METAL CASTING PROCESSES

- Sand Casting
- Other Expendable Mold Casting Processes
- Permanent Mold Casting Processes
- Foundry Practice
- Casting Quality
- Metals for Casting
- Product Design Considerations

Two Categories of Metal Casting Processes

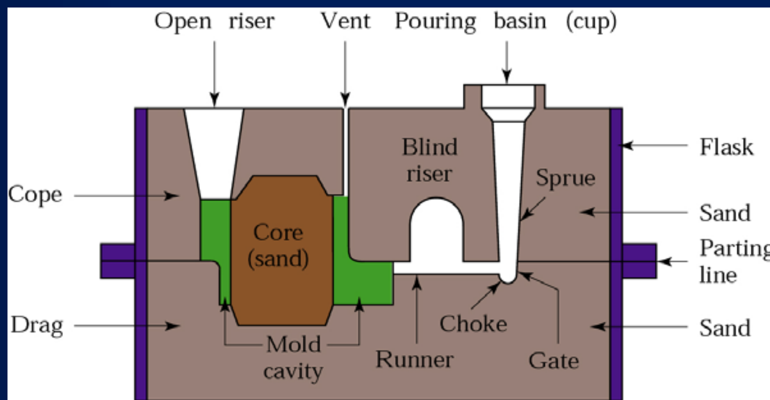
1. *Expendable mold processes* - mold is sacrificed to remove part
   - Advantage: more complex shapes possible
   - Disadvantage: production rates often limited by time to make mold rather than casting itself
2. *Permanent mold processes* - mold is made of metal and can be used to make many castings
   - Advantage: higher production rates
   - Disadvantage: geometries limited by need to open mold

Overview of Sand Casting

- Most widely used casting process, accounting for a significant majority of total tonnage cast
- Nearly all alloys can be sand casted, including metals with high melting temperatures, such as steel, nickel, and titanium
- Parts ranging in size from small to very large
- Production quantities from one to millions

Figure 11.1 - A large sand casting weighing over 680 kg (1500 lb) \
for an air compressor frame
(courtesy Elkhart Foundry, photo by Paragon Inc , Elkhart, Indiana)

Sand Mold Features



Steps in Sand Casting

1. Pour molten metal into sand mold
2. Allow metal to solidify
3. Break up the mold to remove casting
4. Clean and inspect casting
5. Heat treatment of casting is sometimes required to improve metallurgical properties

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Making the Sand Mold

- The *cavity* in the sand mold is formed by packing sand around a pattern, then separating the mold into two halves and removing the pattern
- The mold must also contain gating and riser system
- If casting is to have internal surfaces, a *core* must be included in mold
- A new sand mold must be made for each part produced

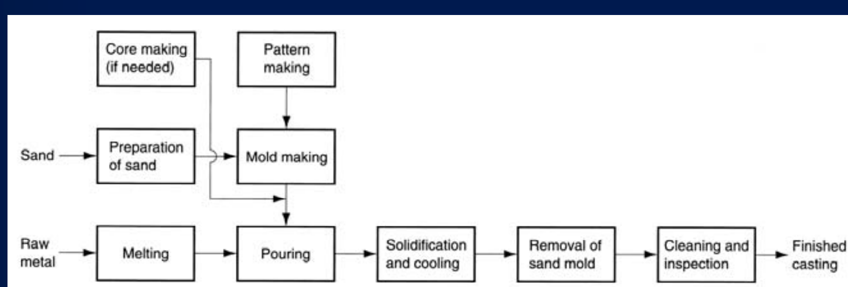

Figure 11.2 - Steps in the production sequence in sand casting The steps include not only the casting operation but also pattern-making and mold-making

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The Pattern

A full-sized model of the part, slightly enlarged to account for shrinkage and machining allowances in the casting

- Pattern materials:
  - Wood - common material because it is easy to work, but it warps
  - Metal - more expensive to make, but lasts much longer
  - Plastic - compromise between wood and metal

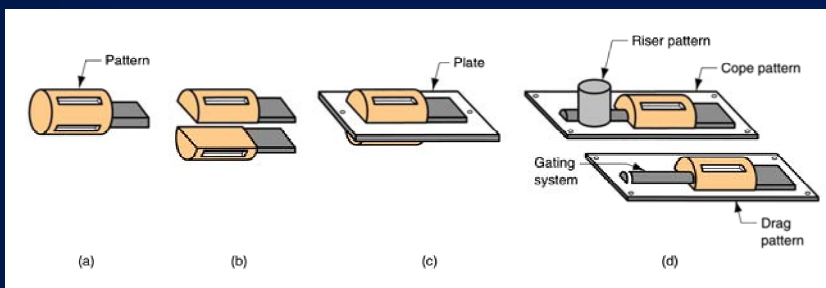

Figure 11.3 - Types of patterns used in sand casting:
(a) solid pattern
(b) split pattern
(c) match-plate pattern
(d) cope and drag pattern

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Core

Full-scale model of interior surfaces of part

- It is inserted into the mold cavity prior to pouring
- The molten metal flows and solidifies between the mold cavity and the core to form the casting's external and internal surfaces
- May require supports to hold it in position in the mold cavity during pouring, called *chaplets*

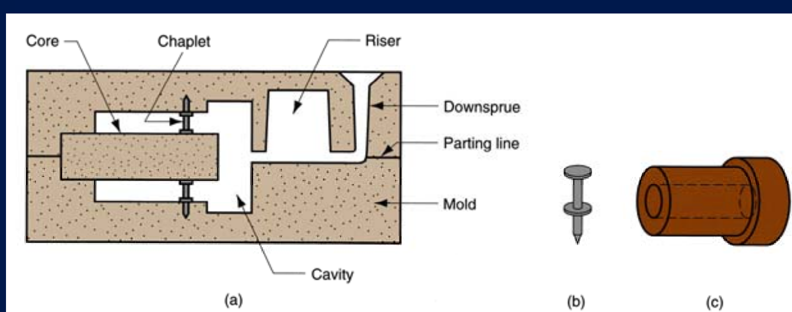
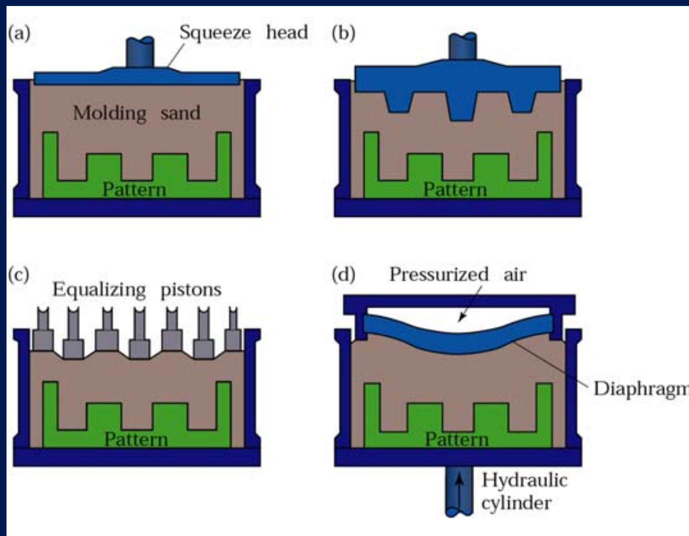


Figure 11.4 - Core held in place in the mold cavity by chaplets
(b) possible chaplet design
(c) casting with internal cavity

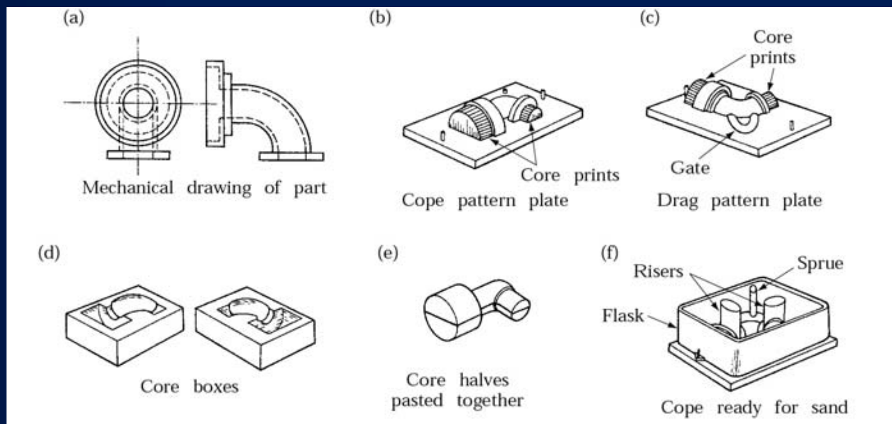
Squeeze Heads



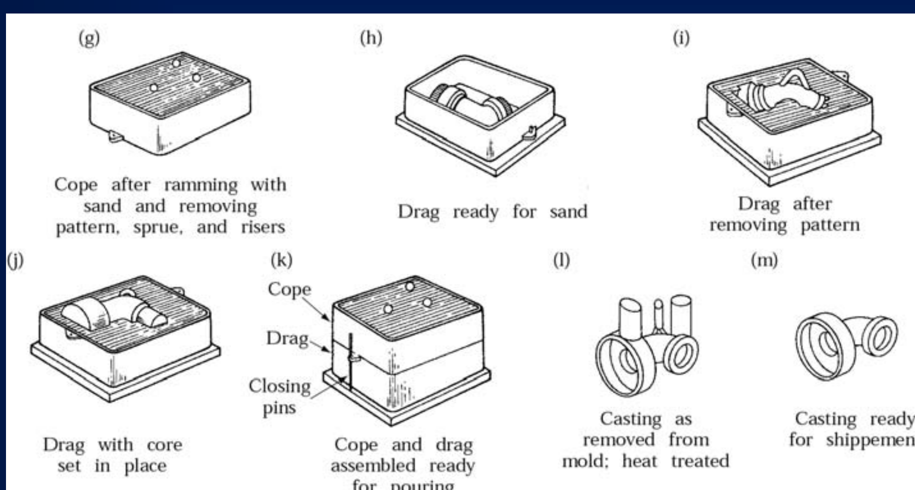
Desirable Mold Properties and Characteristics

- *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 on contact with molten metal
- *Collapsibility* - ability to give way and allow casting to shrink without cracking the casting
- *Reusability* - can sand from broken mold be reused to make other molds?

Sequence of Operations for Sand Casting



Sequence of Operations for Sand Casting (cont.)



Foundry Sands

Silica (SiO_2) or silica mixed with other minerals

- Good refractory properties - capacity to endure high temperatures
- Small grain size yields better surface finish on the cast part
- Large grain size is more permeable, to allow escape of gases during pouring
- Irregular grain shapes tend to strengthen molds due to interlocking, compared to round grains
  - Disadvantage: interlocking tends to reduce permeability

Binders Used with Foundry Sands

- Sand is held together by a mixture of water and bonding clay
  - Typical mix: 90% sand, 3% water, and 7% clay
- Other bonding agents also used in sand molds:
  - Organic resins (e g , phenolic resins)
  - Inorganic binders (e g , sodium silicate and phosphate)
- Additives are sometimes combined with the mixture to enhance strength and/or permeability

Types of Sand Mold

- *Green-sand molds* - mixture of sand, clay, and water;
  - "Green" means mold contains moisture at time of pouring
- *Dry-sand mold* - organic binders rather than clay and mold is baked to improve strength
- *Skin-dried mold* - drying mold cavity surface of a green-sand mold to a depth of 10 to 25 mm, using torches or heating lamps

Furnaces for Casting Processes

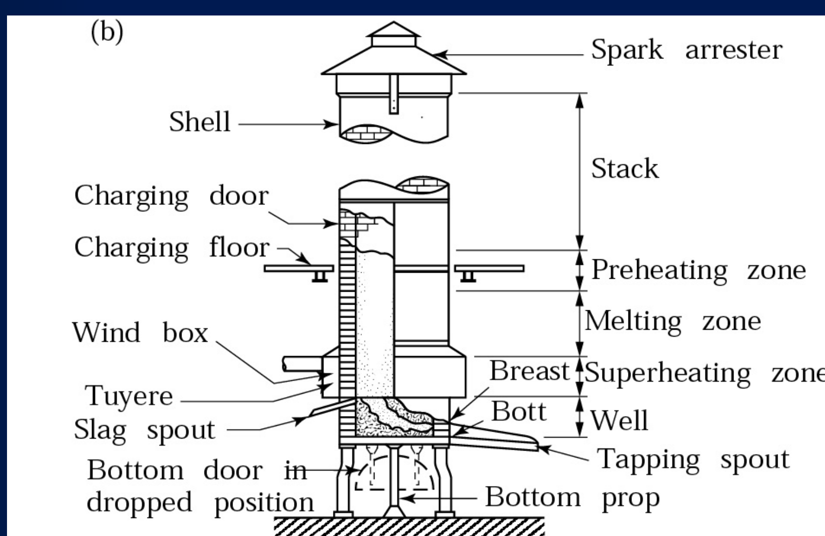
- Furnaces most commonly used in foundries:
  - Cupolas
  - Direct fuel-fired furnaces
  - Crucible furnaces
  - Electric-arc furnaces
  - Induction furnaces

Cupolas

Vertical cylindrical furnace equipped with tapping spout near base

- Used only for cast irons, and although other furnaces are also used, largest tonnage of cast iron is melted in cupolas
- The "charge," consisting of iron, coke, flux, and possible alloying elements, is loaded through a charging door located less than halfway up height of cupola

Cupolas



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Direct Fuel-Fired Furnaces

Small open-hearth in which charge is heated by natural gas fuel burners located on side of furnace

- 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

Crucible Furnaces

Metal is melted without direct contact with burning fuel mixture

- Sometimes called *indirect fuel-fired furnaces*
- 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

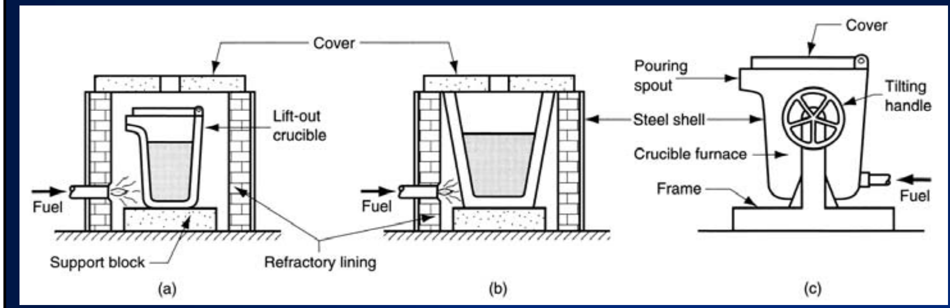

Figure 11.19 - Three types of crucible furnaces:

(a) lift-out crucible,

(b) stationary pot, from which molten metal must be ladled, and

(c) tilting-pot furnace

Electric-Arc Furnaces

Charge is melted by heat generated from an electric arc

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

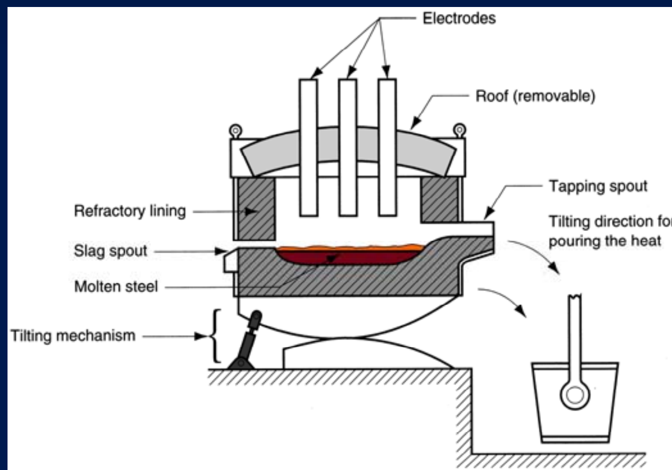

Figure 6.9 - Electric arc furnace for steelmaking

Induction Furnaces

Uses alternating current passing through a coil to develop magnetic field in metal

- Induced current causes rapid heating and melting
- Electromagnetic force field also causes mixing action in liquid metal
- Since metal does not contact heating elements, the environment can be closely controlled, which results in molten metals of high quality and purity
- Melting steel, cast iron, and aluminum alloys are common applications in foundry work

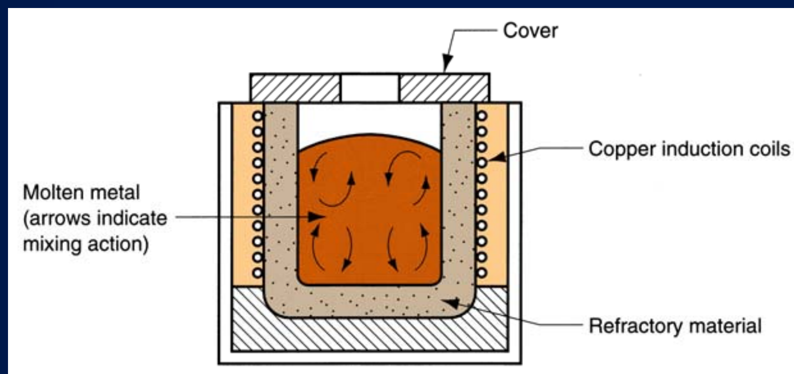

Figure 11.20 - Induction furnace

Ladles

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

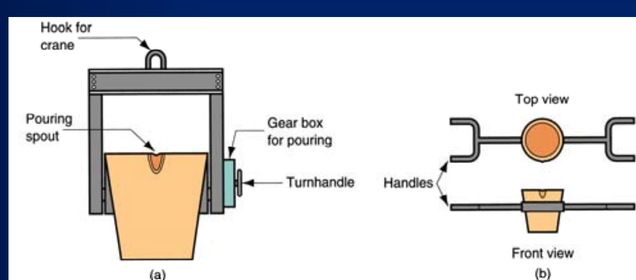

Figure 11.21 - Two common types of ladles: (a) crane ladle, and (b) two-man ladle

Additional Steps After Solidification

- Trimming
- Removing the core
- Surface cleaning
- Inspection
- Repair, if required
- Heat treatment

Trimming

Removal of sprues, runners, risers, parting-line flash, fins, chaplets, and any other excess metal from the cast part

- For brittle casting alloys and when cross-sections are relatively small, appendages can be broken off
- Otherwise, hammering, shearing, hack-sawing, band-sawing, abrasive wheel cutting, or various torch cutting methods are used

Removing the Core

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

Surface Cleaning

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, buffing, and chemical pickling
- Surface cleaning is most important for sand casting, whereas in many permanent mold processes, this step can be avoided
- Defects are possible in casting, and inspection is needed to detect their presence

Heat Treatment

- Castings are often heat treated to enhance 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

Casting Quality

- There are numerous opportunities for things to go wrong in a casting operation, resulting in quality defects in the product
- The defects can be classified as follows:
  - Defects common to all casting processes
  - Defects related to sand casting process

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Misrun

A casting that has solidified before completely filling mold cavity

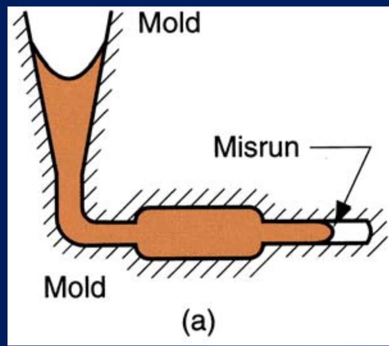

Figure 11.22 - Some common defects in castings: (a) misrun

Cold Shut

Two portions of metal flow together but there is a lack of fusion due to premature freezing

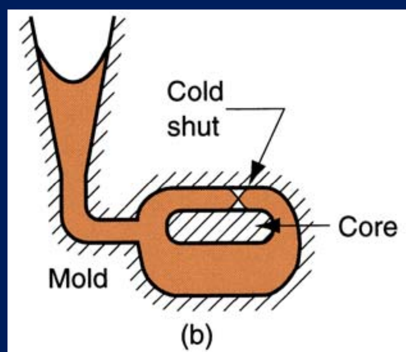

Figure 11.22 - Some common defects in castings: (b) cold shut

Cold Shot

Metal splatters during pouring and solid globules form and become entrapped in casting

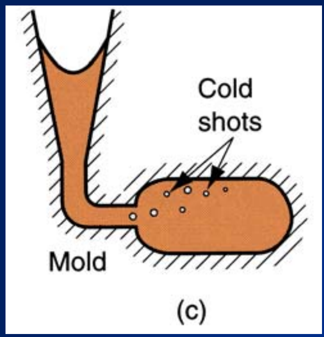

Figure 11.22 - Some common defects in castings: (c) cold shot

Shrinkage Cavity

Depression in surface or internal void caused by solidification shrinkage that restricts amount of molten metal available in last region to freeze

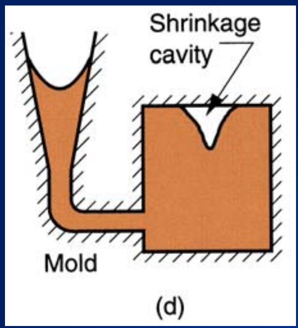

Figure 11.22 - Some common defects in castings: (d) shrinkage cavity

Sand Blow

Balloon-shaped gas cavity caused by release of mold gases during pouring

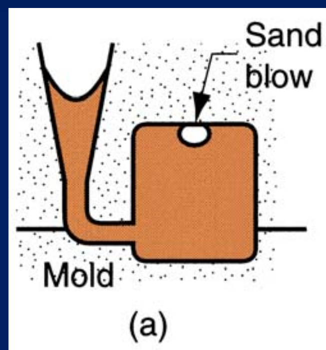

Figure 11.23 - Common defects in sand castings: (a) sand blow

Pin Holes

Formation of many small gas cavities at or slightly below surface of casting

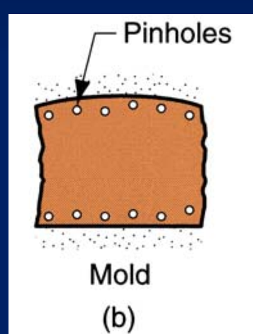

Figure 11.23 - Common defects in sand castings: (b) pin holes

Penetration

When fluidity of liquid metal is high, it may penetrate into sand mold or sand core, causing casting surface to consist of a mixture of sand grains and metal

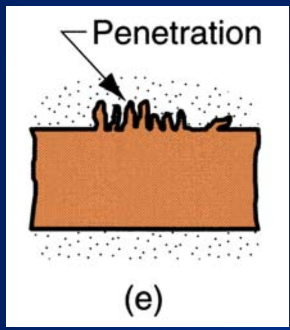

Figure 11.23 - Common defects in sand castings: (e) penetration

Mold Shift

A step in cast product at parting line caused by sidewise relative displacement of cope and drag

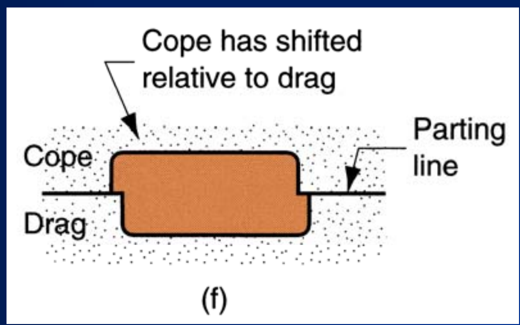

Figure 11.23 - Common defects in sand castings: (f) mold shift

Foundry Inspection Methods

- Visual inspection to detect obvious defects such as misruns, cold shuts, and severe surface flaws
- Dimensional measurements to insure that tolerances have been met
- Metallurgical, chemical, physical, and other tests concerned with quality of cast metal