Metal casting processes

• Casting is one of the oldest manufacturing process. It is the first step in making most of the products.

• Steps:

- Making mould cavity
- Material is first liquefied by properly heating it in a suitable furnace.
- Liquid is poured into a prepared mould cavity
- allowed to solidify
- product is taken out of the mould cavity, trimmed and made to shape

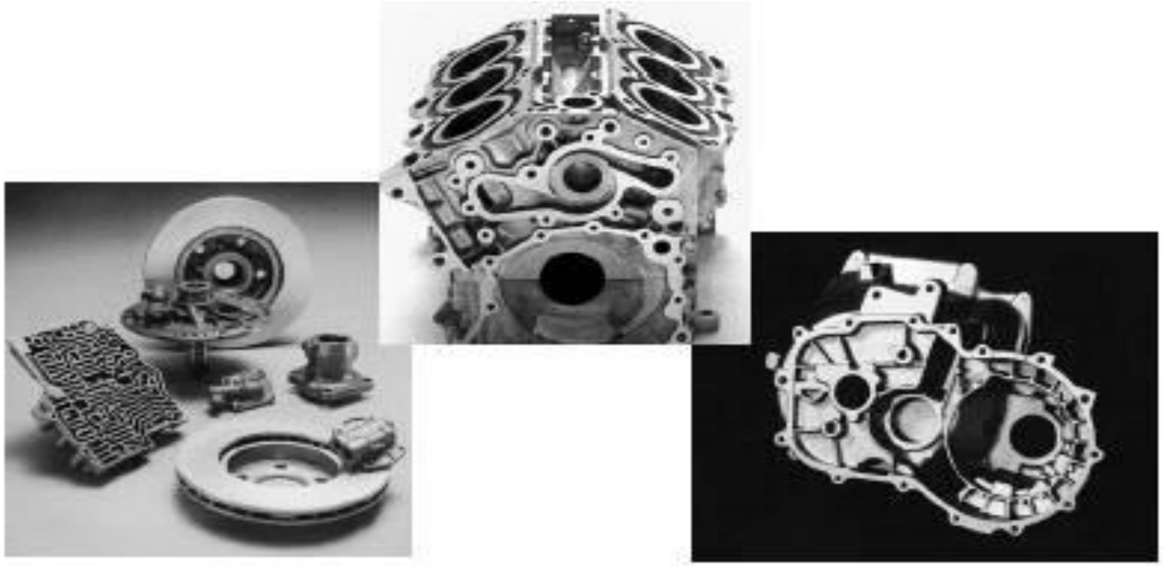
We should concentrate on the following for successful casting operation:

(i)Preparation of moulds of patterns

(ii)Melting and pouring of the liquefied metal

(iii)Solidification and further cooling to room temperature

(iv)Defects and inspection



Advantages

- Molten material can flow into very small sections so that intricate shapes can be made by this process. As a result, many other operations, such as machining, forging, and welding, can be minimized.
- Possible to cast practically any material: ferrous or non-ferrous.
- The necessary tools required for casting moulds are very simple and inexpensive. As a result, for production of a small lot, it is the ideal process.
- There are certain parts (like turbine blades) made from metals and alloys that can only be processed this way. Turbine blades: Fully casting + last machining.
- Size and weight of the product is not a limitation for the casting process.

NPTEL course on Manufacturing processes – I, Pradeep Kumar et al.

Limitations

• Dimensional accuracy and surface finish of the castings made by sand casting processes are a limitation to this technique.

• Many new casting processes have been developed which can take into consideration the aspects of dimensional accuracy and surface finish. Some of these processes are die casting process, investment casting process, vacuum-sealed moulding process, and shell moulding process.

• Metal casting is a labour intensive process

• Automation: a question

Melting of metals

Gases in metals:

The gases in metal is important in deciding the defect free castings. In metal castings, gases may be mechanically trapped, generated due to variation in their solubility at different temperatures and phases, generated because of chemical reaction.

Gases generally present are: hydrogen, nitrogen

Hydrogen: Based on the solubility of hydrogen, metals are divided as

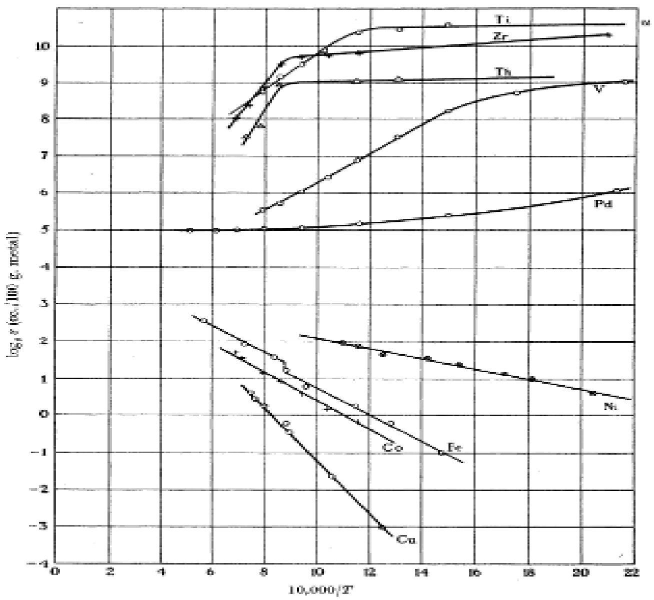
Endothermic (metals like Al, Mg, Cu, Fe, Ni), Exothermic (like Ti, Zr)

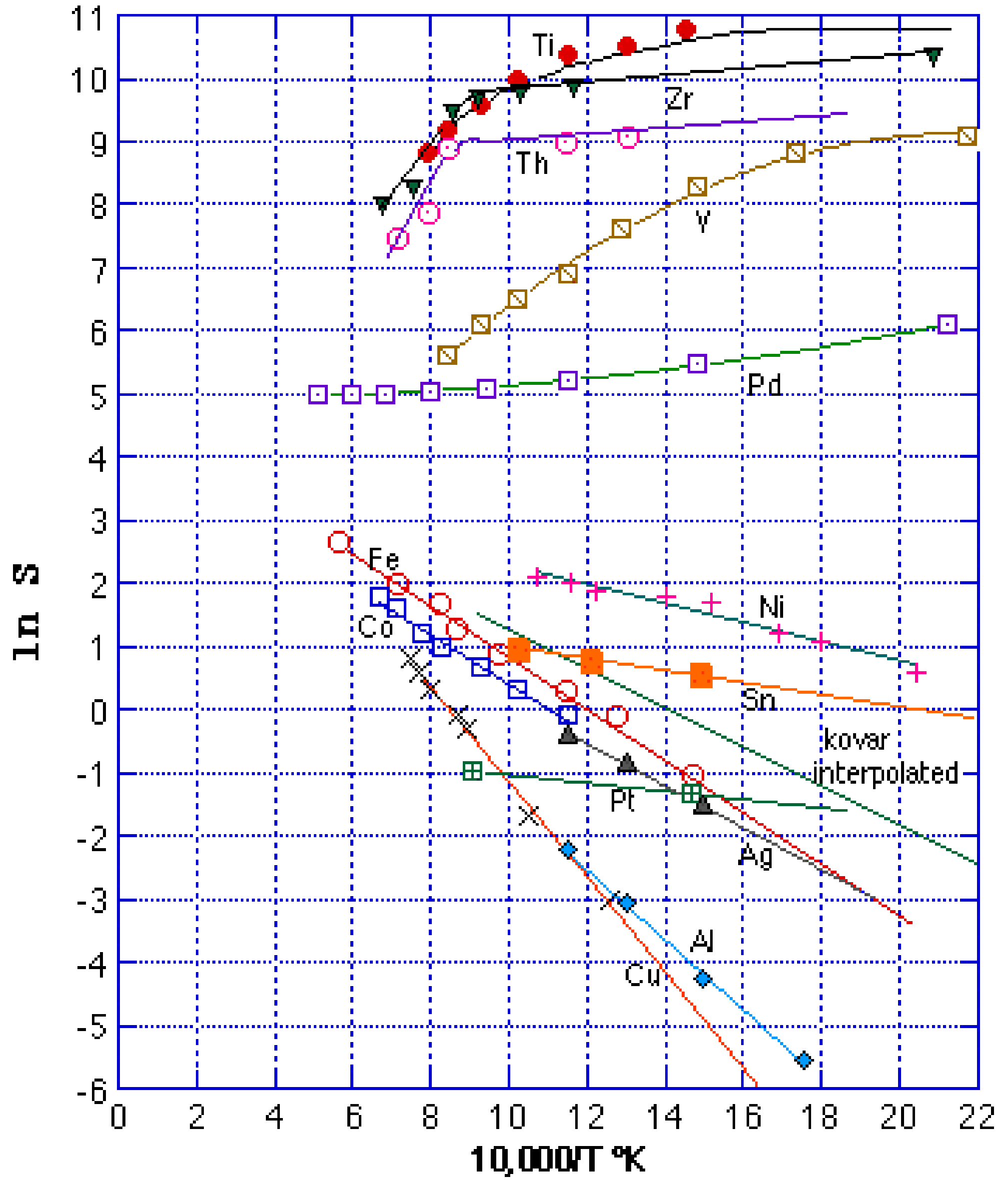
The solubility of hydrogen in various metals are shown in figure. Here solubility S is the volume of H_2 gas absorbed by 100 g. of metal. The solubility of hydrogen in solid and liquid phases (pressure = 1 atm) at solidus temperature is given in table.

$$S = C \exp\left[-E_s/(k\theta)\right]$$

E_S : heat of solution of one mol of hydrogen; sign determines endothermic or exothermic

Metal	Liquid solubility (cc/kg)	Solid solubility (cc/kg)
Fe	**270**	**70**
Mg	260	180
Cu	55	20
Al	7	0.4





Both are Similar graphs

A Theoretical Formula for the Solubility of Hydrogen in Metals, R. H. Fowler and C. J. Smithells, Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences, V160, 1937, p. 37

Sievert's law states that the amt. of hydrogen (and nitrogen) dissolved in a metal varies in proportion with square root of partial pressure of hydrogen in the atmosphere over the melt.

$$\%\text{hydrogen present} = K\sqrt{p_{H_2}}$$

A Ghosh and A K Mallik, *Manufacturing Science*

$$N_{eq}(wt\%) = K_{eq}\sqrt{P_{N_2}} = \sqrt{P_{N_2}}.\exp\left(-\frac{\Delta G_1^0}{RT}\right)$$

Std. free energy for nitrogen in liquid iron

Partial pressure of N_2 in atmosphere over the melt

Gas constant

Temperature (K)

Sources of hydrogen in a melt are furnace dampness, air, oil and grease.

Most of the hydrogen removal techniques are based on the above equation – this is by reducing the partial pressure of hydrogen by bubbling dry insoluble gases through the molten melt.

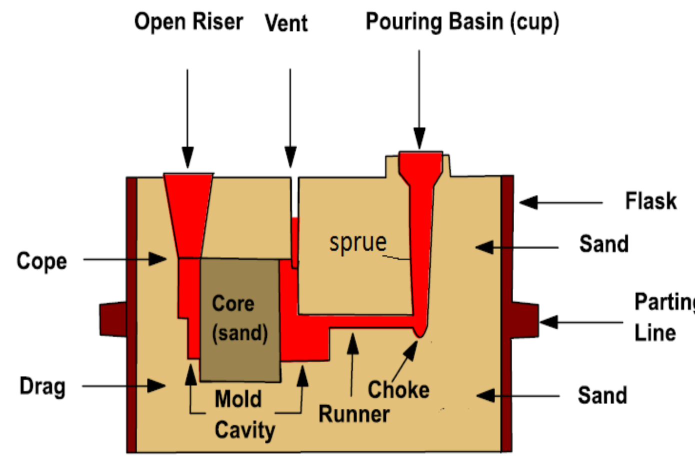
Hydrogen removal:
For non-ferrous metals, chlorine, nitrogen, helium or argon is used.
For ferrous metals and Ni based alloys, nitrogen cannot be used. They form nitrides that affects the grain size. In this case, carbon monoxide is used.

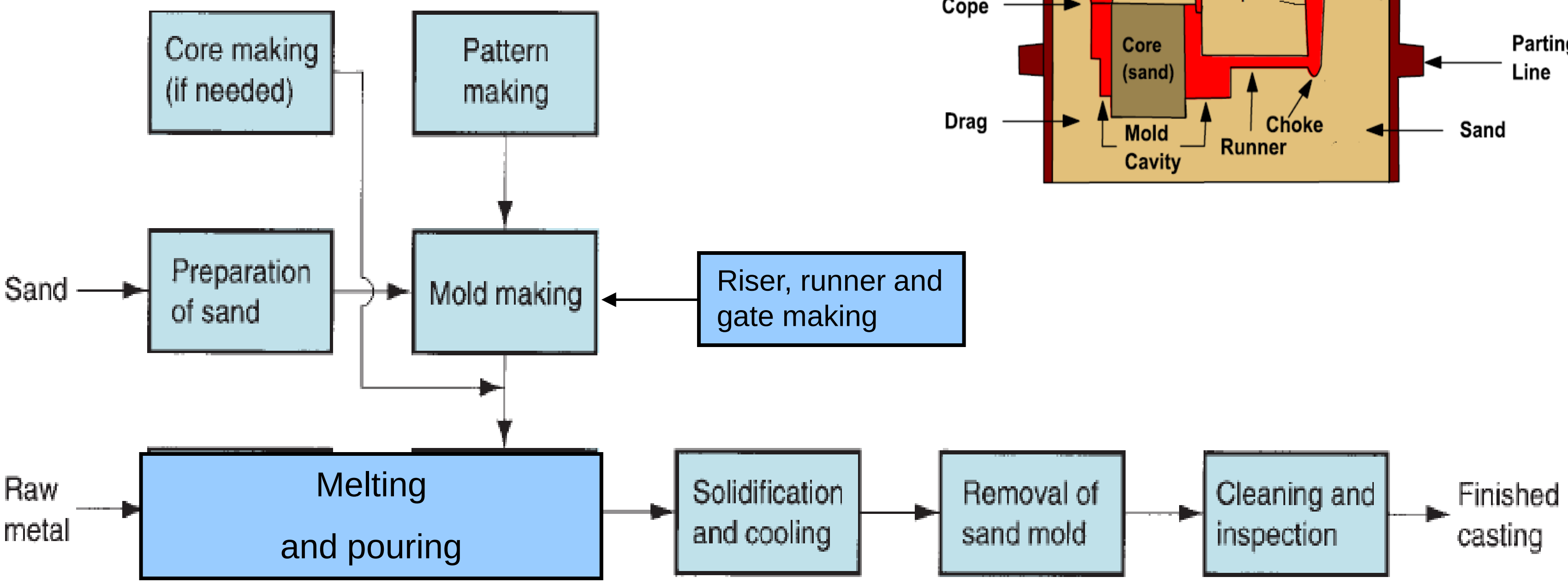
Nitrogen removal: carbon monoxide can be used. A marked decrease in solubility of nitrogen in ferrous metal leads to porosity in casting. **Vacuum melting is used nowadays for preventing the solution of gases in metals.**

Casting processes

Sand Casting

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





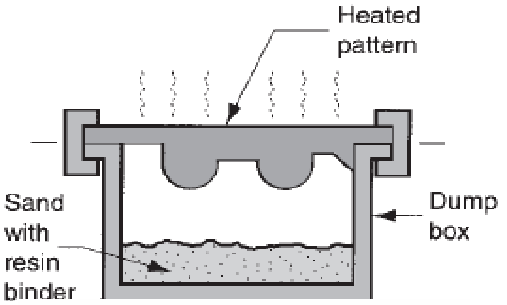
Other casting: Two types – (I) Expendable moulding, (II) Permanent moulding

Expendable moulding processes

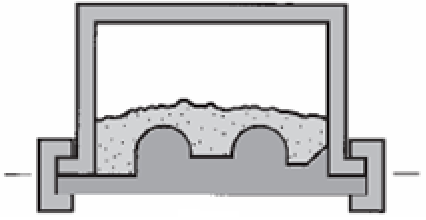
Shell moulding

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.

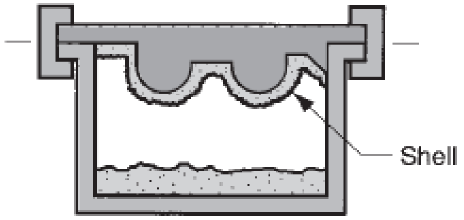
A metal pattern is heated and placed over a box containing sand mixed with thermosetting resin



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

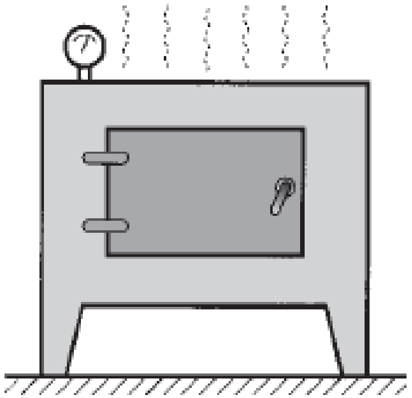


The box is positioned to the previous stage, so that loose, uncured particles drop away

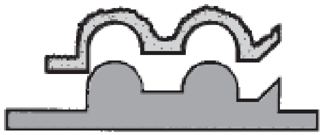


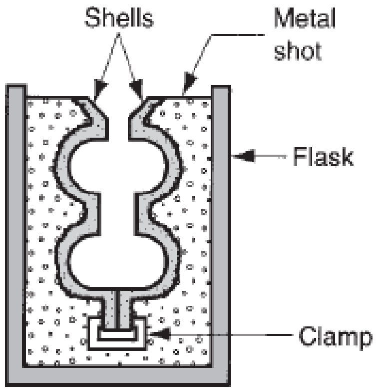
M.P. Groover, *Fundamental of modern manufacturing Materials, Processes and systems*, 4ed

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

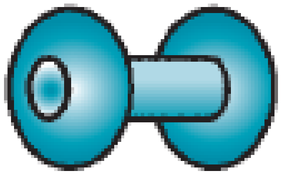


The shell mold is removed from the pattern and two halves of the shell mold are assembled, supported by sand or metal shot in a box, and pouring is completed





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

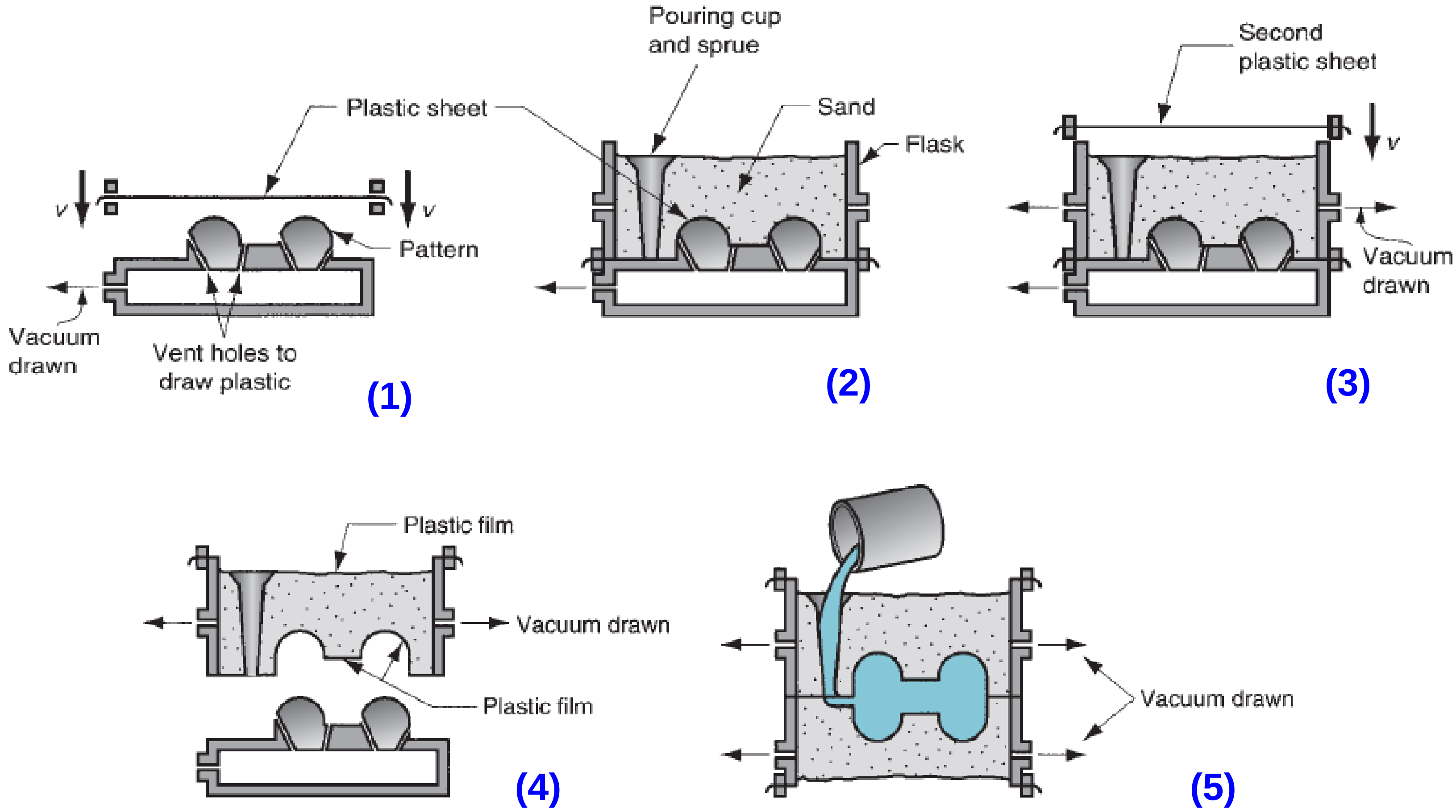
• expensive metal pattern is required, and hence not suitable for small quantities.

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.



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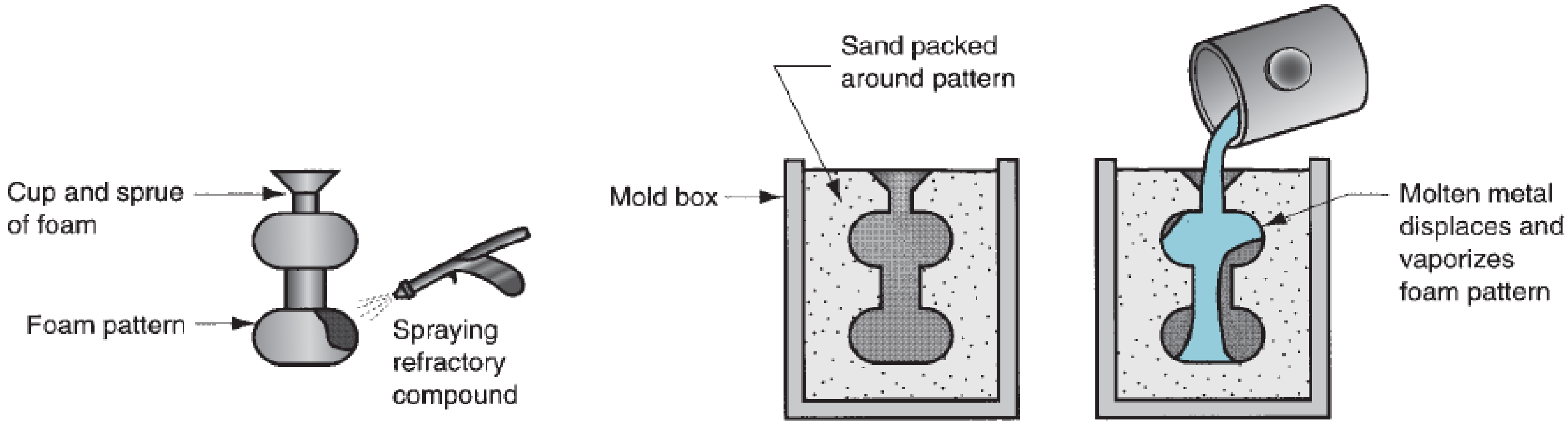
Advantages:

- 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

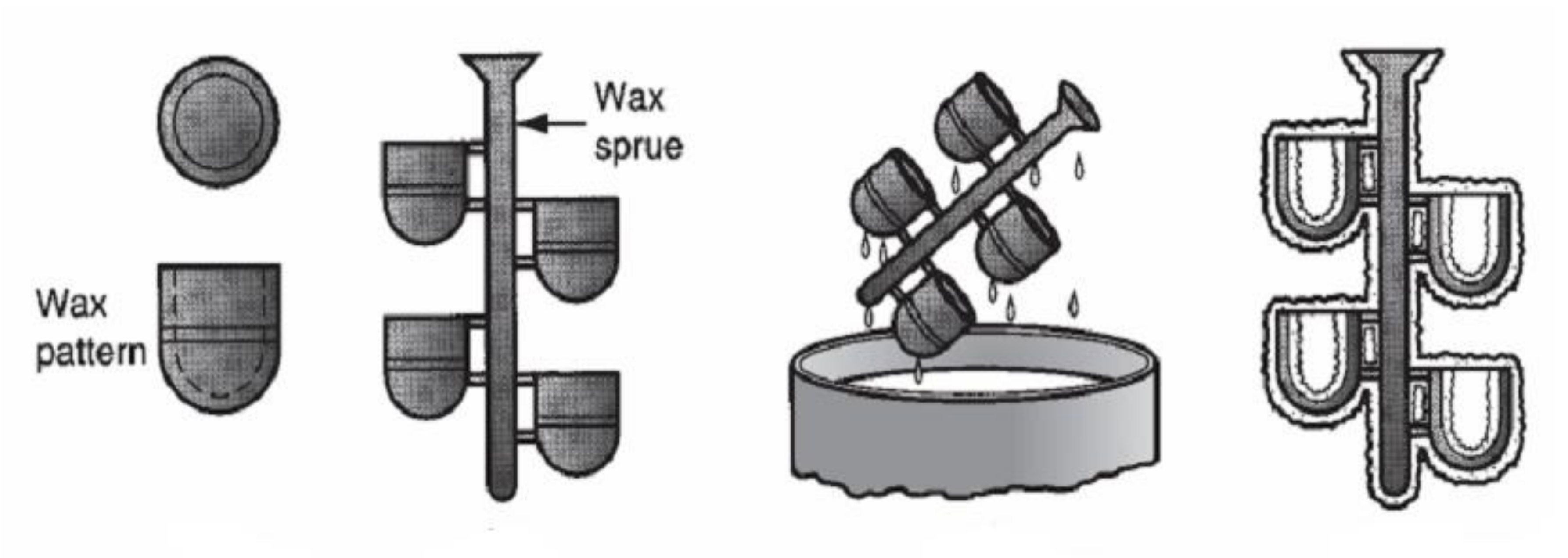
- In this process, a mold of sand packed around a polystyrene foam pattern is used. This pattern will vaporize when the molten metal is poured into the mold.
- The refractory compound will provide a smoother surface on the pattern and to improve its high temperature resistance.
- Molding sands usually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



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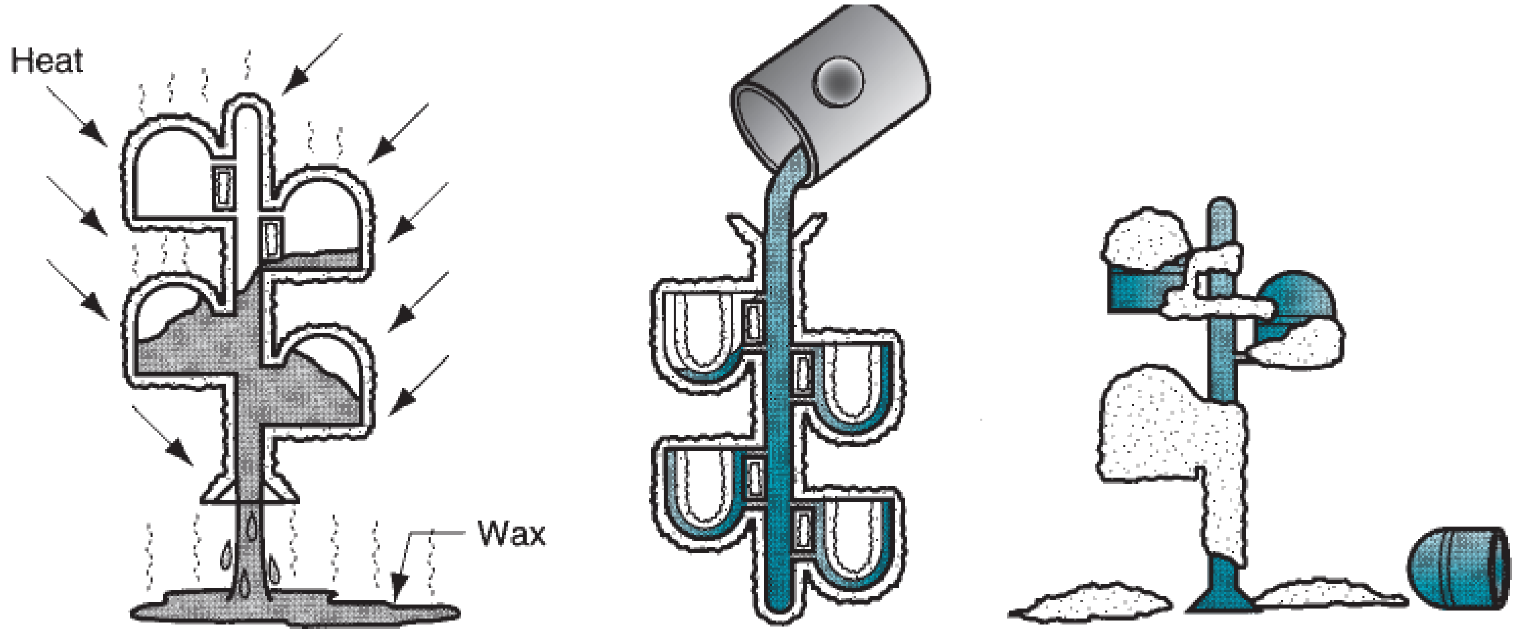

• Wax patterns are first made
• several patterns can be attached to a sprue to form a pattern tree, if required
• the pattern tree is coated with a thin layer of refractory material and later covered with thick coating to make the rigid full mold
• Heating of mold in inverted position to melt the wax 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.

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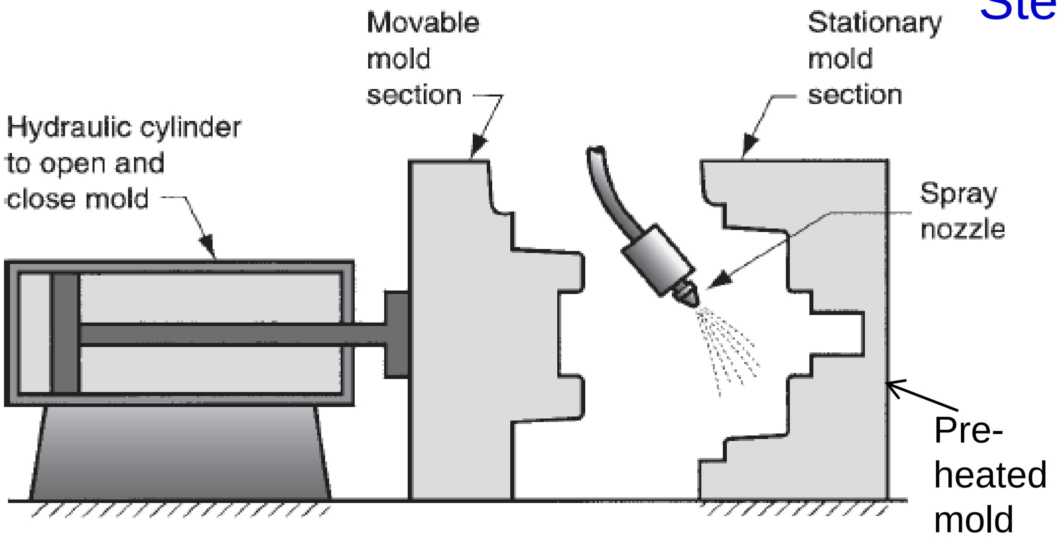
Permanent mold process

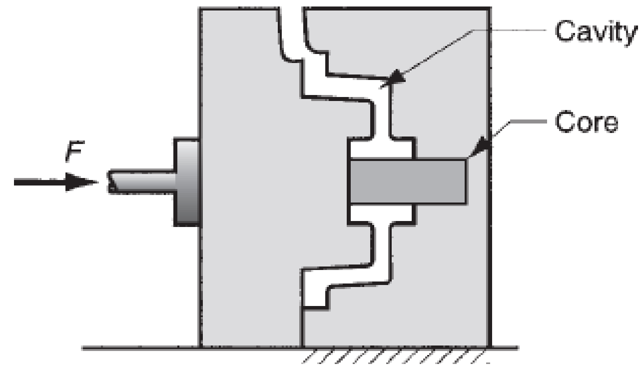
Disadvantage of expendable molding processes is that for every casting a new mold is required.

Permanent mold processes:

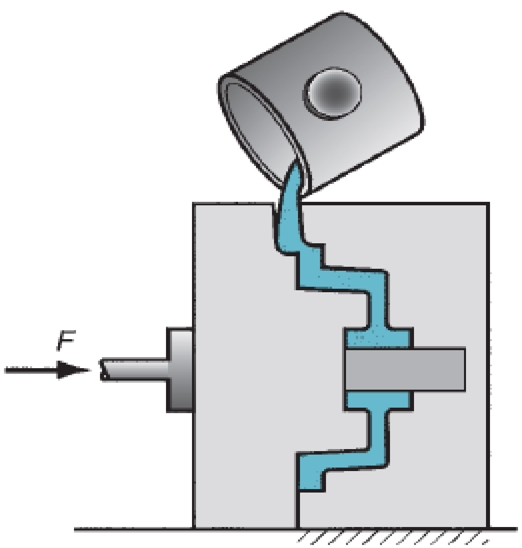
- using only metal mold for casting
- Molds are generally made of steel, CI
- materials that can be cast: Al, Mg, Cu based alloys, CI (affect the mold life, hence not used)
- cores are also made of metal, but if sand is used then called semi permanent-mold casting
- Advantages: good surface finish, dimension 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

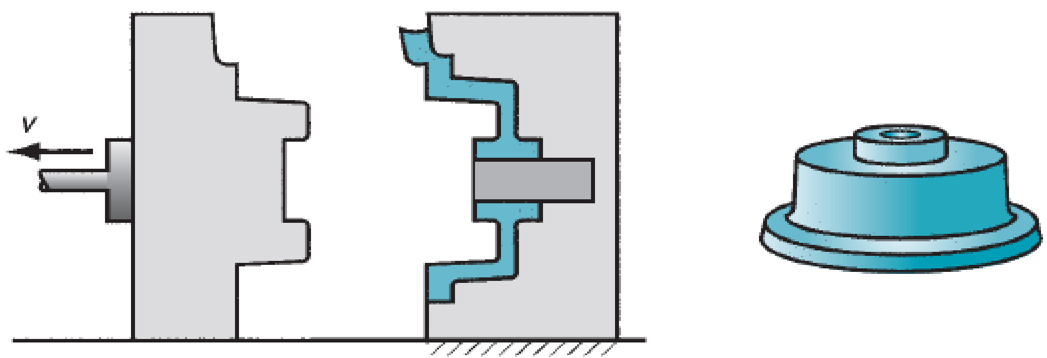
Steps in permanent mold process





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





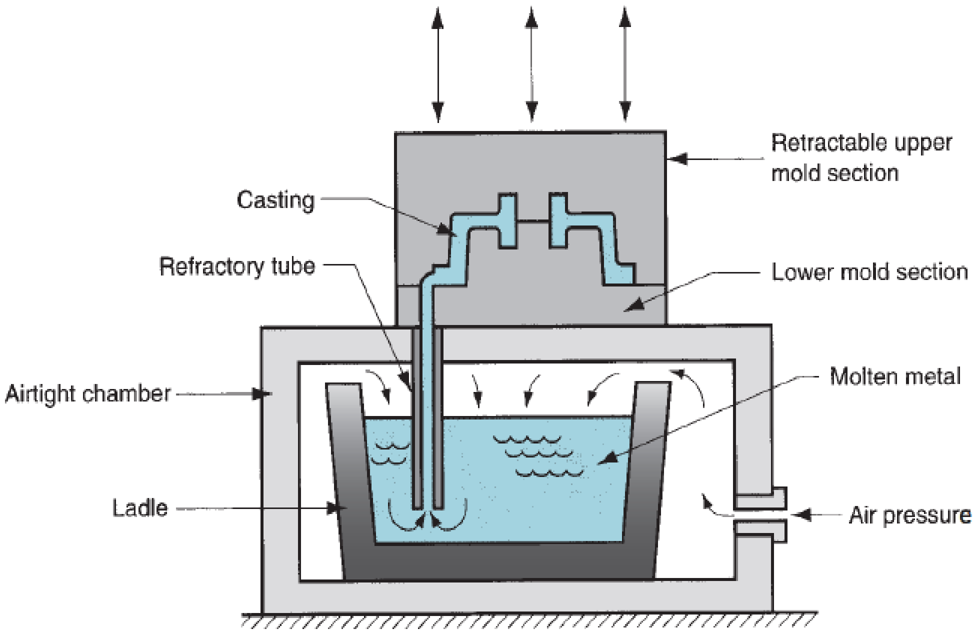
Variations of permanent mold casting

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

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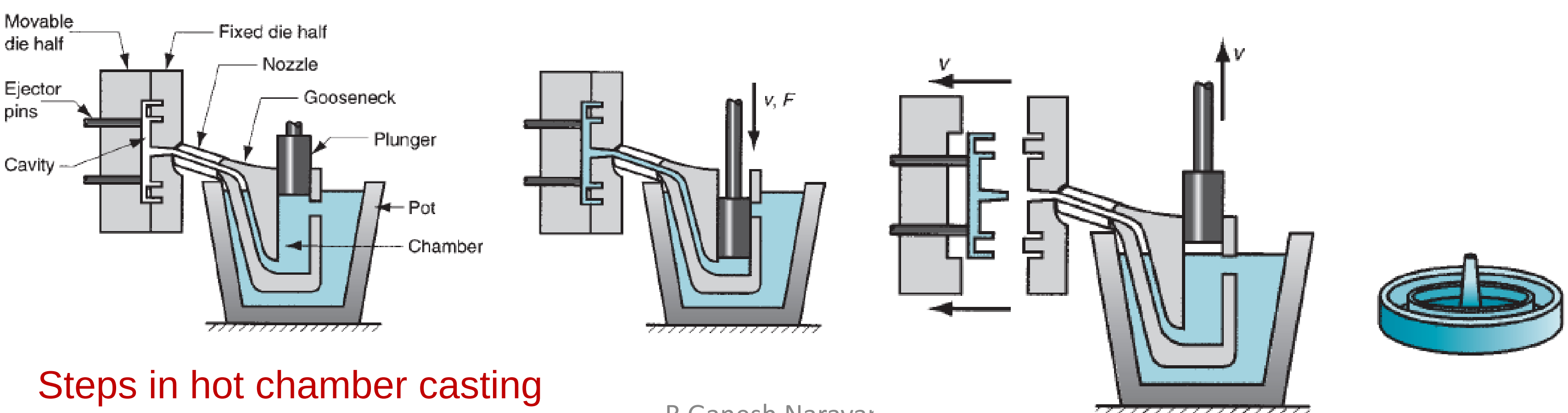
Die casting

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.

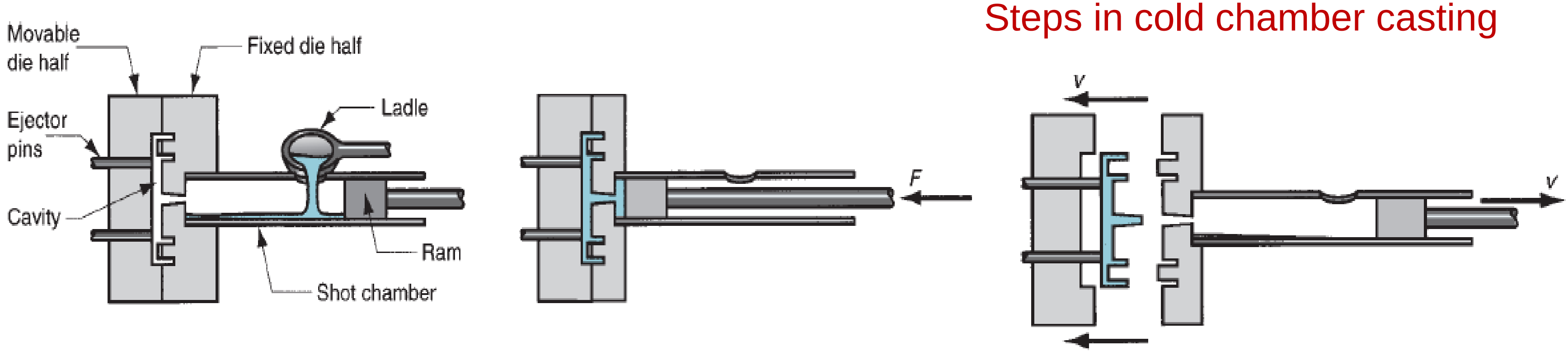


Steps in hot chamber casting

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:

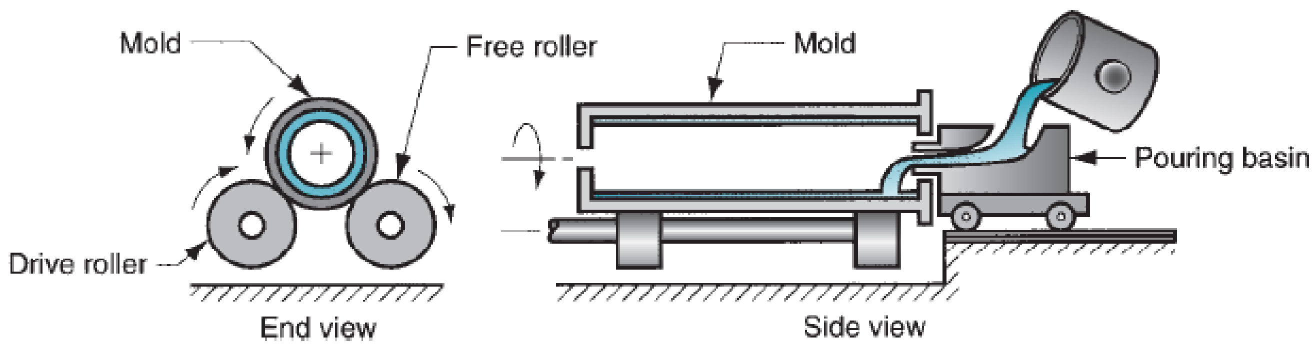
- high production rates and economical
- Close tolerances possible of the order of ±0.076 mm
- thin section with 0.5 mm can be made
- small grain size and good strength casting can be made because of rapid cooling

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

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- 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.

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

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,

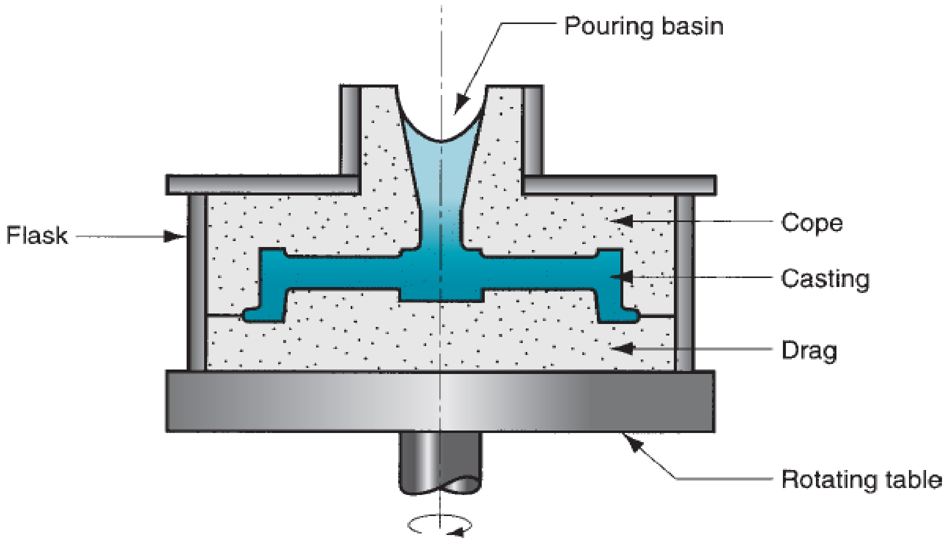
$$N = \frac{30}{\pi}\sqrt{\frac{2gL}{R_{it}^{2} - R_{ib}^{2}}}$$

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.