Introduction

- In casting, the starting work material **is either a liquid or is in a highly plastic condition, and a part is created through solidification of the material.**

- Casting and molding processes **dominate this category of shaping processes.**

- The solidification processes can be classified according to engineering material processed: :

  - **Metals.**
  - **Ceramics, specifically glasses.**
  - **Polymers and polymer matrix composites (PMCs).**

Introduction

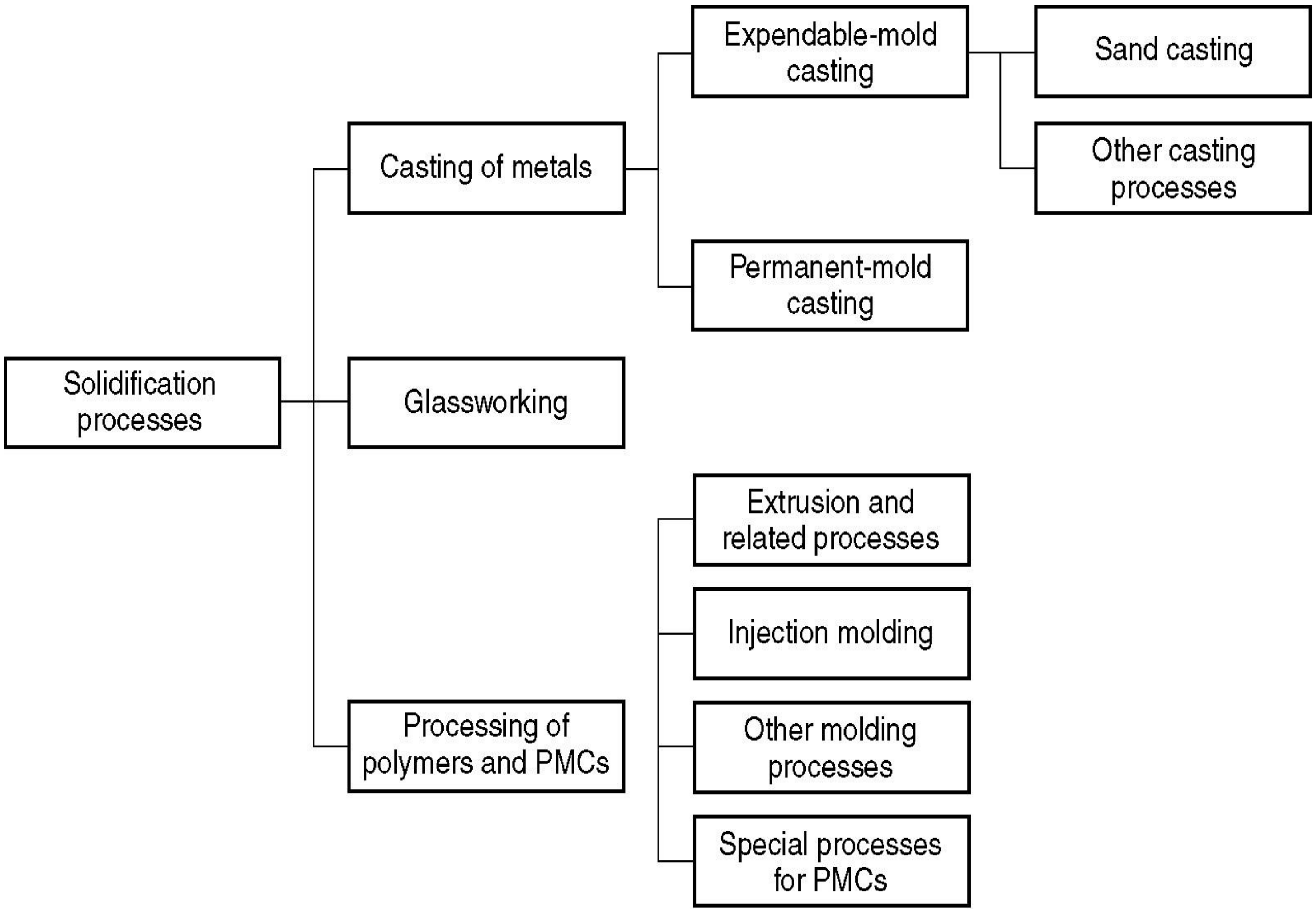


Figure 10.1 Classification of solidification processes.

Introduction

- Casting is the process in **which molten metal flows by gravity or other force into a mold where it solidifies in the shape of the mold cavity.**

- The term *casting* is also applied to the part that is made by this process.

- Principle of casting is pretty simple:
  - Melt the metal.
  - Pour it into a mold.
  - Let it freeze.

- However, to accomplish a successful casting, many variables and factors must be considered.

Introduction

- Casting include both the ***casting of ingots* and the *casting of shapes*.**

  – Ingot casting: **it describes a large casting that is simple in shape and intended for subsequent reshaping by processes such as rolling or forging.**

  – Shape casting: involves the production **of more complex geometries that are much closer to the final desired shape.**

Introduction

- Casting capabilities and advantages can be summarized as follows:
  - **Casting can create complex part geometries, including both external and internal shapes.**
  - **Some casting processes are capable of producing *net shape;* others are capable of producing *near net shape* (need further processing).**
  - **Casting can be used to produce very large parts.**
  - **Can be performed on any metal that can be heated to the liquid state.**
  - **Some casting processes are suited to mass production.**

Introduction

- Casting processes have also disadvantages; different disadvantages for different casting methods:
  - **Limitations on mechanical properties.**
  - **Porosity.**
  - **Poor dimensional accuracy and surface finish for some processes.**
  - **Safety hazards to humans when processing hot molten metals.**
  - **Environmental problems.**

Overview of Casting Technology

- Casting is usually performed in a foundry by foundrymen.

  - A *foundry*: a factory equipped for making molds, melting and handling molten metal, performing the casting process, and cleaning the finished casting.

  - *Foundrymen*: are those workers who perform casting.

Overview of Casting Technology; Casting Processes

- Discussion of casting begins with molds.
  - A mold contains **a cavity whose geometry determines the shape of the cast part.**
  - **The actual size and shape of cavity must be slightly oversized to allow for shrinkage that occurs in the metal during solidification and cooling.**
  - Amount of shrinkage depends on metal type, so design must be made for the particular metal being cast.
  - Molds are made of a variety of materials, including sand, plaster, ceramic, and metal.

Overview of Casting Technology; Casting Processes

- There are two types of molds:
  - ***Open mold*, in which the liquid metal is simply poured until it fills the open cavity.**
  - ***Closed mold*, in which a passage way, called the gating system, is provided to permit the molten metal to flow from outside the mold into the cavity.**

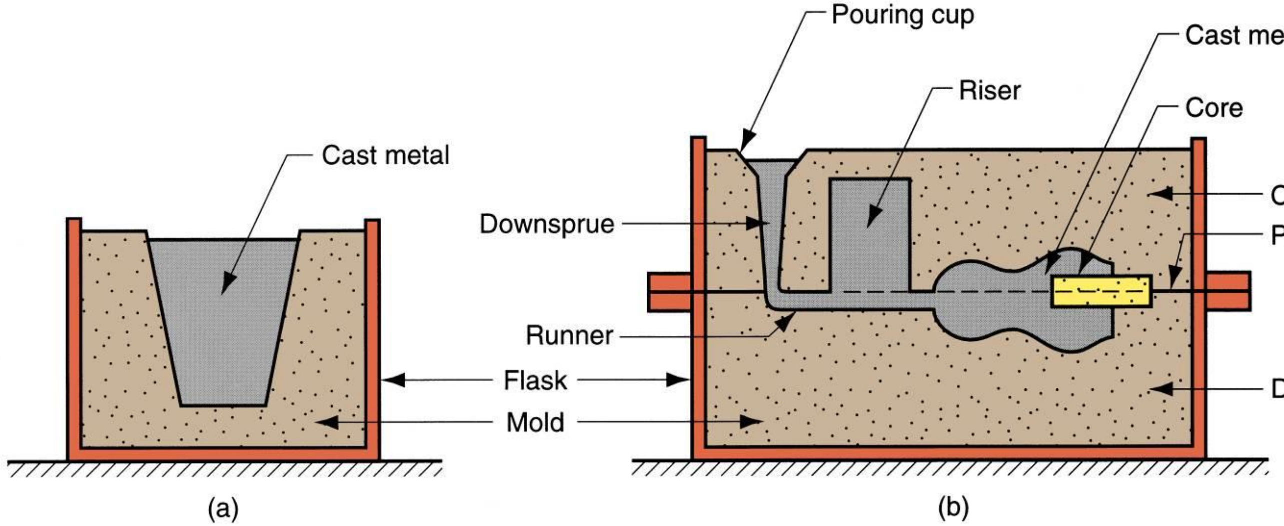


Figure 10.2 (a) Open and (b) Closed molds.

Overview of Casting Technology; Casting Processes

- There are two broad categories of casting:

  - *Expandable mold* casting processes, **in which an expendable mold is used and must be destroyed to remove casting**. These molds are made out of sand, plaster, whose form is maintained by using binders. Ability to produce complex geometries is an advantage of the expandable mold casting.

  - *Permanent mold* casting processes, **in which a permanent mold can be used over and over again. It is made of metal (or, less commonly, a ceramic refractory material).** The mold is composed of two sections that can be separated from each other to remove the casting. Example is die casting. Some permanent mold casting processes have certain economic advantages.

Overview of Casting Technology; Sand Casting Molds

- Sand casting is by far the most important casting process.
  - **Mold consists of 2 halves; *cope* and *drag*.**
    - **Cope is the upper half of the mold.**
    - **Drag is the bottom half of the mold.**
  - **Cope and drag are contained in a box called *flask*. The flask is also divided into 2 halves; one for the cope and the other for the drag.**
  - **Parting line: separates the two halves of the mold.**

Overview of Casting Technology; Sand Casting Molds

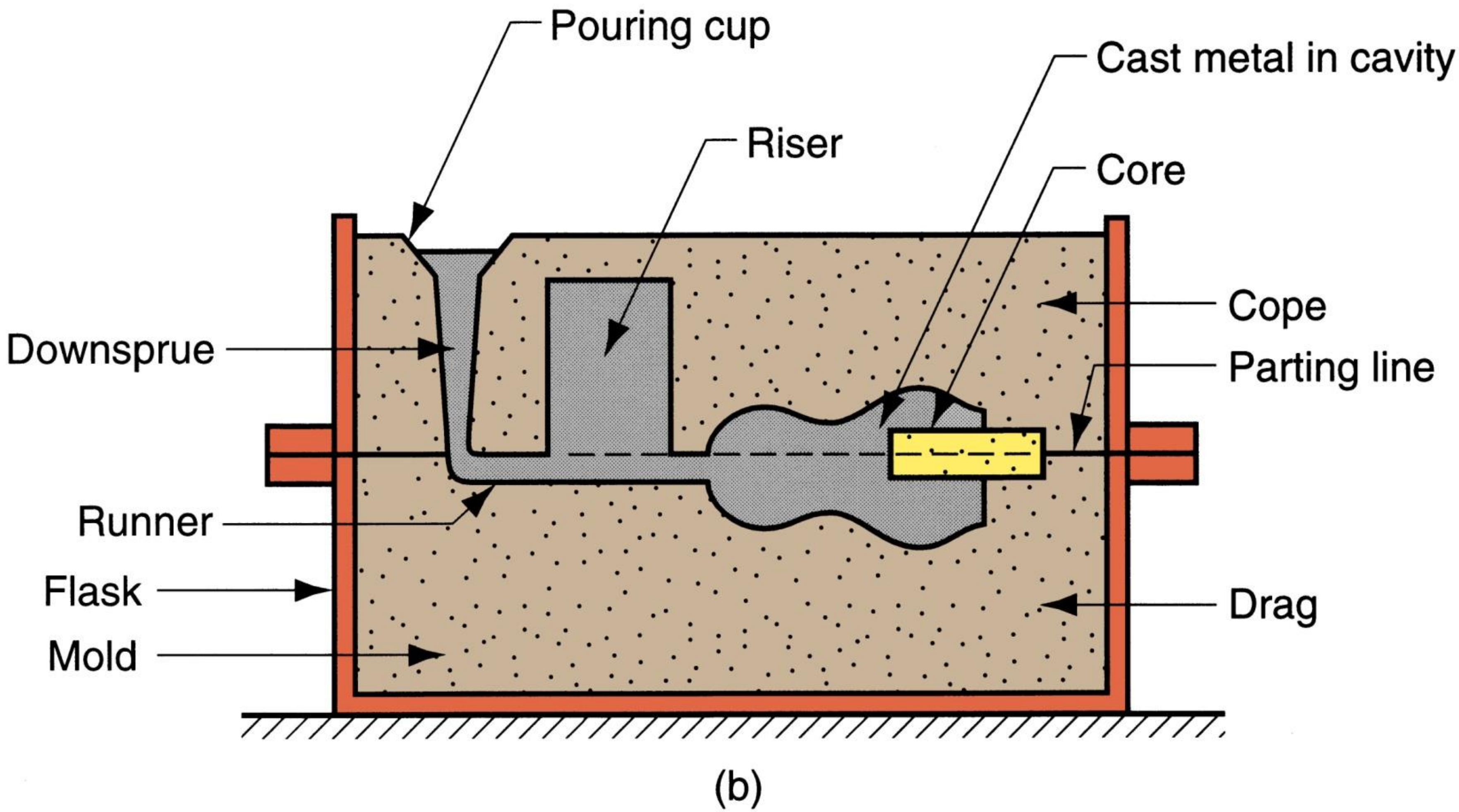
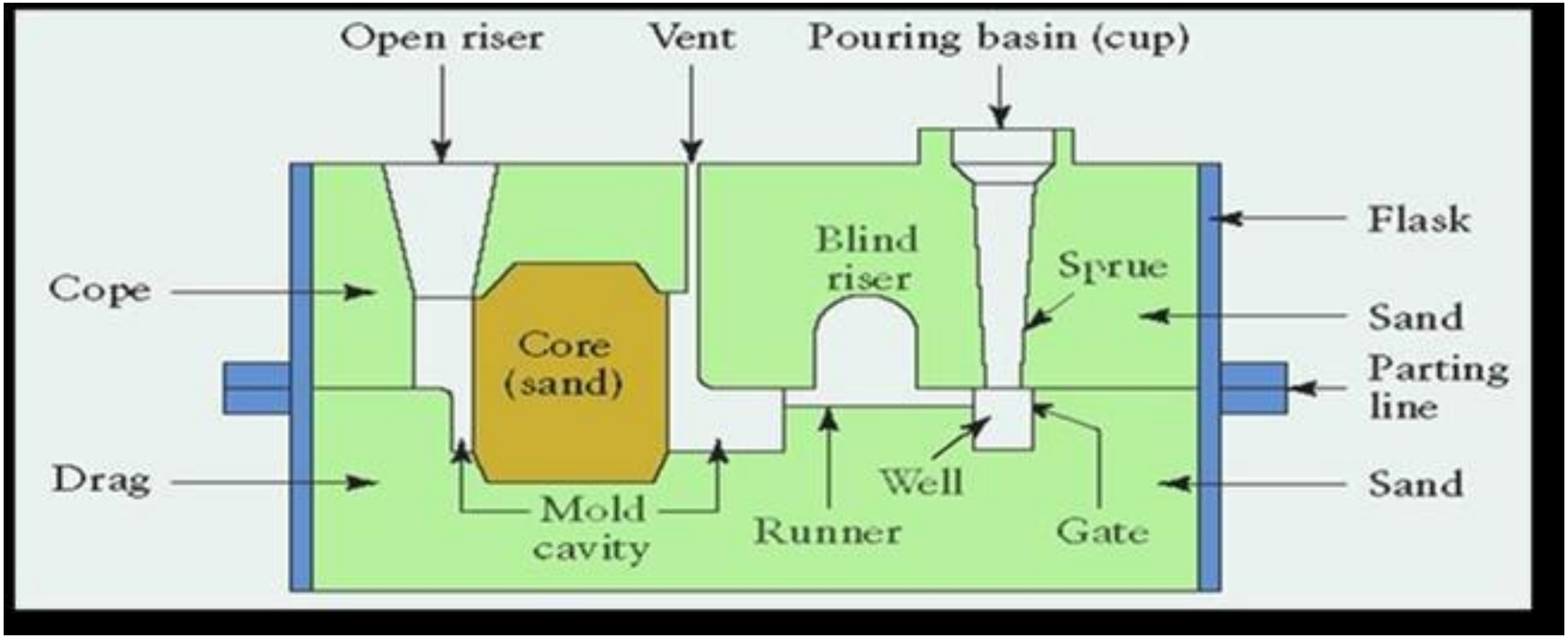


Figure 10.2 (b) Sand casting (closed) mold.



Open riser
Vent
Pouring basin (cup)
Flask
Blind riser
Sprue
Cope
Sand
Core (sand)
Parting line
Drag
Well
Sand
Mold cavity
Runner
Gate

Overview of Casting Technology; Sand Casting Molds

- In sand casting and other expandable mold processes:
  - ***Pattern*: the mold cavity is formed by means of a pattern**.
    - **It is made of wood, metal, plastic, etc, and has the shape of the part to be cast.**
    - The **cavity is formed by packing sand around the pattern.**
    - Usually made **oversized to allow for shrinkage as the metal solidifies.**
    - The cavity **in the mold provides the external surfaces of the cast part.**
    - The *core*; the internal surfaces are determined **by means of a core, which is a form placed inside the mold cavity to define the interior geometry of the part. "Generally made from sand in sand casting**".

Overview of Casting Technology; Sand Casting Molds

- In sand casting and other expandable mold processes:
  - *Gating system*: **is a channel or network of channels, by which molten metal flows into the cavity from outside the mold.**
    - The gating system consists of a ***downsprue* (or simply *sprue*),** through which a metal enters a *runner* that leads into the main cavity.
    - ***Pouring cup*, found at the top of the downsprue. It is often used to minimize splash and turbulence as the metal flows into the downsprue.**

Overview of Casting Technology; Sand Casting Molds

- In sand casting and other expandable mold processes:
  - *Riser*: **<u>is a reservoir in the mold that serves as a source of liquid metal for the casting to compensate for shrinkage during solidification .</u>**
    - It is designed **<u>to freeze after the main casting in order to satisfy its function</u>**

Overview of Casting Technology; Sand Casting Molds

- **The air that previously occupied the cavity, as well as hot gases formed by the reactions of the molten metal, must be evacuated so that the metal will completely fill the empty space.**

  – In sand casting, **the natural porosity of the sand mold permits the air and gases to escape through the walls of the cavity.**

  – In permanent metal molds, **small vent holes are drilled into the mold or machined into the parting line to permit removal of air and gases.**

Heating and Pouring
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 affecting the pouring operation include:
  - The ***pouring temperature***: temperature of the metal introduced into the mold. Here, *superheat* is important; the difference between the temperature at pouring and the temperature at which freezing begins.
  - The ***pouring rate***: volumetric rate at which the molten metal is poured into the mold. Too slow rates will cause freezing before metal fills the cavity and excessive rates will cause turbulence.
  - ***Turbulence***: sudden variations in the magnitude and velocity throughout the liquid. It tends to accelerate the formation of metal oxides. It also aggravates mold erosion due to impact of the flowing molten metal.

Solidification and Cooling Shrinkage

- **Patternmakers account for solidification shrinkage and thermal contraction by making the mold cavities oversized**.

- The amount by which the mold must be made larger relative to final casting size is called ***pattern shrinkage allowance***.

Solidification and Cooling
Riser Design

- **Riser is used in sand casting to feed liquid metal to the casting during freezing to compensate for solidification shrinkage.**

- **The riser must remain molten until after the casting solidifies.**

- Chvorinov's Rule is used to compute the size of the riser that satisfies this requirement.

- **As the riser is not a part of the casting, it will be separated from the cast part after casting is finished. Hence, it is desirable for the volume of metal in the riser to be minimum**.

Solidification and Cooling
Riser Design

- Risers can be designed in various forms:
  - **Side riser: attached to the side of the casting by means of a small channel.**
  - **Top riser: connected to the top surface of the casting.**
- **Risers can be open or blind:**
  - **Open riser: exposed to the outside at the top surface of the cope (disadvantageous as heat will escape faster).**
  - **Blind riser: entirely closed within the mold.**

Sand Casting

- Sand casting is by far most widely used casting process.
- **Nearly all alloys can be sand casted.**
- **Sand casting is one of the few processes that can be used for metals with high melting points, such as steel and nickel.**
- **Parts from small to large sizes and quantities from one to millions can be sand-casted.**

Sand Casting

- Sand casting consists of:
  - **Pouring molten metal into sand mold.**
  - **Allowing the metal to solidify.**
  - **Breaking up the mold to remove the casting.**
  - **Cleaning and inspecting the casting.**
  - **Heat treatment is sometimes required to improve metallurgical properties**

Sand Casting

- The cavity in the sand mold is formed by packing sand around a pattern, and then separating the mold into two halves to remove the pattern.

- The mold also contains the gating and riser system.

- If casting is to have internal surfaces, a core must be included in the mold.

- A new sand mold must be made for each part produced, since the mold is sacrificed to remove the casting.

Sand Casting
Patterns and Cores

- **The *pattern* is a full-sized model of the part, enlarged to account for shrinkage and machining allowances.**
- **Made of plastic, wood or metals.**
- **Wood is cheap and easy to machine.**
- **Wood however, tend to wrap. Thus, limiting the number of times it can be used.**
- **Metal is more expensive, but it can be a good choice if the number of parts to be made is high.**
- **Plastic represent a compromise between wood and metal.**

Sand Casting
Patterns and Cores

- There are various types of patterns:
  - ***Solid pattern***: simplest type and easiest to fabricate. However, it is not the easiest to use in making a sand mold (difficult to determine the parting line, also incorporating the raiser and gating system needs high skill).
  - ***Split patterns***: consist of 2 pieces, dividing the part along a line coinciding with the mold's parting line. These patterns are appropriate for complex part geometries and moderate quantities.

Sand Casting
Patterns and Cores

- There are various types of patterns:

  – ***Match-plate patterns***: appropriate for high production quantities. In these patterns, the two pieces of the split pattern are attached to opposite sides of a wood or metal plate. Holes in the plate allow the cope and drag of the mold to be aligned accurately.

  – ***Cope-and-drag patterns***: appropriate for high production quantities. Similar to match-plate patterns except that split pattern halves are attached to separate plates so that the cope-and-drag sections can be fabricated independently, instead of using the same tooling for both.

Sand Casting
Patterns and Cores

- There are various types of patterns:

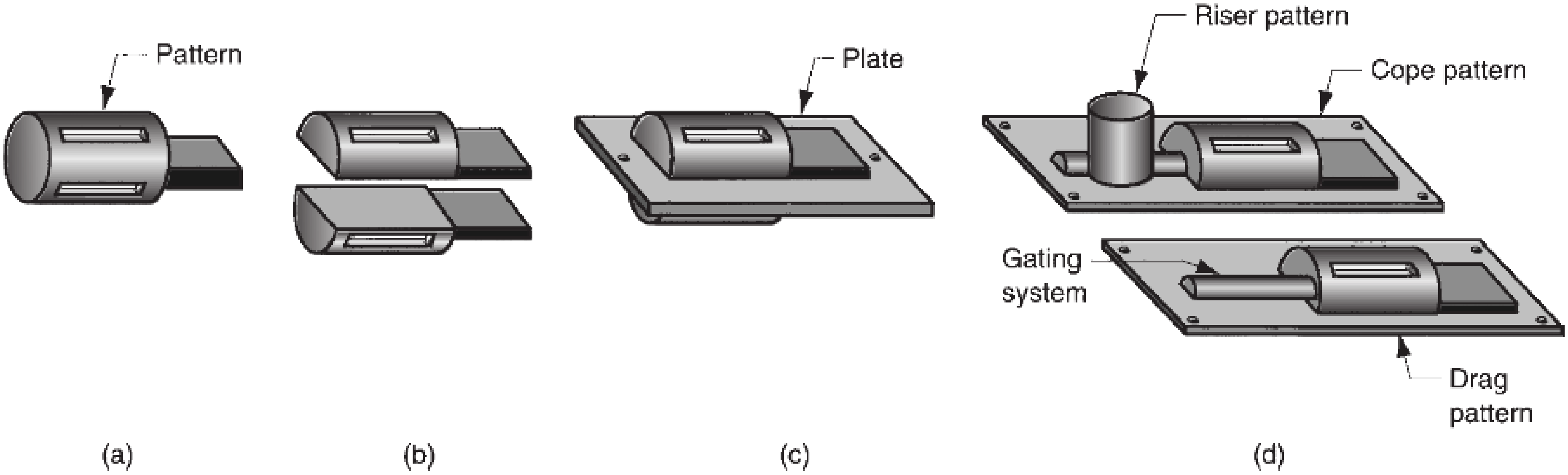


Fig. 11.1 Types of patterns used in sand casting (a) solid pattern, (b) split pattern, (c) match-plate pattern, and (d) cope-and-drag pattern.

Sand Casting
Patterns and Cores

- **The *core* defines the internal features of a casting.**

- Usually made of sand, compacted into the desired shape.

- As with the pattern, the actual size of the core must account for the shrinkage and machining.

- ***Chaplets*: supports for the core. The may or may not be necessary depending on the part's geometry. They are made of metals that have higher melting points than the casting.**

Sand Casting
Patterns and Cores

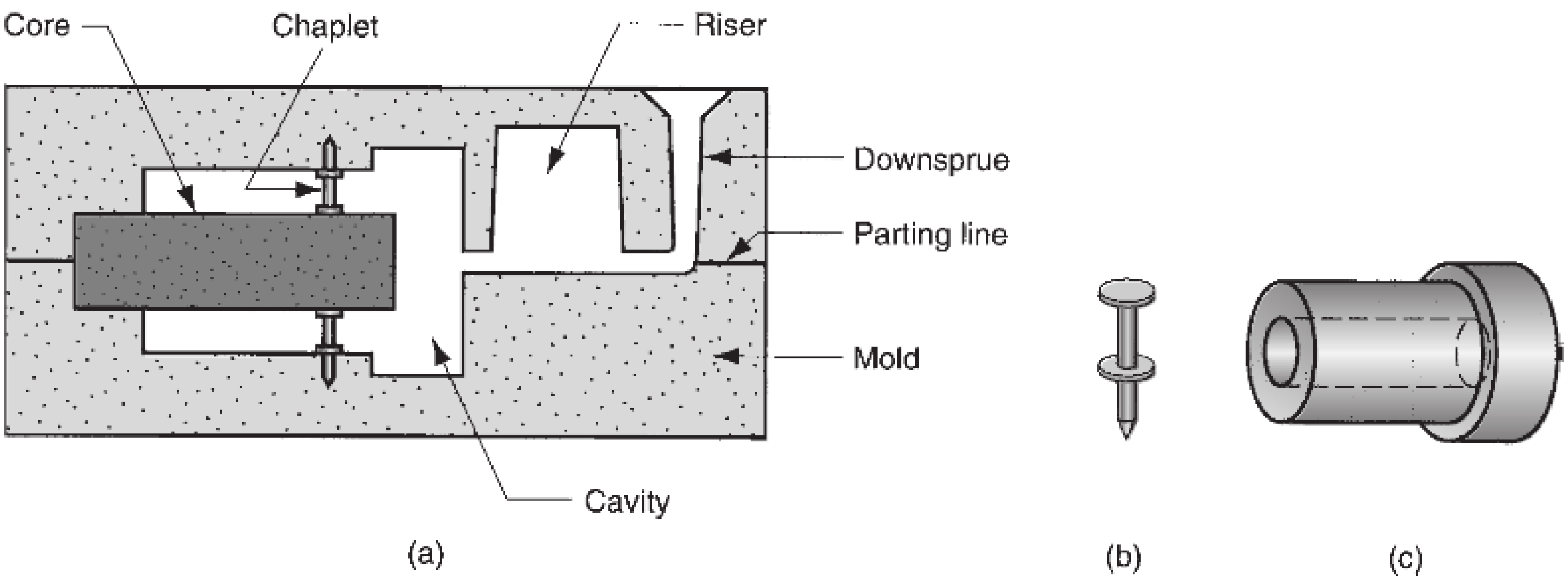


Fig. 11.2 (a) Core held in place in the mold cavity by chaplets, (b) possible chaplet design, and (c) casting with internal cavity
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Sand Casting
Molds and mold making

- **Foundry sands are silica, or silica mixed with other minerals.**

- **Sand should be able to stand high temperatures without melting or degrading.**

- Sand should have appropriate size to provide a good surface finish on the cast part and allow for gases to escape during pouring.

- Small sizes provide a good surface finish but have lower permeability compared to large sizes.

- **Sand particles are held together by water and clay (by volume: 90%, 3% and 7%, respectively).**

Sand Casting
Molds and mold making

- The mold cavity is formed by compacting the sand around the pattern for both cope and drag contained in the flask.

- The simplest packing process is hand hammering, accomplished manually by a foundry worker.

- In addition, various machines have been developed to mechanize the packing procedure.

Sand Casting
Molds and mold making

- The quality of the sand mold is determined by:
  - Strength: the mold's ability to maintain its shape and resist erosion caused by the flow of molten metal. It depends on grain size and shape and binders quality.
  - Permeability: ability of the mold to allow gases to pass through the sand voids.
  - Thermal stability: ability of the sand at the surface of the mold cavity to resist cracking and buckling upon contact with the molten metal.
  - Collapsibility: ability of the sand to give way and allow the casting to shrink without cracking the casting. It also refers to the ability to remove the sand from the casting during cleaning.
  - Reusability: ability to reuse the sand to make other molds.

Sand Casting
Molds and mold making

- Sand molds classifications:

  - Green-sand molds: made of sand, clay and water. They contain moisture at the time of pouring. They possess good strength, good collapsibility and permeability, good reusability and the least expensive of the molds. Moisture however, can cause some defects in the castings.

  - Dry-sand molds: made of organic binders. The mold is backed in an oven at temperatures between 200 and 320 ºC for strengthening and hardening reasons. Better dimensional accuracy compared to green-sand molds but more expensive.

  - Skin-dried mold: the advantages of dry-sand molds are partially achieved by drying the surface of a green-sand mold to a depth of 10 to 25 mm.

Sand Casting
The Casting Operation

- After the core is positioned and the two halves of the mold are clamped together, the casting is performed.
- The gating and the riser system in the system must be designed to deliver liquid metal into the cavity, and provide for a sufficient reservoir of molten metal during solidification shrinkage.
- Air and gasses must be allowed to escape.
- Following solidification and cooling, the sand mold is broken away from the casting to retrieve the part.
- The part is then cleaned, gating and riser system is separated and sand is removed.
- Finally, casting is inspected.

Casting Quality

- There are numerous opportunities for things to go wrong in a casting operation, resulting in quality defects in the cast product.

- Some of the defects are common to any and all casting process. They include: *Misruns, Cold shuts, Cold shots, Shrinkage cavities, Microporosity, and Hot tearing*.

- Other defects found primarily in sand casting include: *Sand blows, Pinholes, Sand wash, Scab, Penetration, Mold shifts, Core shifts, and Mold Cracks*.

Casting Quality

- ***Misruns***: castings that solidify before completely filling the mold cavity. Typical causes include (1) fluidity of the molten metal is insufficient, (2) pouring temperature is too low, (3) pouring is done too slowly, and/or (4) cross section of the mold cavity is too thin.

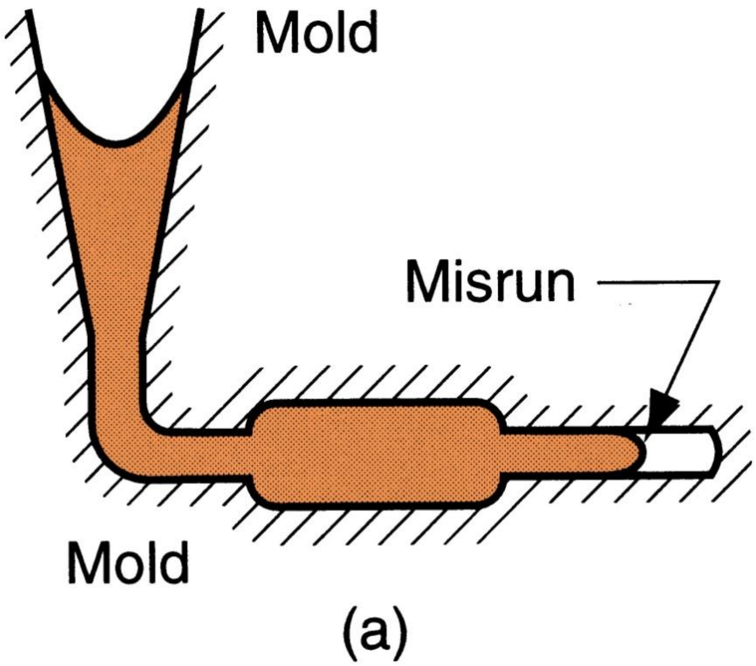

Figure 11.13 (a) Misruns.

Casting Quality

- ***Cold shuts***: occurs when two portions of the metal flow together but there is a lack of fusion between **them due to premature freezing.** Its causes are similar to those of a misrun.

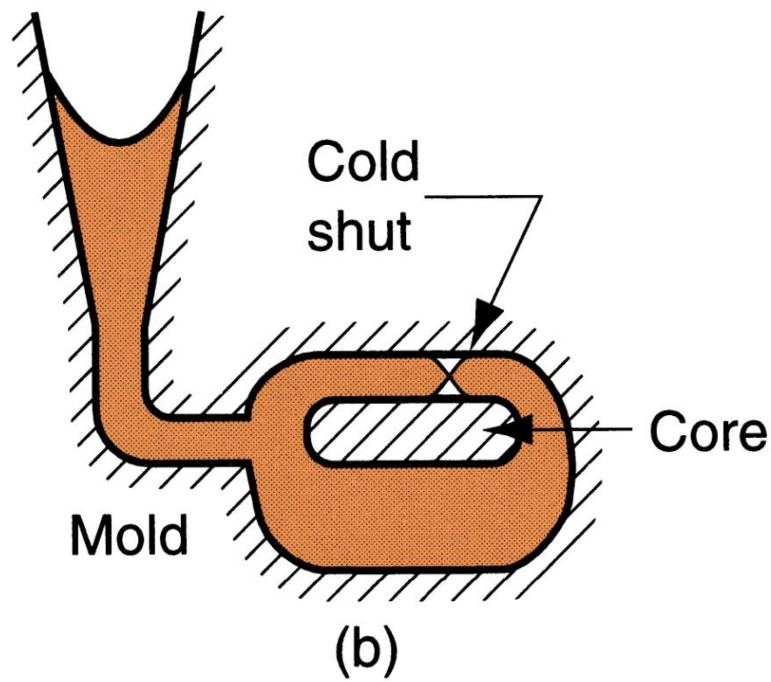

Figure 11.13 (b) Cold shuts.

Casting Quality

- ***Shrinkage cavities***: is a depression in the surface or an internal void in the casting, caused by solidification shrinkage that restricts the amount of molten metal available in the last region to freeze. It often occurs near the top of the casting, in which case it is referred to as a "pipe". The problem can often be solved by proper riser design.

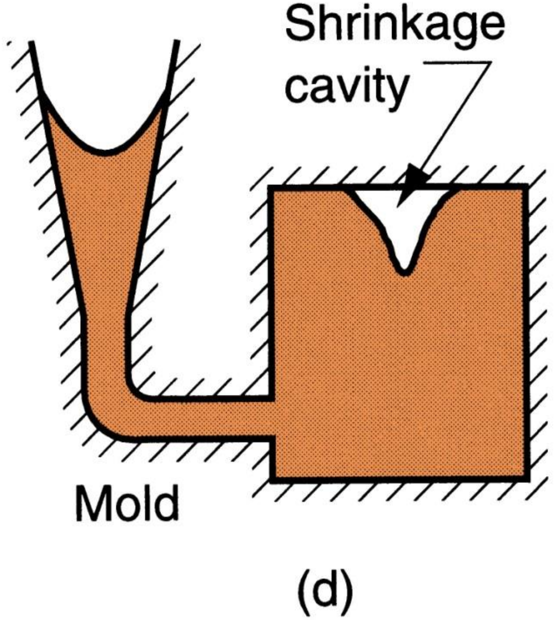

Figure 11.13 (d) Shrinkage cavities.

Casting Quality

- ***Hot tearing (hot cracking)***: occurs when the casting is restrained from contraction by an unyielding mold during the final stages of solidification or early stages of cooling after solidification. In sand-casting and other expendable-mold processes, it is prevented by compounding the mold to be collapsible. In permanent-mold processes, hot tearing is reduced by removing the part from the mold immediately after solidification.

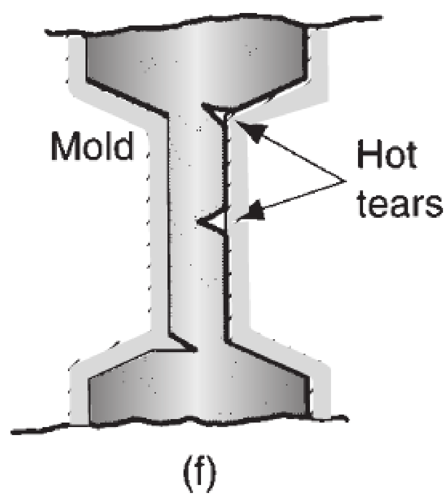

Figure 11.13 (f) Hot tearing.

Casting Quality

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

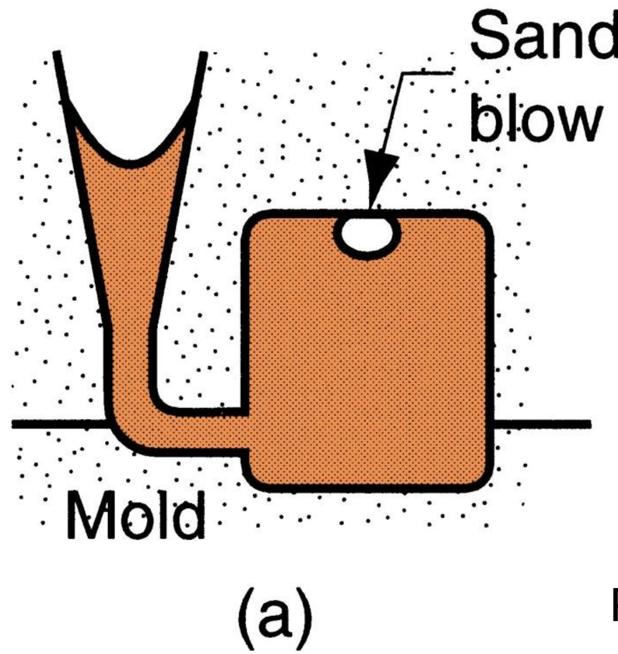

Figure 11.14 (a) Sand blow.

Casting Quality

- ***Pinholes***: also caused by release of gases during pouring, consist of many small gas cavities formed at or slightly below the surface of the casting.

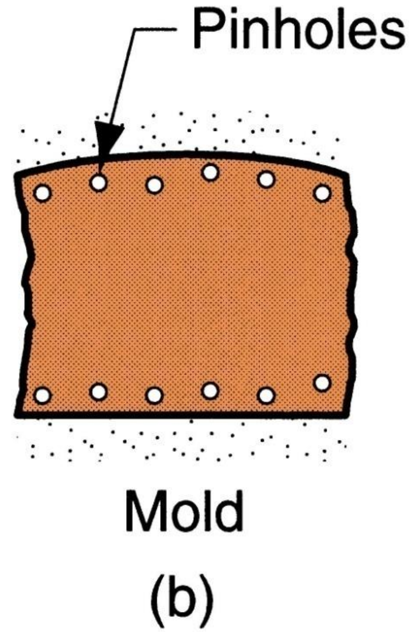

Figure 11.14 (b) Pinholes.

Casting Quality

- ***Sand wash***: an irregularity in the surface of the casting that results from erosion of the sand mold during pouring, and the contour of the erosion is formed in the surface of the final cast part.

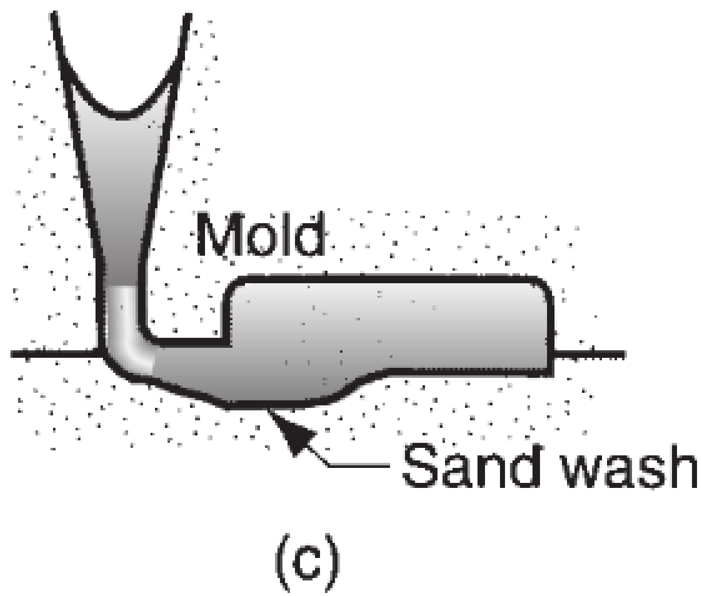

Figure 11.14 (c) Sand wash.

Casting Quality

- ***Scabs***: are rough areas on the surface of the casting due to encrustations of sand and metal. It is caused by portions of the mold surface flaking off during solidification and becoming imbedded in the casting surface.

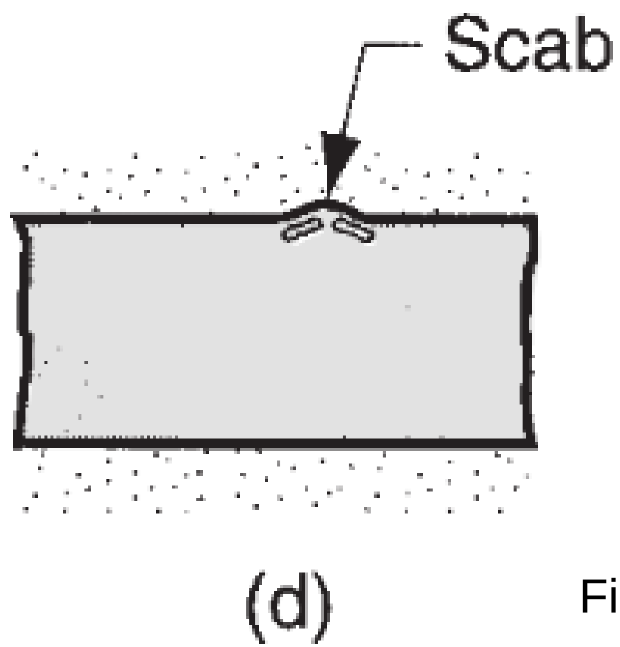

Figure 11.14 (d) Scabs.

Casting Quality

- ***Penetration***: refers to a surface defect that occurs when the f**<u>luidity of the liquid metal is high,</u>** and it penetrates into the sand mold or sand core. Upon freezing, the casting surface consists of a mixture of sand grains and metal. Harder packing of the sand mold helps to alleviate this condition.

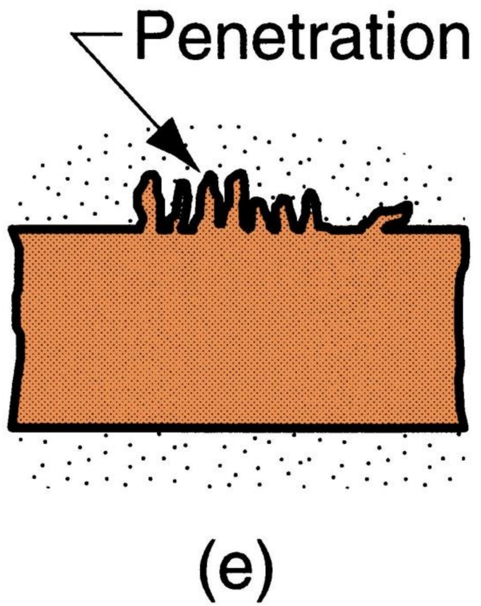

Figure 11.14 (e) Penetration.

Casting Quality

- ***Mold shift***: refers to a defect caused by a sidewise displacement of the mold cope relative to the drag.

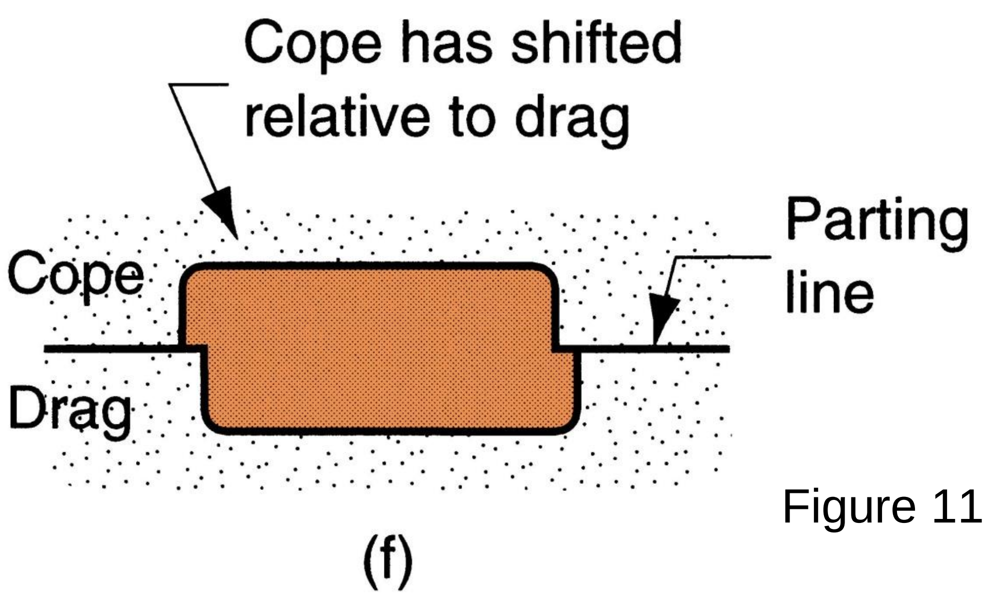

Figure 11.14 (f) Mold shift.

Casting Quality

- ***Core shift***: similar to mold shift, but it is the core that is displaced, and the displacement is usually vertical. Core shift and mold shift are caused by buoyancy of the molten metal.

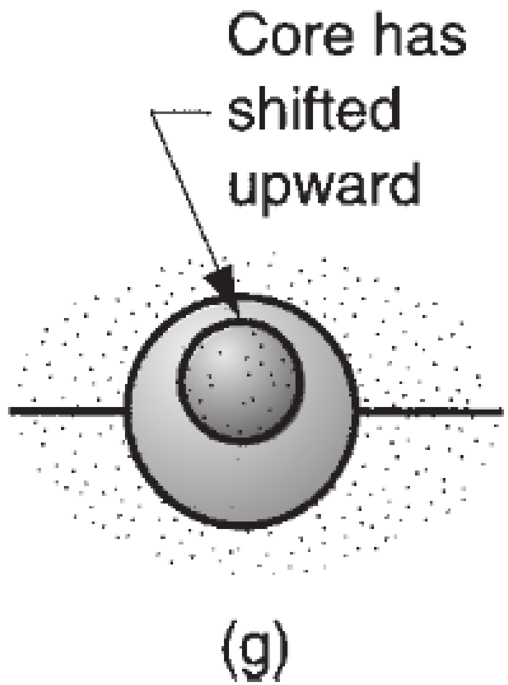

Figure 11.14 (g) Core shift.

Casting Quality

- ***Mold crack***: occurs when mold strength is insufficient, and a crack develops, into which liquid metal can seep to form a “fin” on the final casting.

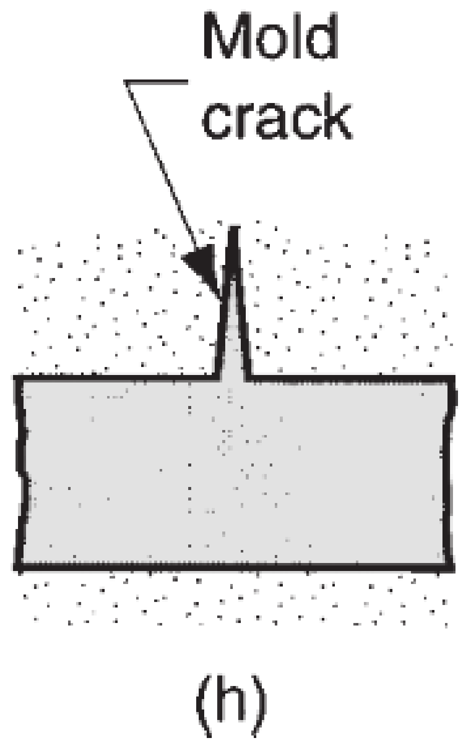

Figure 11.14 (h) Mold crack.