Steps in Sand Casting:

Figure (2-4) explains steps of sand casting.

1. Pattern making.
2. Core making if required.
3. Sand preparation.
4. Mold making.
5. Pour molten metal into sand mold.
6. Allow metal to solidify.
7. Break up the mold to remove casting.
8. Clean and inspect the casting.
9. Heat treatment of casting if needed to improve metallurgical properties.

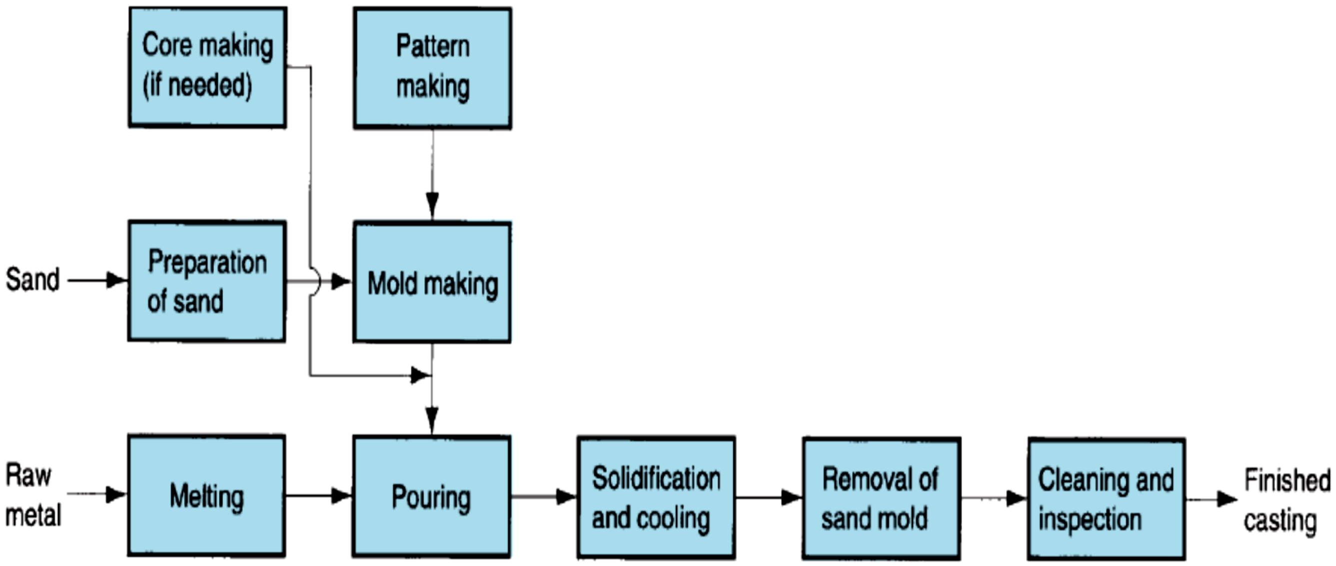


Figure (2-4) Steps of sand casting.

Types of Pattern Used in Sand Casting:

- Pattern is a full-sized model of the part, enlarged to account for shrinkage and machining allowances in the final casting.
- Pattern materials includes wood, plastics, and metals.
- Selection of pattern material depends on: the total quantity of castings to be made.

Pattern Types:

Figure (2-5) states the pattern types.

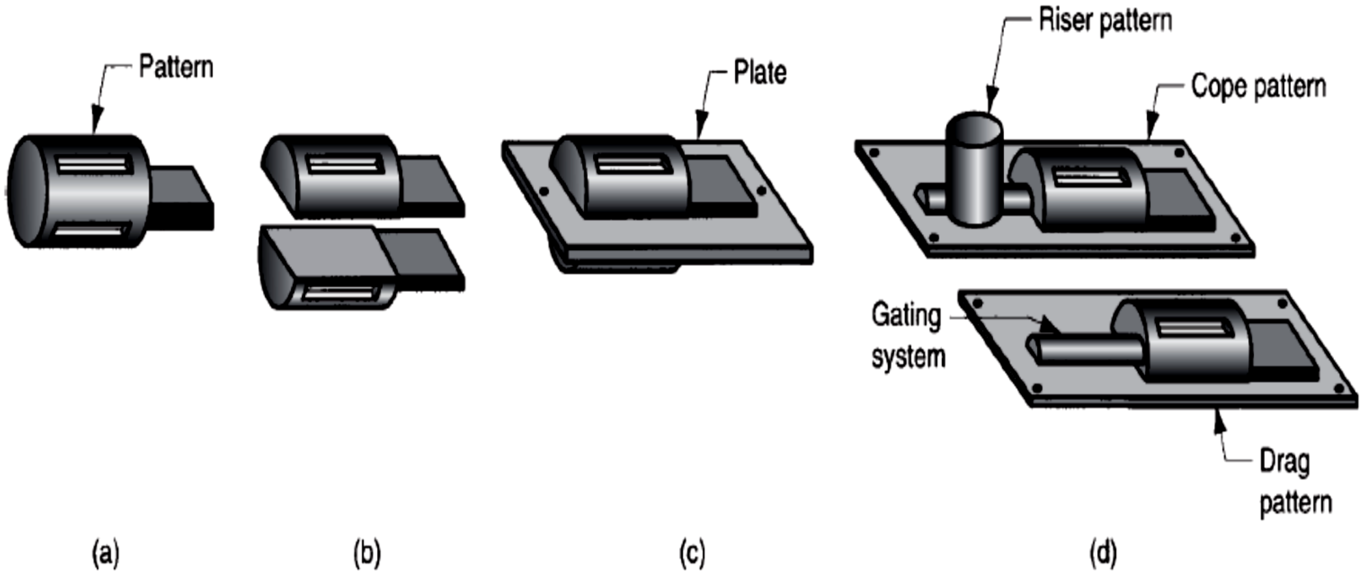


Figure (2-5) Pattern Types; (a) solid pattern, (b) split pattern, (c) match-plate pattern, (d) cope and drag pattern

(a) Solid Pattern: made of one piece, adjusted in size for shrinkage and machining, limited to very low production quantities.
(b) Split Patterns: consist of two pieces, appropriate for complex parts and moderate production quantities.
(c) Match-Plate Patterns: two pieces of the split pattern are attached to opposite sides of a wood or metal plate, used for higher production quantities.
(d) Cope and Drag Patterns: split pattern halves are attached to separate plates.

Core in Sand Casting:

Figure (2-6) explains the core used in sand casting.

Core: a full-scale model of the interior surfaces of the part**,** inserted into the mold cavity prior to pouring, the core is usually made of sand, the actual size of the core includes allowances for shrinkage and machining, the core may require supports to hold it in position, these supports, called chaplets, are made of a metal with a higher melting temperature.

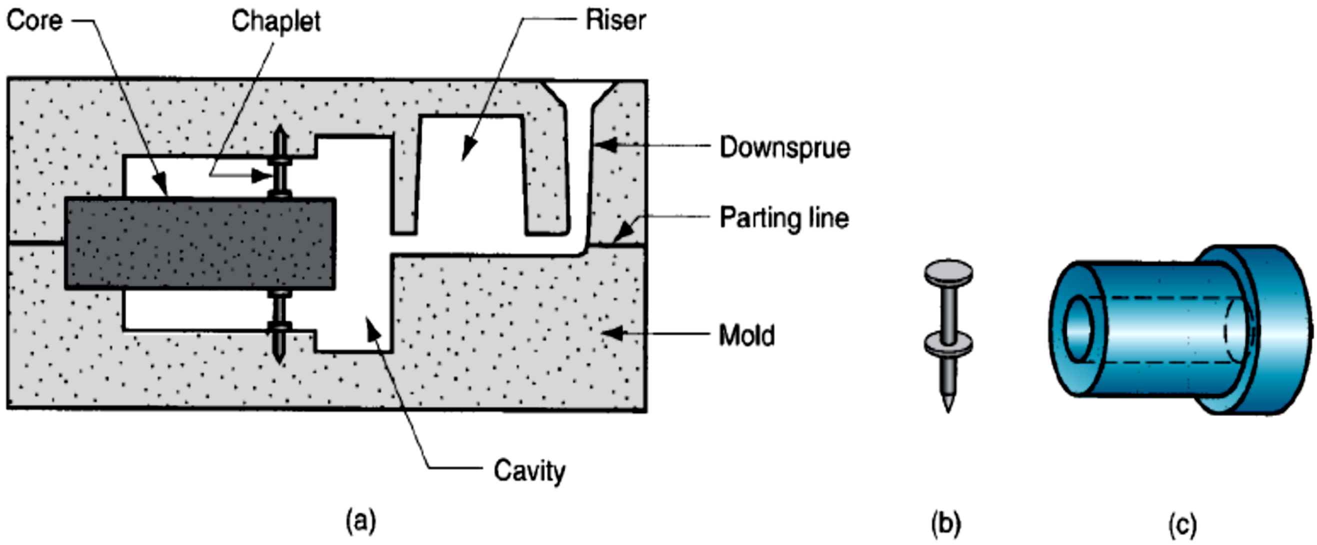


Figure (2-6) (a) core held in place in the mold cavity by chaplets, (b) chaplets design, (c) final casting

Figure (2-7) Chaplets

Desirable Mold Properties in Sand Casting:

- **Strength**: to maintain shape and resist erosion.
- **Permeability**: to allow hot air and gases to pass through voids in sand.
- **Thermal Stability**: to resist cracking and buckling on contact with molten metal.
- **Collapsibility**: ability to give way and allow casting to shrink without cracking the casting, also, ability to remove the sand from casting during cleaning.
- **Reusability**: can be used to make other molds.

(B) Shell-Mold Casting:

The process is described below and stated as in figure (2-8).

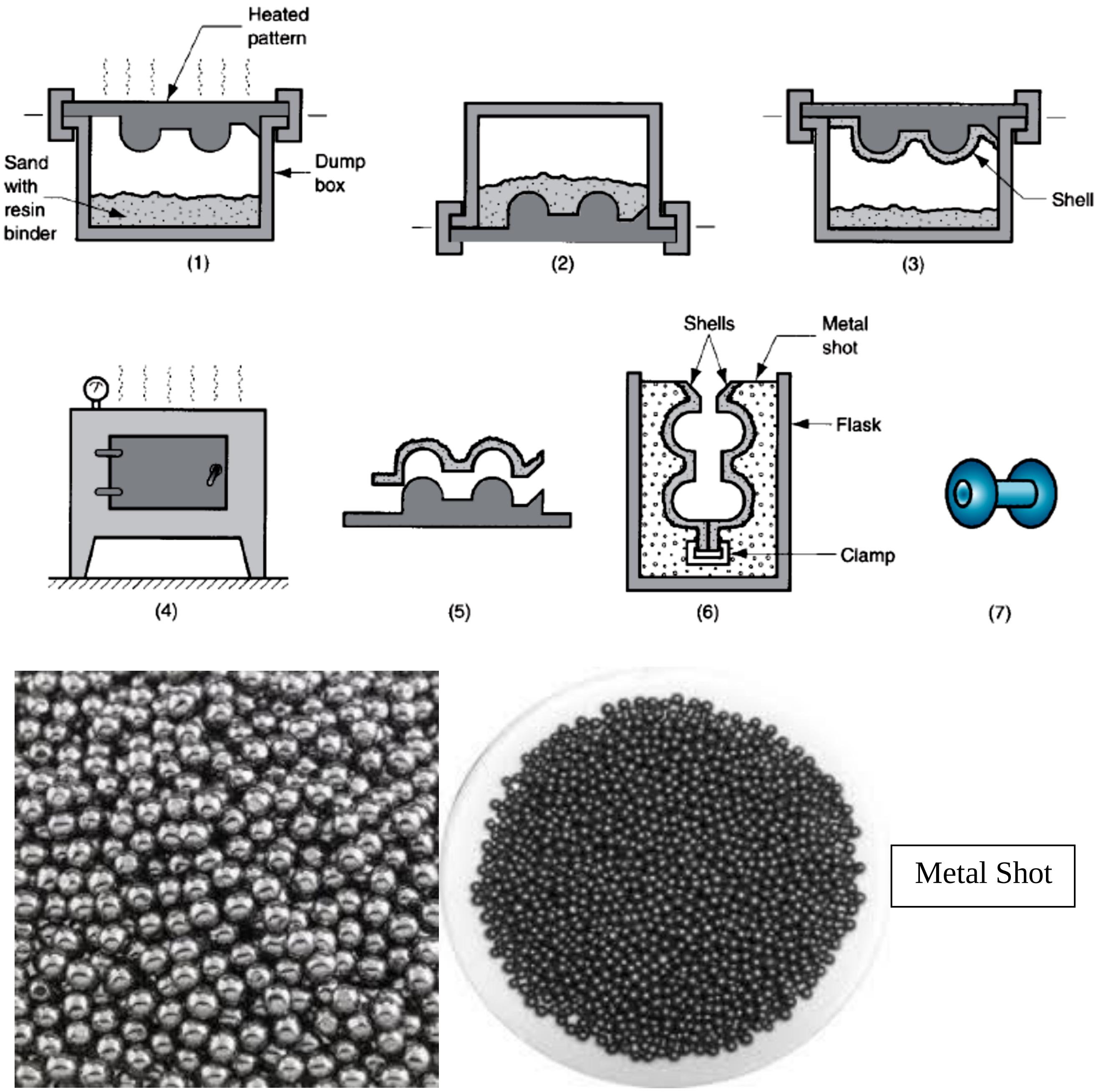


Figure (2-8) Steps in Shell Molding

1- The two pieces pattern (match-plate or cope and drag) is made of metal (e.g. aluminum or steel), it is heated to (175-370ºC) and coated with a lubricant, e.g. silicone spray.
2- The dump box (which contains a sand) and pattern is inverted many times to generate the sand shell onto the pattern.
3- Each heated half-pattern is covered with a mixture of sand and a thermoset resin/epoxy binder. The binder glues a layer of sand to the pattern, forming a shell. The process may be repeated many time to get a thicker shell.

4- The assembly is baked into oven to cure it.
5- The patterns are removed and the shell molds are generated.
6- The two half-shells are joined together by a clamp to form the mold and supported by sand or metal shot in a flask. The molten metal is poured into the mold.
7- The shell is broken to get the final casting.

Advantages:

1- Smoother cavity permits easier flow of molten metal.
2- Better surface finish on final casting.
3- Good dimensional accuracy.
4- Suitable for mass production and can be mechanized.
5- Machining processes often not required.
6- Mold collapsibility usually avoids cracks in final casting.

Disadvantages:

1- Expensive metal pattern.
2- Difficult to justify for small quantities.

Area of Application:

Mass production of steel castings of less than 10kg. Examples: gears, valve bodies, bushings, and camshafts.

(C) Evaporative-Foam Process

Also called: expanded polystyrene process, lost-foam process, lost-pattern process, full-mold process. Figure (2-9) shows samples of polystyrene patterns. Figure (2-10) explains the steps of evaporative-foam process.

Figure (2-9) polystyrene patterns

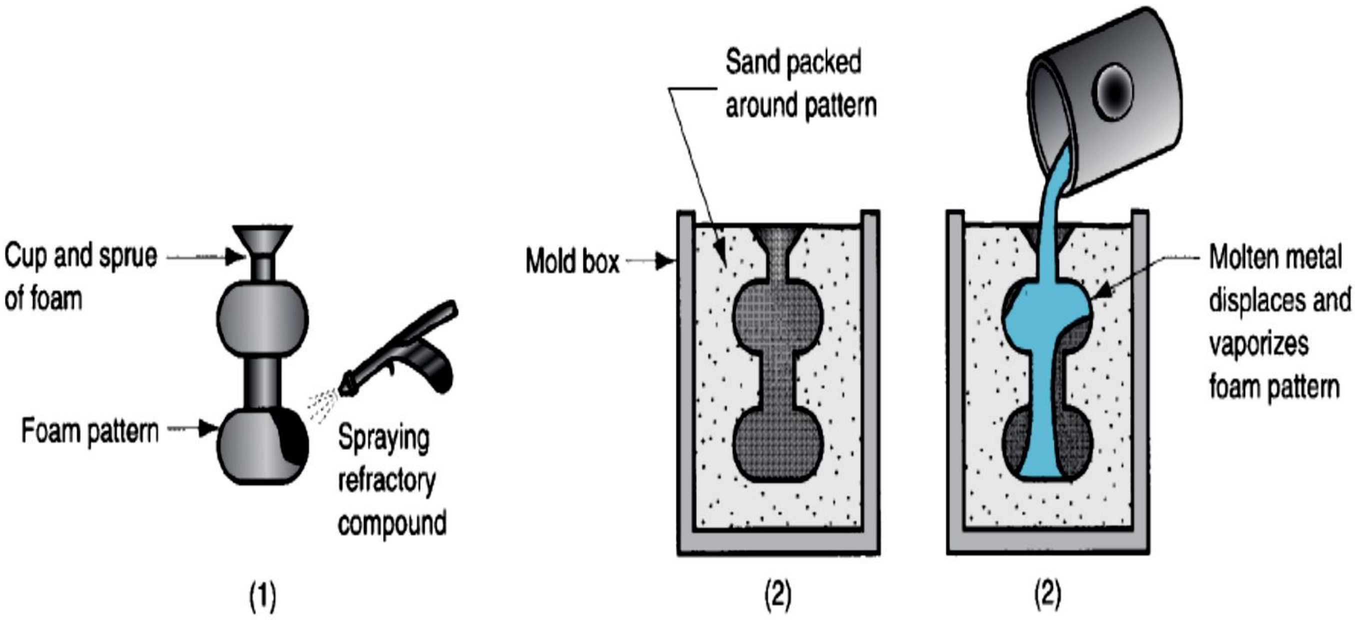


Figure (2-10) Evaporative-foam process

1- Pattern of polystyrene is coated with refractory compound (to provide a smoother surface on the pattern and to improve its high temperature resistance).
2- Foam pattern is placed in mold box, and sand is compacted around the pattern.
3- Molten metal is poured into the portion of the pattern that forms the pouring cup and sprue. As the metal enters the mold, the polystyrene foam is vaporized ahead of the advancing liquid.

Advantages:

Not need to remove the pattern from the mold.

Disadvantages:

New pattern is needed for every casting.

Area of Application:

The process has been applied to mass produce castings for automobiles engines.

(D) Lost Wax Casting:

Also called Investment casting (to cover completely with refractory material the wax pattern).

In this process, the pattern is made of **Wax**, which is melted after making the mold to produce the mold cavity. Figure (2-11) illustrates the steps of lost wax casting.

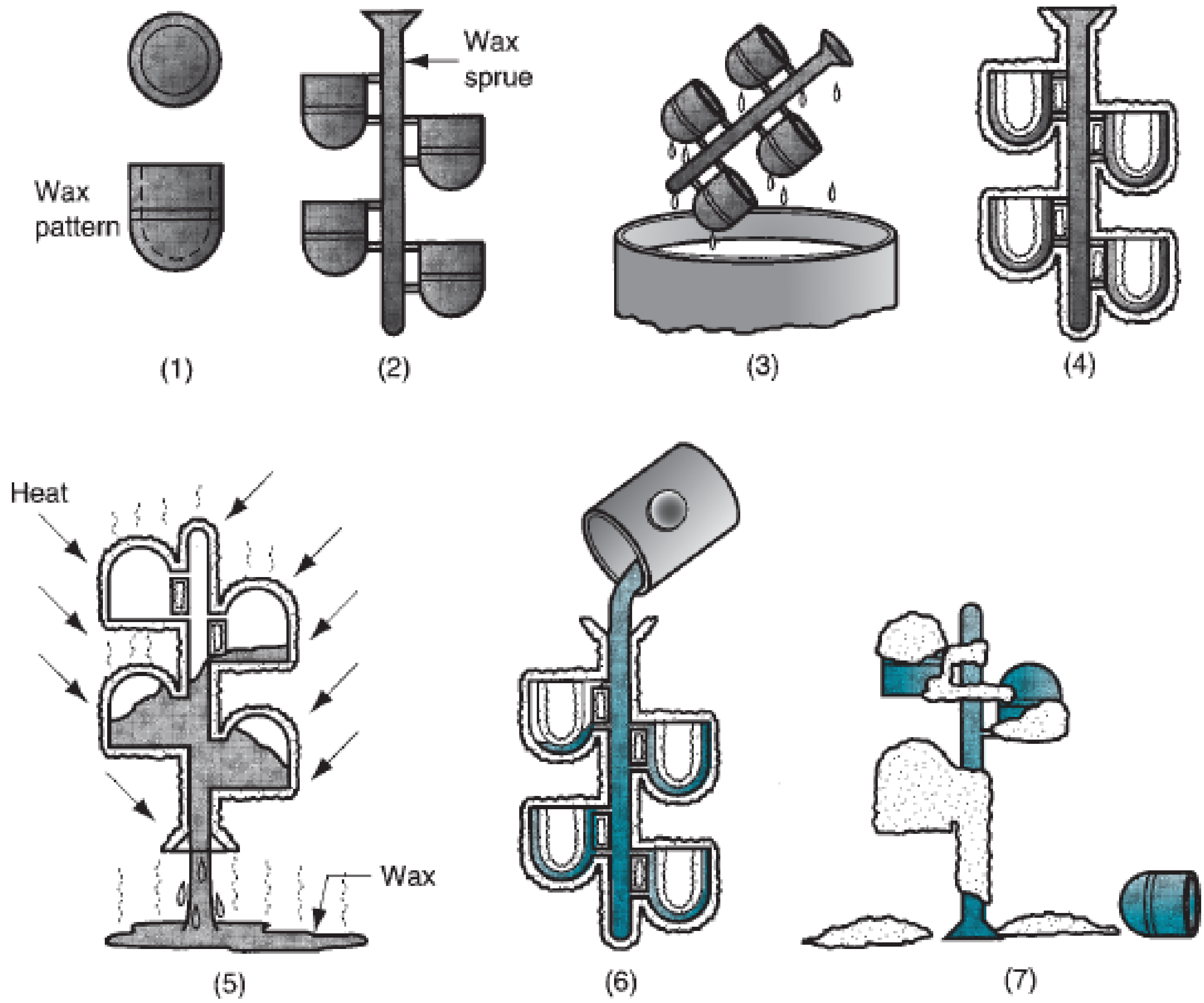


Figure (2-11) Lost wax casting

1- Wax patterns are produced.
2- Several patterns are attached to a sprue to form a pattern tree.
3- The pattern tree is coated with a thin layer of refractory material.
4- The full mold is formed by covering the coated tree with sufficient refractory material to make it rigid.
5- The mold is held in an inverted position and heated to melt the wax and permit it to drip out of the cavity.
6- The mold is preheated to a high temperature, which ensures that all contaminants are eliminated from the mold, it also permits the liquid metal

to flow more easily into the detailed cavity, the molten metal is poured, it solidifies.

7- The mold is broken away from the finished casting. Parts are separated from the sprue.

Advantages:

1- Complicated parts can be casted by this process.
2- Good dimensional accuracy and good surface finish.
3- No or little additional machining processes are required.
4- Wax can be reused.

Disadvantages:

1- Very expensive process because many steps are involved.
2- It requires a skilled labors.

Area of Application:

Castings are normally small in size, complex parts can be produced by this process such as art pieces, jewelry, dental fixtures, pinion gears, components of turbine engines and blades. Also, all types of metals including steels, stainless steel and other high temperature alloys can be casted by this method.

Permanent-Mold Casting:

Figure (2-12) explains the main steps in the permanent mold casting.

1- Mold is preheated and coated (preheating facilitates metal flow through the gating system and into the cavity and the coatings aid heat dissipation and lubricate the mold surfaces).
2- Cores (if used) are inserted and mold is closed.
3- Molten metal is poured into the mold.
4- Mold is opened (mold does not collapse, so, it must be opened before considerable cooling contraction occurs in order to prevent cracks in the casting).
5- Casted part.

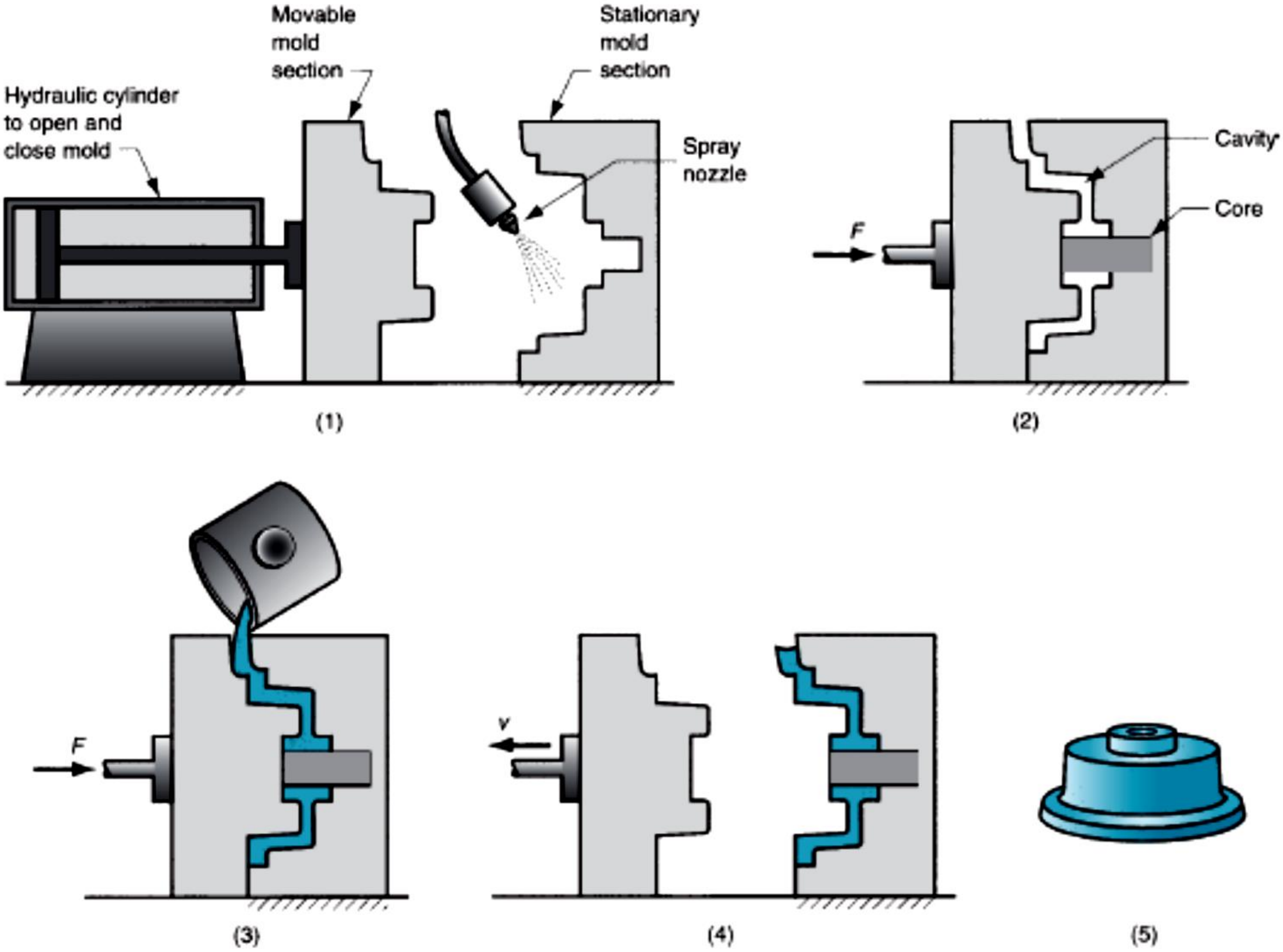


Figure (2-12) steps of permanent mold casting

Advantages:

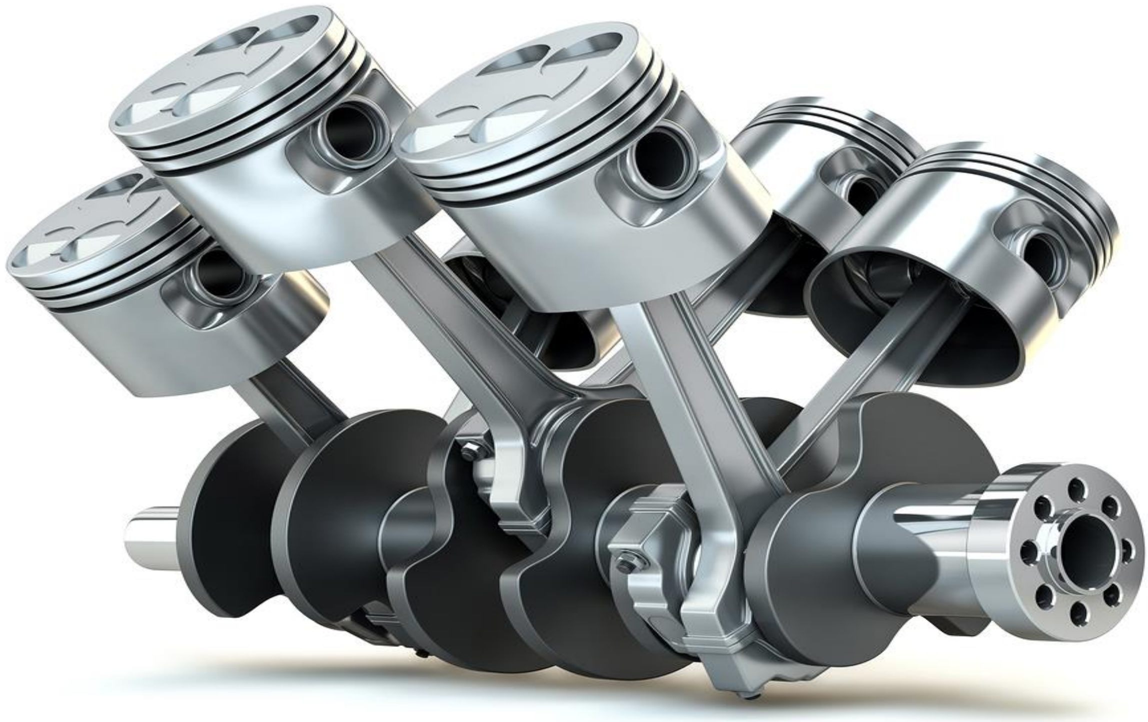
1. Good surface finish.
2. Close dimensional control.
3. Castings have finer grain structure (stronger castings) because of rapid solidification through metal mold.

Disadvantages:

1. Limited to metals of lower melting points.
2. Simple castings can be produced by this type because of the need to open the mold and mold expenses.
3. It is suited to high-volume production.

Typical Products:

Automotive pistons, pump bodies, and certain castings for aircraft and missiles.



Low-Pressure Casting:

Figure (2-13) explains the low pressure casting process.

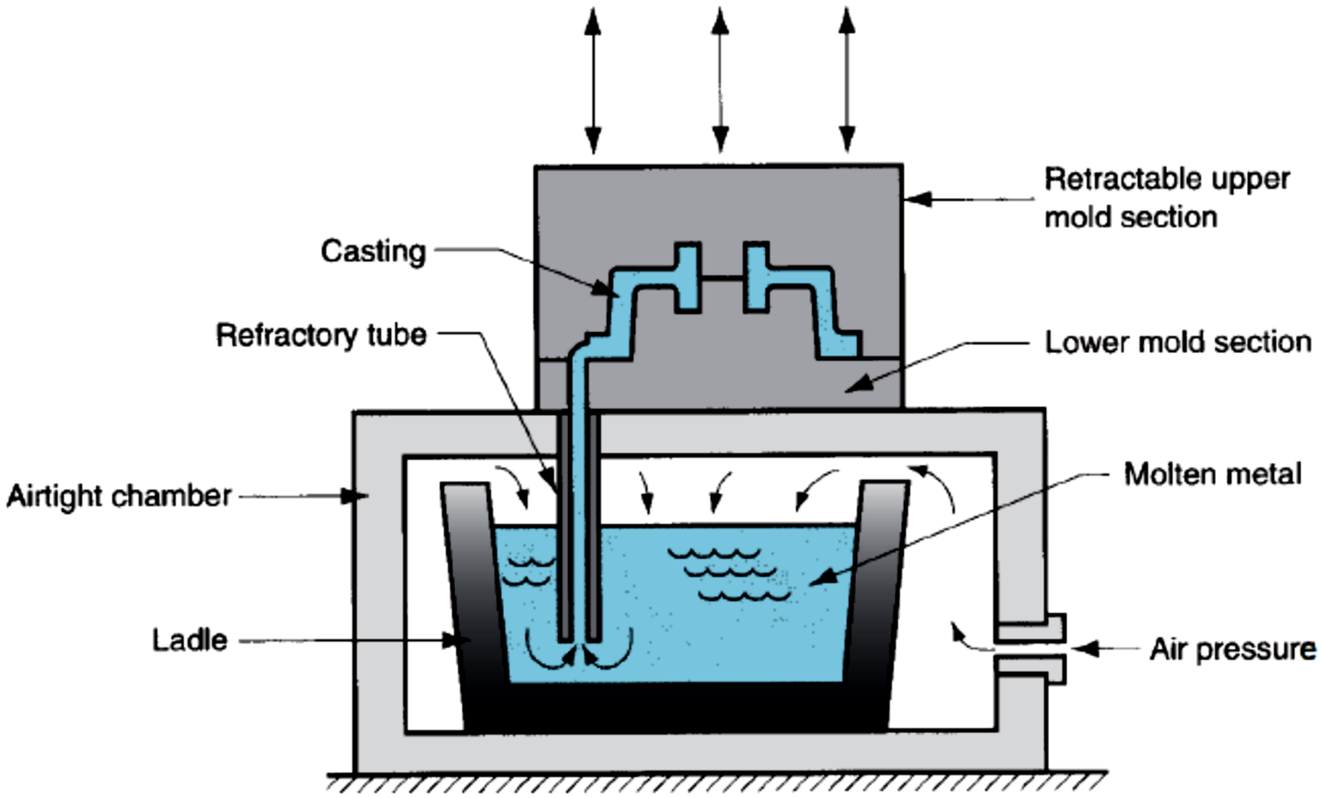


Figure (2-13) low-pressure casting

1. The liquid metal is forced into the cavity under low pressure – approximately 0.1 MPa (1bar).
2. Pressure is maintained until the casting has solidified.
3. Clean molten metal from center of the ladle is introduced into the mold rather than metal that has been exposed to air.
4. Gas porosity and oxidation defects are minimized and then mechanical properties are improved.

Die Casting:

1. In this type, the molten metal is injected into the mold cavity under high pressure – typically 7 to 350 MPa (70 to 3500 bar).
2. The pressure is maintained during solidification.
3. Molds are called dies.
4. It is divided into **hot-chamber casting** and **cold-chamber casting**.

(a) Hot-Chamber Casting:

In this process, the metal is melted in a container attached to the die machine and a piston is used to inject the liquid metal into the die cavity until solidify. The injection pressure reaches to (70 – 350 bar).

Steps of this process are stated in figure (2-14).

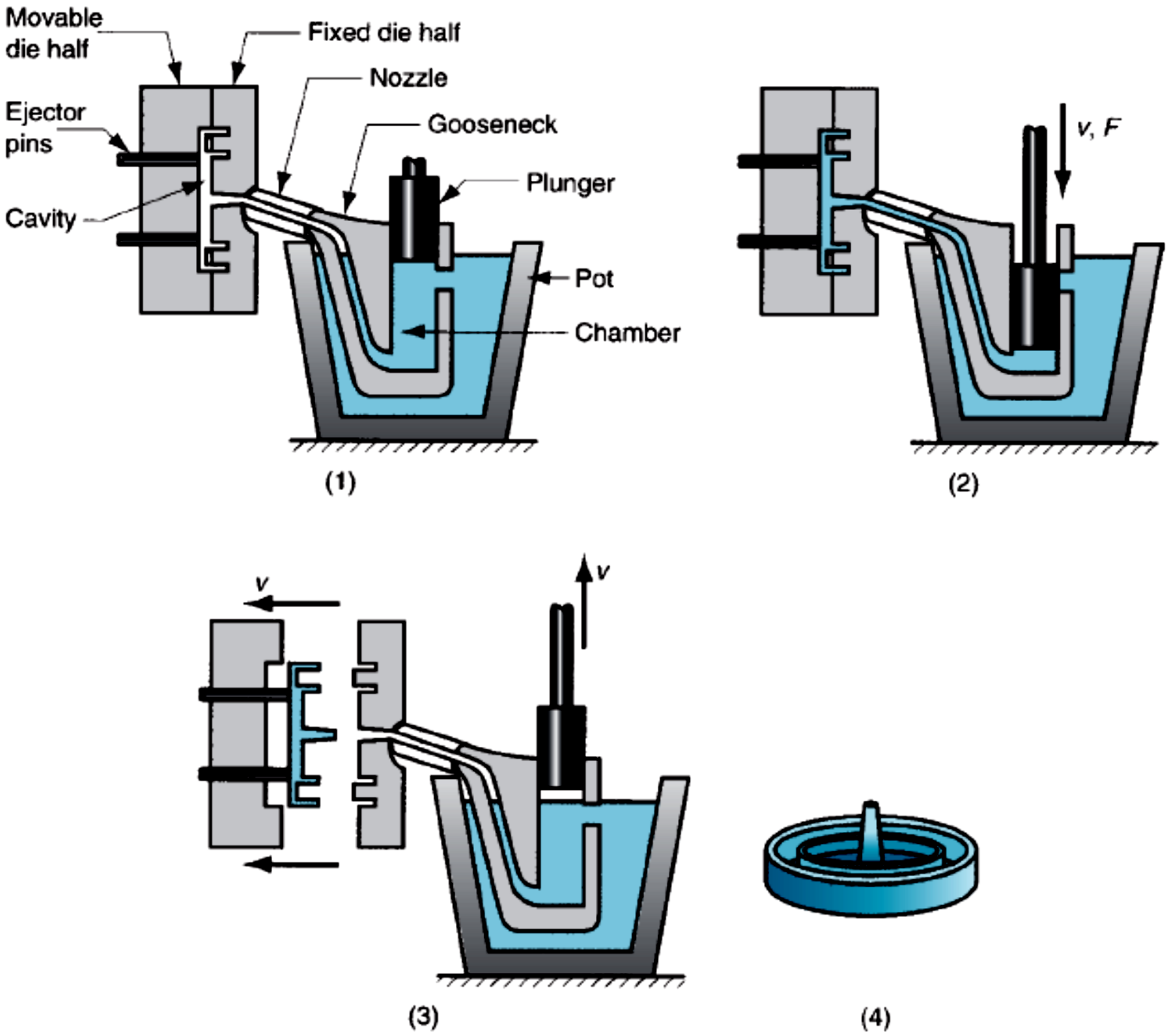


Figure (2-14) hot-chamber casting

1. With die closed and plunger withdrawn, molten metal flows into the chamber.
2. Plunger forces metal in chamber to flow into die, maintaining pressure during cooling and solidification.
3. Plunger is withdrawn, die is opened and solidified part is ejected.
4. Finished casting.

Advantages:

1. High productivity (up to 500 parts per hour).
2. Close tolerances.
3. Good surface finish.

Disadvantages:

1. Injection system is submerged in the molten metal therefore there is a hardship in this process.
2. It is limited to low-melting-point metals that do not chemically attack the plunger and other components.
3. Metals include zinc, tin, lead and sometimes magnesium.
4. Simple shapes.

Area of Application:

Mass production of non-ferrous alloys.

(b) Cold-Chamber Casting:

In this process, metal is melted in separated furnace and then is poured by ladle into the chamber. A ram is used to inject the metal into the die until solidify. The injection pressure reaches to (140 – 1400 bar). Steps of this method are explained in figure (2-15).

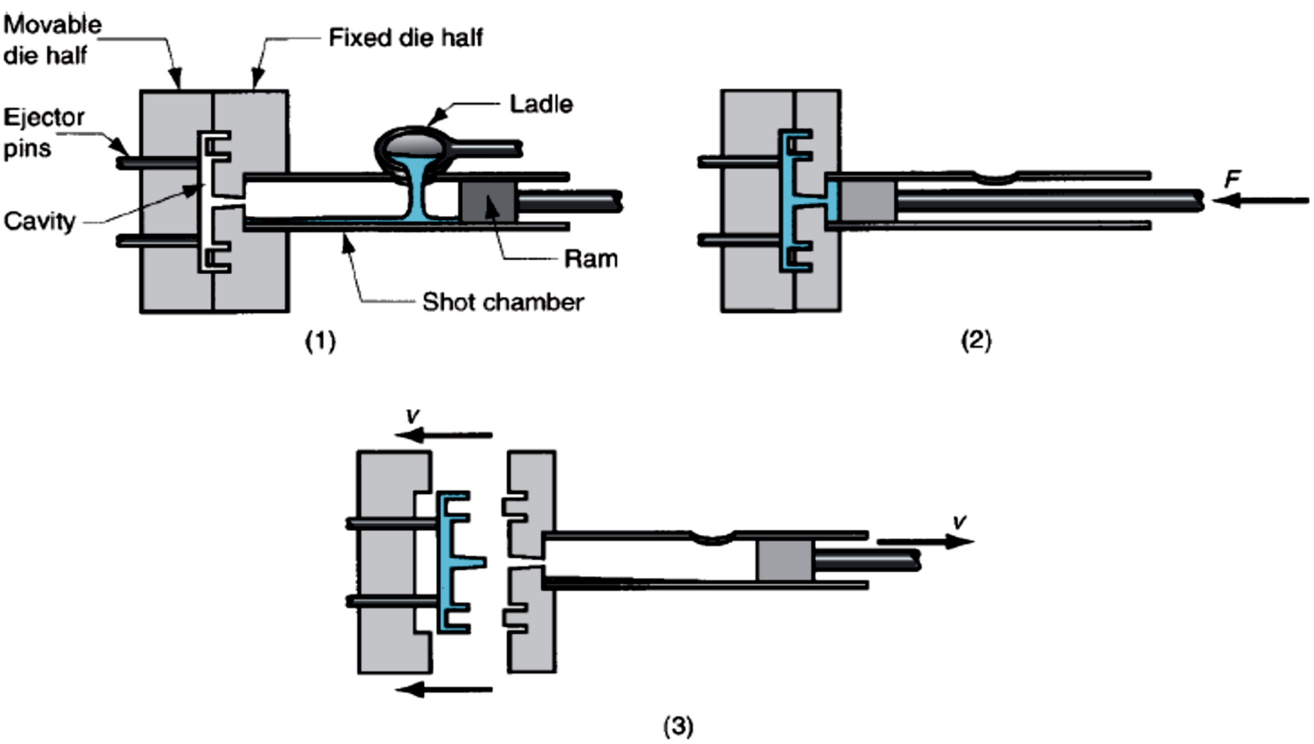


Figure (2-15) cold-chamber casting

1. With die closed and ram withdrawn, molten metal is poured into the chamber.
2. Ram forces metal to flow into die, keeping pressure during cooling and solidification.
3. Ram is withdrawn, die is opened and casting is ejected (gating system is simplified).

Advantages:

1. High productivity but less than hot-chamber.
2. High melting points metals such aluminum, brass and magnesium alloys can be used in this process.
3. Close tolerances.
4. Good surface finish.

Disadvantages:

1. It is not fast as in hot-chamber because of the need to pour the metal into chamber from an external container.
2. Simple shapes.

Area of Application:

Mass production for high melting points alloys.

Centrifugal Casting:

In which the mold is rotated at high speed so that centrifugal force distributes the molten metal to the outer regions of the die cavity. This process includes:

(a) True Centrifugal Casting.
(b) Semi-Centrifugal Casting.
(c) Centrifuge Casting.

(a) True Centrifugal Casting:

In this process, molten metal is poured into a horizontal rotating mold at one end to produce a tubular parts such as pipes, tubes, bushings and rings. Figure (2-16) illustrates true centrifugal setup.

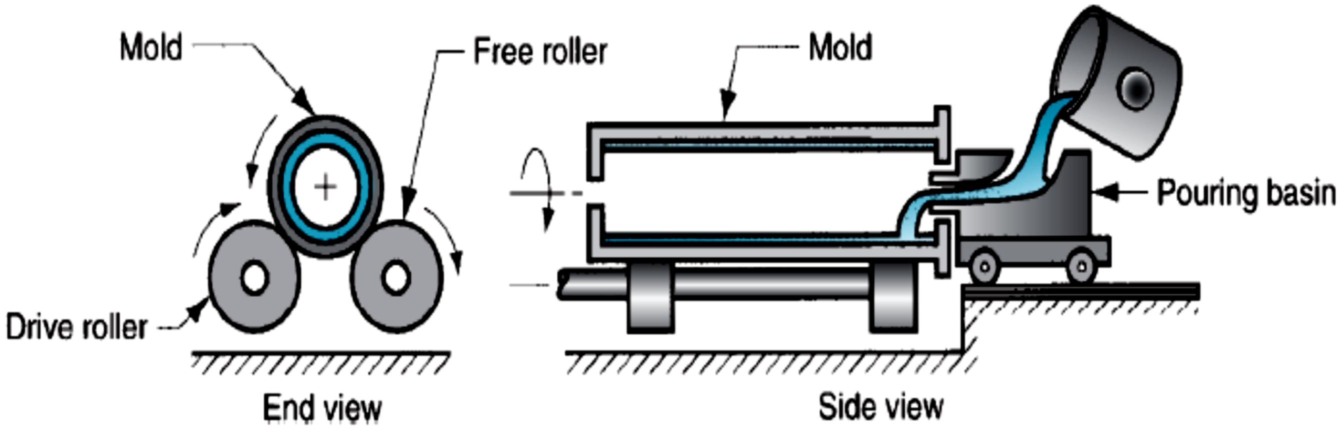


Figure (2-16) true centrifugal casting

Characteristics of True Centrifugal Casting:

1. Mold rotates at a speed between 300 to 3000 rpm.
2. Outside shape of the casting can be round, octagonal, hexagonal and so on.
3. Castings have a fine grain microstructure, which is resistant to atmospheric corrosion.
4. Since metal is heavier than impurities, most of them are closer to the inner diameter and can be later machined away.
5. Surface finish along the inner diameter is also much worse than along the outer surface.

In this process, the mold orientation can be either horizontal or vertical. Horizontal orientation is more common.

Mold Rotational Speed in Horizontal Orientation:

Centrifugal force is:

$$F = \frac{mv^2}{R}$$

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

$$F = \frac{2mv^2}{D}$$

The G-factor is the ratio of centrifugal force divided by weight:

$$GF = \frac{F}{W} = \frac{\frac{2mv^2}{D}}{mg} = \frac{2v^2}{Dg}$$

$$v = R\omega = R\frac{2\pi N}{60} = \frac{2\pi ND}{120} = \frac{\pi ND}{60}$$

Then:

$$GF = \frac{2\left(\frac{\pi ND}{60}\right)^2}{Dg}$$

Rearranging this and solving for rotational speed N:

$$N = \frac{30}{\pi}\sqrt{\frac{2gGF}{D}}$$

Where:

F: centrifugal force (N),

m: mass (kg),

v: velocity (m/s),

R: inside radius of the mold (m),

D: inside diameter of the mold (m),

W: weight (force of gravity, N),

g: acceleration of gravity (m/s^2),

ω: angular velocity (rad/s),

N: rotational speed (rev/min).

GF: G-factor (gravity factor) values of GF=60 to 80 on an empirical basis.

Example (5):

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

Solution:
The inside diameter D of the mold = outside diameter of the casting (copper tube)

D = 25cm = 0.25m

Then

$$N = \frac{30}{\pi}\sqrt{\frac{2gGF}{D}} = \frac{30}{\pi}\sqrt{\frac{2(9\cdot 81)(65)}{0\cdot 25}} = 682\ rev/min$$

Mold Rotational Speed in Vertical Orientation:

In this case, the inside profile of the casting wall takes on a parabolic shape. Then, from the parabolic shape as in figure (2-17), the height of the metal inside the vertical mold will be:

$$y_t - y_b = \frac{\omega^2}{2g}(R_t^2 - R_b^2)$$

$$\omega^2 = \left(\frac{2\pi N}{60}\right)^2 = \left(\frac{\pi N}{30}\right)^2$$

$$y_t - y_b = L$$

$$L = \frac{\left(\frac{\pi N}{30}\right)^2}{2g}(R_t^2 - R_b^2)$$

$$\therefore \quad N = \frac{30}{\pi}\sqrt{\frac{2gL}{(R_t^2 - R_b^2)}}$$

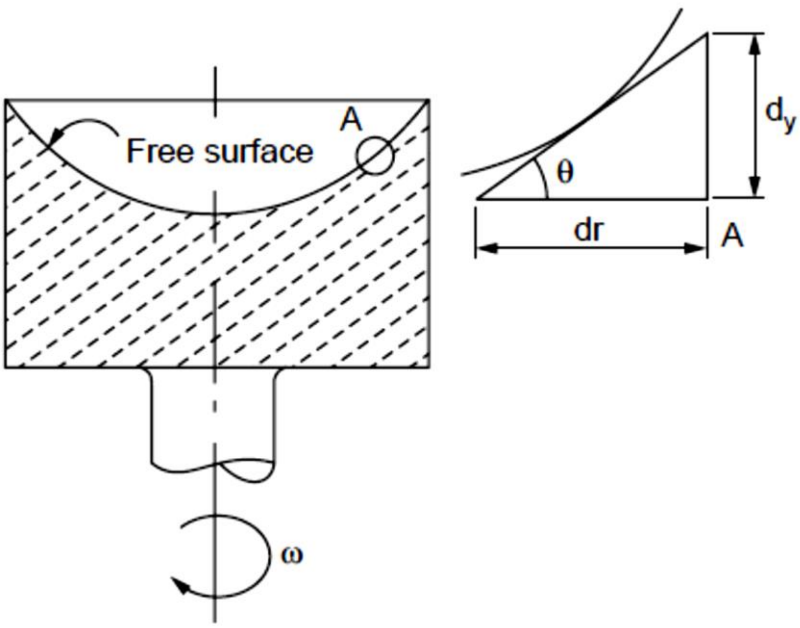


Figure (2-17) centrifugal vertical mold

Where:

L: vertical length of the casting,

R_t: inside radius at the top of the casting,

R_b: inside radius at the bottom of the casting,

(b) Semi-Centrifugal Casting:

Figure (2-18) explains this process. In this method:

1. Centrifugal force is used to produce solid castings rather than tubular parts.
2. Density of the metal in the final casting is greater in the outer sections than at the center of rotation.
3. The process is used on parts in which the center of casting is machined away (thus eliminating the portion of the casting where the quality is lowest), such as wheels and pulleys.

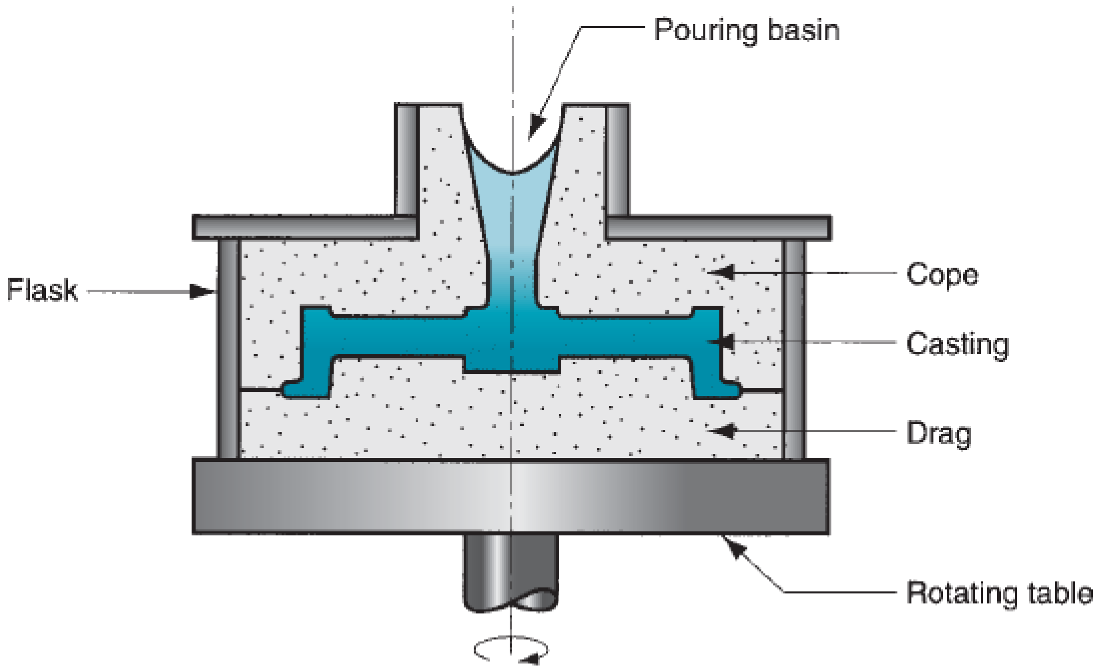


Figure (2-18) Semi-Centrifugal Casting

(c) Centrifuge Casting:

In centrifuge casting, as shown in figure (2-19):

1. The mold is designed with part cavities located away from the axis of rotation.
2. The molten metal poured into the mold is distributed to these cavities by centrifugal force.

3. The process is used for smaller parts, and radial symmetry of the part is not a requirement as it is for the other two centrifugal casting methods.
4. Products such as yokes, valve bonnets, valve bodies and pillow blocks can be manufactured by this method.

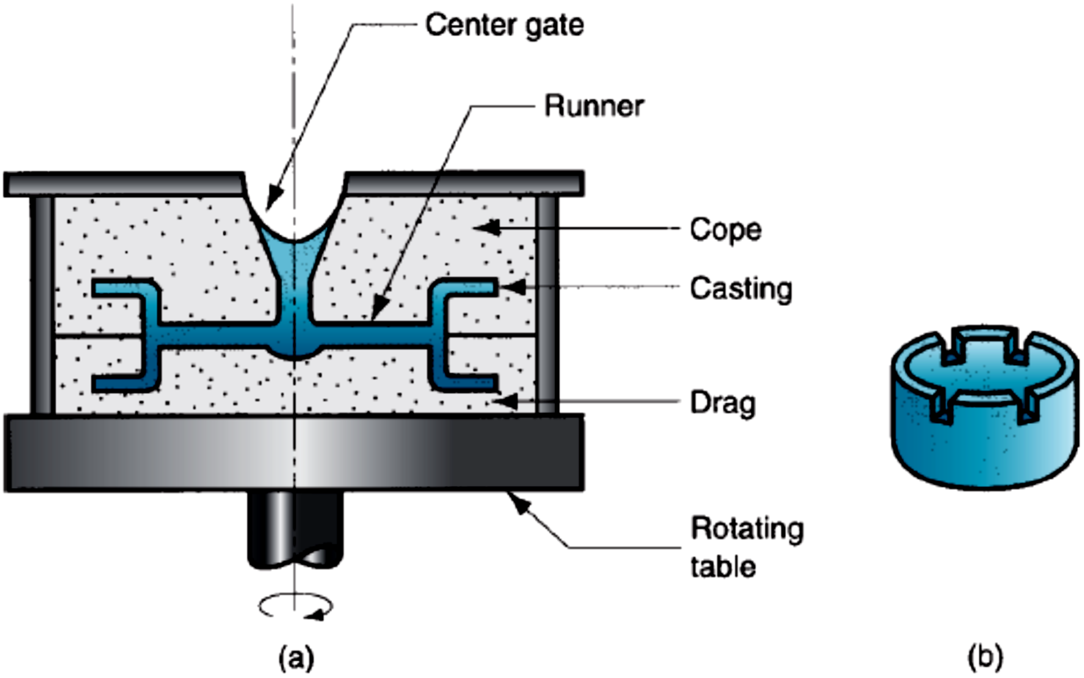
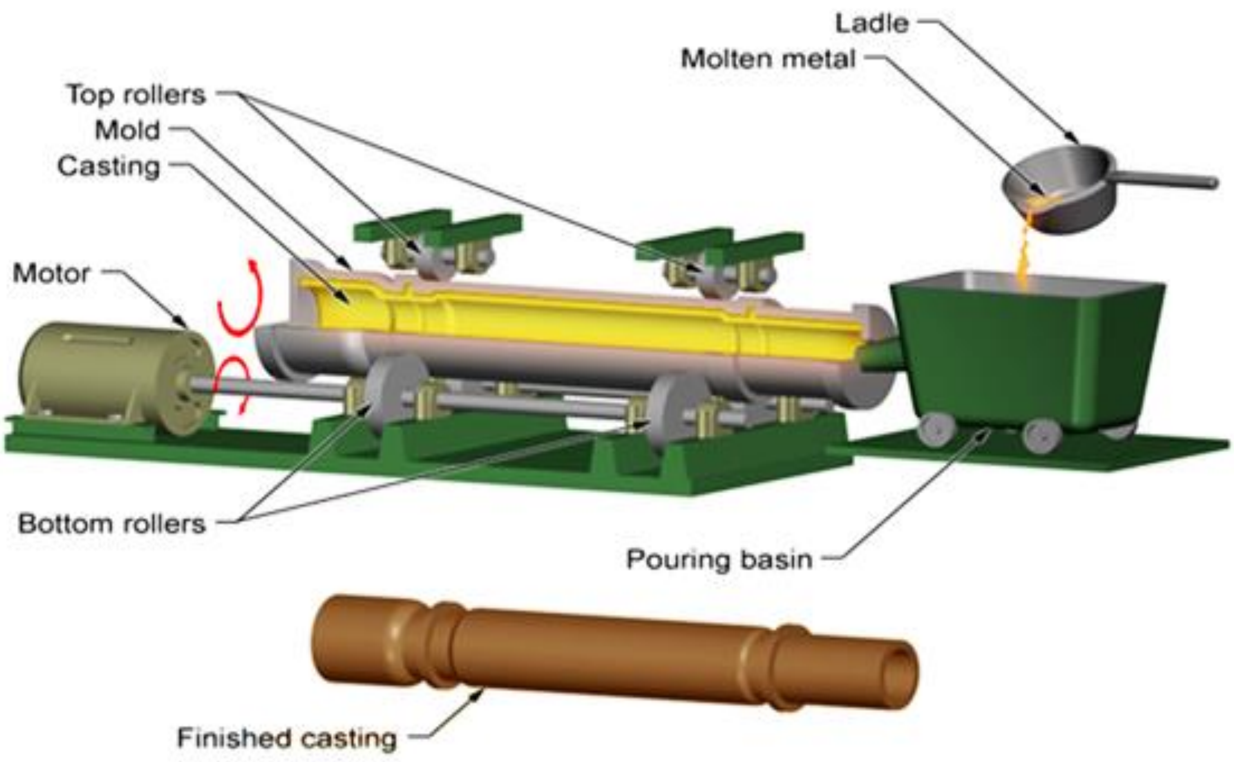
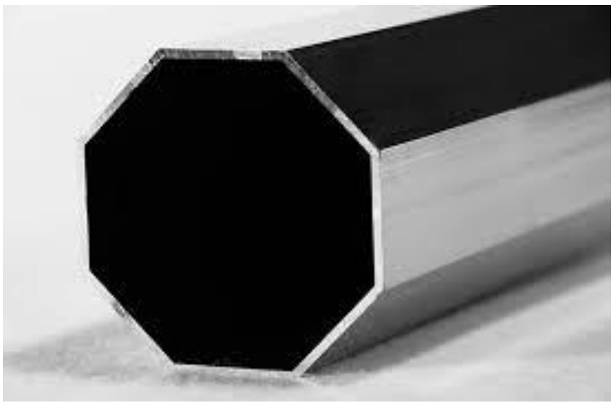
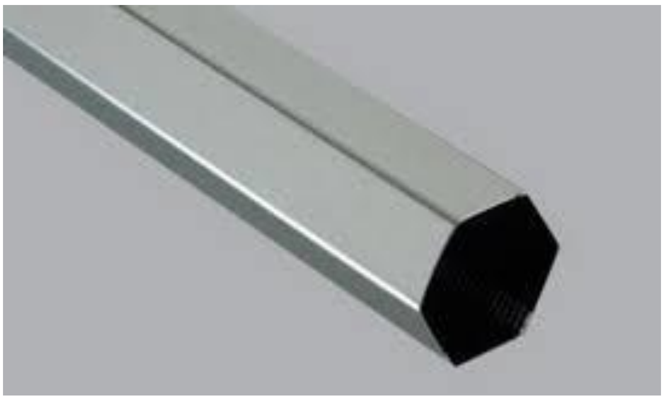


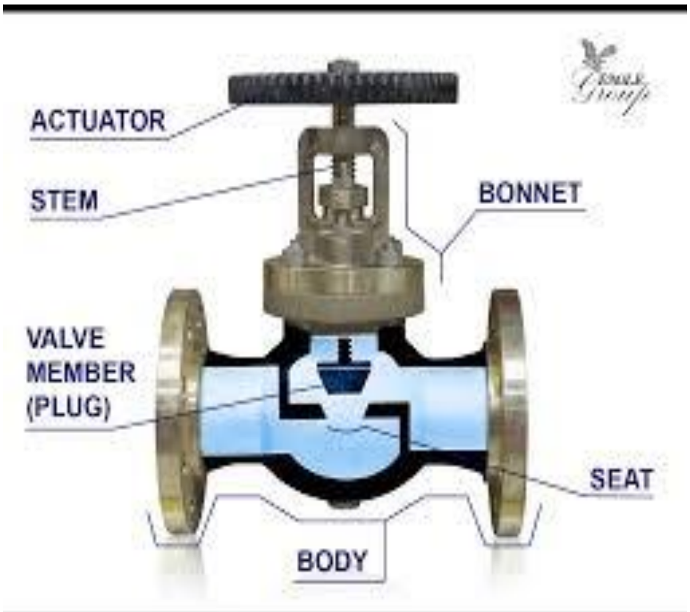
Figure (2-19) Centrifuge Casting




VS
Pipe
Tube







Continuous Casting:

Figure (2-20) illustrates this process. In this process:

1. It is consists of continuously pouring of molten metal into a mold which has the ability to cool the molten metal to reach solidification.
2. There are many rollers that control the movement of metal billets and many water jets to attain further solidification.
3. The die or mold maybe integrated with furnace or maybe separated.

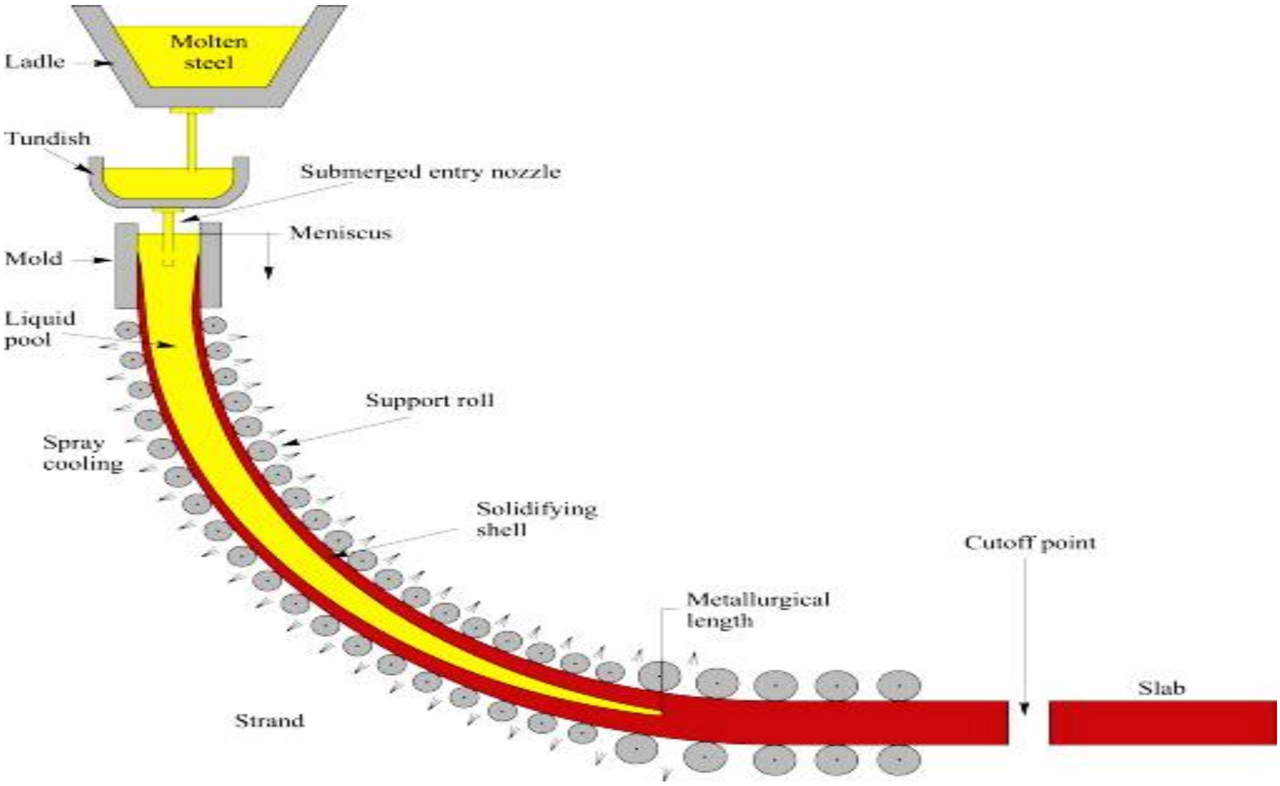


Figure (2-20) Continuous Casting Process

Area of Application:

It is used to solidify most of the steel, aluminum and many other alloys such as copper.

Casting Quality:

Below some of defects that appear in the casting which are common to all casting processes:

(a) Misruns: casting solidifies before completely fill the mold. Reasons are (1) too low pouring temperature, (2) slow pouring, (3) too thin cross-sections of the mold cavity, (4) fluidity of the molten metal is insufficient.

(b) Cold Shuts: two portions flow together but without fusion between them due to premature freezing. Causes are similar to those of a misrun.

(c) Cold Shots: when splattering occurs during pouring, solid globules of metal are formed and entrapped in the casting. Pouring procedures and proper gating system design that avoid splattering can prevent this defect.

(d) Shrinkage Cavity: depression in the surface or voids in the casting resulting from shrinkage during solidification. It often occurs near the top of the casting. The problem can often be solved by proper riser design but may require some changes in the part design as well.

(e) Microporosity: network of small voids distributed throughout the casting. It is caused by localized solidification shrinkage of the final molten meal. The defect occurs more often in alloys because of the manner they solidify.

(f) Hot Tearing or Hot Cracking: cracks caused by low mold collapsibility. They occur when the material is restricted from contraction by an unyielding mold during the final stages of solidification or early stages of cooling after solidification. It is separation of the metal at a point of high tensile stress caused by the metal's inability to shrink naturally. In the expendable molds, a proper mold design (collapsible) can solve the problem. In the permanent molds, it is reduced by removing the casting from the mold immediately after solidification.

Figure (2-21) shows the casting defects.

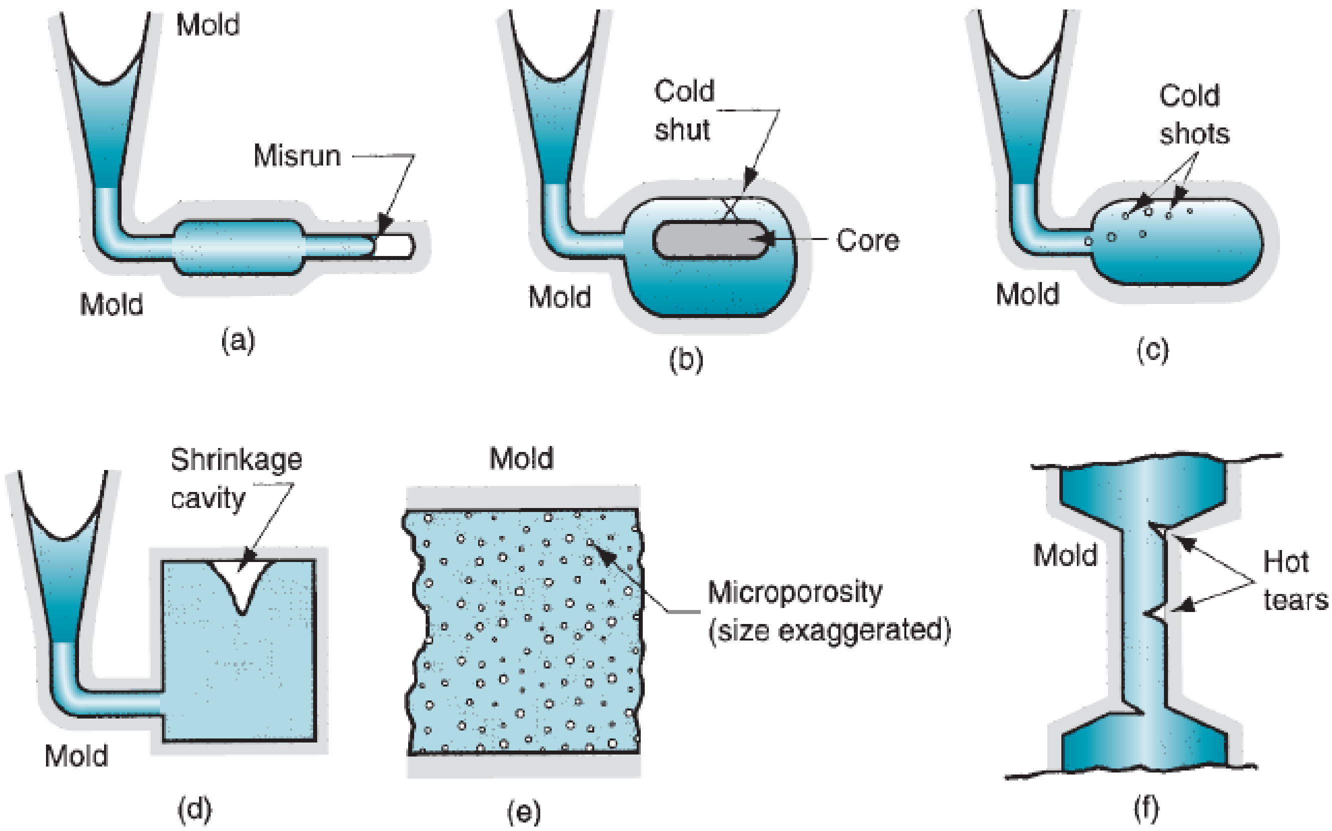


Figure (2-21) Common Casting Defects.

Defects of Sand-Mold Castings:

Figure (2-22) states sand-mold castings defects.

(a) Sand Blow: it is a balloon-shaped gas cavity caused by release of mold gases during pouring. Usual causes are low permeability, poor venting, and high moisture content of the sand mold.

(b) Pinholes: it is also caused by release of gases during pouring. It is consists of many small gas cavities.

(c) Sand Wash: it is irregularity in the casting surface. It is results from erosion of sand mold during pouring.

(d) Scabs: are rough areas on the casting surface due to encrustations of sand and metal. It is caused by portions of mold flaking off during solidifcation and imbed in the casting.

(e) Penetration: it is occurs when fluidity of liquid metal is high and penetrates into the sand mold or sand core. Harder packing of sand mold helps alleviate this defect.

(f) Mold Shift: it is a sidewise displacement of the mold cope relative to the drag.

(g) **Core Shift:** it is displacement of the core during pouring and displacement is usually vertical.

(h) **Mold Crack:** it is occurs when mold strength is insufficient and a crack develops, then, the liquid metal seeps into this crack to form a "fin" on the casting.

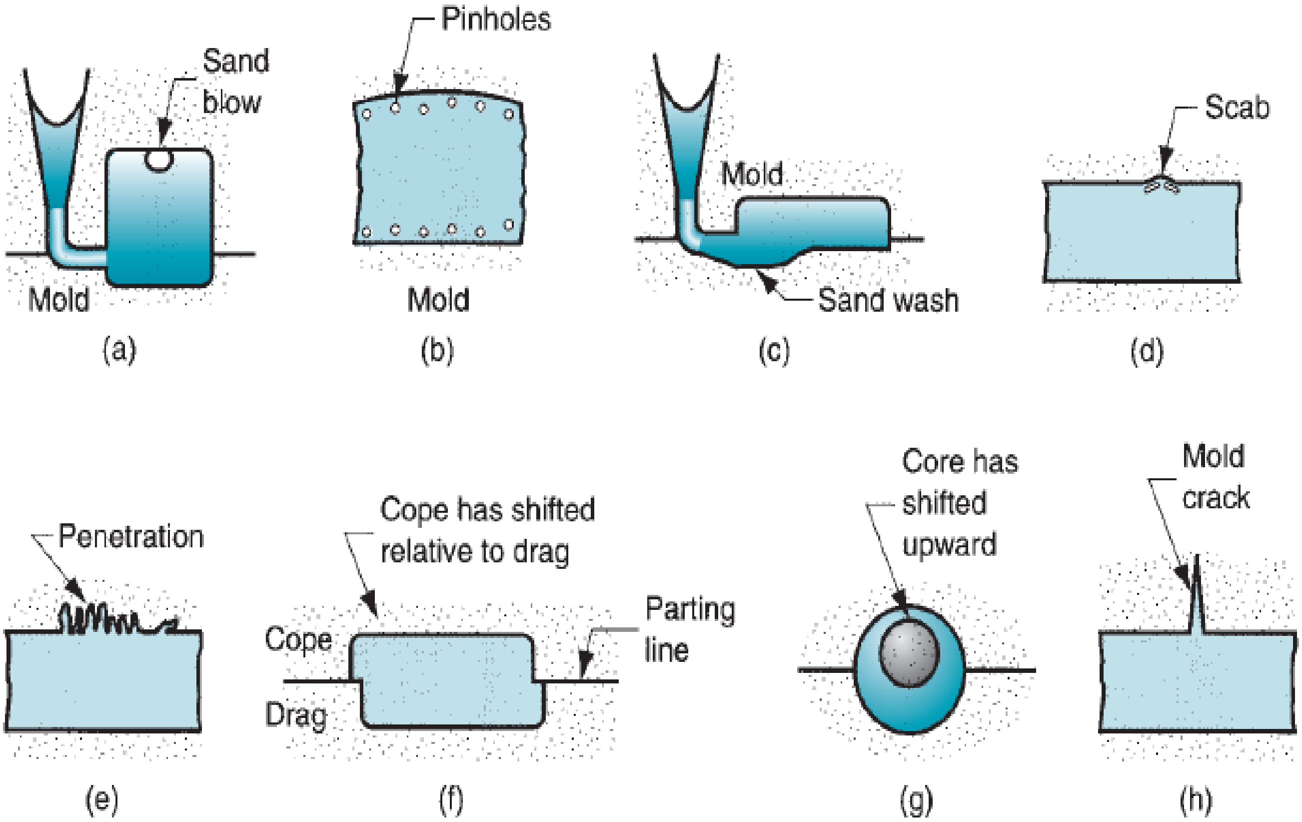


Figure (2-22) Common Defects of Sand-Mold Castings.