduced

Otherwise, as the velocity of the flowing molten metal increases toward the base of the sprue, air can be aspirated into the liquid and taken into the mould cavity.

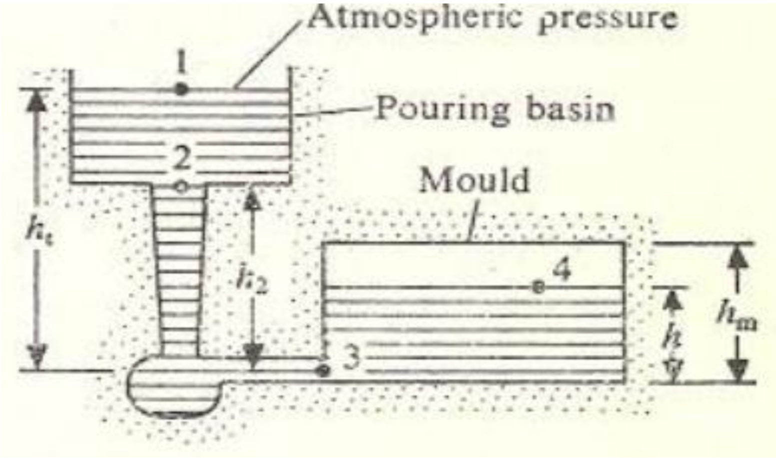
To prevent this condition, the sprue is designed with a taper, so that the volume flow rate, $Q = Av$ remains the same at the top and bottom of the sprue.

The mould filling time is given by, $\boxed{t_f = \frac{V}{Q} = \frac{V}{A_g v_3}}$

A_g = cross-sectional area of gate; V = volume of mould

(b) Bottom gating

$$h_1 + \frac{p_1}{\rho g} + \frac{v_1^{\,2}}{2g} + F_1 = h_3 + \frac{p_3}{\rho g} + \frac{v_3^{\,2}}{2g} + F_3$$



(b) Bottom gating

Applying Benoulli's equation between point 1 and 3, we get

$$gh_t = \frac{p_3}{\rho} + \frac{v_3^2}{2}$$

Further, applying Bernoulli's equation between point 3 and 4, with the assumption that v_4 is very small and all the kinetic energy at station 3 is lost after the liquid metal enters the mould, We can write:

$$\frac{p_3}{\rho} = gh$$

From above equations, the velocity of the liquid metal at the gate can be found:

$$v_g = v_3 = \sqrt{2g(\underline{h_t - h})}$$

Effective head

Assuming in the mould the height moves up by '*dh*' in a time '*dt*'; A_m and A_g are mould area and gate area, then

$$A_m dh = A_g v_g dt$$

Combining above two eqns., we get

$$\frac{1}{\sqrt{2g}}\frac{dh}{\sqrt{h_t - h}} = \frac{A_g}{A_m}dt$$

At t=0, h=0 and at $t=t_f$ (filling time), $h=h_m$.
Integrating above equation between these limits, we have

$$\frac{1}{\sqrt{2g}}\int_0^{h_m}\frac{dh}{\sqrt{h_t - h}} = \frac{A_g}{A_m}\int_0^{t_f}dt \Rightarrow$$

(Check integration)

$$\boxed{t_f = \frac{A_m}{A_g}\frac{1}{\sqrt{2g}}2(\sqrt{h_t} - \sqrt{h_t - h_m})}$$

Cooling and Solidification

Solidification of pure metals

- Change of molten metal to solid state

- Solidification of pure metals and alloys are different

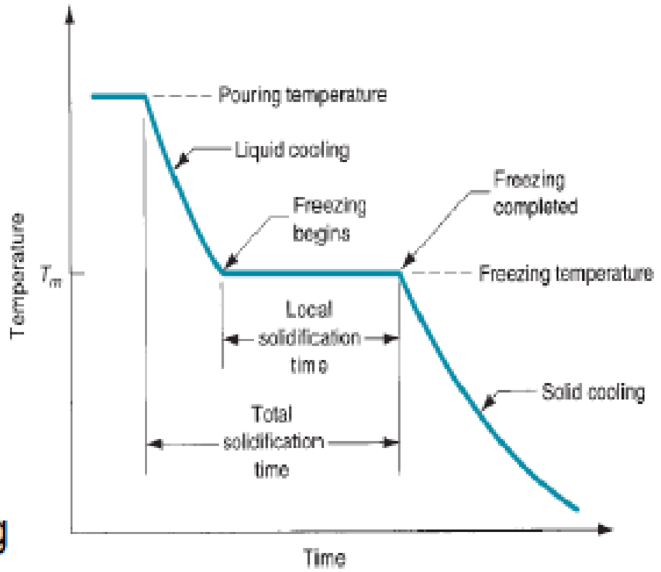
- The cooling curve of pure metals is shown in figure. Here solidification occurs at constant temperature equal to its freezing point.

-The solidification occurs at prescribed time duration.

- Local solidification time: time between freezing start and freezing completion. In this time, the molten metal heat of fusion is delivered into mould.

- Total solidification time: time between pouring and final solidification

- First liquid cooling occurs till freezing starts. Then solidification occurs for a time duration, till freezing completes. Even after solidification is over, solid cooling occurs at a particular rate as shown in the figure.

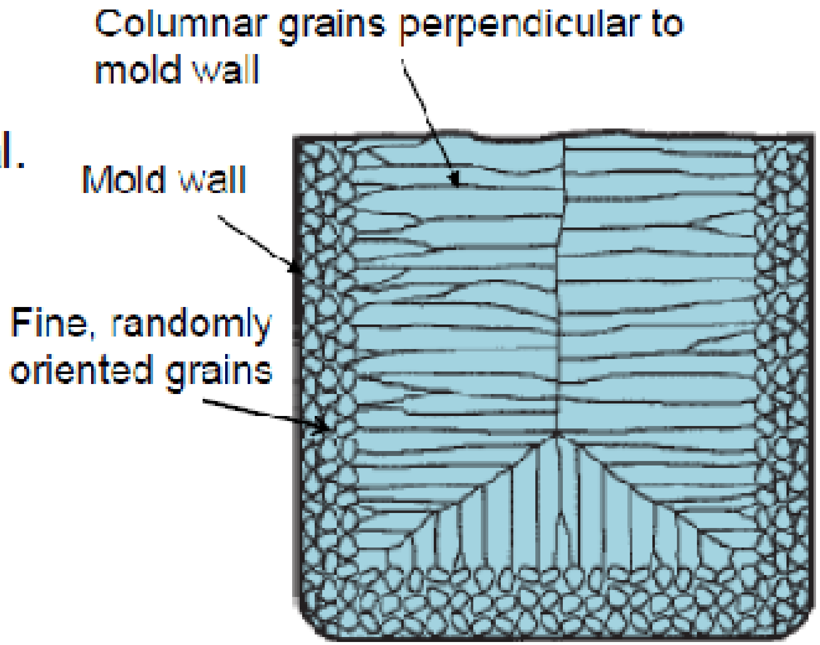


The grain structure in pure metals depends on the heat transfer into the mold and thermal properties of the metal.

The mold wall acts as a chiller and hence solidification starts first in the molten metal closer to the mold wall.

A thin skin of solid metal is first formed near the mold wall. The solidification continues inwards towards the mold center.

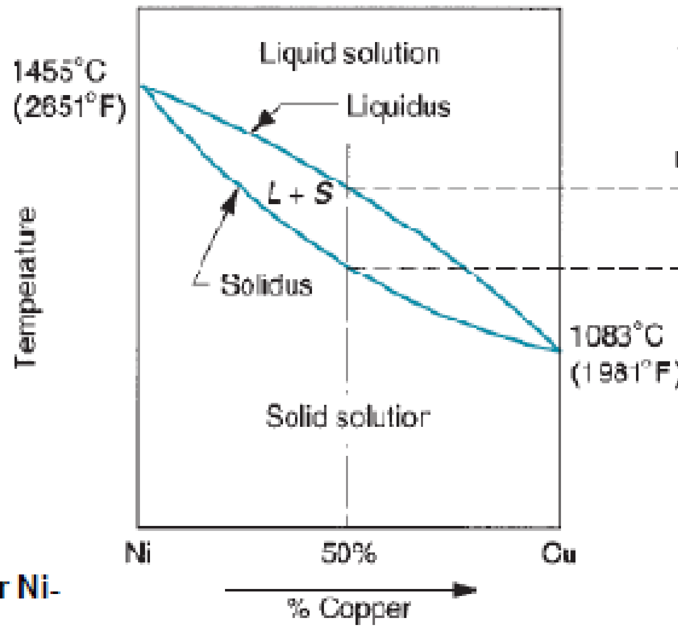
The initial skin formed near the mold wall has gone through fast removal of heat and hence fine, equiaxed and randomly oriented grains are formed.



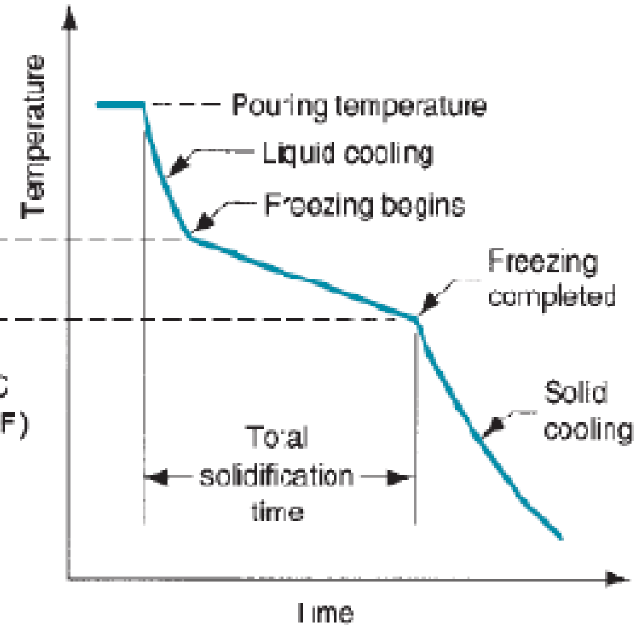
Grain structure in casting of pure metals

When the solidification continues inwardly, heat is removed through the mold wall and thin solid skin. Here the grains grow as needles with preferred orientation. As these needles enlarge, side branches develop, and as these branches grow, further branches form at right angles to the first branches. **This type of grain growth is referred to as dendritic growth**. It occurs at the freezing of pure metals and in alloys.

Solidification of alloys



Phase diagram for Ni-Cu alloy system



Cooling curve for 50%Ni-50% Cu during casting

- Important: Mushy zone formation, segregation of elements

- In alloys, solidification will not occur at a particular temperature. It happens at a temperature range. This range depends on the alloy composition.

- Referring above figure, solidification occurs between liquidus line and solidus line. Freezing starts at liquidus temperature and ends at solidus temperature. A skin layer is formed at the mold end and the dendrites grow in a similar fashion normal to the mold wall.

- However, because of the temperature difference between the liquidus and solidus line, the nature of the dendritic growth is such that an advancing zone is formed in which both liquid and solid metal exist together. The solid portions are the dendrite structures that have formed sufficiently to hold small regions of liquid metal in the matrix. This solid–liquid region has a soft consistency and hence called the **mushy zone**. Depending on the conditions of solidification, the mushy zone can be a narrow zone, or it can exist throughout the casting.

- Slowly the liquid islands solidify as the temperature of the casting goes down to the solidus.

- **Another complexity is the segregation of elements.** As solidification continues and the dendrites grow, an imbalance in composition between the solidified metal and the remaining molten metal will develop. This composition imbalance will finally result in the segregation of the elements.

- Segregation of elements can be microscopic and macroscopic. At microscopic level, chemical composition varies with each grain. This is due to out of balancing of composition between the first solidified region and the last solidified region. Thus, the variation in chemical composition within single grains of the casting is generated.

- At macroscopic level, the chemical composition varies throughout the entire casting. Since the regions of the casting that freeze first (say near the mold walls) are richer in one component than the other, the remaining molten metal has got reduction in that component by the time freezing occurs at the mold center. This creates difference in composition at different cross sections of the casting. This is called **ingot segregation.**

Eutectic alloys:

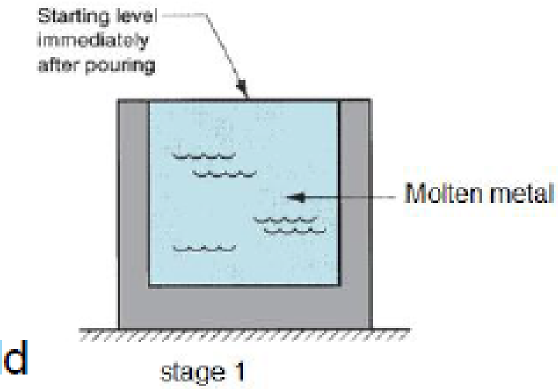
In these alloys, solidification occurs at a constant temperature rather than over a temperature range. For these alloys, the solidus and liquidus are at the same temperature.

Example:
(i) 61.9% tin and 38.1% lead has a melting point of 183°C. This composition is the eutectic composition of the Pb-Sn alloy system. The temperature 183°C is its eutectic temperature.

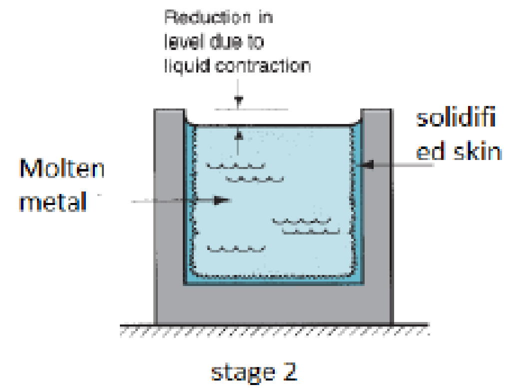
(ii) Aluminum–silicon (11.6% Si) and cast iron (4.3% C)

Solidification shrinkage

Major three stages in shrinkage:
(i) Contraction of liquid before solidification during cooling
(ii) Contraction during liquid to solid phase change
(iii) Contraction of solid metal during cooling to RT

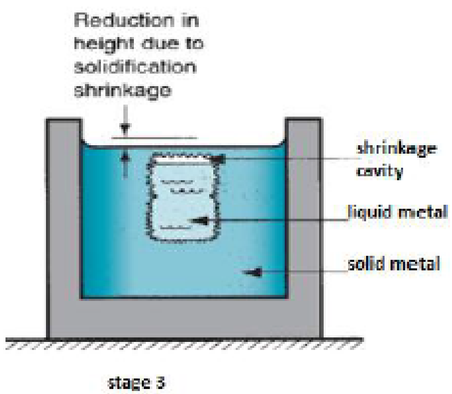


Stage 1: The level of poured molten metal is shown in a mold container.



Stage 2: Solidification front has started at the mold wall. The level of liquid metal has reduced at the open surface due to liquid contraction. The amount of liquid contraction is app. 0.5%.

Stage 3: Two effects are seen in this stage.

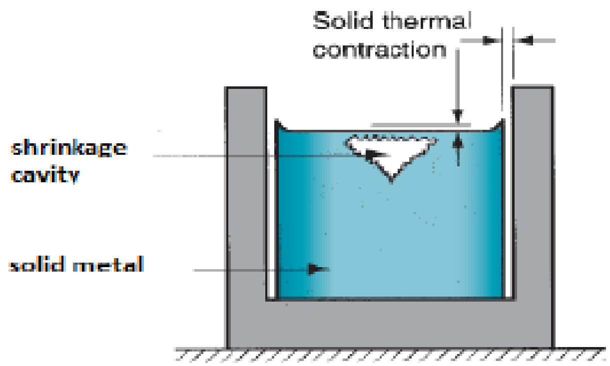


First effect – contraction causes further reduction in the height of the casting.

Second effect – top centre portion is the last to get freezed. The amount of liquid metal present to feed the top centre portion of the casting becomes restricted. Absence of metal in this region creates a void in the casting. This will be converted into **'shrinkage cavity'**.

Stage 4:

Once solidified, both height and diameter contracts resulting in **shrinkage cavity** at the top centre. **This will be seen as a 'Pipe', in case casting is done in a tube like container which does not have mold wall at the bottom.**



stage 4

Solidification shrinkage occurs almost in all metals because the solid phase has a higher density than the liquid phase.

The phase transformation that occurs during solidification causes a reduction in the volume per unit weight of metal. But cast iron containing high carbon content is an exception, whose solidification during the final stages is complicated by graphitization, which results in expansion. This will tend to oppose the decrease in cast volume associated with the phase change.

Compensation for shrinkage cavity : by providing riser, by following shrink rule to have shrinkage allowances

Directional solidification

There are few methods by which damages due to shrinkage can be minimized. They are directional solidification methods.

Method 1: Providing risers:

It is desirable for the regions of the casting far away from the liquid metal supply to freeze first and for solidification to progress from these remote regions toward the location of riser. In this way, molten metal will continually be available from the risers to prevent shrinkage voids during freezing.

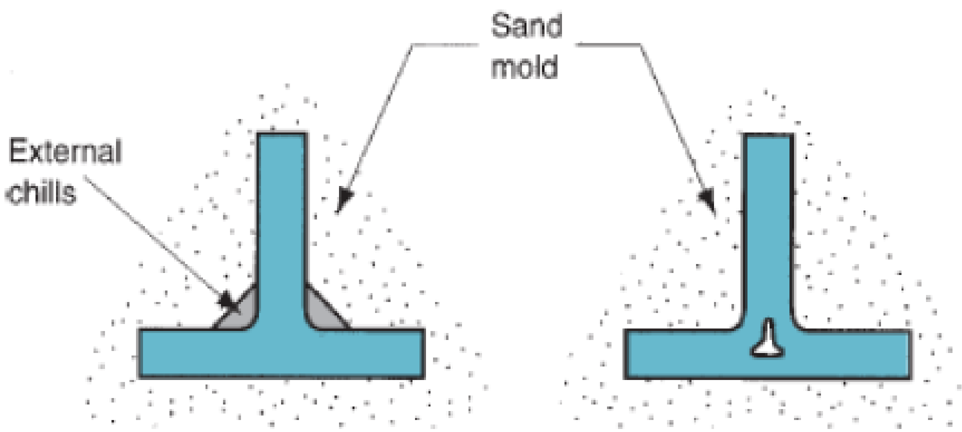
For example, the regions of the cast with lower V/A ratios should be placed far away from the riser location. Solidification will start from these locations and it will progress towards the riser location where bulkier sections of the cast are present. Hence the bulkier sections will continually received molten metal from the risers till freezing.

Method 2: Providing chills:

Chills can be provided at appropriate locations in order to have rapid solidification at those points. Internal and external chills can be provided.

Internal chills: small metal parts are placed inside the mould cavity before pouring so that the molten metal will solidify first around these parts. The internal chill should have a chemical composition similar to the metal being poured, so that it can be made out of same cast metal.

External chills: They are metal inserts kept in mould walls that can extract heat from the molten metal more rapidly than the surrounding sand in order to promote localized solidification. They are mainly used in sections of the casting that are difficult to supply with molten metal.

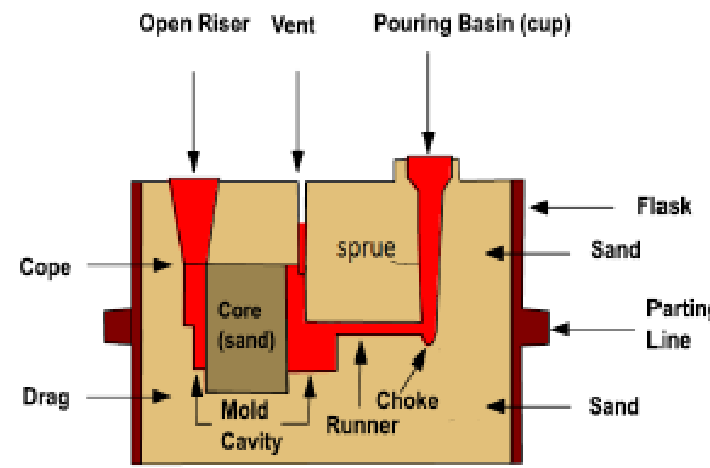


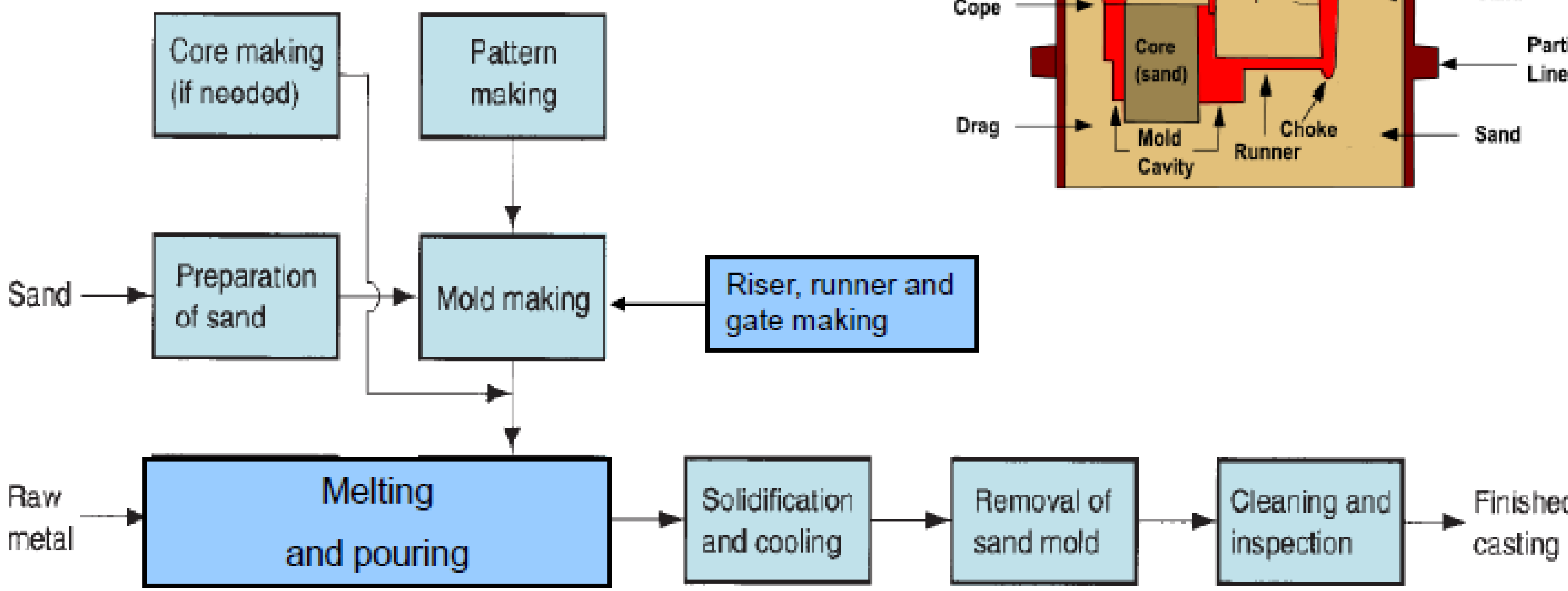
With external chill Without external chill

Casting processes

Sand Casting

We have already seen sand casting processes. The steps involved in this process is shown here briefly.





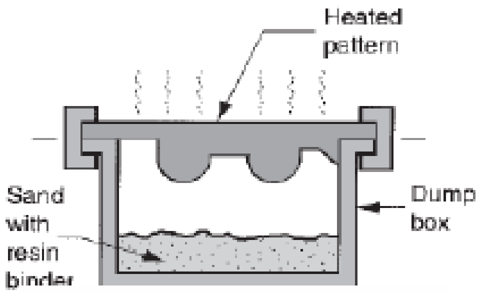
Other casting: Two types – (I) Expendable moulding, (II) Permanent moulding

Expendable moulding processes

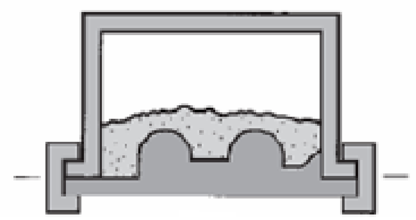
Shell moulding

The shell moulding is a casting process in which the mould is a thin shell of 9 mm thick. This is made of sand held together by thermosetting resin binder.

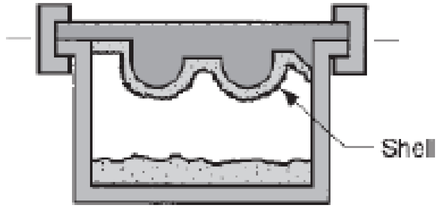
A metal pattern is heated and placed over a box containing sand mixed with thermosetting resin



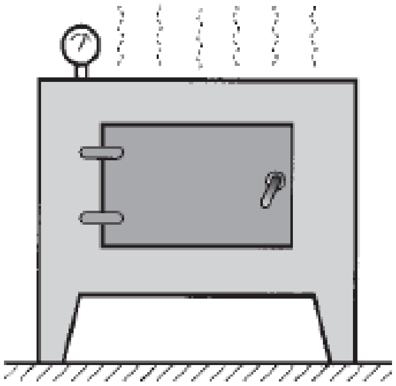
The dump box is inverted so that sand and resin mixture fall on the hot pattern, causing a layer of the mixture to partially cure on the pattern surface to form a hard shell



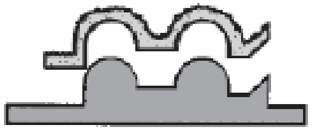
The box is positioned to the previous stage, so that loose, uncured particles drop away

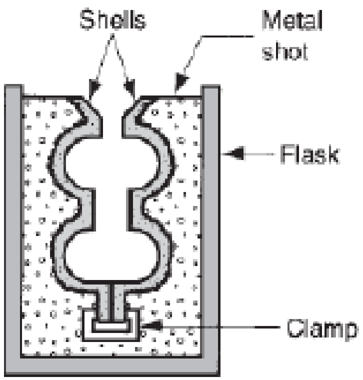


sand shell is heated in oven for several minutes to complete curing

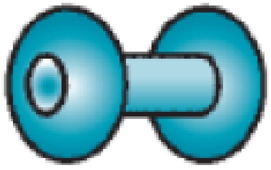


The shell mold is removed from the pattern and two halves of the shell mold are assembled, supported by sand or metal shot in a box, and pouring is completed





The part made by this method is shown here



Advantages of shell moulding process

- The surface of the shell mould is smoother than conventional green sand mould. This permits easier flow of molten metal during pouring and better surface finish on the final casting.
- Surface finish of the order of 2.5 μm can be obtained. Good dimensional tolerances of the order of ± 0.25 mm can be reached in a small to medium sized parts.
- Machining operations are reduced because of good surface finish.
- can be mechanized for mass production and will be economical too.

Disadvantages

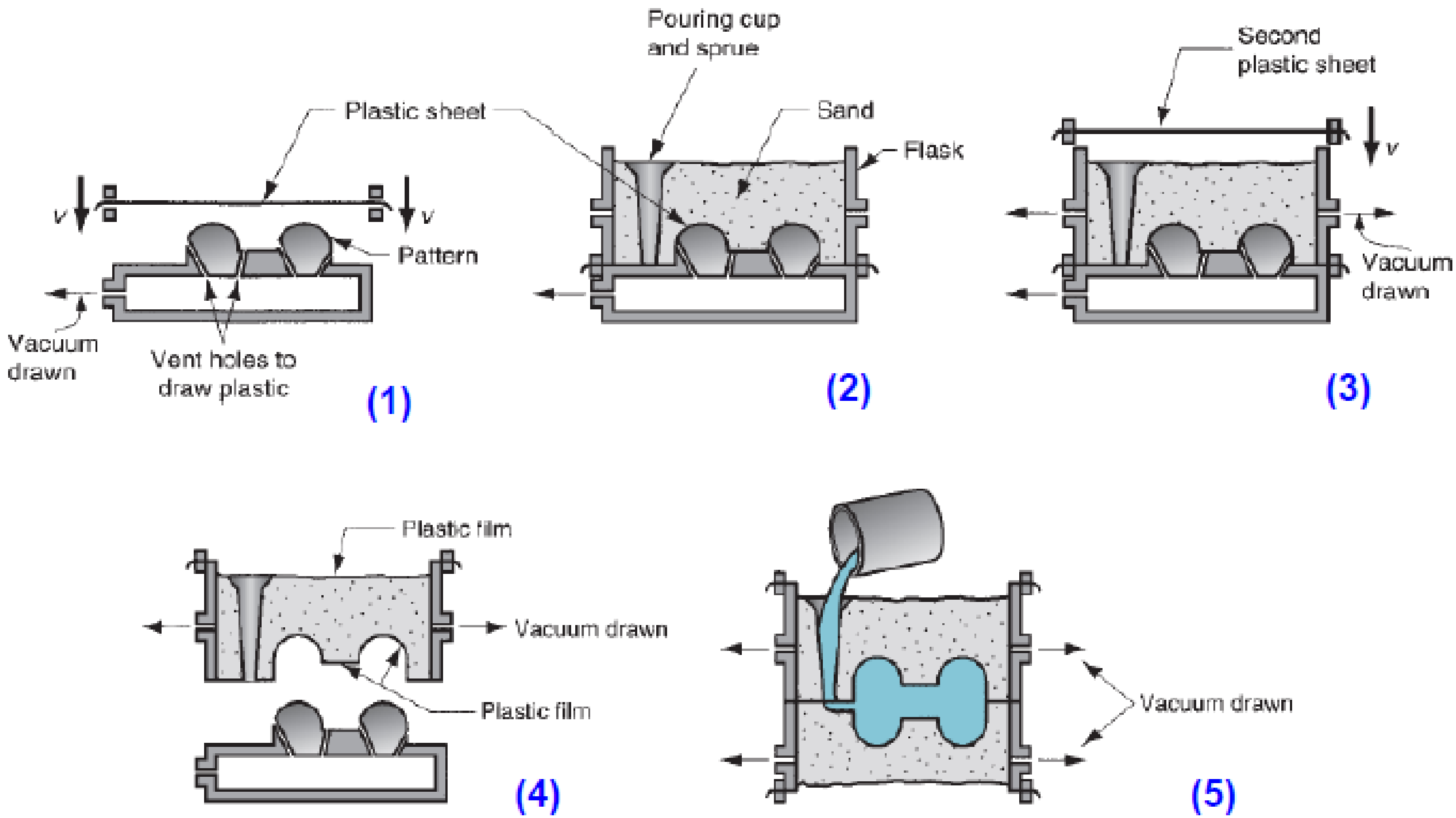
- expensive metal pattern is required, and hence not suitable for small quantities.

Examples of parts made using shell molding include gears, valve bodies, bushings, and camshafts.

Vacuum moulding

In this process, a sand mold is held together by vacuum pressure and not by a chemical binder.

The term vacuum in this process refers to the making of the mold, rather than the casting operation. Casting operation is same as any other process.



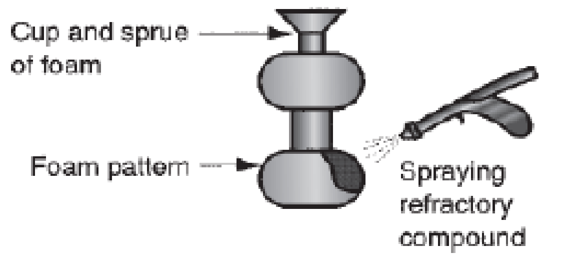
Advantages:

- No binders are used and hence sand is readily recovered in vacuum molding
- Mechanical ramming is not required
- Since no water is mixed with the sand, moisture related defects are absent from the product

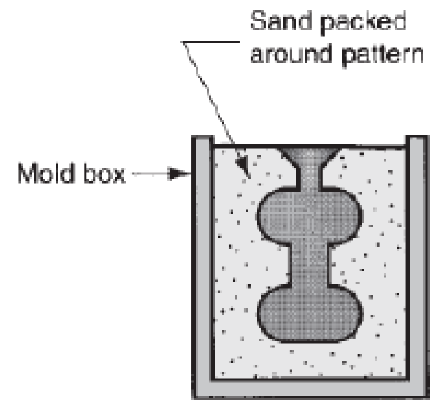
Disadvantages:

- relatively slow and not readily adaptable to mechanization

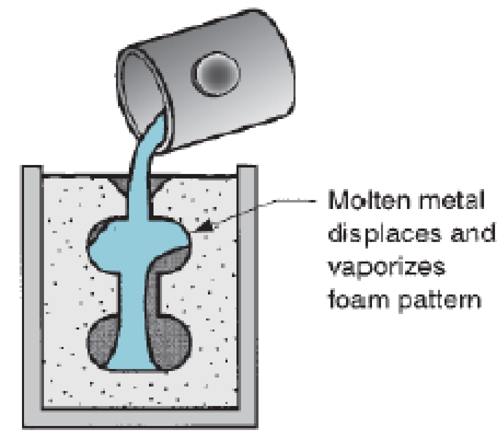
EXPANDED POLYSTYRENE PROCESS



Polystyrene pattern is coated with refractory compound



Pattern is placed in the mold box and packed with sand around it



molten metal is poured into the portion of the pattern

- In this process, a mold of sand packed around a polystyrene foam pattern is used. This pattern will vaporize when the molten metal is poured into the mold.
- The refractory compound will provide a smoother surface on the pattern and to improve its high temperature resistance.
- Molding sands usually include bonding agents.
- Also called as lost-foam process, lost pattern process, evaporative-foam process.

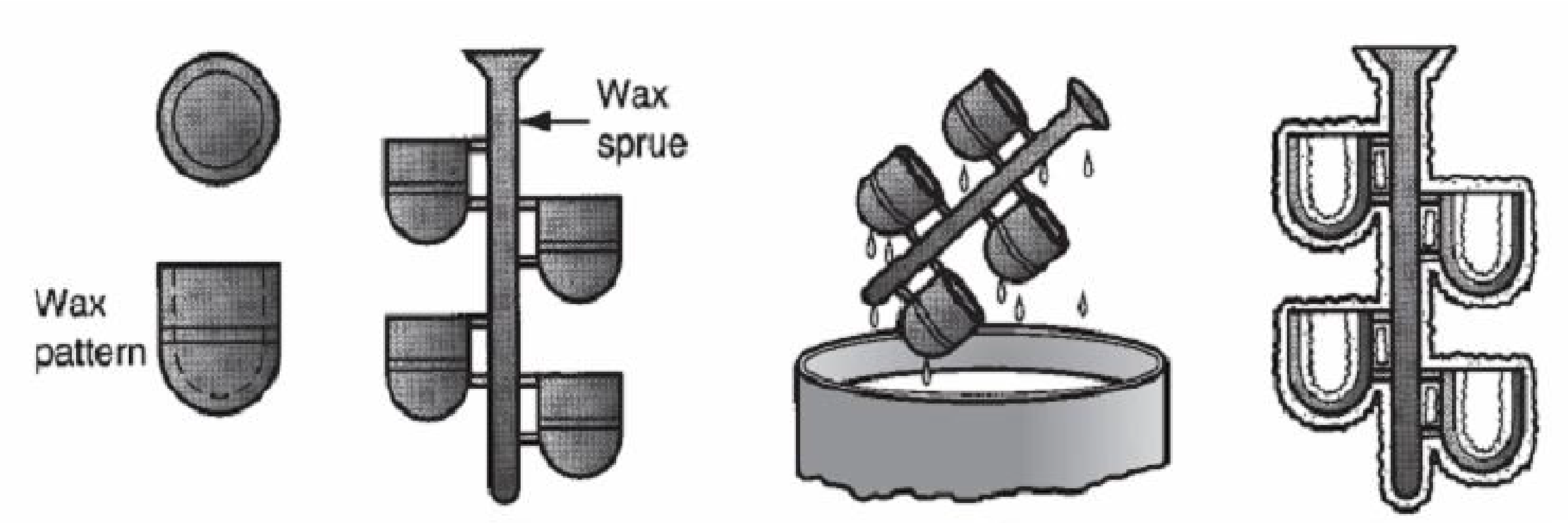
- The foam pattern includes risers, sprue, gating system, internal core.
- Parting lines and draft considerations are reduced.

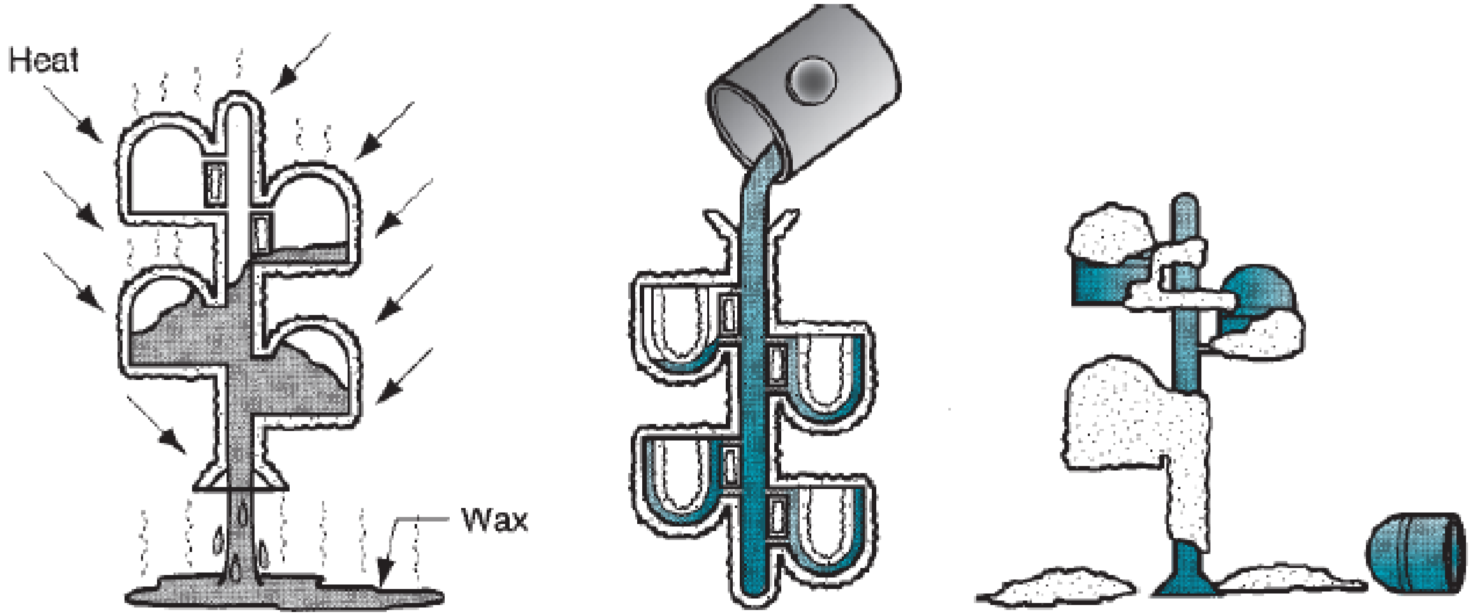
Investment casting

In this casting process, a pattern made of wax is coated with a refractory material to make the mold surface, after which the wax is melted away while pouring the molten metal.

“Investment” means “to cover completely” which refers to the coating of the refractory material around the wax pattern.

This is a precision casting process. Using this we can make castings of high accuracy with intricate details.





- Wax patterns are first made
- several patterns can be attached to a sprue to form a pattern tree, if required
- the pattern tree is coated with a thin layer of refractory material and later covered with thick coating to make the rigid full mold
- Heating of mold in inverted position to melt the wax and permit it to drip out of the cavity
- the mold is preheated to a high temperature so that contaminants are eliminated from the mold
- the molten metal is poured and it solidifies
- the mold is removed from the finished casting

Refractory coating:

• Slurry of very fine grained silica or other refractory, in powder form, mixed with plaster to bond the mold into shape. The small grain size of the refractory material delivers smooth surface and captures the intricate depths of the wax pattern.

• Mold is allowed to dry in air for about 8 hours to harden the binder.

Advantages:

(1) Complex and intricate parts can be cast
(2) tolerances of 0.075 mm are possible
(3) good surface finish is possible
(4) In general, additional machining is not required – near net shaped part

Applications:

- Steels, stainless steels, high temperature alloys can be cast
- Examples of parts: machine parts, blades, components for turbine engines, jewelry, dental fixtures

Plaster mold and ceramic mold casting

Plaster mold:

- similar to sand casting, except mold is made of POP and not sand
- To minimize contraction, curing time, reduce cracking, additives like talc and silica flour are mixed with the plaster.
- Curing time: 20 mts, baking time: several hours
- Permeability is low. This problem is solved by using a special mold composition and treatment known as the Antioch process. IN this operation, about 50% of sand is mixed with the plaster, heating the mold in an autoclave, and then drying is done. Good permeability is attained by this treatment.
- Used only for Al, Mg, Cu based alloys

Ceramic mold:

- mold is made of refractory ceramic materials which can withstand high temp. than plaster.
- Ceramic molding can be used to cast steels, CI, and other high temp. alloys.

Permanent mold process

Disadvantage of expendable molding processes is that for every casting a new mold is required.

Permanent mold processes:

• using only metal mold for casting

• Molds are generally made of steel, CI

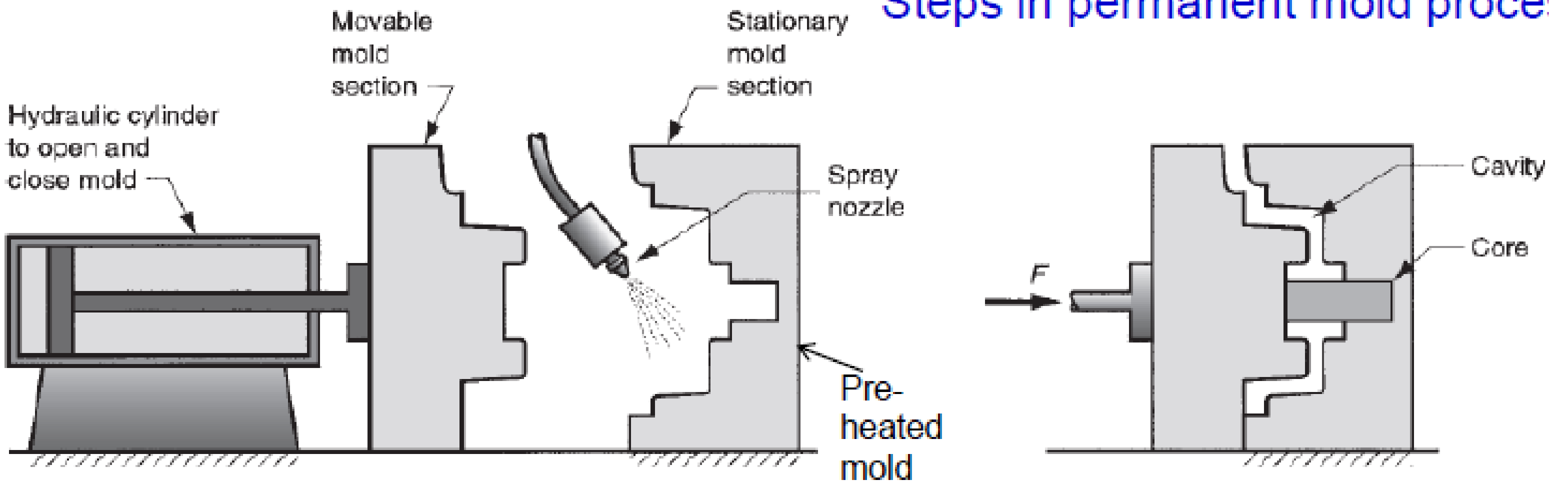
• materials that can be cast: Al, Mg, Cu based alloys, CI (affect the mold life, hence not used)

• cores are also made of metal, but if sand is used then called semi permanent-mold casting

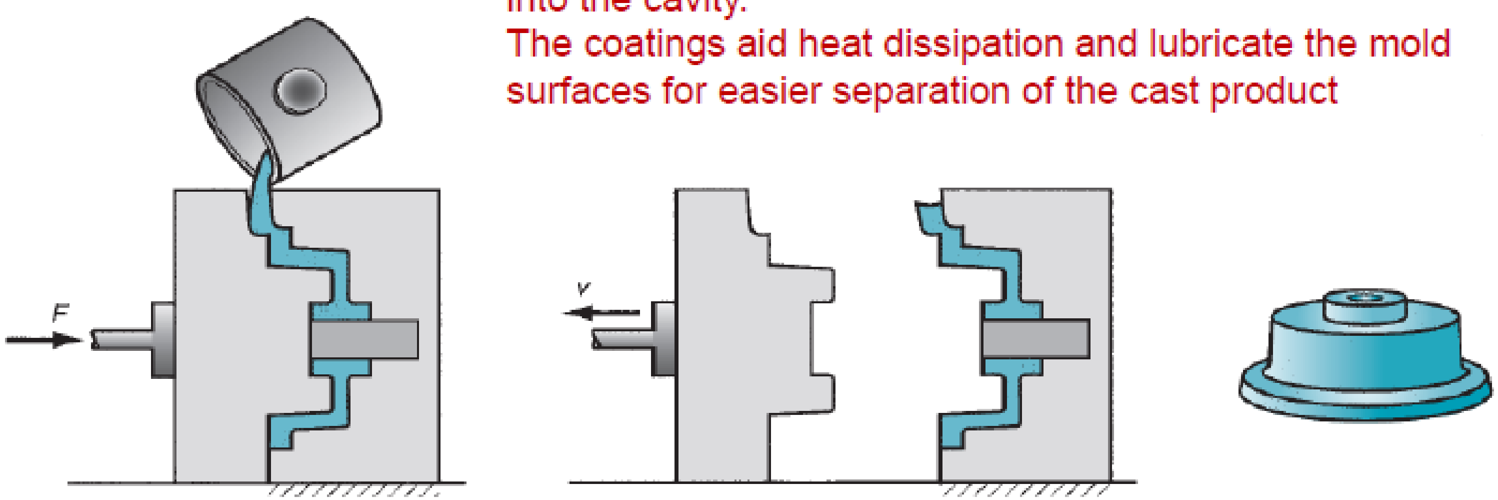
• Advantages: good surface finish, dimension tolerance, rapid solidification causes fine grains to form giving stronger products

• limitations: restricted to simple part geometries, low melting point metals, mold cost is high. Best suitable for small, large number of parts

Steps in permanent mold process



Preheating facilitates metal flow through the gating system and into the cavity.
The coatings aid heat dissipation and lubricate the mold surfaces for easier separation of the cast product



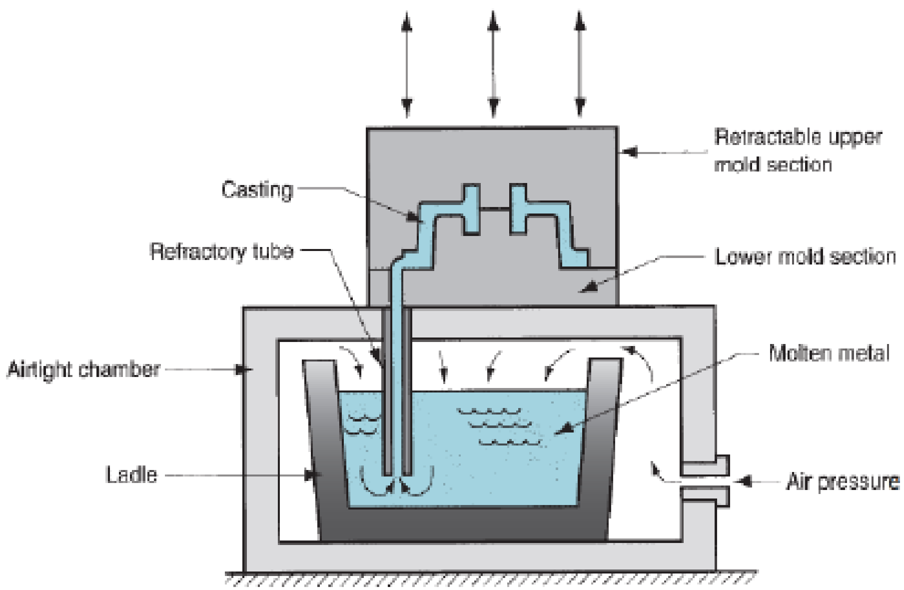
Variations of permanent mold casting

Low pressure casting:

• In the earlier casting process, metal flow in mold cavity is by gravity pull, but in low pressure casting, liquid metal is forced into the cavity under low pressure, app. 0.1 MPa, from beneath the surface so that metal flow is upward.

• advantage: molten metal is not exposed to air; gas porosity and oxidation defects are minimized

Vacuum permanent mold casting: variation of low pressure casting, but in this vacuum is used to draw the molten metal into the mold cavity.



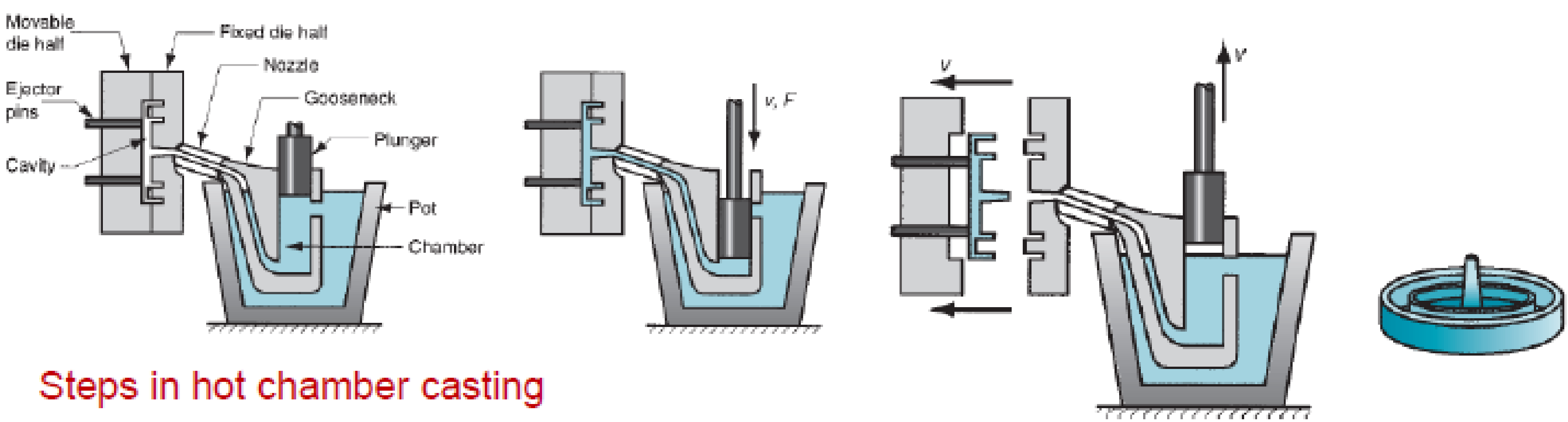
Low pressure casting

Die casting

In this process, high pressure of app. 7 to 350 MPa is used to pressurize the molten metal into die cavity. The pressure is maintained during solidification.
Category: hot chamber machines, cold chamber machines

hot chamber machines:

- Molten metal is melted in a container attached to the machine, and a piston is used to pressurize metal under high pressure into the die. Typical injection pressures are between 7 and 35 MPa.
- Production rate of 500 parts/hour are common.
- Injection system is submerged into the molten metal and hence pose problem of chemical attack on the machine components. Suitable for zinc, tin, lead, Mg.

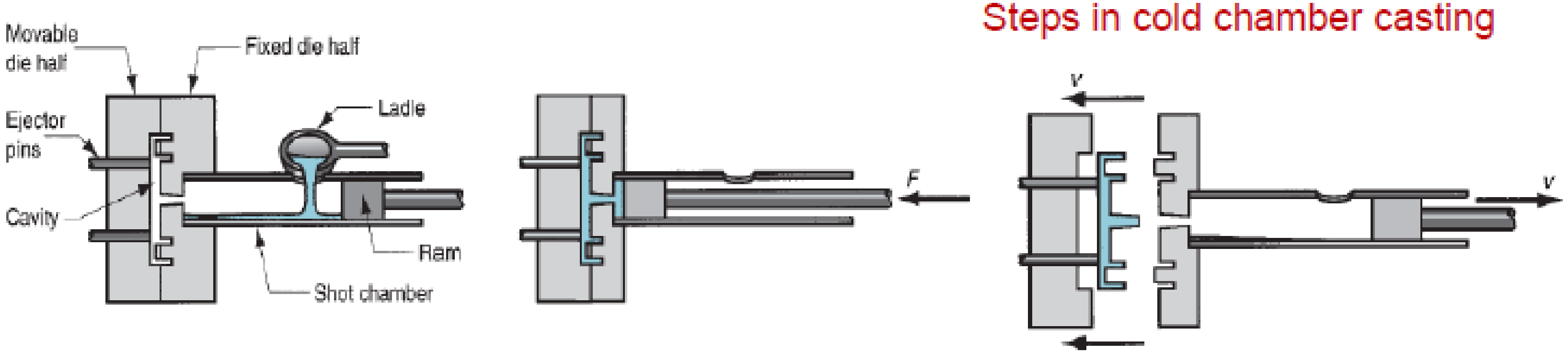


Steps in hot chamber casting

cold chamber machines:

- Molten metal is poured from an external unheated container into the mold cavity and piston is used to inject the molten metal into the die cavity.
- Injection pressure: 14 to 140 MPa.
- Though it is a high production operation, it is not as fast as hot chamber machines.

Steps in cold chamber casting



Die casting molds are made of tool steel, mold steel, maraging steels. Tungsten and molybdenum with good refractory qualities are also used for die cast steel, CI.

Advantages of die casting:

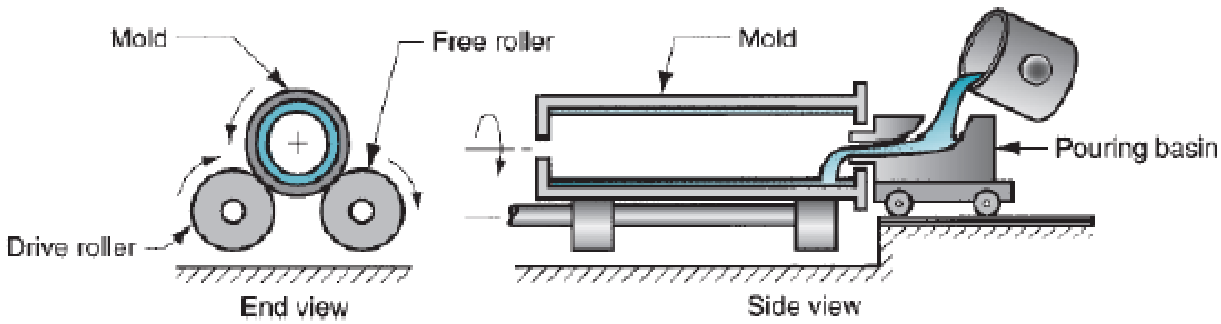
- high production rates and economical
- Close tolerances possible of the order of ±0.076 mm
- thin section with 0.5 mm can be made
- small grain size and good strength casting can be made because of rapid cooling

Centrifugal casting

- In this method, the mold is rotated at high speed so that the molten metal is distributed by the centrifugal force to the outer regions of the die cavity

- includes : true centrifugal casting, semicentrifugal casting

True centrifugal casting:



- Molten metal is poured into a rotating mold to produce a tubular part (pipes, tubes, bushings, and rings)
- Molten metal is poured into a horizontal rotating mold at one end. The high-speed rotation results in centrifugal forces that cause the metal to take the shape of the mold cavity. The outside shape of the casting can be non-round, but inside shape of the casting is perfectly round, due to the radial symmetry w.r.t. forces

- Orientation of the mold can be **horizontal or vertical**

For horizontal centrifugal casting:

$$\text{centrifugal force} = F = \frac{mv^2}{R}$$

Where *F* – force in N, *m* – mass in kg, *v* – velocity in m/s, *R* – inner radius of mold in m

Here we define G-factor (GF) as the ratio of centrifugal force to weight.

$$GF = \frac{\left(\frac{mv^2}{R}\right)}{mg} = \frac{v^2}{Rg}$$

For horizontal centrifugal casting, GF is equal to 60 to 80

Putting $v = 2\pi RN/60$ in the above eqn. and after rearrangement gives,

$$N = \frac{30}{\pi}\sqrt{\frac{2g(GF)}{D}}$$

Where *N* is rotational speed in rev/min., *D* is inner diameter of mold in m

If the G-factor is very less, because of the reduced centrifugal force, the liquid metal will not remain forced against the mold wall during the upper half of the circular path but will go into the cavity. This means that slipping occurs between the molten metal and the mold wall, which indicates that rotational speed of the metal is less than that of the mold.

Vertical centrifugal casting:

In this because of the effect of gravity acting on the liquid metal, casting wall will be thicker at the base than at the top. The difference in inner and outer radius can be related to speed of rotation as,

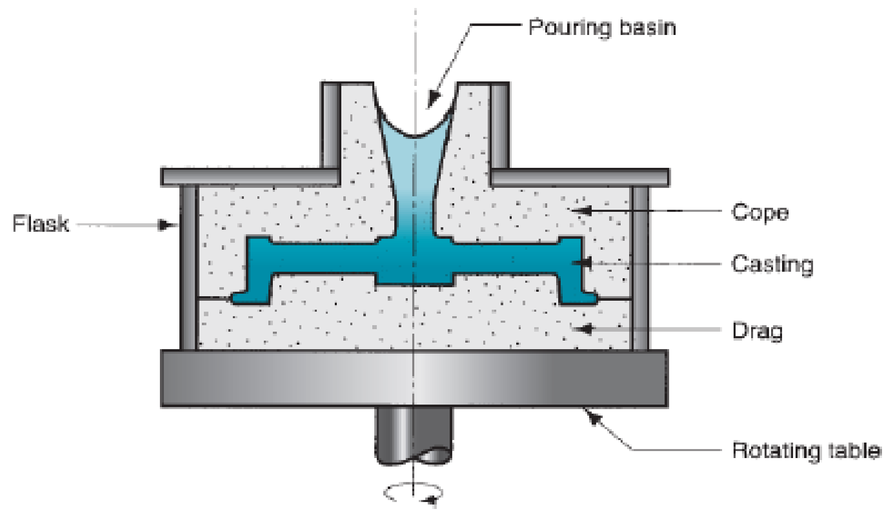
$$N = \frac{30}{\pi}\sqrt{\frac{2gL}{R_{it}^{2} - R_{ib}^{2}}}$$

where
L - vertical length of the casting in m,
R_{it} - inner radius at the top of the casting in m,
R_{ib} - inner radius at the bottom of the casting in m

It is observed from the eqn. that for $R_{it} = R_{ib}$, the speed of rotation N will be infinite, which is practically impossible.

Solidification shrinkage at the exterior of the cast tube will not be an issue, because the centrifugal force continually moves molten metal toward the mold wall during freezing. Impurities in the casting will be on the inner wall and can be removed by machining after solidification.

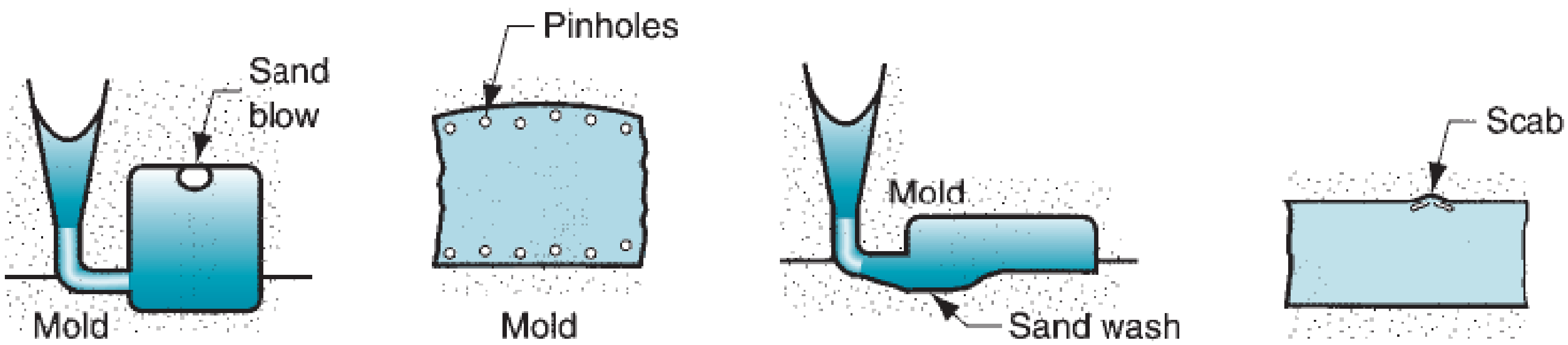
Semicentrifugal casting:



In this process, centrifugal force is used to produce non-tubular parts (solid), and not tubular parts. GF will be around 15 by controlling the rotation speed. Molds are provided with riser at the center.

Generally the density of metal will be more at the outer sections and not at the center of rotation. So parts in which the center region (less denser region) can be removed by machining (like wheels, pulleys) are usually produced with this method.

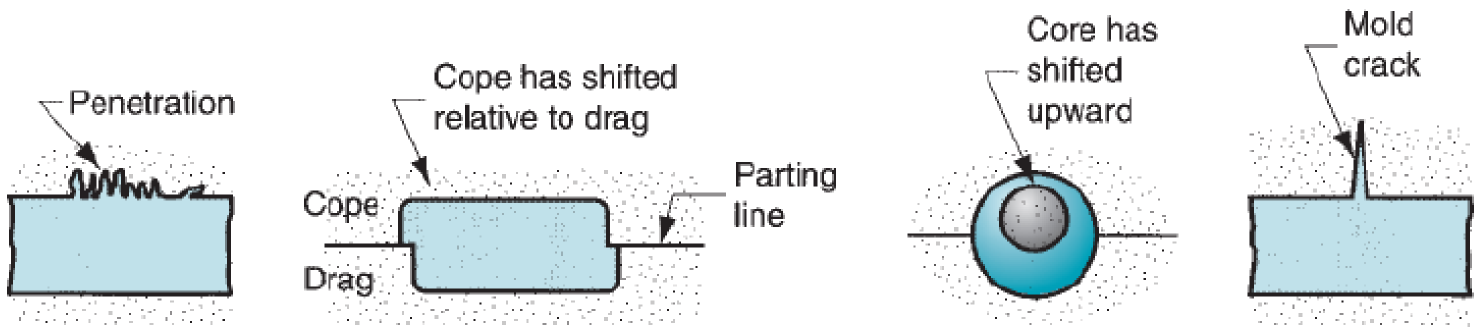
Defects in sand castings



Sand blow and Pinholes: defect consisting of a balloon-shaped gas cavity or gas cavities caused by release of mold gases during pouring. It is present just below the casting top surface. Low permeability, bad gas venting, and high moisture content of the sand mold are the usual causes.

Sand wash: surface dip that results from erosion of the sand mold during pouring. This contour is formed in the surface of the final cast part.

Scab: It is caused by portions of the mold surface flaking off during solidification and gets embedded in the casting surface.



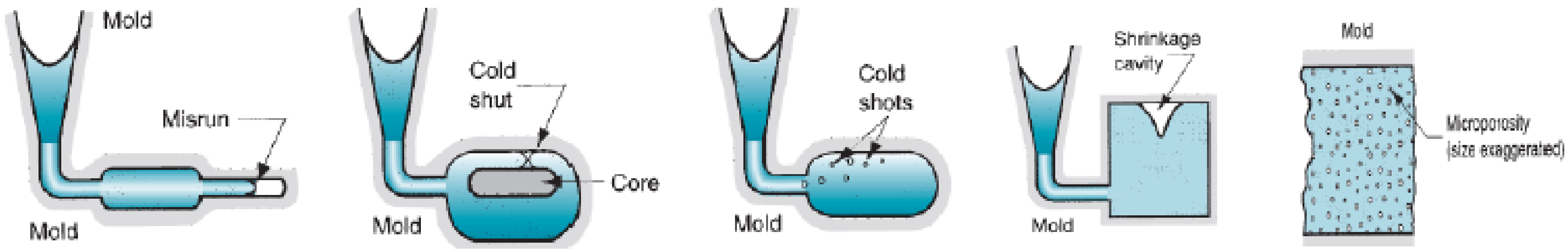
Penetration: surface defect that occurs when the liquid penetrates into the sand mold as the fluidity of liquid metal is high, After solidifying, the casting surface consists of a mixture of sand and metal. Harder ramming of sand mold minimize this defect.

Mold shift: defect caused by displacement of the mold cope in sideward direction relative to the drag. This results in a step in the cast product at the parting line.

Core shift: displacement of core vertically. Core shift and mold shift are caused by buoyancy of the molten metal.

Mold crack: ‘fin’ like defect in cast part that occurs when mold strength is very less, and a crack develops, through which liquid metal can seep.

Common defects in casting



Misruns: castings that solidify before completely filling the mold cavity. This occurs because of (1) low fluidity of the molten metal, (2) low pouring temperature, (3) slow pouring, (4) thinner cross-section of the mold cavity.

Cold Shuts: This defect occurs when two portions of the metal flow together but no fusion occurs between them due to premature freezing.

Cold shots: forming of solid globules of metal that are entrapped in the casting. Proper pouring procedures and gating system designs can prevent this defect.

Shrinkage cavity: cavity in the surface or an internal void in the casting, caused by solidification shrinkage that restricts the amount of molten metal present in the last region to freeze. It is sometimes called as ‘pipe’. Proper riser design can solve this problem.

Microporosity: network of small voids distributed throughout the casting caused by localized solidification shrinkage of the final molten metal.