((<u>Manufacturing</u>))

<u>Permanent Mold Casting Processes:</u>

In <u>permanent mold casting</u>, the mold is reused many times. The processes include:

1) Basic permanent mold casting. 2) Slush Casting. 3) Low Pressure casting.

4) Vacuum Permanent mold casting. 5) Die casting. 6) Centrifugal casting.

1. <u>The Basic Permanent Mold Process:</u>

It is a process in which fluid metal is poured into metal molds & subjected to hydrostatic pressure [see fig. (1) below]. For hollow parts, either permanent core made of metal or sand is used.

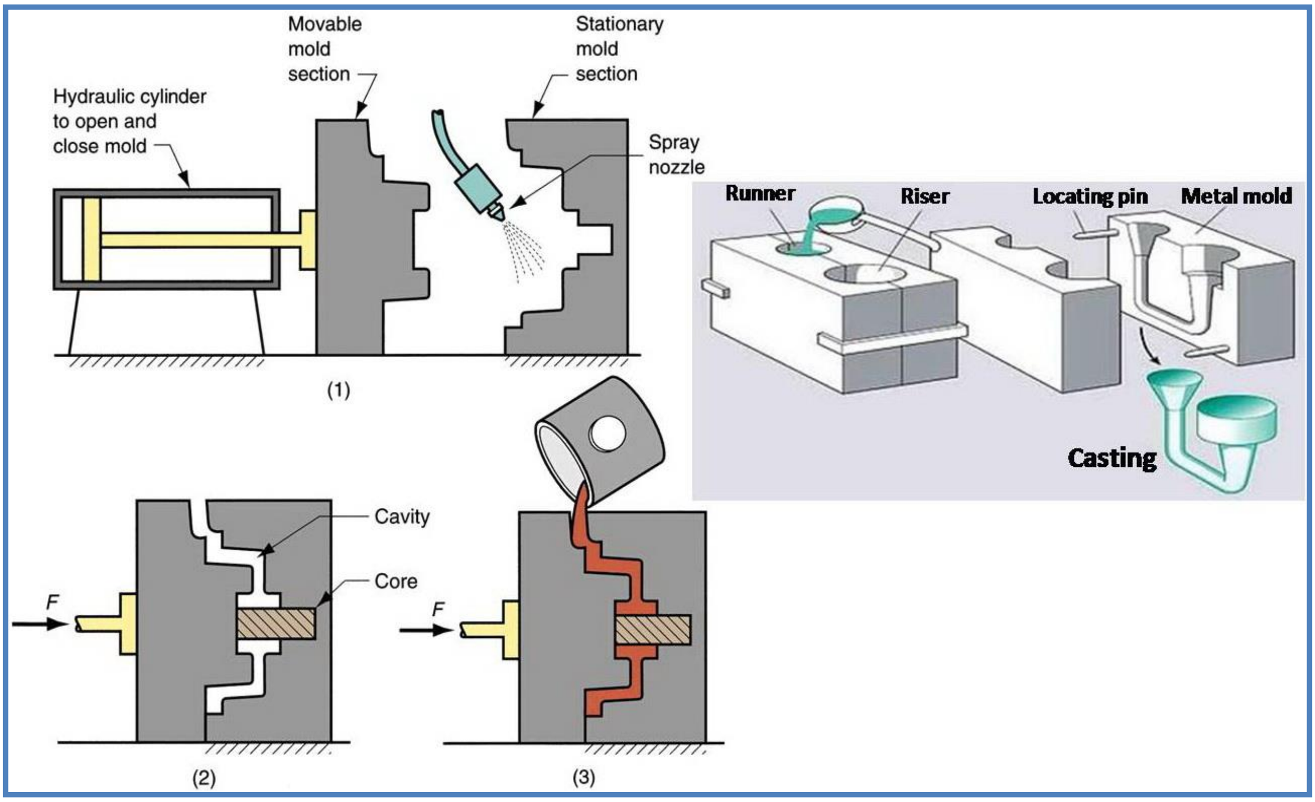

Fig. (1): Steps in Permanent mold casting.

Permanent mold casting is a metal casting process that shares similarities to both sand casting and die casting. As in sand casting, molten metal is poured into a mold which is clamped shut until the material cools and solidifies into the desired part shape.

Permanent mold casting, like die casting, uses a metal mold (die) that can be reused for several thousand cycles. Because the molten metal is poured into the die and not forcibly injected, permanent mold casting is often referred to as *<u>gravity die casting</u>*.

- **Uses a metal mold constructed of <u>two sections</u> designed for <u>easy, precise opening and closing</u> [see fig. (1) above].**
- **Molds used for casting lower melting point alloys are commonly made of steel or cast iron.**
- **Molds used for casting steel must be made of refractory material, due to the very high pouring temperatures.**

<u>Steps in permanent mold casting</u> <u>(referring to fig. (1) above)</u>*<u>:</u>*

(1) Mold is preheated and coated.
(2) Cores (if used) are inserted and mold is closed [see fig. (1) above].
(3)) molten metal is poured into the mold, where it solidifies.

***<u>Advantages</u>* of permanent mold casting:**

- Good dimensional control and surface finish
- <u>More rapid solidification</u> caused by the cold metal mold results in a <u>finer grain structure</u>, so castings are stronger

<u>Limitations:</u>

- Generally <u>limited to metals of lower melting point</u>
- <u>Simpler part geometries</u> compared to sand casting because of <u>need to open the mold</u>
- <u>High cost</u> of mold

<u>Applications of Permanent Mold Casting:</u>

- Due to <u>high mold cost</u>, process is best suited to high volume production and can be automated accordingly.
- Typical parts: automotive pistons, pump bodies, and certain castings for aircraft and missiles.
- Metals commonly cast: aluminum, magnesium, copper-base alloys, and cast iron.

2. *<u>Slush Casting:</u>*

Slush Casting is a special type of <u>permanent mold casting</u> to create a hollow casting without using cores [see fig. (2) below]. In the process the material is poured into the mold and allowed to cool until a desired wall thickness is obtained, the not yet solidified molten metal is poured out. It is a relatively inexpensive process.

- This is useful for making <u>hollow ornamental</u> objects such as <u>candlesticks, lamp's holder, statues</u> etc.

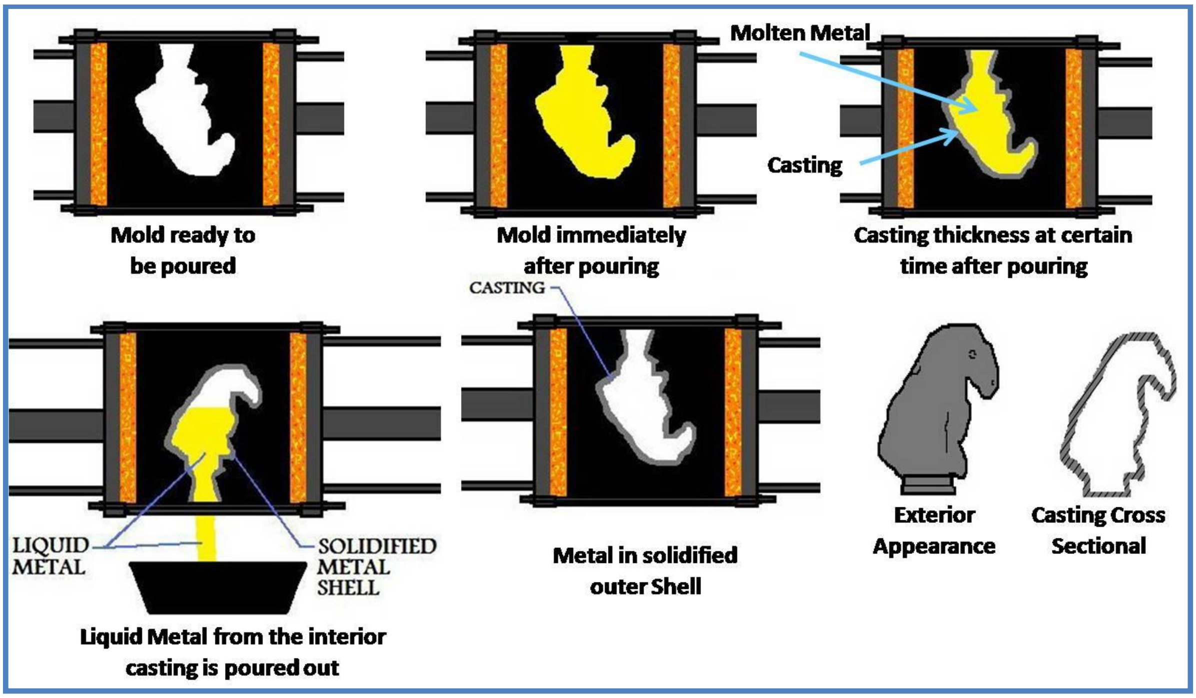

Fig. (2): The steps to form a Slush casting.

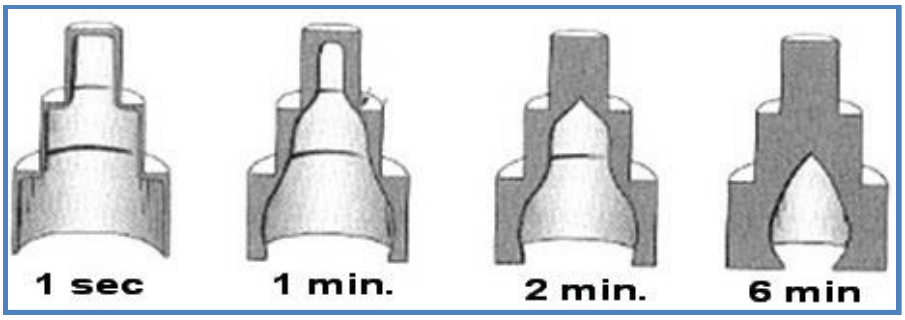

Fig. (3): Variation of the Shell thickness with time of solidification.

- **The thickness of the shell is controlled by the amount of time allowed before the mold is drained as shown in Fig. (3) above.**
- **Low-melting-point metals such as lead, zinc, and tin are used.**
- **The exterior appearance is important, but the strength and interior geometry of the casting are minor considerations.**

3. *Low Pressure Casting:*

Instead of using gravity to assist in the metal pour and flow in the mold, a low pressure of up to 0.1 MPa (15 psi) gas is applied to the molten metal [see fig. (4) below].

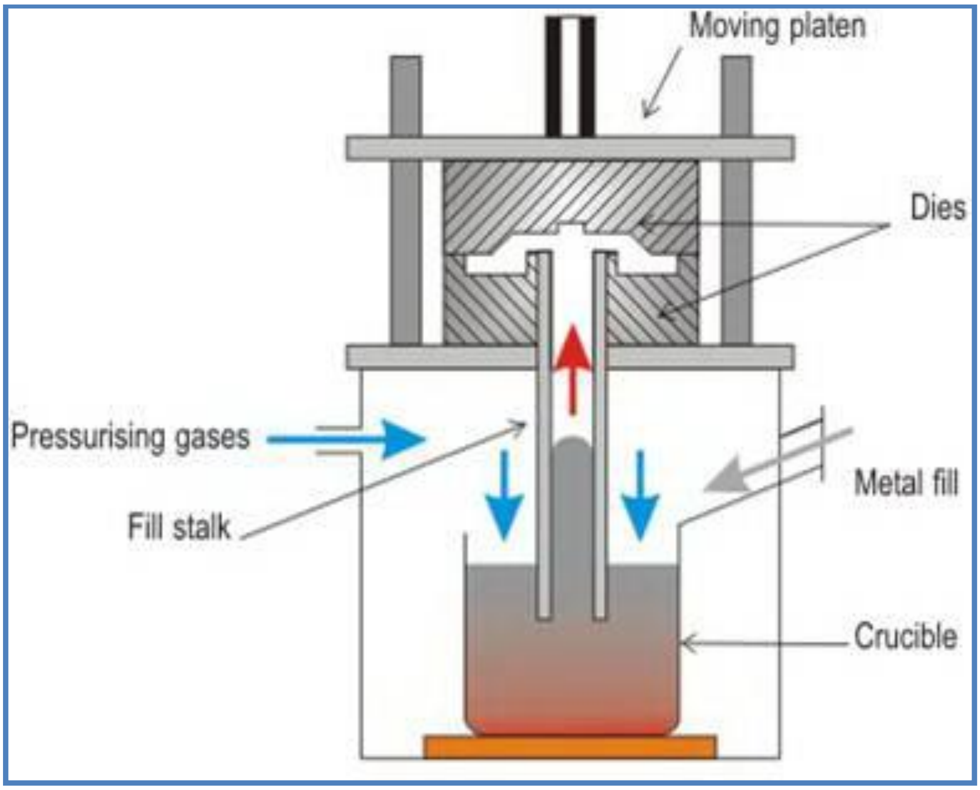

Fig. (4): Low Pressure Casting process.

- **The maintenance of pressure on the melt causes complete fill of the mold and compensates for any shrinkage on cooling.**
- **Thin wall castings can be made.**
- **The metal cools inwardly in the mold to the stalk and freezes while the pressure (P) is held, then (P) is released & the still molten in stalk return to the pot, the process is used to cast :**

  1 – Al in plaster. 2 – Cast Iron. 3 – Steel mold.
- **Mechanical properties are superior.**
- **Gas porosity and oxidation defects are minimized.**

Low – Pressure Casting (L– P casting) ***is a stage between hydrostatic casting*** **(Permanent mold)** ***& high – pressure die casting.***

4. *Vacuum Permanent Mold Casting:*

It is similar to the low-pressure permanent mold casting, except a vacuum is used instead of a pressure [see fig. (5) below].

- **Reduced air pressure from the vacuum in the mold is used to draw the liquid metal into the cavity (rather than forcing it by pressure).**
- **Thin wall castings can be made as in the low-pressure permanent mold casting. In addition, the yields are high since no risers are used.**
- **Advantages: Reduced air porosity, greater strength.**

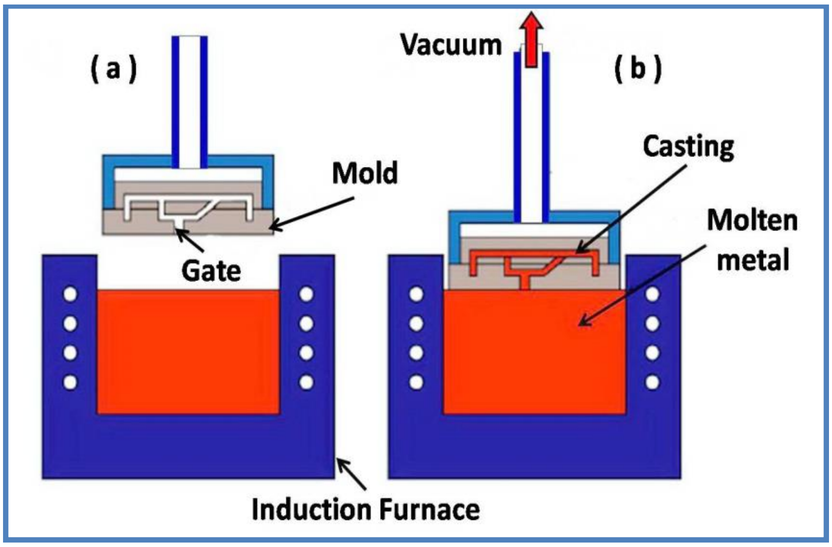

Fig. (5): Vacuum Permanent mold casting (a) before the process (b) Casting perfomed.

5. Squeeze Casting:

Squeeze casting is a combination of casting and forging in which a molten metal is poured into a preheated lower die, and the upper die is closed to create the mold cavity after solidification begins [figure (6)].

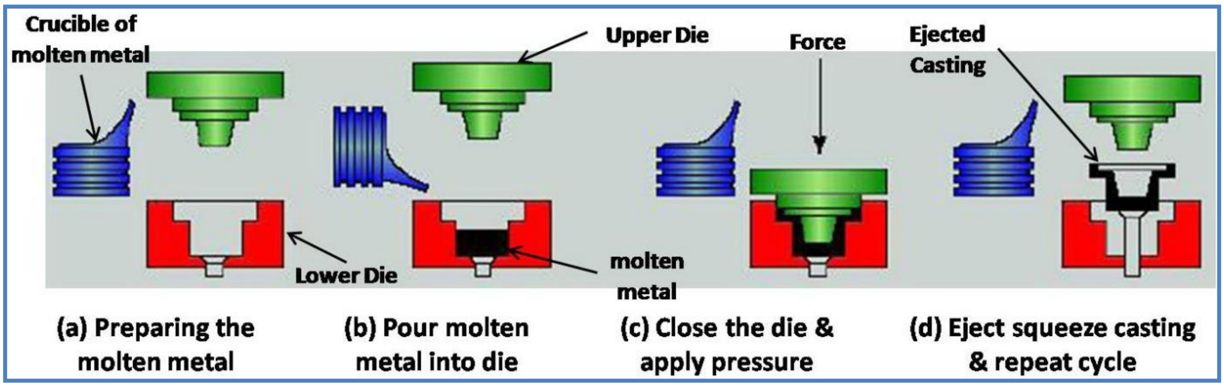

Fig. (6): Squeeze Casting Process.

- **This differs from the usual permanent-mold casting process in which the die halves are closed prior to pouring or injection.**
- **Owing to the hybrid nature of the process, it is also known as liquid–metal forging.**
- **The pressure applied by the upper die in squeeze casting causes the metal to completely fill the cavity, resulting in good surface finish and low shrinkage.**
- **The required pressures are significantly less than in forging of a solid metal billet and much finer surface detail can be imparted by the die than in forging.**
- **Squeeze casting can be used for both ferrous and non-ferrous alloys, but aluminum and magnesium alloys are the most common due to their lower melting temperatures.**
- **Automotive parts are a common application.**

6. Semi – Solid Metal Casting:

It is a family of net-shape and near net-shape processes performed on metal alloys at temperatures between the liquidus and solidus [figure (7)].

- **The alloy is a mixture of solid and molten metal during casting; it is in the mushy state.**

- **In order to flow properly, the mixture must consist of solid metal globules in a liquid rather than the dendritic solid shapes that form during freezing of a molten metal, with the fraction solid being in the range of 30 to 65%.**

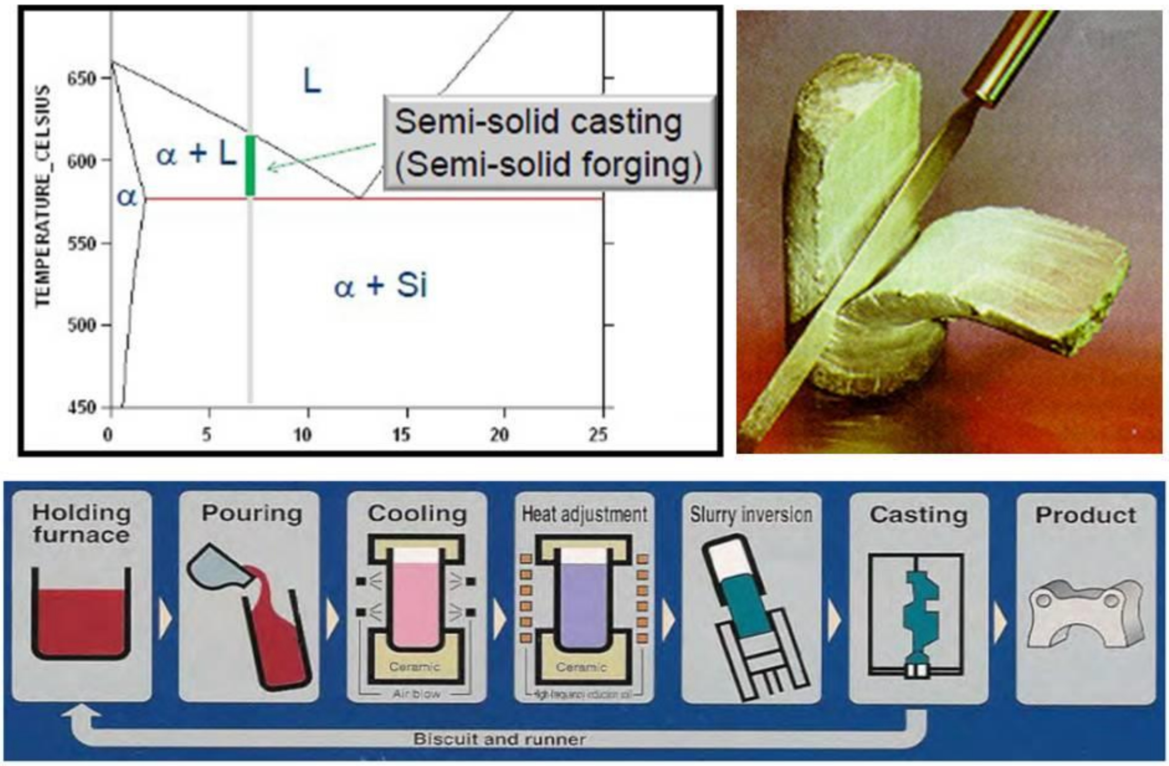

Fig. (7): Semi – Solid Metal Casting Process.

Metals: **Aluminum, magnesium, and some copper alloys.**

Size Range: **Ounces to about 1 pound, limited to a diameter of feed stock. Some SSM Houses can produce parts up to 15-20 pounds.**

7. *Die Casting:*

Die casting is a permanent-mold casting process in which the molten metal is injected into the mold cavity under high pressure.

Die casting is a manufacturing process that can produce geometrically complex metal parts through the use of reusable molds, called dies, hence the name die casting. *This process is a further development of Permanent – mold casting.*

- **A permanent mold casting process in which molten metal is injected into mold cavity under high pressure, typical pressures are (7 to 350 MPa).**
- **Pressure is maintained during solidification, then mold is opened and part is removed.**
- **Use of high pressure to force metal into die cavity is what distinguishes this from other permanent mold processes.**
- **It differs from sand casting. Sand casting uses a mold made of sand which is a poor conductor of heat, so the cooling process is very slow, molten metal is simply poured into the mold and the mold is expendable. In permanent mold casting, by contrast, the mold is made from steel or other metal which is a good conductor, so the cooling is fast, it can be reused and the molten metal is being injected.**

***Die Casting Machines*:**

Die casting operations are carried out in special die casting machines which is designed to hold and accurately close two mold halves and keep them closed while liquid metal is forced into cavity [figure(8)].

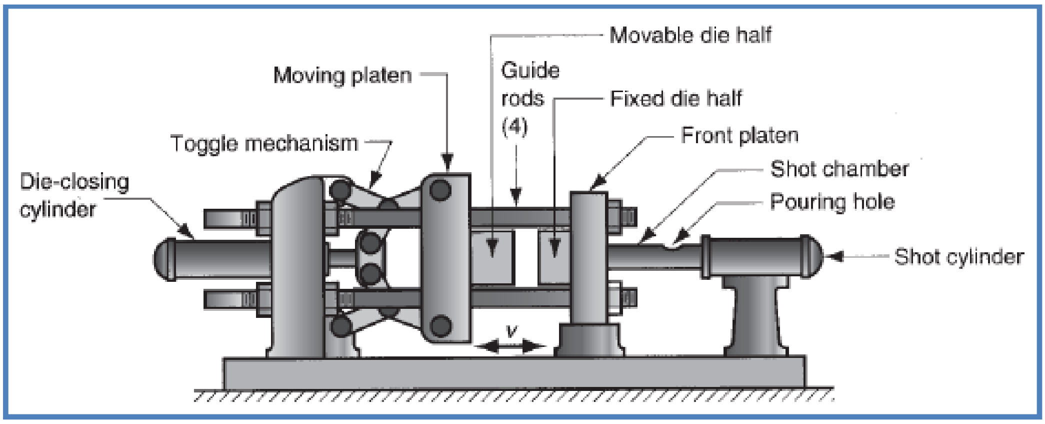

Fig. (8): General configuration of a Die Casting machine.

The Four Steps of Die Casting

There are four key steps in the process of die casting, the die casting machine should be at the required temperature, to ensure the molten metal not to solidify too quickly. According to the size of the casting, heating can take from several hours to several minutes. The four steps are:

1) Spray the mold with lubricant and close it, allowing for an easier removal of the cast object later on.

2) Inject the molten metal into the die. The metal is inserted at an extremely high pressure, which allows the metal to conform to the precise shape of the die.

3) Cool the mold, and wait for the metal to solidify. In some cases, the mold may be immersed or sprayed with cold water to help the casting become solid faster. A high pressure is maintained inside the mold, which ensures the metal doesn't change properties while inside the die.

4) Open the die and remove the solid cast!

There are two main types of Die – Casting machines:

1. **Hot-chamber machine.**
2. **Cold-chamber machine.**

1) *Hot-Chamber Die Casting:*

Metal is melted in a container, and a piston injects liquid metal under high pressure into the die [see fig. (9) below].

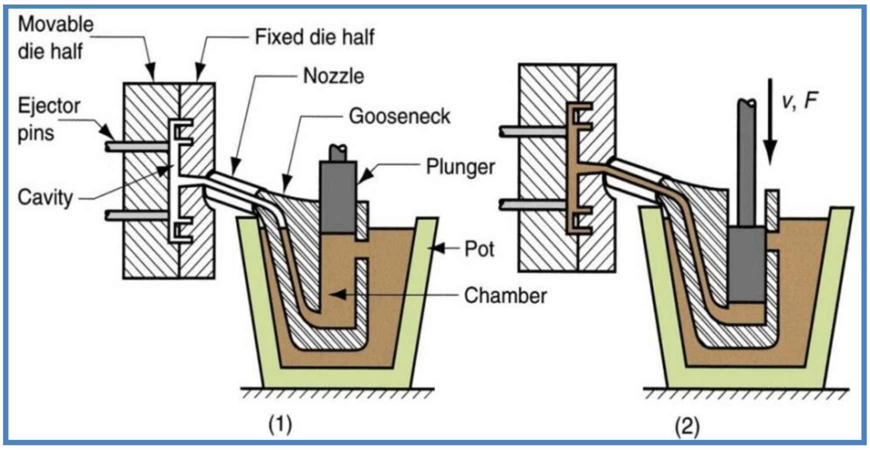

Fig. (8): Cycle in hot - chamber casting.

- **High production rates - 500 parts per hour not uncommon.**
- **Applications limited to low melting-point metals that do not chemically attack plunger and other components due to the hot metal that is poured in to them.**
- **Casting metals: zinc, tin, lead, and magnesium.**

- **With die closed and plunger withdrawn, molten metal flows into the chamber.**
- **Plunger forces metal in chamber to flow into die, maintaining pressure during cooling and solidification.**

2) *Cold Chamber Die Casting Machine:*

Molten metal is poured into unheated chamber from external melting container (ladle), and a piston injects metal under high pressure into die cavity *at pressure as much as (10 times) than that in the Hot – Chamber process.* [see fig. (10) below]:

- **High production but not usually as fast as hot-chamber machines because of pouring step**
- **Casting metals: aluminum, brass, and magnesium alloys**

Advantages of hot-chamber process favor its use on low melting-point alloys (zinc, tin, lead)

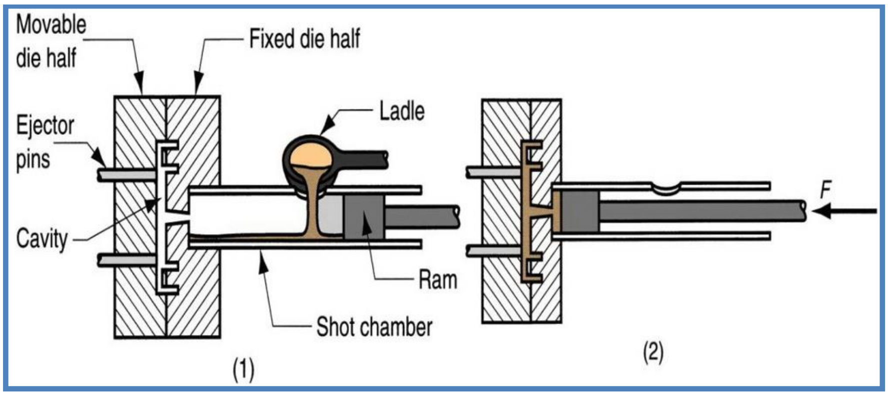

Fig. (10): Cycle in cold-chamber casting.

(1) **With die closed and ram withdrawn, molten metal is poured into the chamber.**
(2) **Ram forces metal to flow into die, maintaining pressure during cooling and solidification.**

Molds for Die Casting:

- **Usually made of tool steel, mold steel, or maraging steel (a strong tough low-carbon martensitic steel which contains up to 25 percent nickel and in which hardening precipitates are formed by aging)**
- **Tungsten and molybdenum (good refractory qualities) used to die cast steel and cast iron.**
- **Ejector pins required to remove part from die when it opens.**
- **Lubricants must be sprayed into cavities to prevent sticking.**

Advantages of die casting:

- **Economical for large production quantities.**
- **Good accuracy and surface finish.**
- **Thin sections are possible.**
- **Rapid cooling provides small grain size and good strength to casting.**

Disadvantages:

- **Generally limited to metals with low metal points.**
- **Part geometry must allow removal from die.**

Dies in Die – Casting:

A die is a tool containing a cavity that imparts a shape to a solid, molten, or powder metal or other material, such as wax or plastic [see fig. (11) below].

***Die:* consisting of a pair (or a combination of pairs) of mating members for producing certain casting, including all supporting & actuating elements of the tool [fig. (12) below].**

Two dies are used in die casting; one is called the "cover die half" and the other the "ejector die half". Where they meet is called the parting line.

The cover die contains the sprue (for hot-chamber machines) or shot hole (for cold-chamber machines).

- **One of the design considerations in dies for die casting is that a taper on cavity walls must be added so the part can be removed from the die.**
- **A second concern is where to locate the parting line to form the two die halves so the part can be easily removed after forming.**
- **Thermal expansion of the die material must be considered as well as thermal contraction of the part during cooling**
- **The dies must be massive and strong enough to withstand the subjected high load of metal injected inside it.**

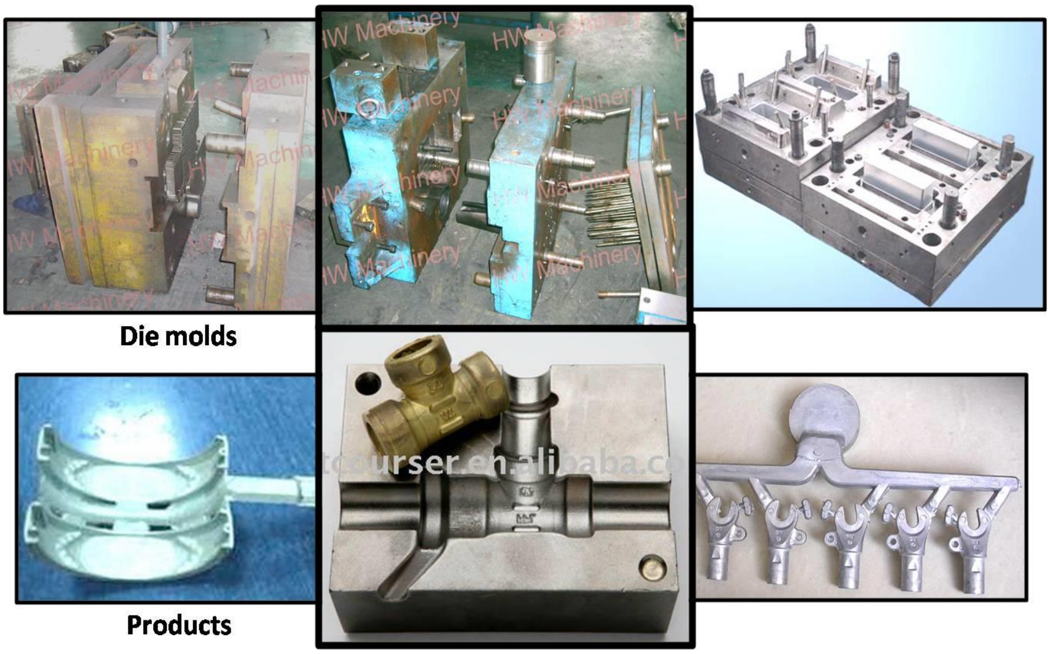

Fig. (11): The Die molds and its products.

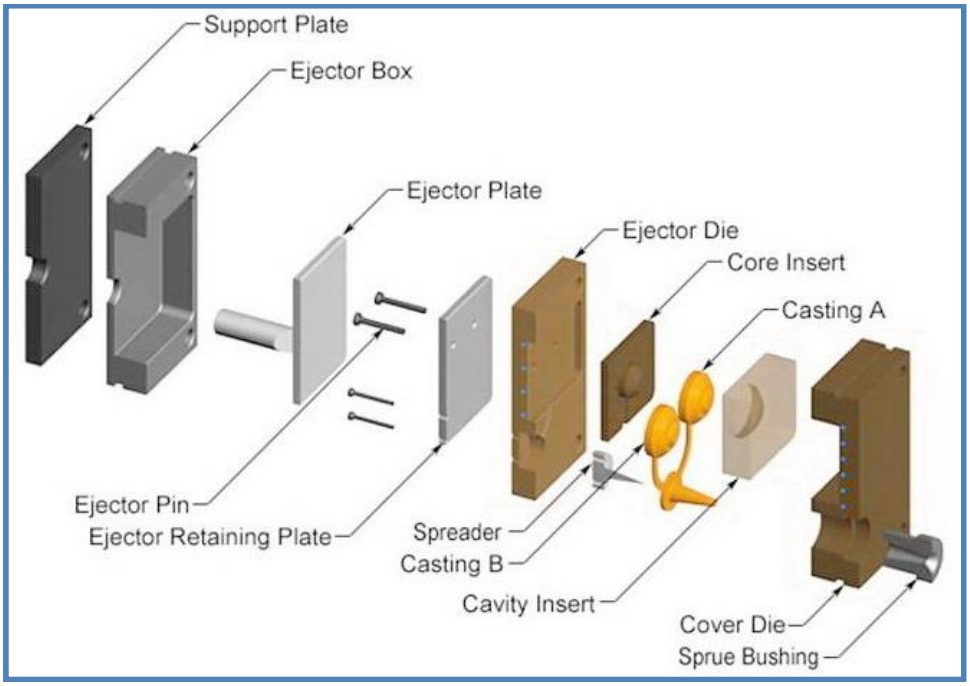

Fig. (12): The main components of Dies in Die casting.

<u>*Types of Dies are*</u> <u>[see fig. (13) below]</u>*:*

- **<u>*Single Cavity*</u>: (turns out only (1) casting for each cycle of operation.**
- **<u>*Multi Cavity*</u>: large – quantity production of small & moderate size pieces, a number of cavities may be sunk in a single Die & may be gated from common sprue.**

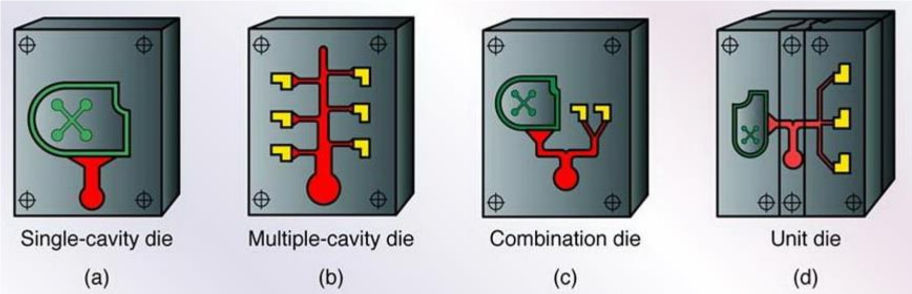

Fig. (13): The types of Dies in Die casting.

- **<u>*Combination*</u>: the cavities are of (2) or more different shapes & produces as many different part at one time.**
- **<u>*Unit*</u>: consist of a die holder in which several die elements may be placed & filled at the same time.**

8. *Centrifugal Casting:*

A family of casting processes in which the molten metal is pouring into mold which is rotated at high speed so centrifugal force distributes molten metal to outer regions of the die cavity.

<u>*The group includes:*</u>

- **<u>True</u> centrifugal casting.**
- **<u>Semi-centrifugal</u> casting.**
- **<u>Centrifuge</u> casting.**

<u>*Centrifugal Casting produces:*</u>

- ***Good quality.***
- ***Accurate casting.***
- ***Saves material.***
- ***Dense product & have fine grained structure with uniform & high physical properties.***
- ***Less subjected to directional variation than static casting.***

<u>*True Centrifugal Casting:*</u>

Molten metal is poured into rotating mold to produce a tubular part (*hollow cylindrical shapes such as pipe are produced*) [see fig. (14) below].

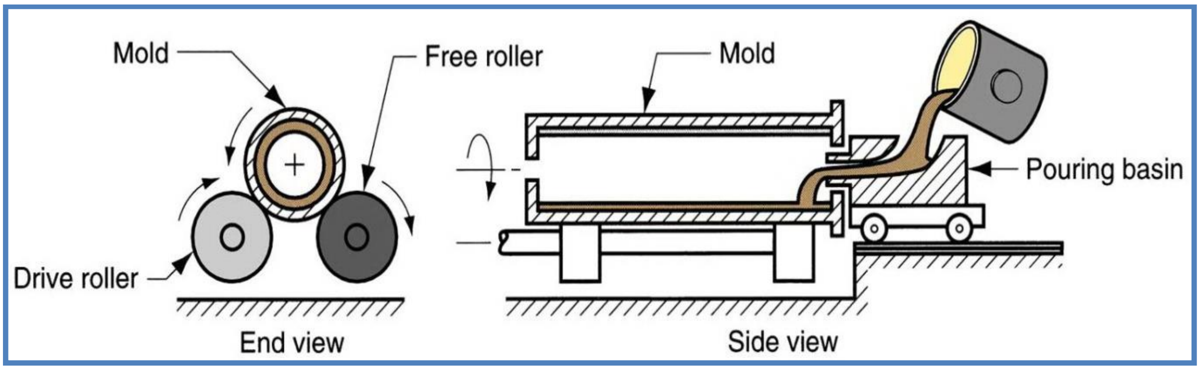

Fig. (14): Setup for true centrifugal casting.

- **In some operations, mold rotation commences after pouring rather than before.**
- **The mold can be rotated about a vertical, horizontal axis [see fig. (15) below].**

- **The length and outside diameter are fixed by the mold cavity dimensions while the inside diameter is determined by the amount of molten metal poured into the mold.**
- **Parts: pipes, tubes, bushings, and rings.**
- **<u>Outside</u> shape of casting can be <u>round, octagonal, hexagonal</u>, etc , but <u>inside</u> shape is (theoretically) <u>perfectly round</u>, due to radially symmetric forces.**

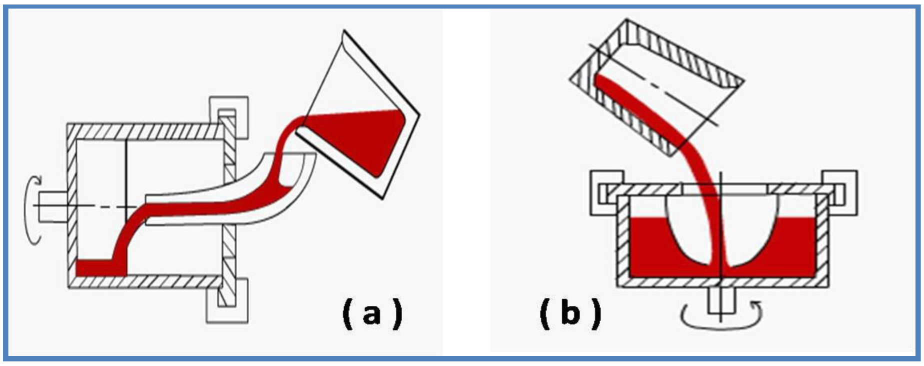

Fig. (15): Centrifugal casting (a) Horizontal axis (b) Vertical axis.

<u>Mold Speed of Rotation:</u>

Let us consider how fast the mold must rotate in horizontal centrifugal casting for the process to work successfully. Centrifugal force is defined by this physics equation:

$$F = \frac{m.V^2}{R}$$

Where:

F = force, N; m = mass, kg; V = velocity, m/s; and R = inside radius of the mold, m.

The force of gravity is its weight W=mg, where *m* is given in kg, and g = acceleration of gravity, 9.8 m/s^2. The so-called G-factor GF is the ratio of centrifugal force divided by weight:

$$GF = \frac{m.V^2}{R.W} = \frac{m.V^2}{R.m.g} = \frac{V^2}{R.g}$$

Velocity V can be expressed as:

$$V = \frac{2\,\pi.\ R.N}{60} = \frac{\pi.R.N}{30}$$

Where: *N* = rotational speed, rev/min.

Substituting this expression into Eq. in above equation, we obtain:

$$N = \frac{30}{\pi} . \sqrt{\frac{2\,g.GF}{D}}$$

Where: D = inside diameter of the mold, m.

If the G-factor (GF) is too low in centrifugal casting, the liquid metal will not remain forced against the mold wall during the upper half of the circular path but will ''rain'' inside the cavity. Slipping occurs between the molten metal and the mold wall, which means that the rotational speed of the metal is less than that of the mold. On an empirical basis, values of [GF = 60 to 80] are found to be appropriate for horizontal centrifugal casting.

<u>Example:</u>

A true centrifugal casting operation is to be performed horizontally to make copper tube sections with OD ¼ 25 cm and ID ¼ 22.5 cm. What rotational speed is required if a G-factor of 65 is used to cast the tubing?

Solution:

The inside diameter of the mold D = OD of the casting = 25 cm = 0.25 m., it can compute the required rotational speed as follows:

$$N = \frac{30}{\pi} \cdot \sqrt{\frac{2\,g.GF}{D}}$$

$$N = \frac{30}{\pi}\sqrt{\frac{2(9.8)(26)}{0.25}} = 61.7\ \text{rev/min.}$$

***In vertical centrifugal casting*, the effect of gravity acting on the liquid metal causes the casting wall to be thicker at the base than at the top. The inside profile of the casting wall takes on a parabolic shape. The difference in inside radius between top and bottom is related to speed of rotation as follows:**

$$N = \frac{30}{\pi} \cdot \sqrt{\frac{2\,g.L}{R_t^2 - R_b^2}}$$

Where:

L = vertical length of the casting, (m), R_t = inside radius at the top of the casting, (m); and R_b = inside radius at the bottom of the casting, (m). it can be used to determine the required rotational speed for vertical centrifugal casting.

One can see from the formula that for R_t to equal R_b, the speed of rotation N would have to be infinite, which is impossible of course. As a practical matter, part lengths made by vertical centrifugal casting are usually no more than about twice their diameters.

Semi-centrifugal Casting:

It is similar to Centrifugal casting except that in this type the Centrifugal force is used to produce solid castings rather than tubular parts [see fig. (16) below].

- **Molds are designed with risers at center to supply feed metal.**
- **Density of metal in final casting is greater in outer sections than at center of rotation (because of condensation).**
- **Examples: wheels and pulleys.**

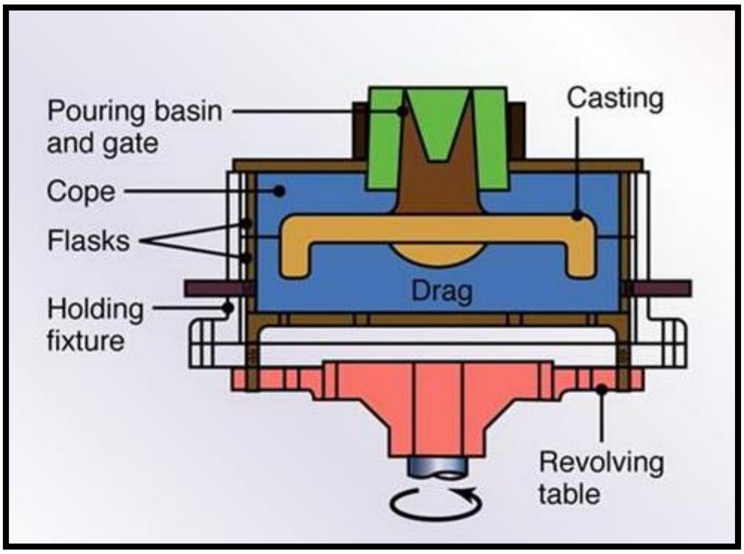

Fig. (16): Semi-centrifugal casting.

Centrifuge Casting:

Mold is designed with part cavities located away from axis of rotation (*placed at a certain radius from the axis of rotation*), so that molten metal poured from the center into mold is distributed to these cavities by centrifugal force [see fig. (17) below].

- Used for smaller parts.
- Radial symmetry of part is not required as in other centrifugal casting methods.

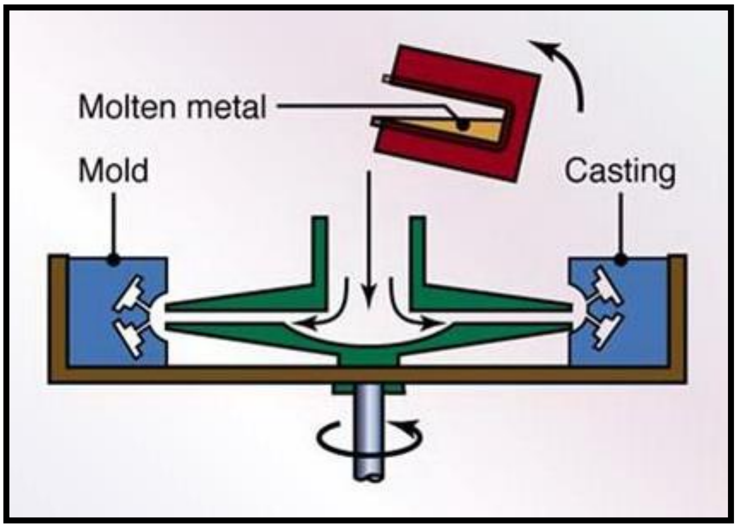

Fig. (17): Centrifuge casting.

Furnaces for Casting Processes:

Furnaces most commonly used in foundries are:

- Direct fuel-fired furnaces
- Crucible furnaces
- Electric-arc furnaces
- Induction furnaces

1. *Direct Fuel-Fired Furnaces:*

Small open-hearth in which charge is heated by natural gas fuel burners located on side of furnace [see fig. (18) below].

- Furnace roof assists heating action by reflecting flame down against charge.
- At bottom of hearth is a tap hole to release molten metal.
- Generally used for nonferrous metals such as copper-base alloys and aluminum.

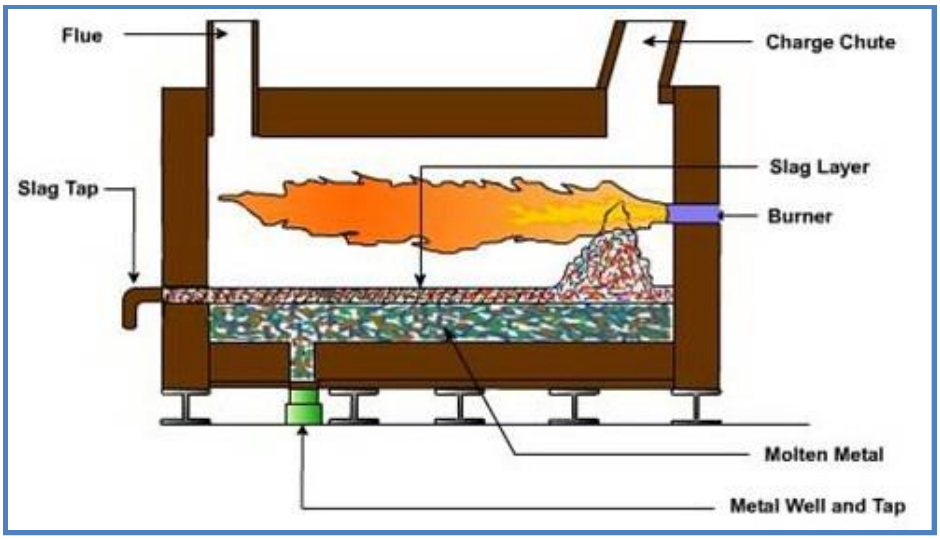

Fig. (18): Direct Fuel – Fired Furnace.

2. *Crucible Furnaces:*

Metal is melted without direct contact with burning fuel mixture. Sometimes called *indirect fuel-fired furnaces* [see fig. (19) below].

- **Container (crucible) is made of refractory material or high-temperature steel alloy.**
- **Used for nonferrous metals such as bronze, brass, and alloys of zinc and aluminum**

Three types used in foundries: (a) lift-out type, (b) stationary, (c) tilting.

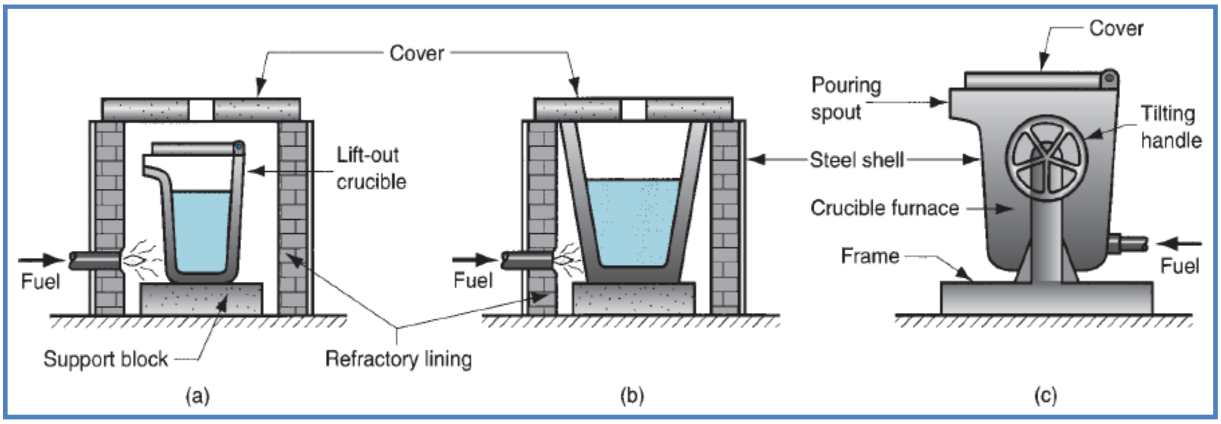

Fig. (19): Crucible Furnace.

3. ***Electric - Arc Furnaces:***

Charge is melted by heat generated from an electric arc [see fig. (20) below].

- **High power consumption, but electric-arc furnaces can be designed for high melting capacity.**
- **Used primarily for melting steel.**

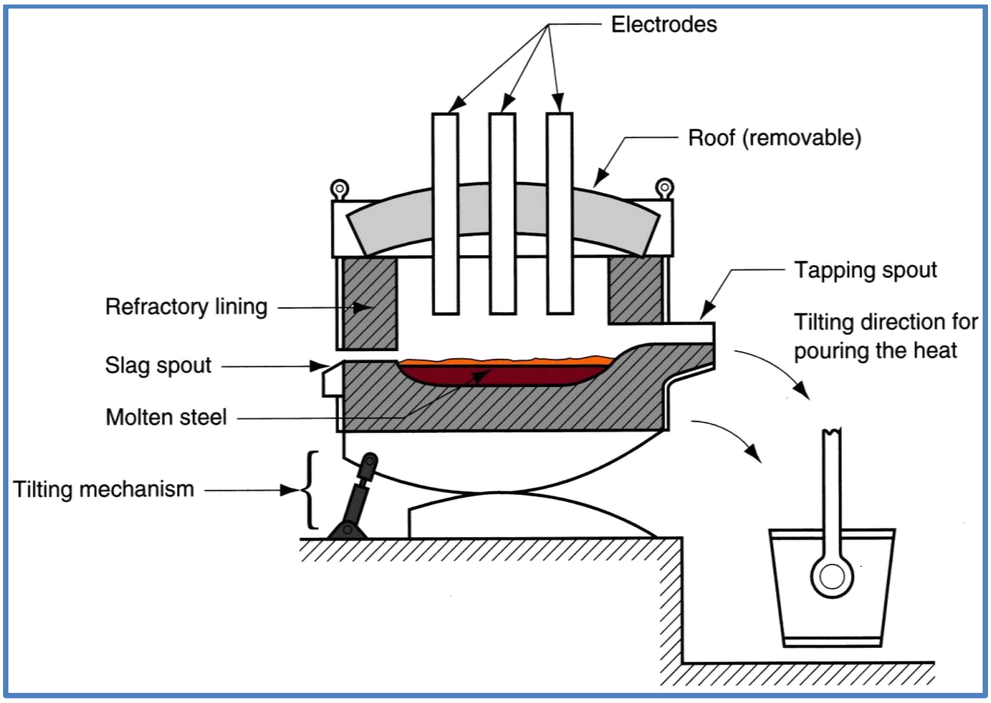

Fig. (20): Electric - Arc Furnace.

4. ***Induction Furnaces:***

Uses alternating current passing through a coil to develop magnetic field in metal, in which the induced current causes rapid heating and melting [see fig. (21) below].

- **Electromagnetic force field also causes mixing action in liquid metal.**
- **Since metal does not contact heating elements, environment can be closely controlled to produce molten metals of high quality and purity.**
- **Melting steel, cast iron, and aluminum alloys are common applications in foundry work.**

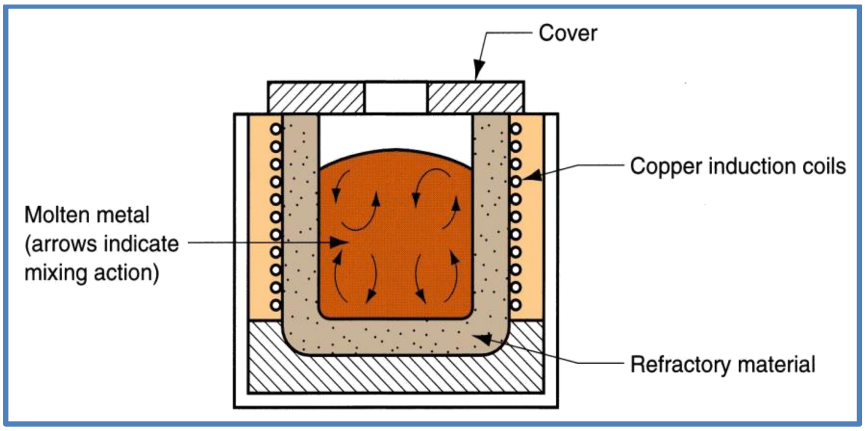

Fig. (21): Induction Furnace.

Ladles:

- **Moving molten metal from melting furnace to mold is sometimes done using crucibles**
- **More often, transfer is accomplished by *ladles*.**

Fig. (22) shows the crucible and two types of ladles (a) Crane ladle (b) Two man ladle.

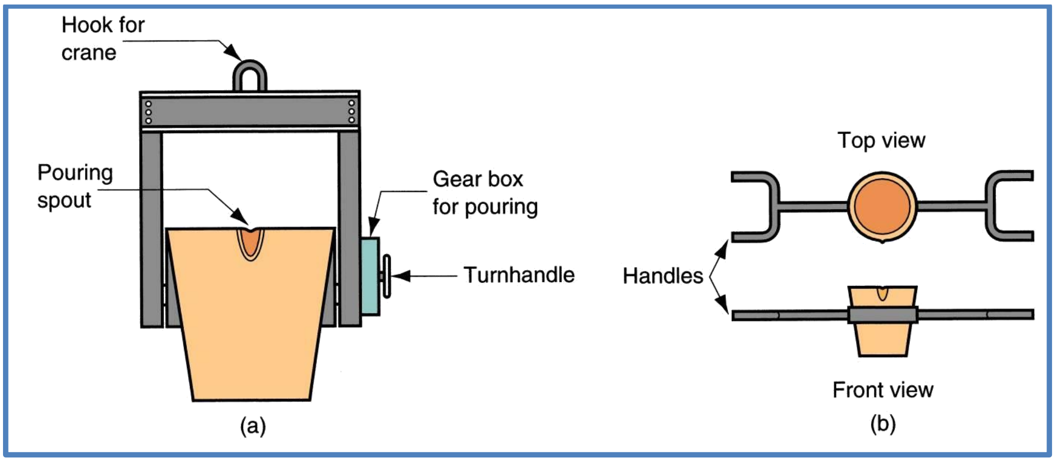

Fig. (22): Two common types of ladles.

Additional Steps After Solidification:

1. Trimming:

- **<u>Removal of</u> sprues, runners, risers, parting-line flash, fins, chaplets, and any other excess metal from the cast part [see fig. (23) below].**
- **Otherwise, hammering, shearing, hack-sawing, band-sawing, abrasive wheel cutting, or various torch cutting methods are used.**

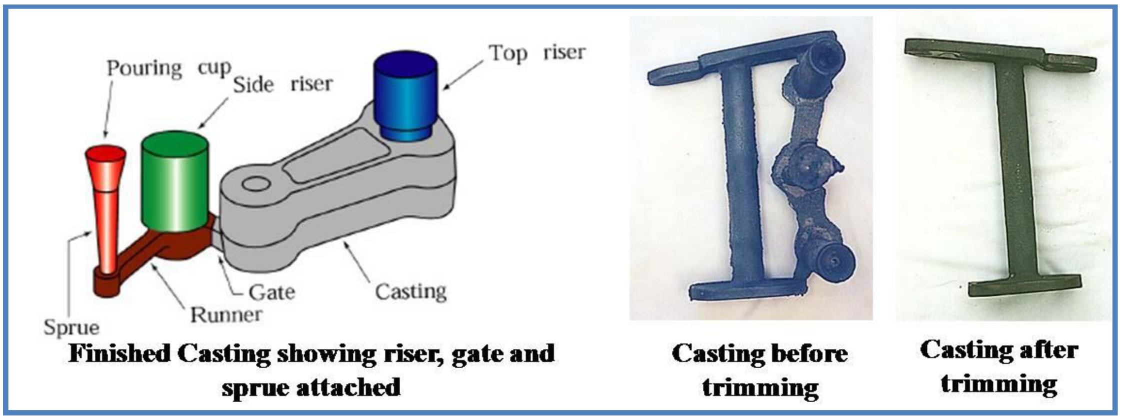

Fig. (23): Casting before and after Trimming.

2. ***Removing the Core:***

If cores have been used, they must be removed.

- **Most cores are chemically bonded or oil bonded, and they often fall out of casting as the binder deteriorates.**
- **In some cases, they are removed by shaking casting, manually or mechanically.**
- **In rare cases, cores are removed by chemically dissolving bonding agent.**
- **Solid cores must be hammered or pressed out.**

3. ***Surface Cleaning:***

It is the process of removal of sand from casting surface and otherwise enhancing appearance of surface.

- **Cleaning methods:** **tumbling, air-blasting with coarse sand grit or metal shot, wire brushing, polishing and buffing, and chemical pickling (to give a light finish to by bleaching or painting and wiping)**
- **Surface cleaning is most important for sand casting:**
  - **In many *permanent mold processes*, this step can be avoided.**

4. ***Heat Treatment:***

Castings are often heat treated to enhance good mechanical properties.

Reasons for heat treating a casting:

- **For subsequent processing operations such as machining.**
  - **To bring out the desired properties for the *application of the part in service*.**