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

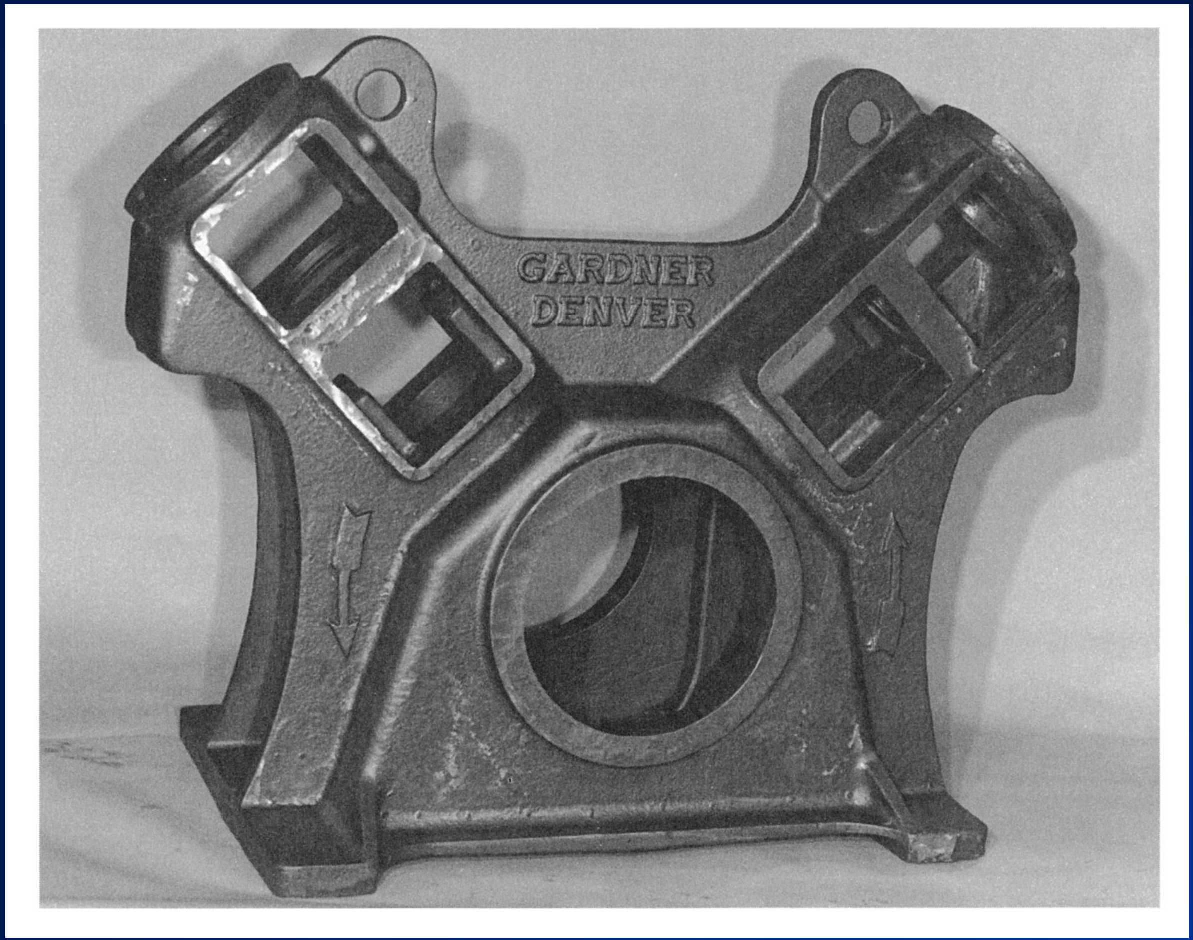


Figure 11.1 - A large sand casting weighing over 680 kg (1500 lb) \
for an air compressor frame
(courtesy Elkhart Foundry, photo by Paragon Inc , Elkhart, Indiana)

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

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

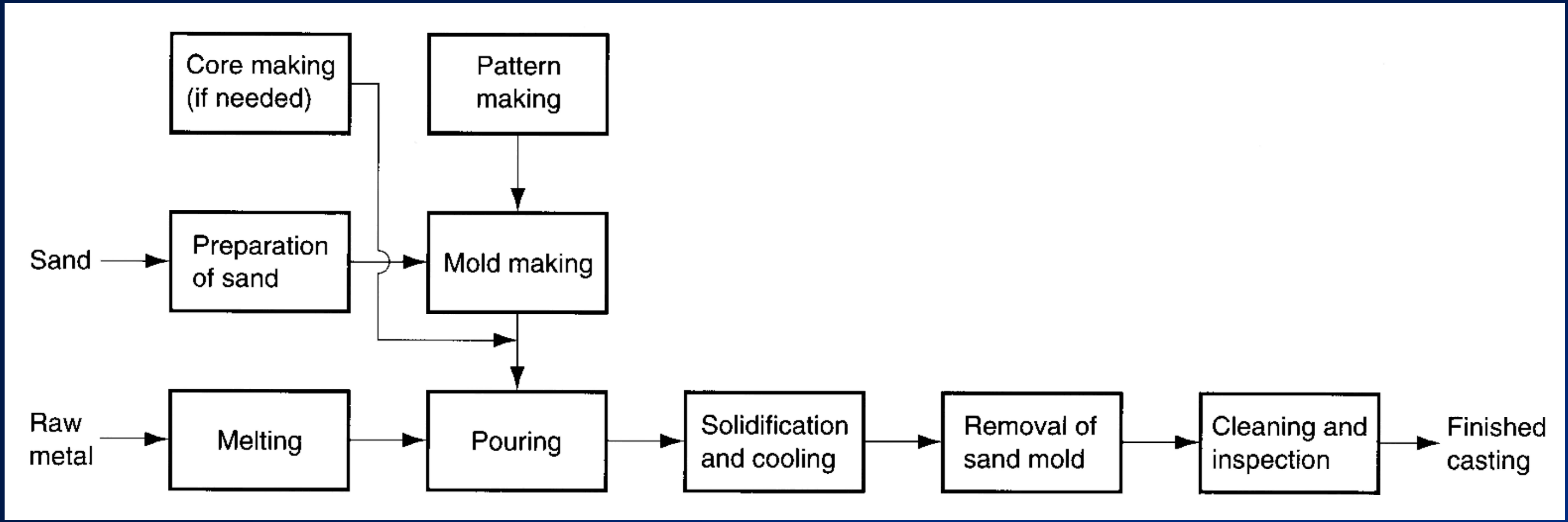


Figure 11.2 - Steps in the production sequence in sand casting

The steps include not only the casting operation but also pattern-making and mold-making

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

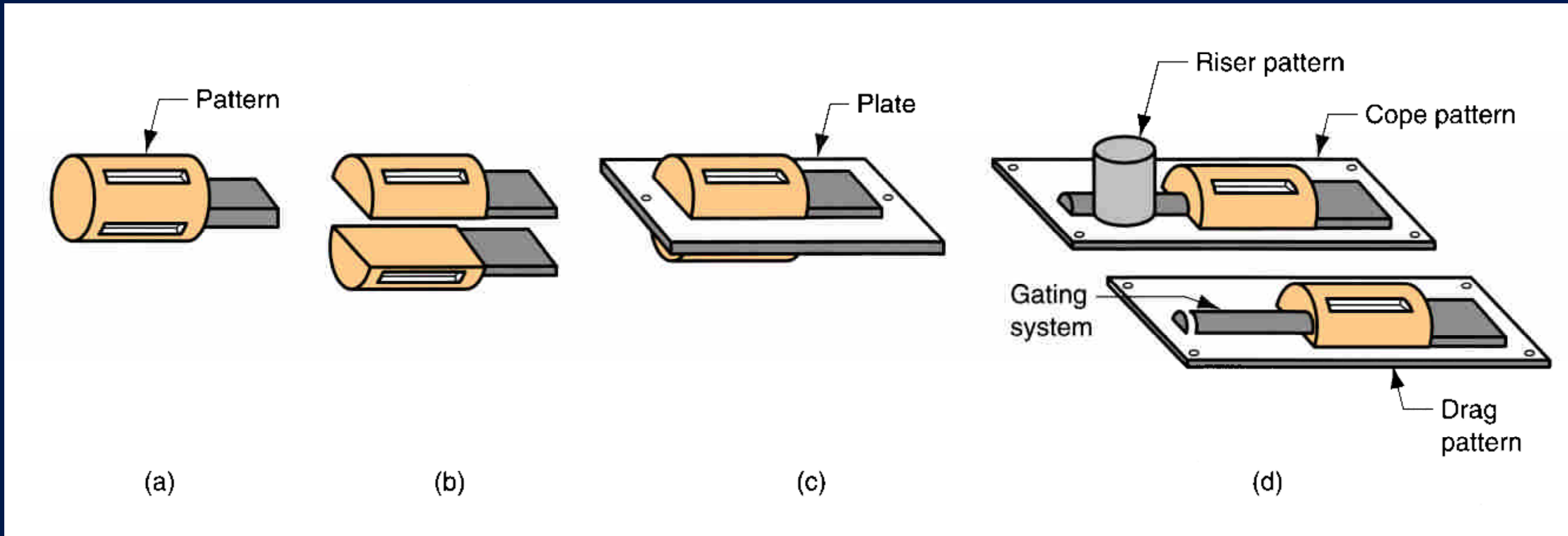


Figure 11.3 - Types of patterns used in sand casting:

(a) solid pattern

(b) split pattern

(c) match-plate pattern

(d) cope and drag pattern

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*

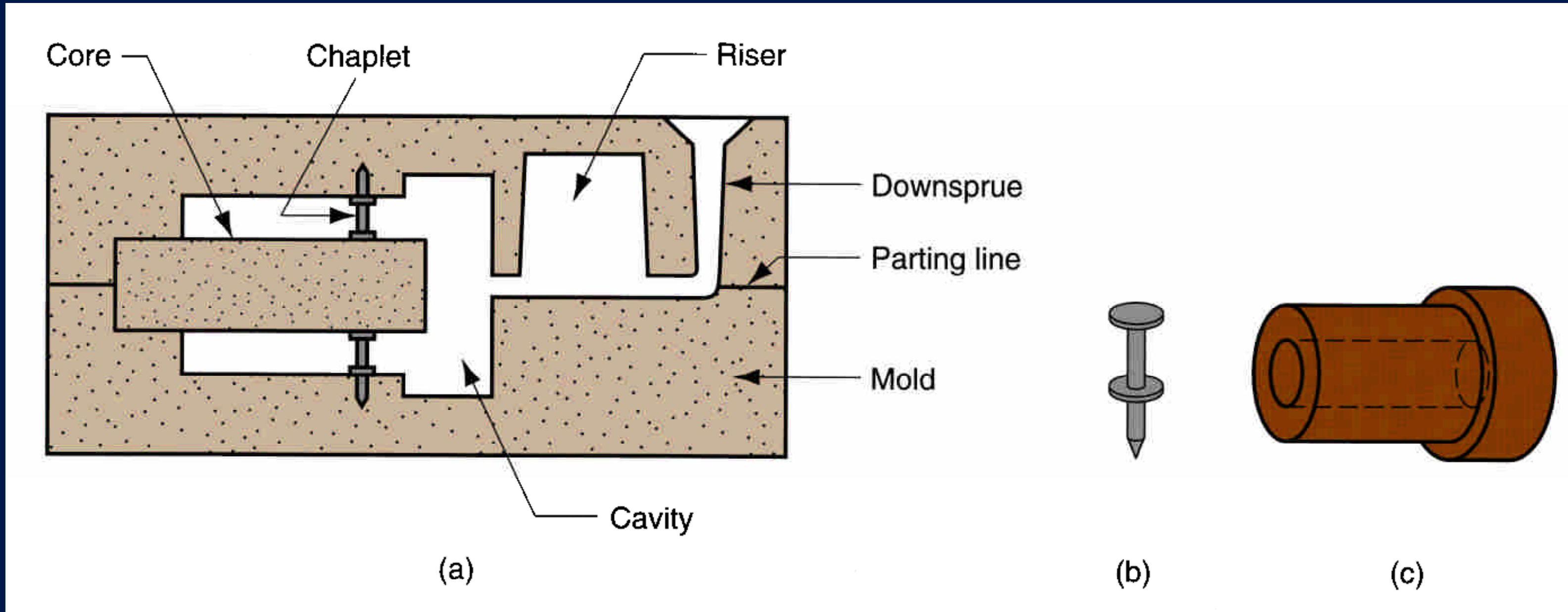


Figure 11.4 - Core held in place in the mold cavity by chaplets

(b) possible chaplet design

(c) casting with internal cavity

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?

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

Buoyancy in Sand Casting Operation

- During pouring, buoyancy of the molten metal tends to displace the core
- Core displacement can cause casting to be defective

Force tending to lift core = weight of displaced liquid less the weight of core itself

$$F_b = W_m - W_c$$

where F_b = buoyancy force; W_m = weight of molten metal displaced; and W_c = weight of core

Other Expendable Mold Casting Processes

- Shell Molding
- Vacuum Molding
- Expanded Polystyrene Process
- Investment Casting
- Plaster Mold and Ceramic Mold Casting

Shell Molding

Casting process in which the mold is a thin shell of sand held together by thermosetting resin binder

- Developed in Germany during early 1940s

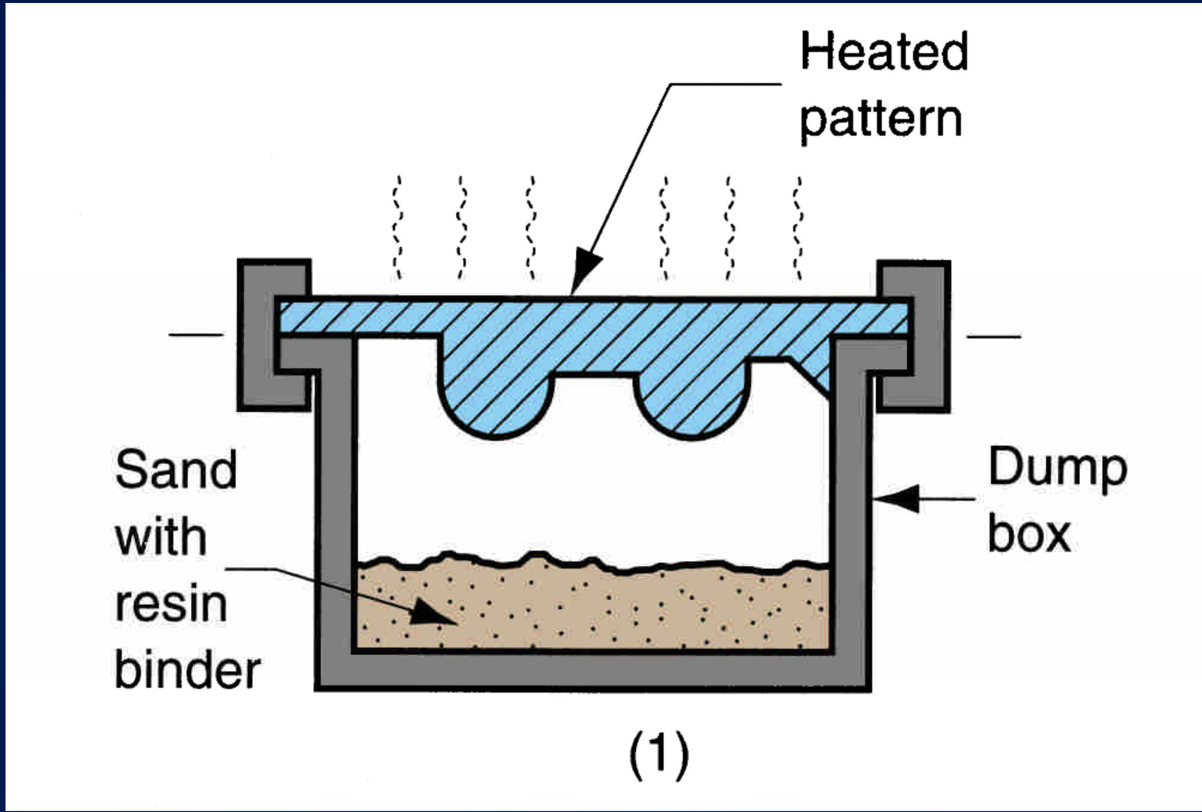


Figure 11.5 - Steps in shell-molding: (1) a match-plate or cope-and-drag metal pattern is heated and placed over a box containing sand mixed with thermosetting resin

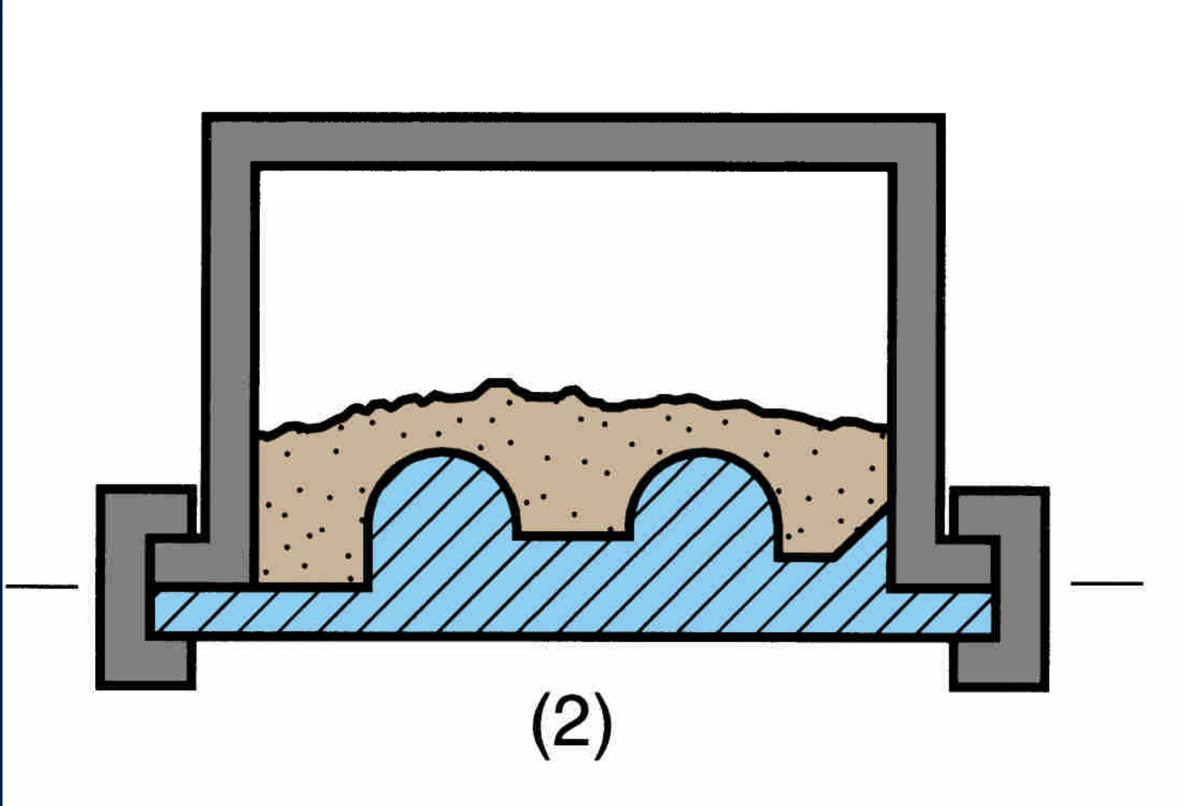


Figure 11.5 - Steps in shell-molding: (2) box is inverted so that sand and resin fall onto the hot pattern, causing a layer of the mixture to partially cure on the surface to form a hard shell

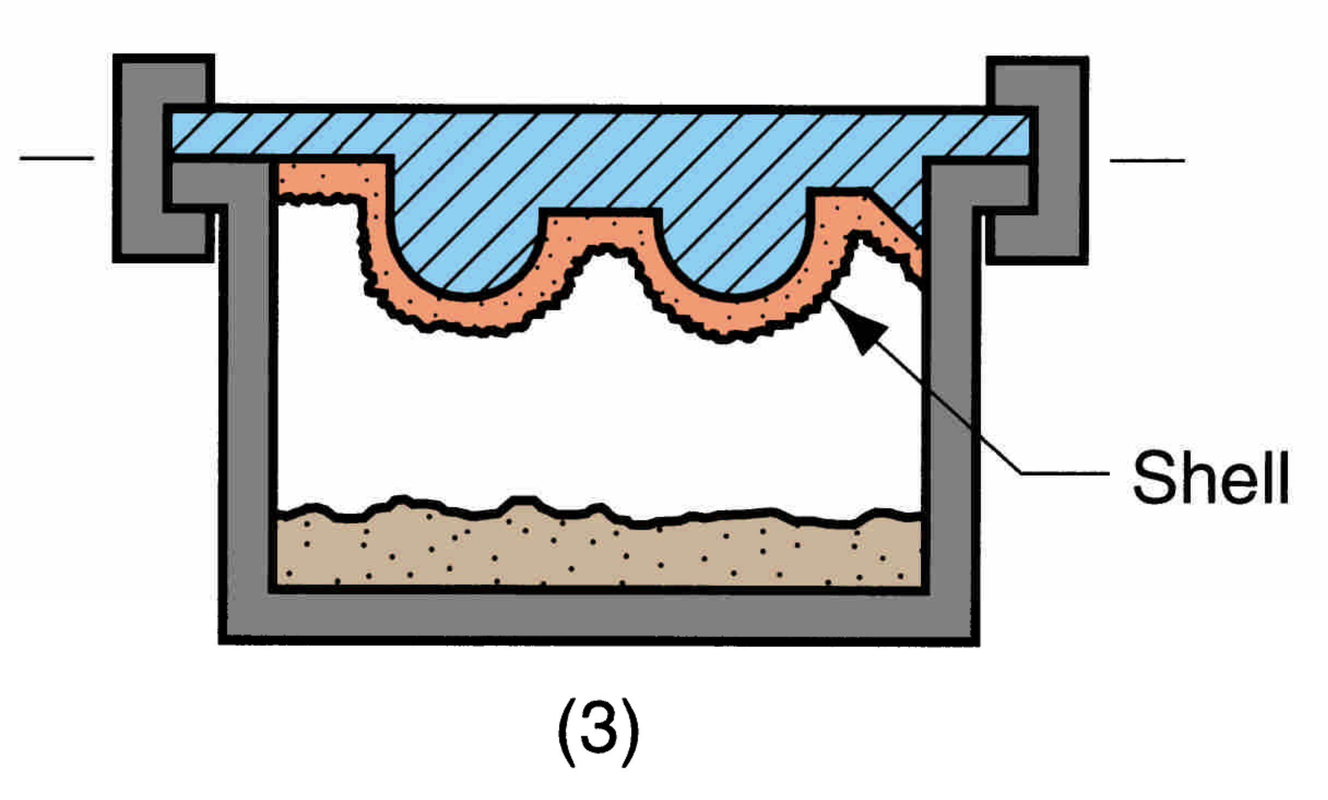
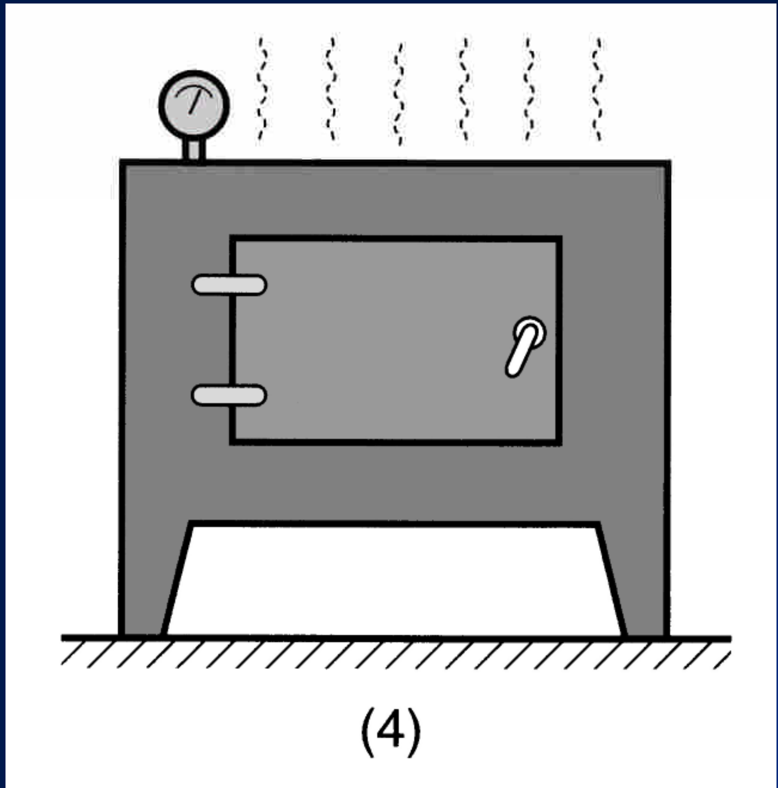


Figure 11.5 ‑ Steps in shell‑molding: (3) box is repositioned so that loose uncured particles drop away



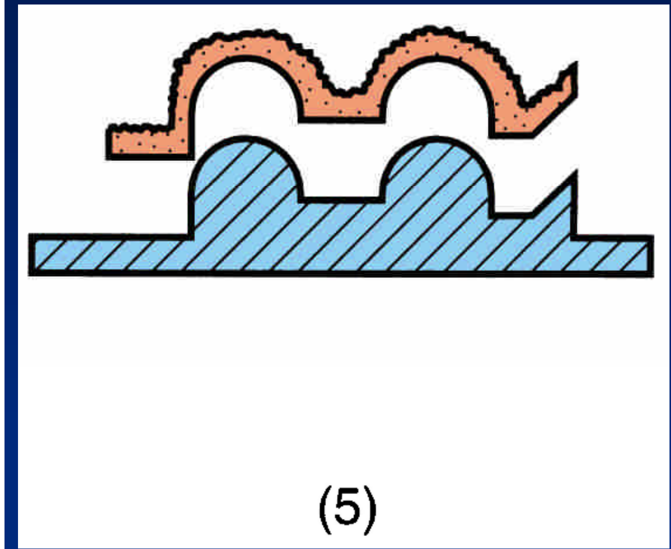
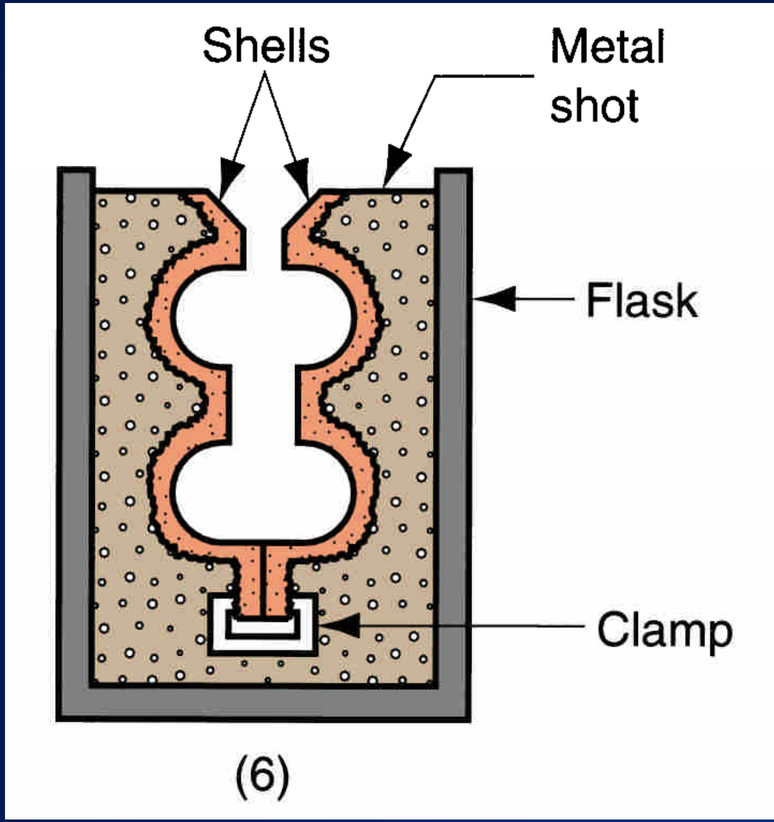


Figure 11.5 ‑ Steps in shell‑molding:

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

(5) shell mold is stripped from the pattern



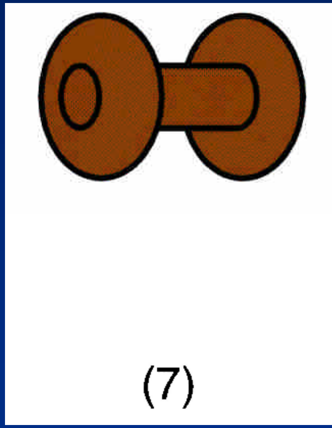


Figure 11.5 - Steps in shell-molding:

(6) two halves of the shell mold are assembled, supported by sand or metal shot in a box, and pouring is accomplished

(7) the finished casting with sprue removed

Advantages and Disadvantages of Shell Molding

- Advantages:
  - Smoother cavity surface permits easier flow of molten metal and better surface finish on casting
  - Good dimensional accuracy
  - Machining often not required
  - Mold collapsibility usually avoids cracks in casting
  - Can be mechanized for mass production
- Disadvantages:
  - More expensive metal pattern
  - Difficult to justify for small quantities

Vacuum Molding

Uses sand mold held together by vacuum pressure rather than by a chemical binder

- The term "vacuum" refers to mold making rather than casting operation itself
- Developed in Japan around 1970

Advantages and Disadvantages of Vacuum Molding

- Advantages:
  - Easy recovery of the sand, since binders not used
  - Sand does not require mechanical reconditioning normally done when binders are used
  - Since no water is mixed with sand, moisture-related defects are absent
- Disadvantages:
  - Slow process
  - Not readily adaptable to mechanization

Expanded Polystyrene Process

Uses a mold of sand packed around a polystyrene foam pattern which vaporizes when molten metal is poured into mold

- Other names: *lost-foam process*, *lost pattern process*, *evaporative-foam process*, and *full-mold process*
- Polystyrene foam pattern includes sprue, risers, gating system, and internal cores (if needed)
- Mold does not have to be opened into cope and drag sections

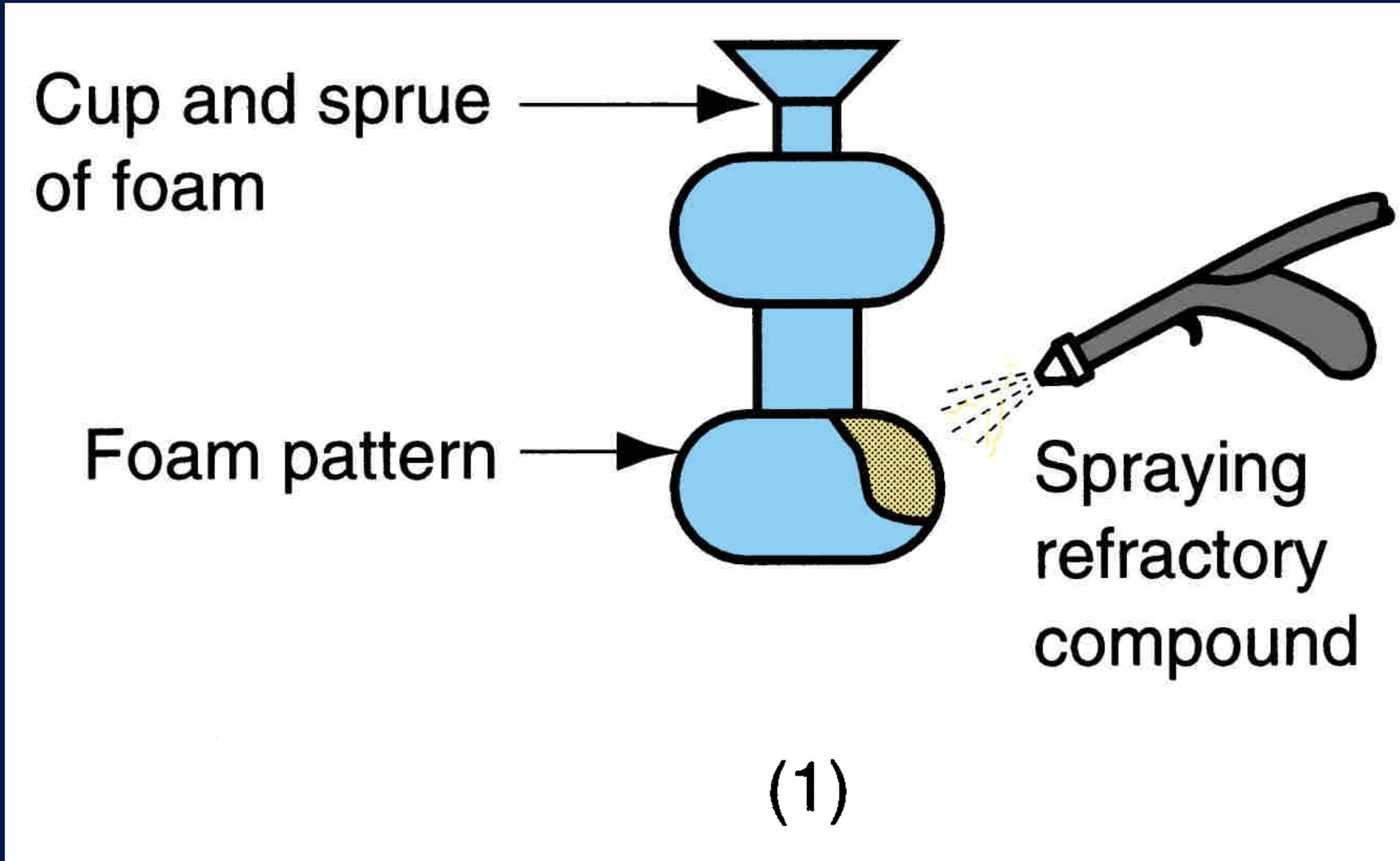


Figure 11.7 ‑ Expanded polystyrene casting process:
(1) pattern of polystyrene is coated with refractory compound

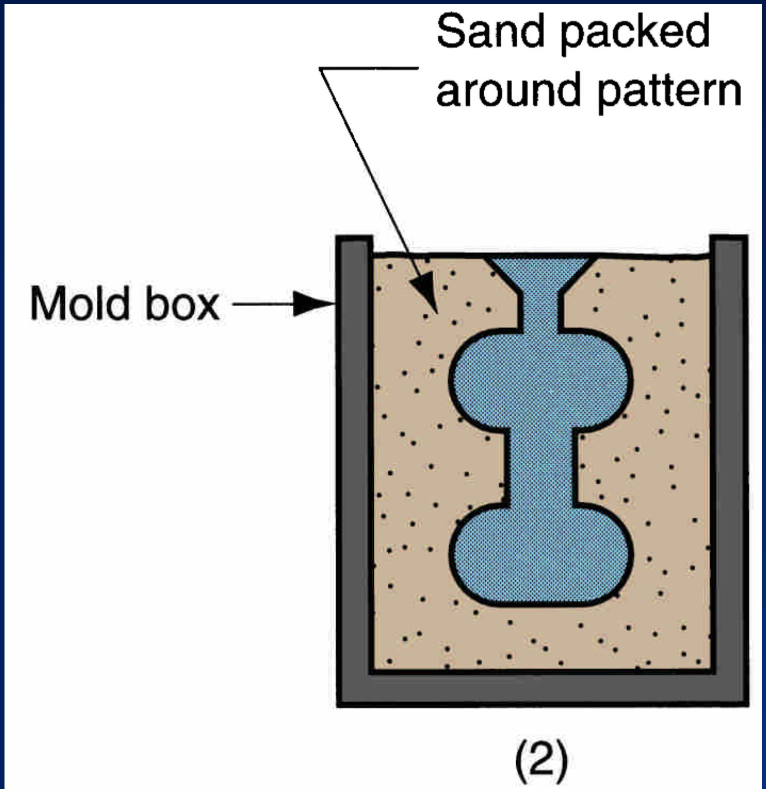


Figure 11.7 - Expanded polystyrene casting process: (2) foam pattern is placed in mold box, and sand is compacted around the pattern

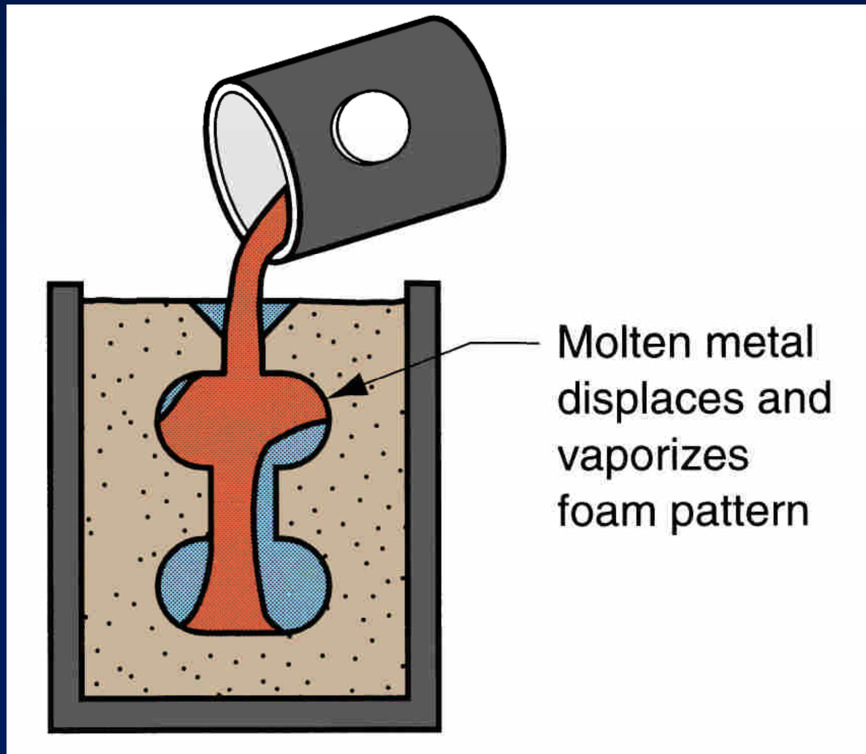


Figure 11.7 ‑ Expanded polystyrene casting process:

(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, thus allowing the resulting mold cavity to be filled.

Advantages and Disadvantages of Expanded Polystyrene Process

- Advantages:
  - Pattern need not be removed from the mold
  - Simplifies and expedites mold-making, since two mold halves (cope and drag) are not required as in a conventional green-sand mold
- Disadvantages:
  - A new pattern is needed for every casting
  - Economic justification of the process is highly dependent on cost of producing patterns

Applications of Expanded Polystyrene Process

- Mass production of castings for automobile engines
- Automated and integrated manufacturing systems are used to
  - Mold the polystyrene foam patterns and then
  - Feed them to the downstream casting operation

Investment Casting (Lost Wax Process)

A pattern made of wax is coated with a refractory material to make mold, after which wax is melted away prior to pouring molten metal

- "Investment" comes from one of the less familiar definitions of "invest" - "to cover completely," which refers to coating of refractory material around wax pattern
- It is a precision casting process - capable of castings of high accuracy and intricate detail

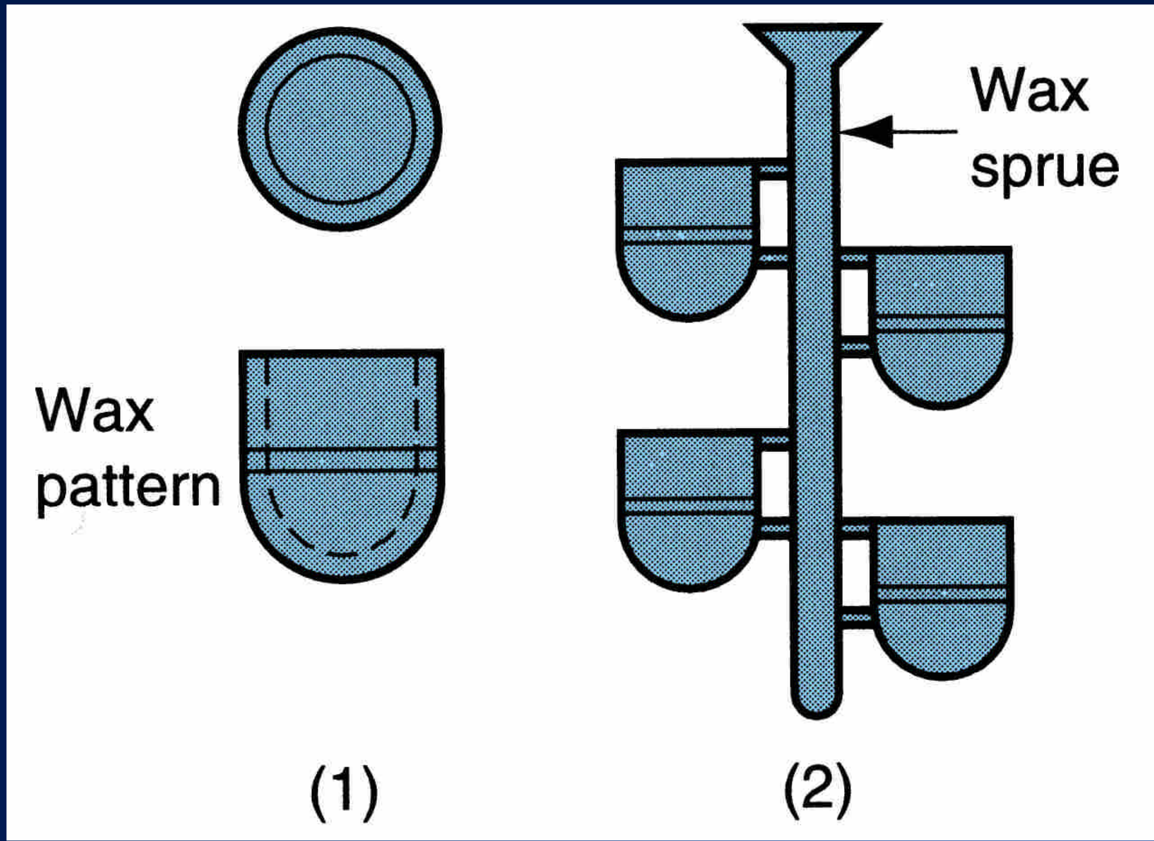


Figure 11.8 - Steps in investment casting:

(1) wax patterns are produced

(2) several patterns are attached to a sprue to form a pattern tree

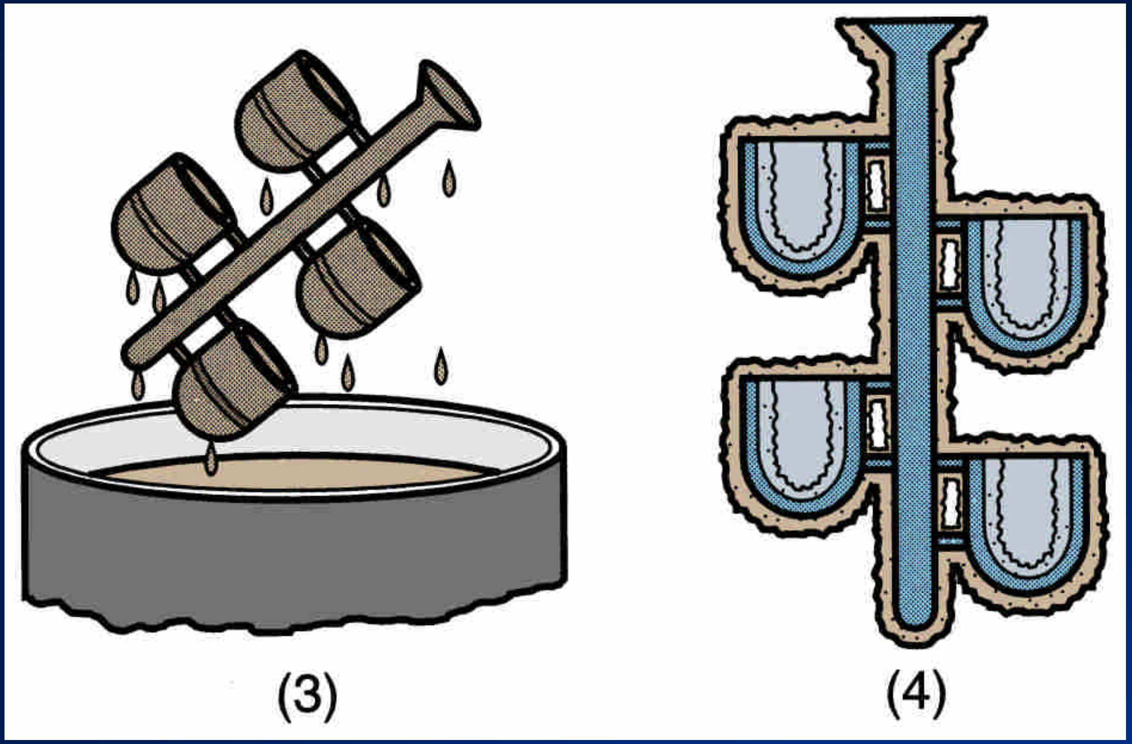


Figure 11.8 ‑ Steps in investment casting:

(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

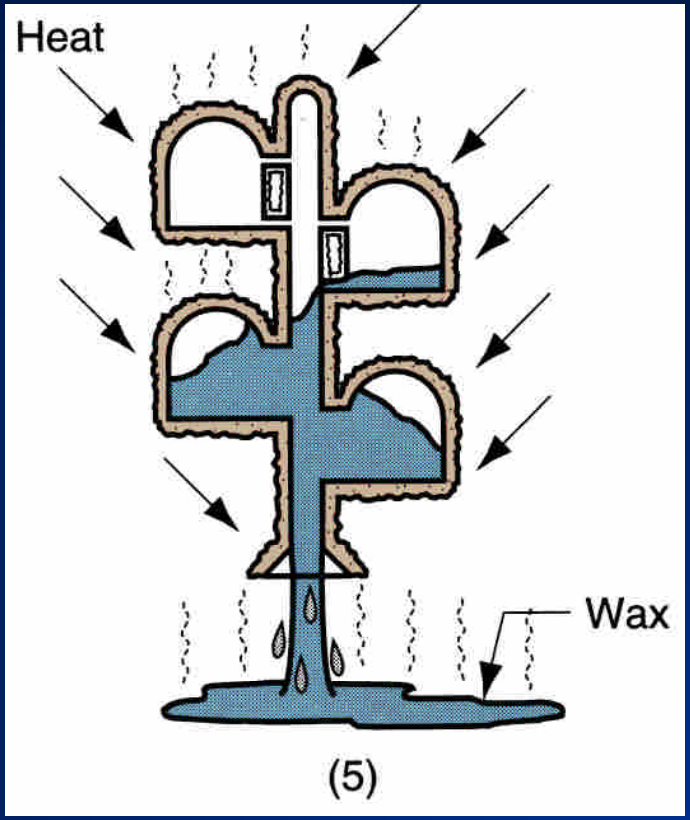


Figure 11.8 - Steps in investment casting:

(5) the mold is held in an inverted position and heated to melt the wax and permit it to drip out of the cavity

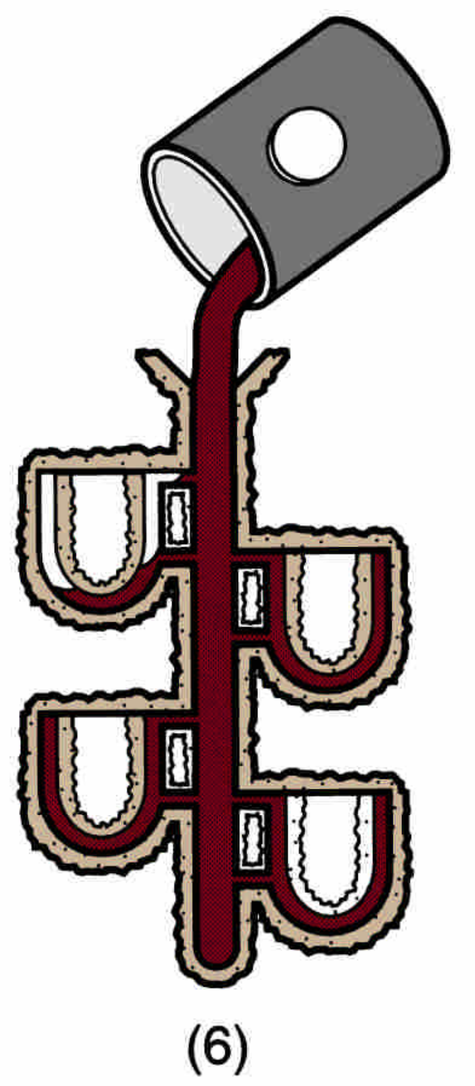


Figure 11.8 - Steps in investment casting:

(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

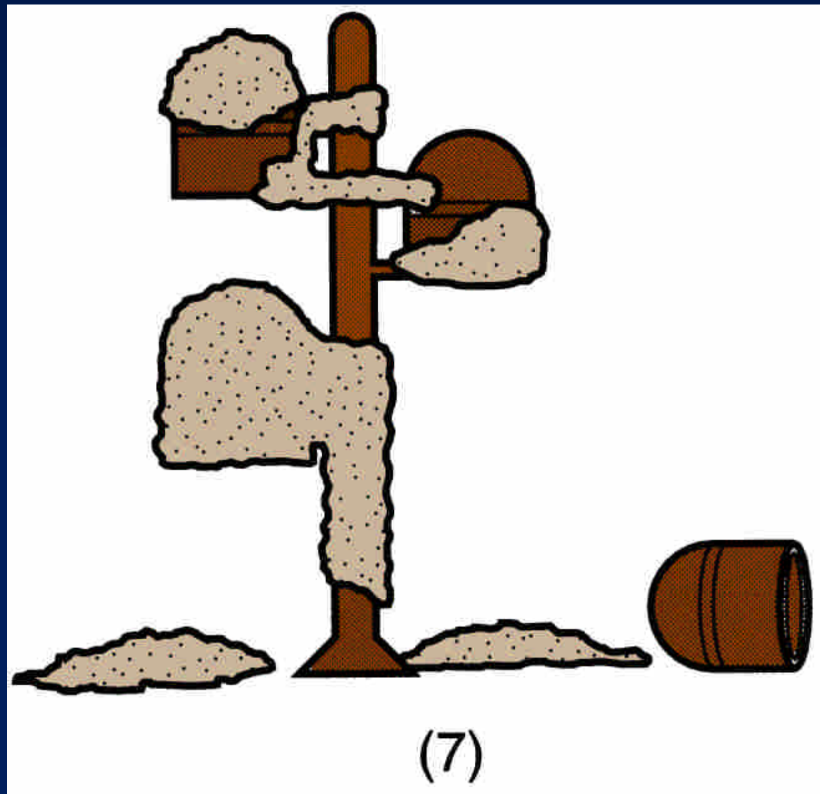


Figure 11.8 - Steps in investment casting:
(7) the mold is broken away from the finished casting - parts are separated from the sprue

Advantages and Disadvantages of Investment Casting

- Advantages:
  - Parts of great complexity and intricacy can be cast
  - Close dimensional control and good surface finish
  - Wax can usually be recovered for reuse
  - Additional machining is not normally required - this is a net shape process
- Disadvantages
  - Many processing steps are required
  - Relatively expensive process

Figure 11 9 - A one-piece compressor stator with 108 separate airfoils made by investment casting (courtesy Howmet Corp)

Plaster Mold Casting

Similar to sand casting except mold is made of plaster of Paris (gypsum - $CaSO_4$-$2H_2O$)

- In mold-making, plaster and water mixture is poured over plastic or metal pattern and allowed to set
  - Wood patterns not generally used due to extended contact with water
- Plaster mixture readily flows around pattern, capturing its fine details and good surface finish

Advantages and Disadvantages of Plaster Mold Casting

- Advantages:
  - Good dimensional accuracy and surface finish
  - Capability to make thin cross-sections in casting
- Disadvantages:
  - Moisture in plaster mold causes problems:
    - Mold must be baked to remove moisture
    - Mold strength is lost when is over-baked, yet moisture content can cause defects in product
  - Plaster molds cannot stand high temperatures, so limited to lower melting point alloys

Ceramic Mold Casting

Similar to plaster mold casting except that mold is made of refractory ceramic materials that can withstand higher temperatures than plaster

- Ceramic molding can be used to cast steels, cast irons, and other high-temperature alloys
- Applications similar to those of plaster mold casting except for the metals cast
- Advantages (good accuracy and finish) also similar

Permanent Mold Casting Processes

- Economic disadvantage of expendable mold casting: a new mold is required for every casting
- In permanent mold casting, the mold is reused many times
- The processes include:
  - Basic permanent mold casting
  - Die casting
  - Centrifugal casting

The Basic Permanent Mold Process

Uses a metal mold constructed of two sections designed for easy, precise opening and closing

- 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

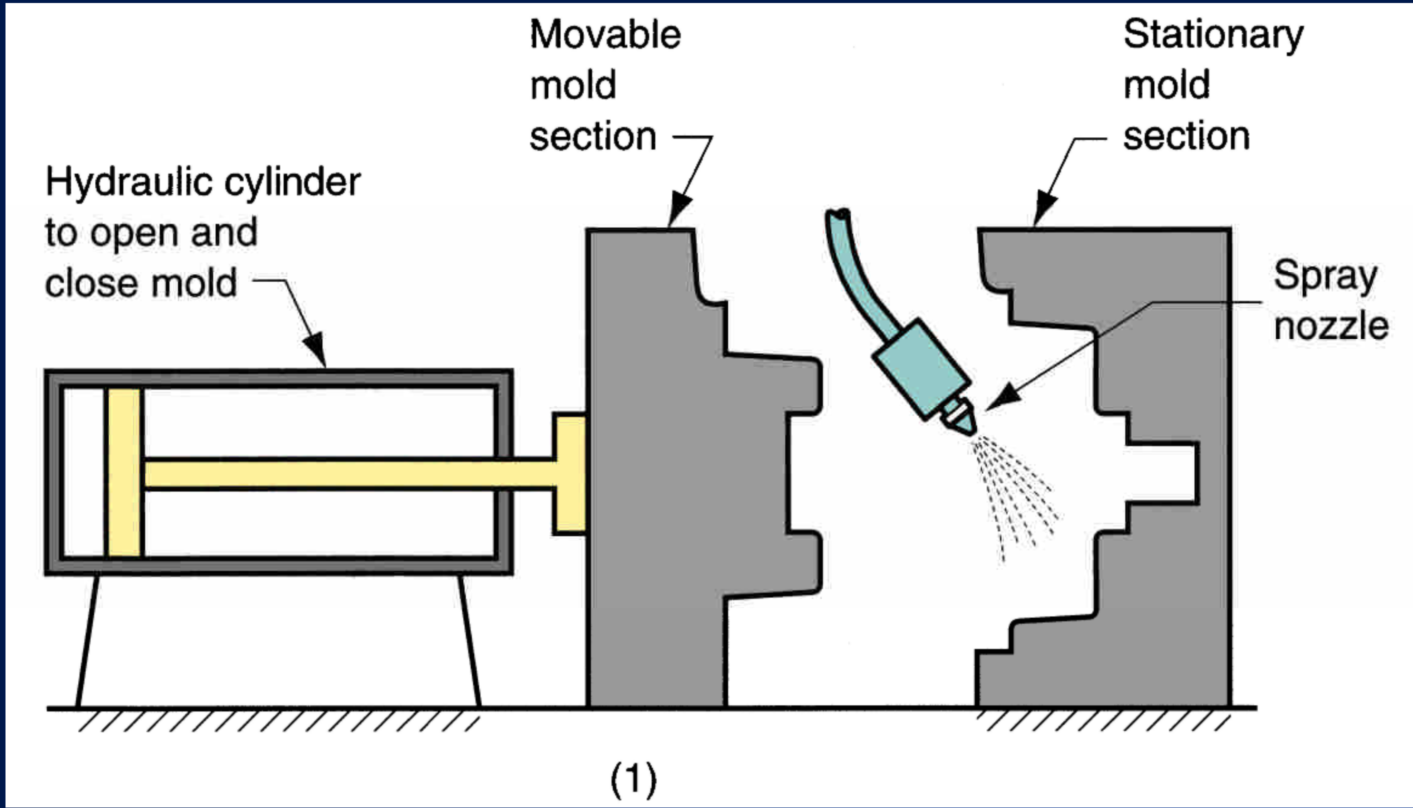


Figure 11.10 - Steps in permanent mold casting:
(1) mold is preheated and coated

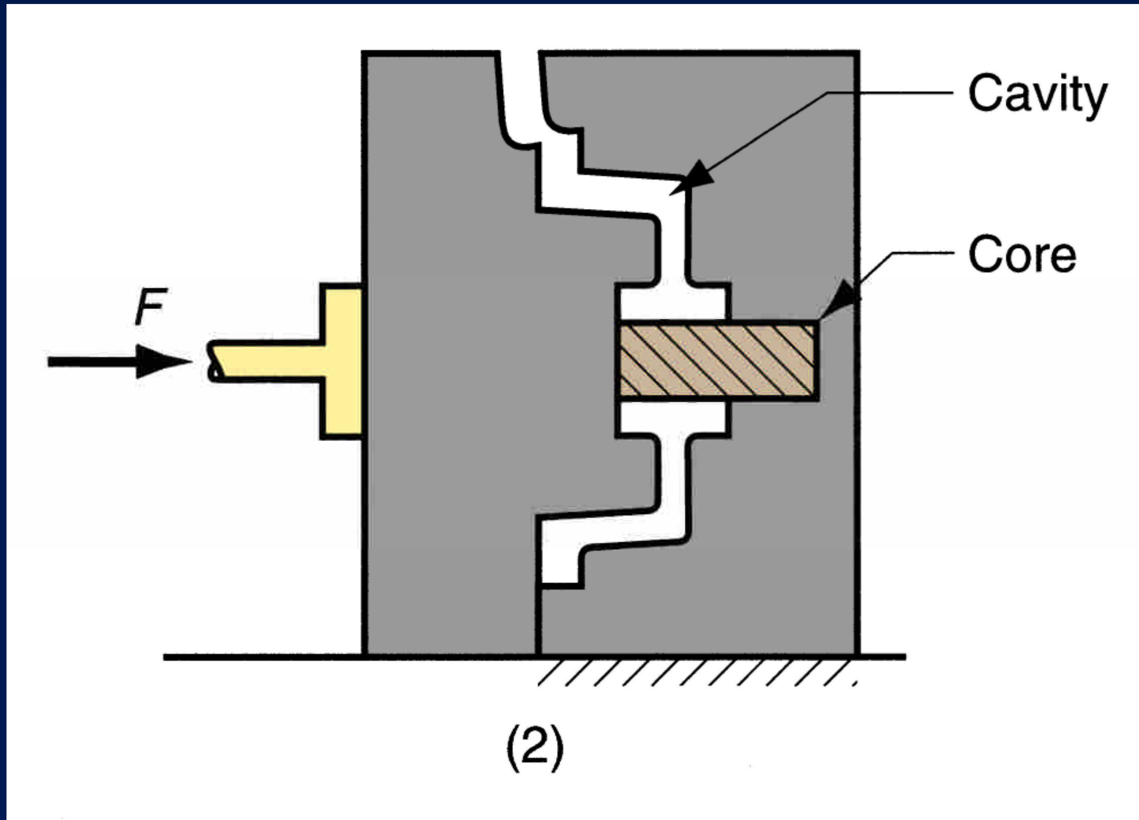


Figure 11.10 - Steps in permanent mold casting:
(2) cores (if used) are inserted and mold is closed

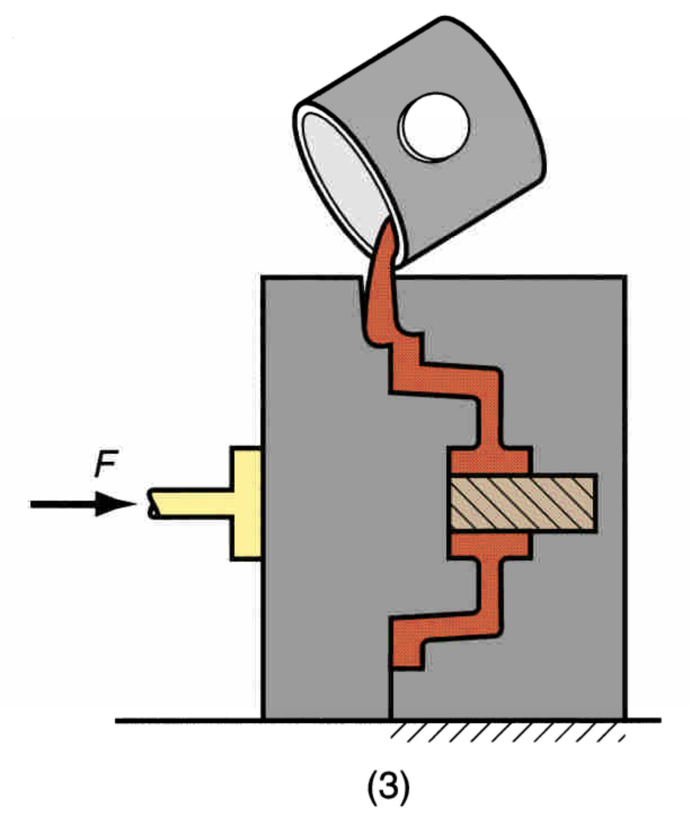


Figure 11.10 - Steps in permanent mold casting:

(3) molten metal is poured into the mold

Advantages and Limitations of Permanent Mold Casting

- Advantages:
  - Good dimensional control and surface finish
  - More rapid solidification caused by the cold metal mold results in a finer grain structure, so stronger castings are produced
- Limitations:
  - Generally limited to metals of lower melting point
  - Simple part geometries compared to sand casting because of the need to open the mold
  - High cost of mold

Applications of Permanent Mold Casting

- Due to high mold cost, 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

Die Casting

A permanent mold casting process in which molten metal is injected into mold cavity under high pressure

- Pressure is maintained during solidification, then mold is opened and part is removed
- Molds in this casting operation are called *dies*; hence the name die casting
- Use of high pressure to force metal into die cavity is what distinguishes this from other permanent mold processes

Die Casting Machines

- Designed to hold and accurately close two mold halves and keep them closed while liquid metal is forced into cavity
- Two main types:
  1. Hot-chamber machine
  2. Cold-chamber machine

Hot-Chamber Die Casting

Metal is melted in a container, and a piston injects liquid metal under high pressure into the die

- High production rates - 500 parts per hour not uncommon
- Applications limited to low melting-point metals that do not chemically attack plunger and other mechanical components
- Casting metals: zinc, tin, lead, and magnesium

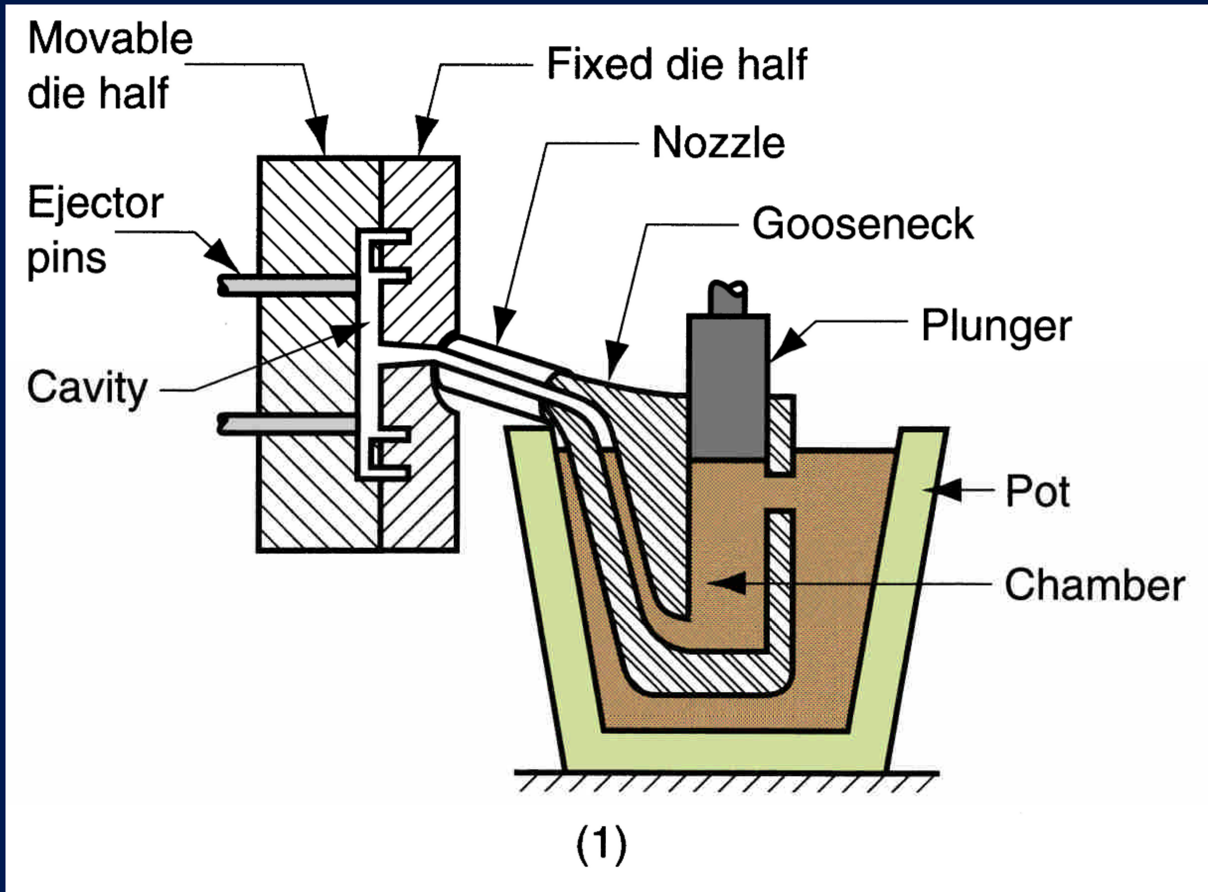


Figure 11.13 - Cycle in hot-chamber casting:

(1) with die closed and plunger withdrawn, molten metal flows into the chamber

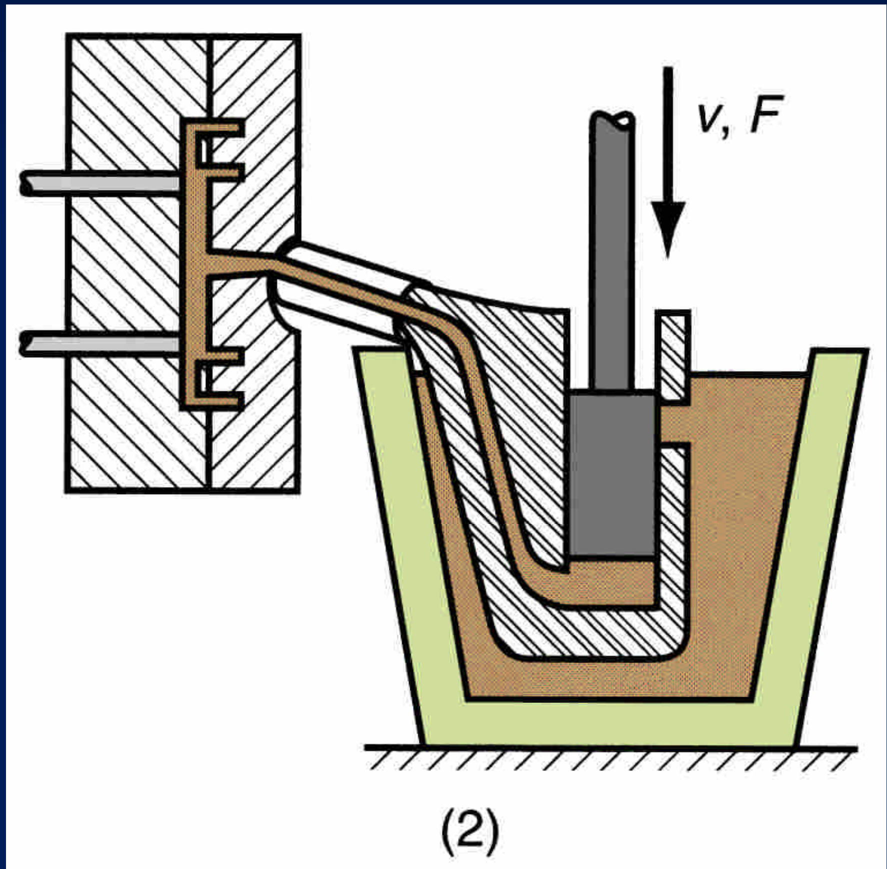


Figure 11.13 - Cycle in hot-chamber casting:

(2) plunger forces metal in chamber to flow into die, maintaining pressure during cooling and solidification

Cold-Chamber Die Casting Machine

Molten metal is poured into unheated chamber from external melting container, and a piston injects metal under high pressure into die cavity

- 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)

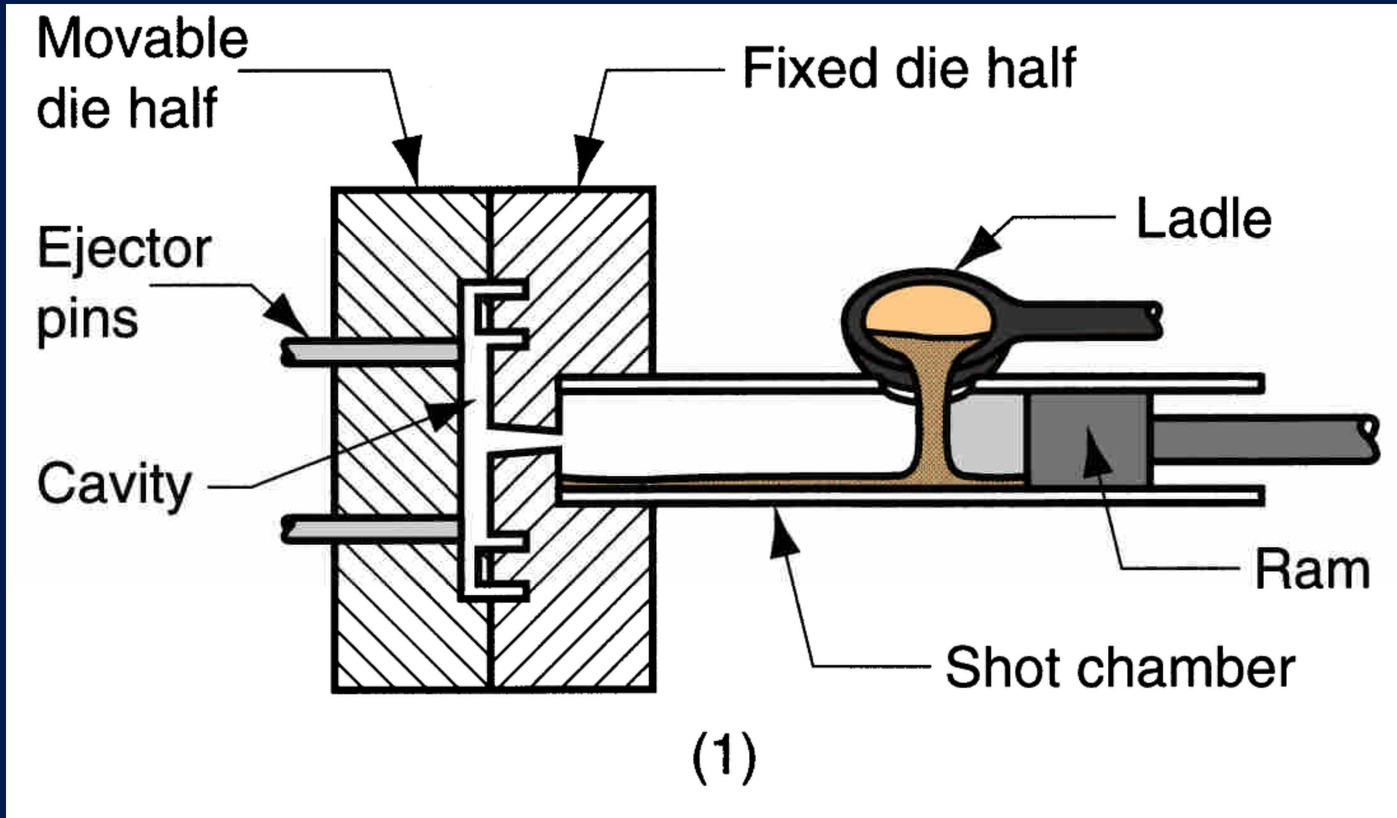


Figure 11.14 - Cycle in cold-chamber casting:
(1) with die closed and ram withdrawn, molten metal is poured into the chamber

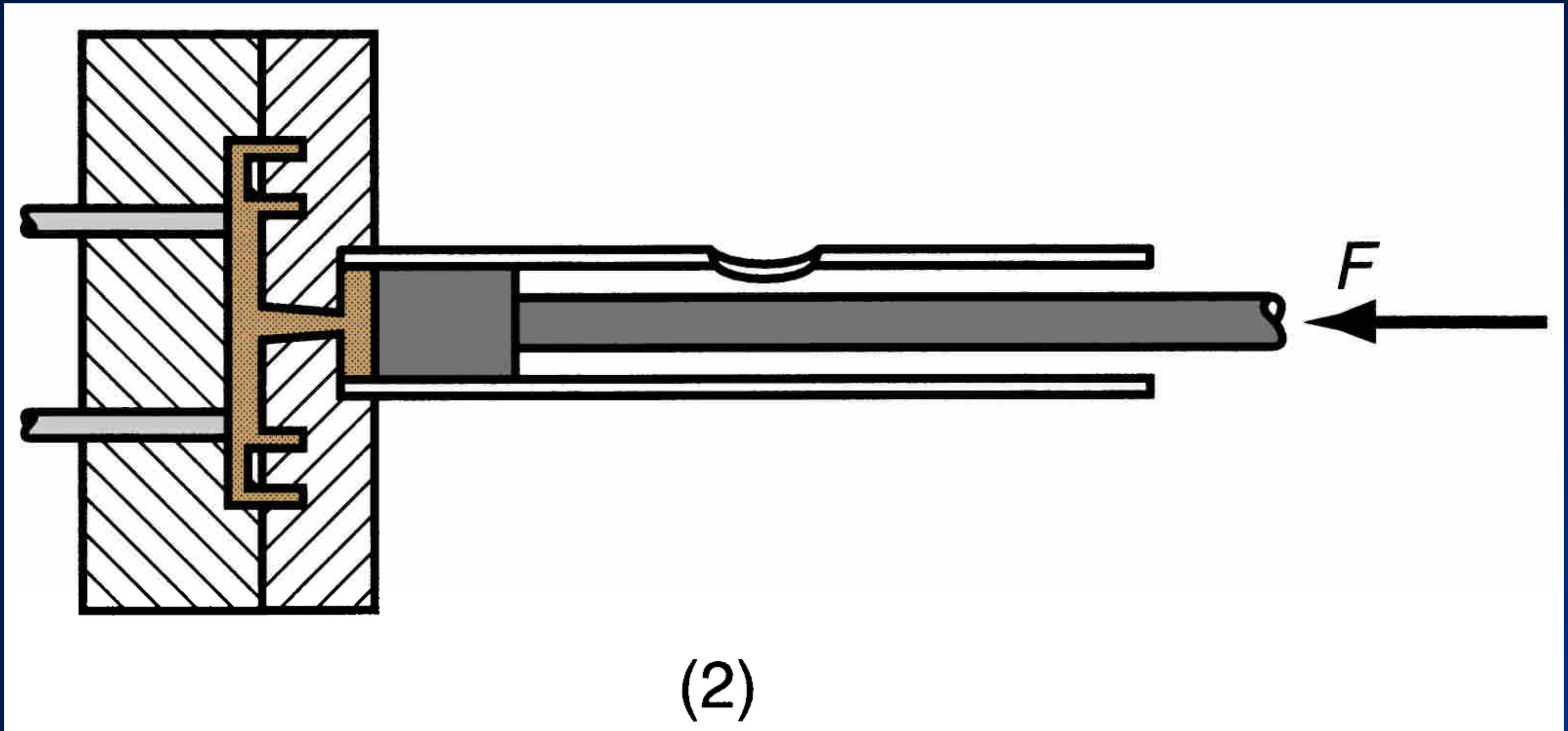


Figure 11.14 - Cycle in cold-chamber casting:

(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
- 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 and Limitations of Die Casting

- Advantages:
  - Economical for large production quantities
  - Good dimensional 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 cavity

Centrifugal Casting

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

- The group includes:
  - True centrifugal casting
  - Semicentrifugal casting
  - Centrifuge casting

True Centrifugal Casting

Molten metal is poured into rotating mold to produce a tubular part

- In some operations, mold rotation commences after pouring rather than before
- Parts: pipes, tubes, bushings, and rings
- Outside shape of casting can be round, octagonal, hexagonal, etc , but inside shape is (theoretically) perfectly round, due to radially symmetric forces

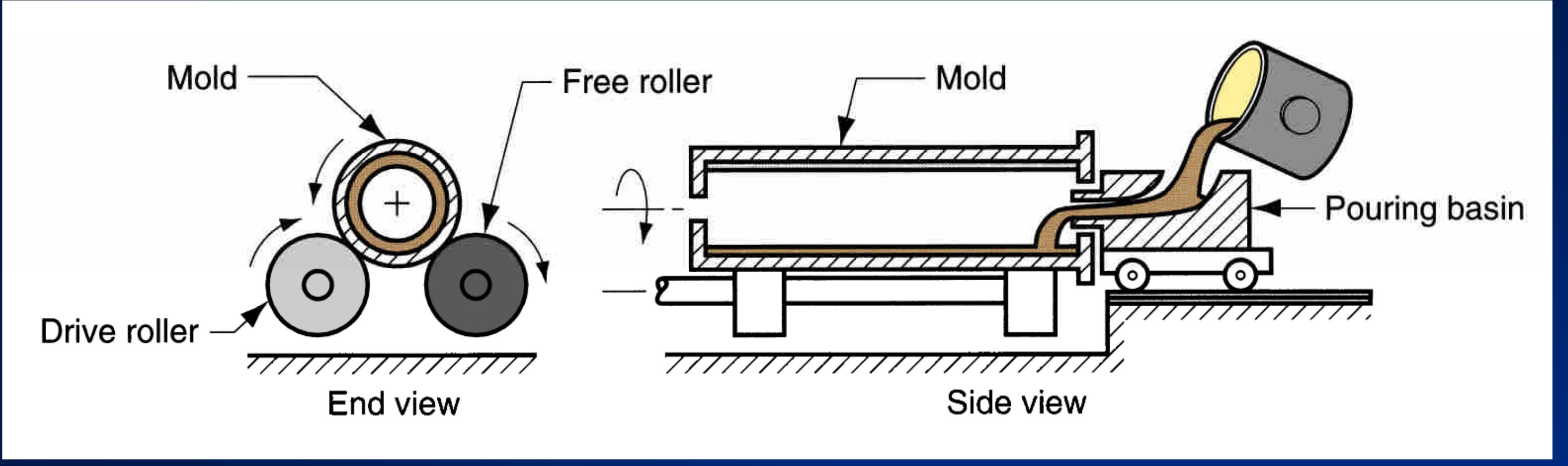


Figure 11.15 - Setup for true centrifugal casting

Semicentrifugal Casting

Centrifugal force is used to produce solid castings rather than tubular parts

- 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
- Often used on parts in which center of casting is machined away, thus eliminating the portion where quality is lowest
- Examples: wheels and pulleys

Centrifuge Casting

- Mold is designed with part cavities located away from axis of rotation, so that molten metal poured into mold is distributed to these cavities by centrifugal force
- Used for smaller parts
- Radial symmetry of part is not required as in other centrifugal casting methods

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

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

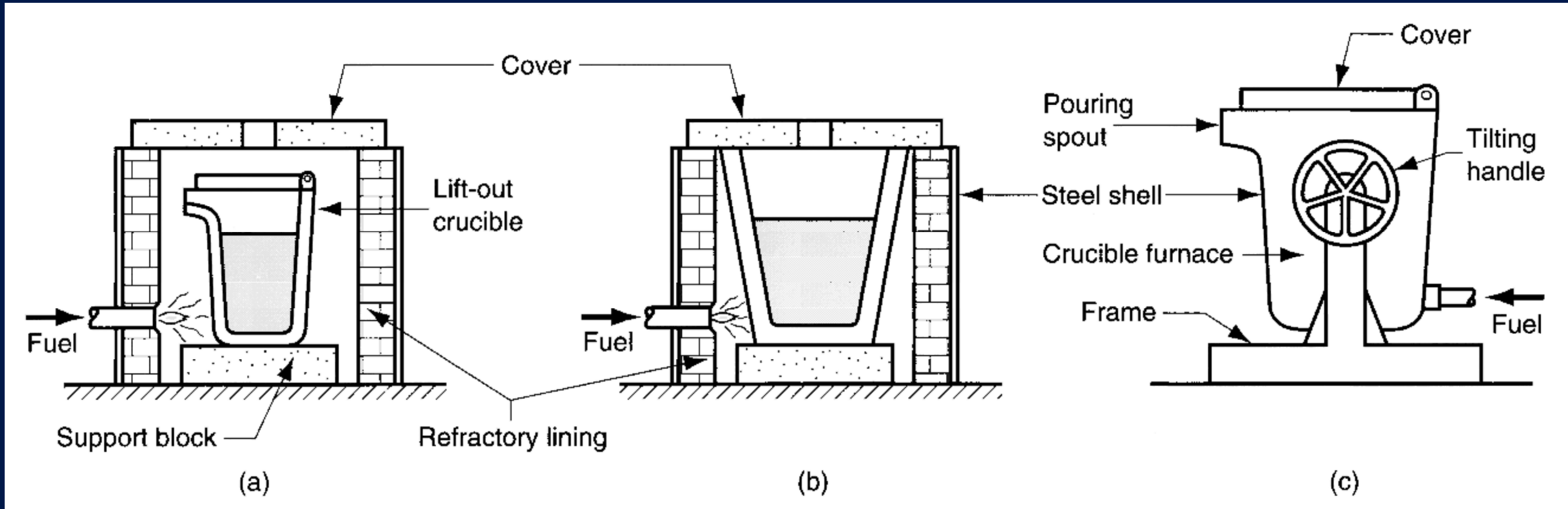


Figure 11.19 - Three types of crucible furnaces:

(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

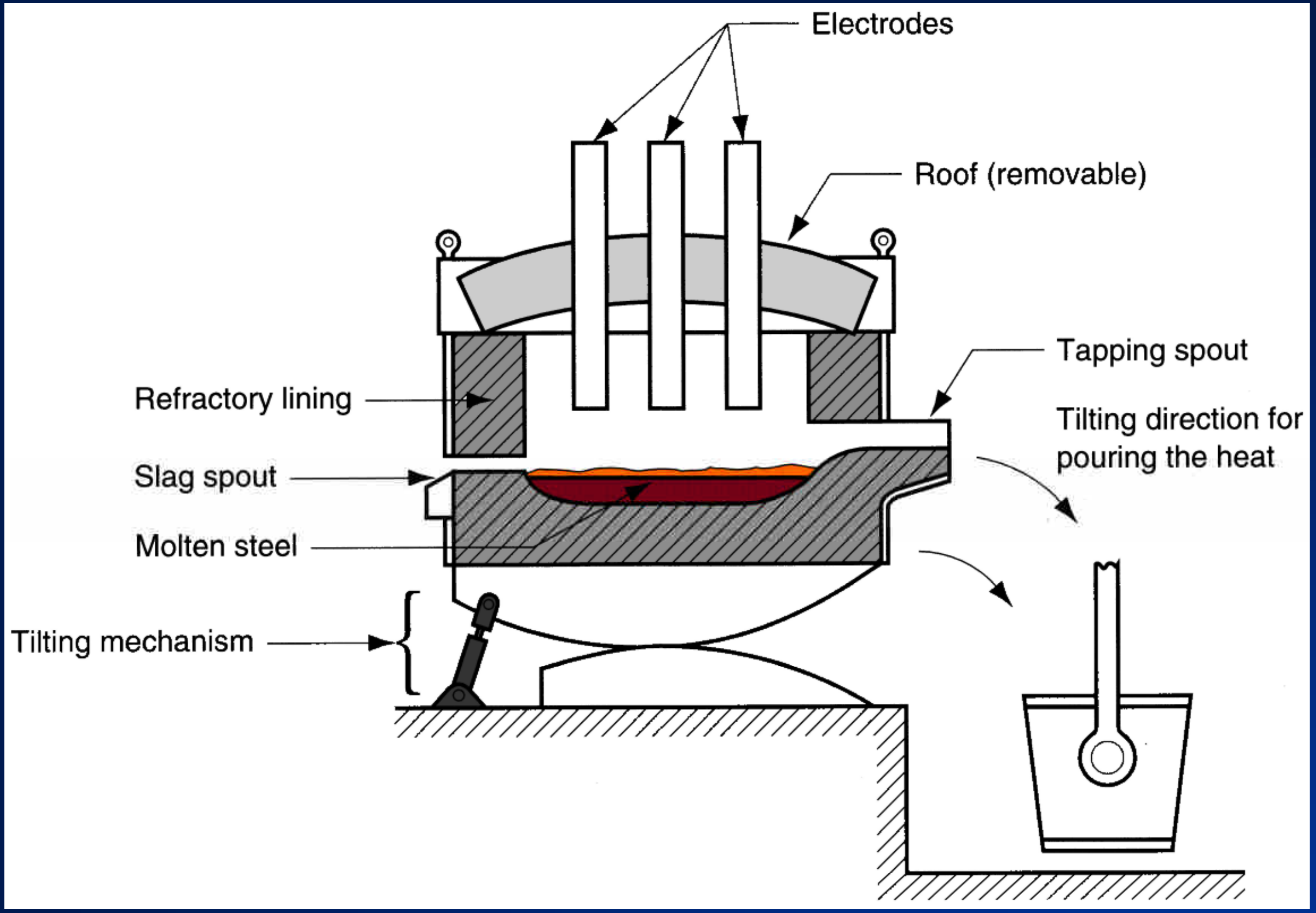


Figure 6.9 - Electric arc furnace for steelmaking

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

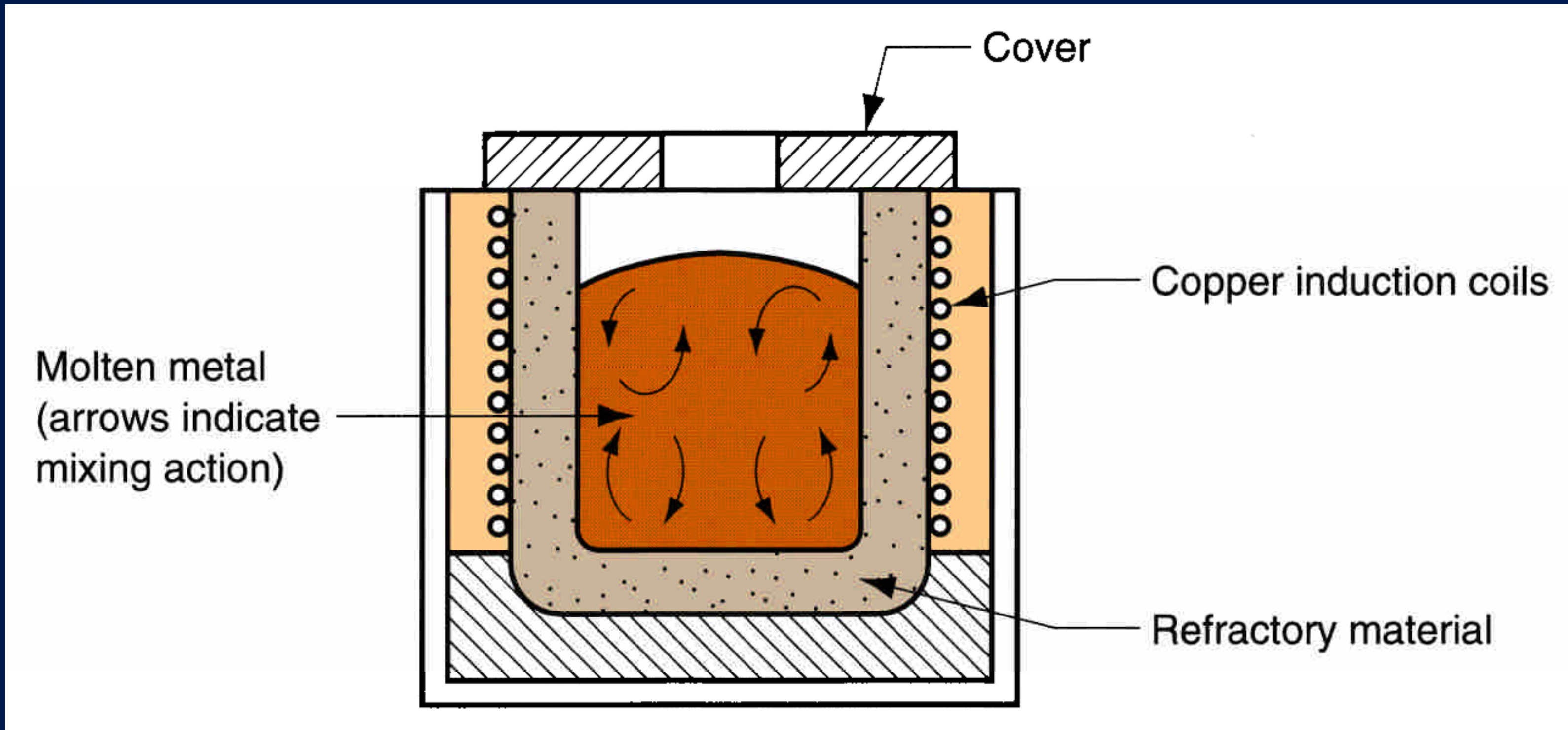


Figure 11.20 - Induction furnace

Ladles

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

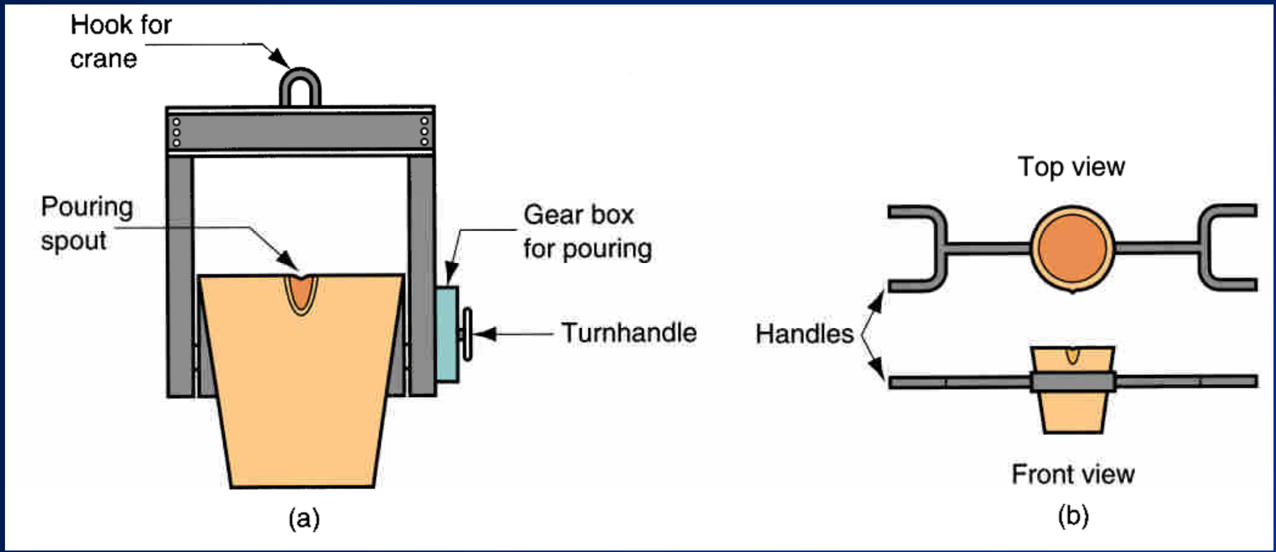


Figure 11.21 ‑ Two common types of ladles: (a) crane ladle, and (b) two‑man ladle

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

Misrun

A casting that has solidified before completely filling mold cavity

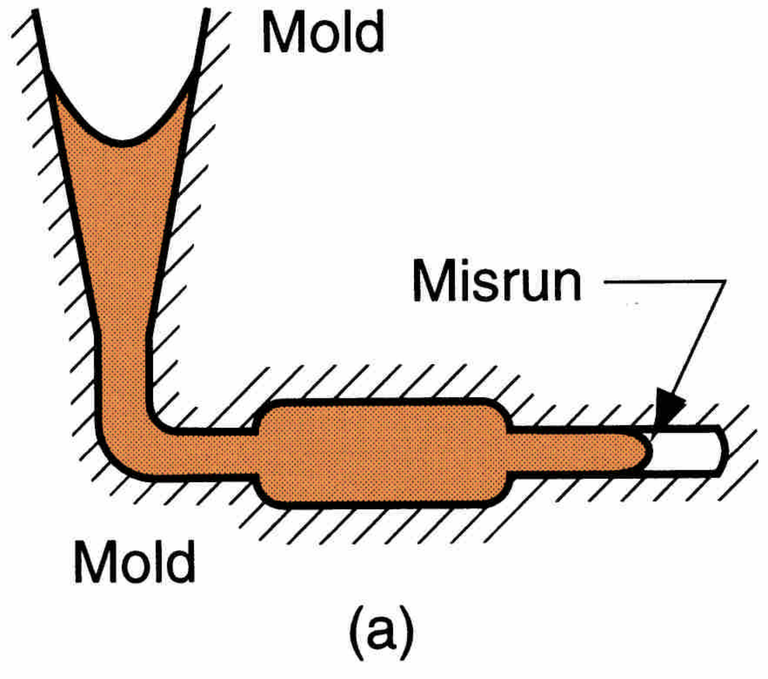


Figure 11.22 - Some common defects in castings: (a) misrun

Cold Shut

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

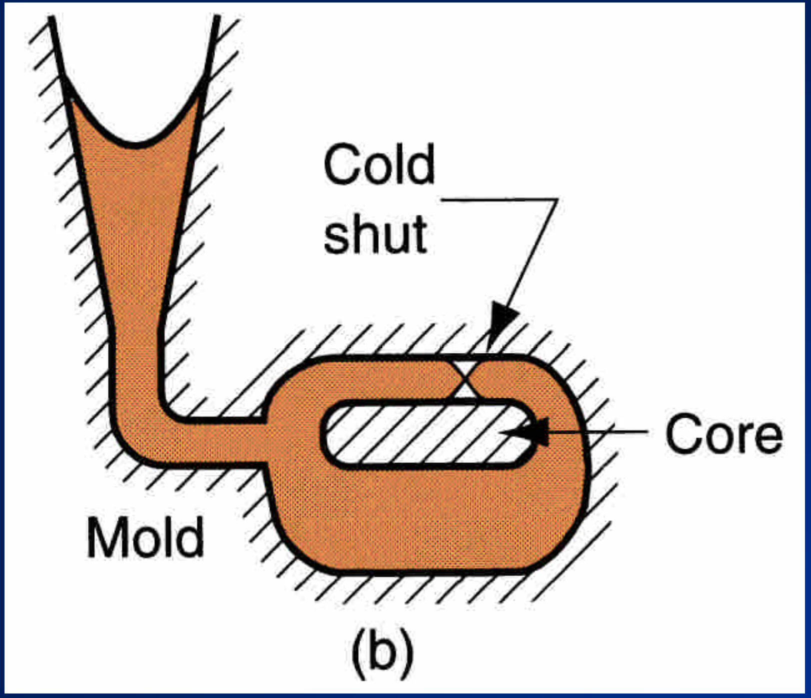


Figure 11.22 - Some common defects in castings: (b) cold shut

Cold Shot

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

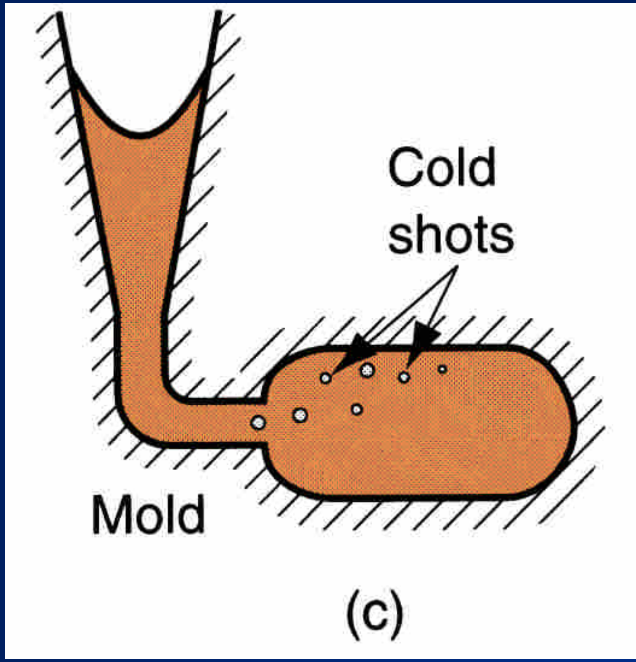


Figure 11.22 - Some common defects in castings: (c) cold shot

Shrinkage Cavity

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

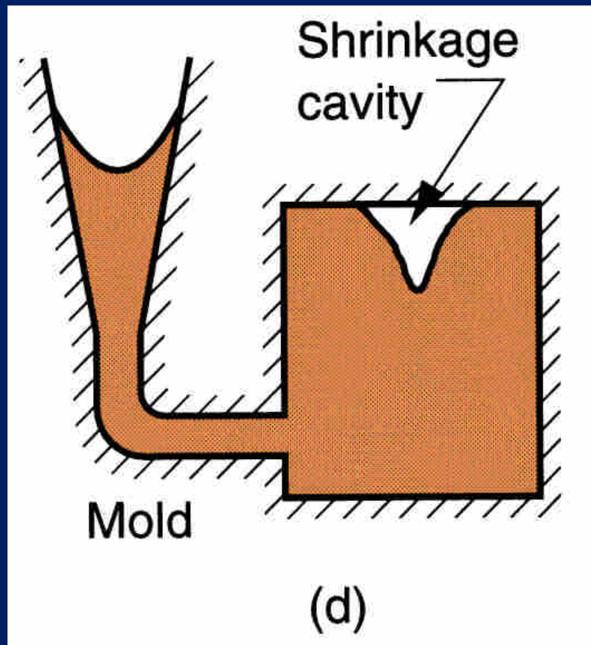


Figure 11.22 - Some common defects in castings: (d) shrinkage cavity

Sand Blow

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

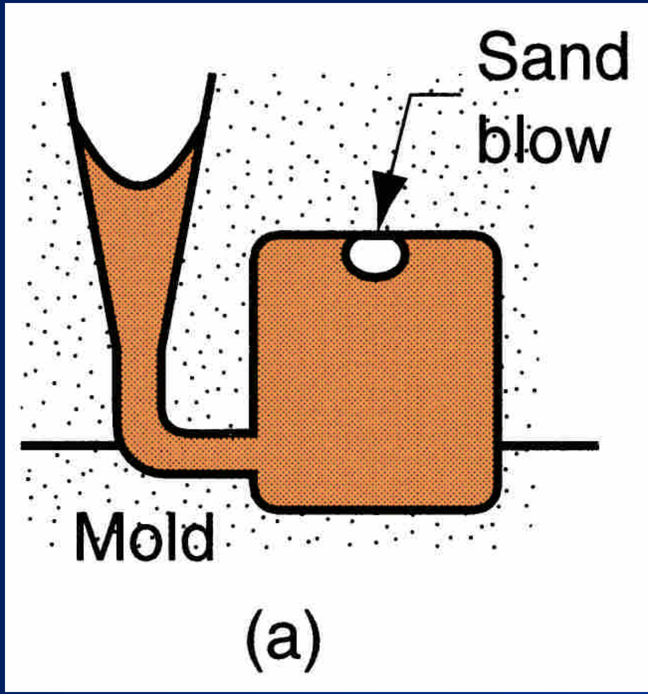


Figure 11.23 - Common defects in sand castings: (a) sand blow

Pin Holes

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

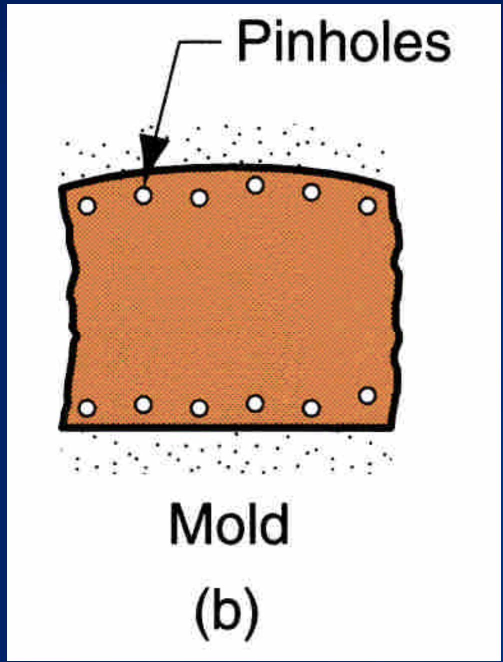


Figure 11.23 - Common defects in sand castings: (b) pin holes

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

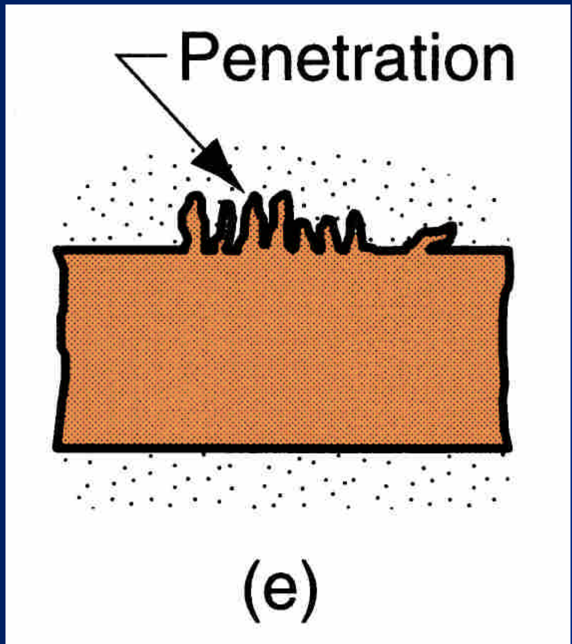


Figure 11.23 - Common defects in sand castings: (e) penetration

Mold Shift

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

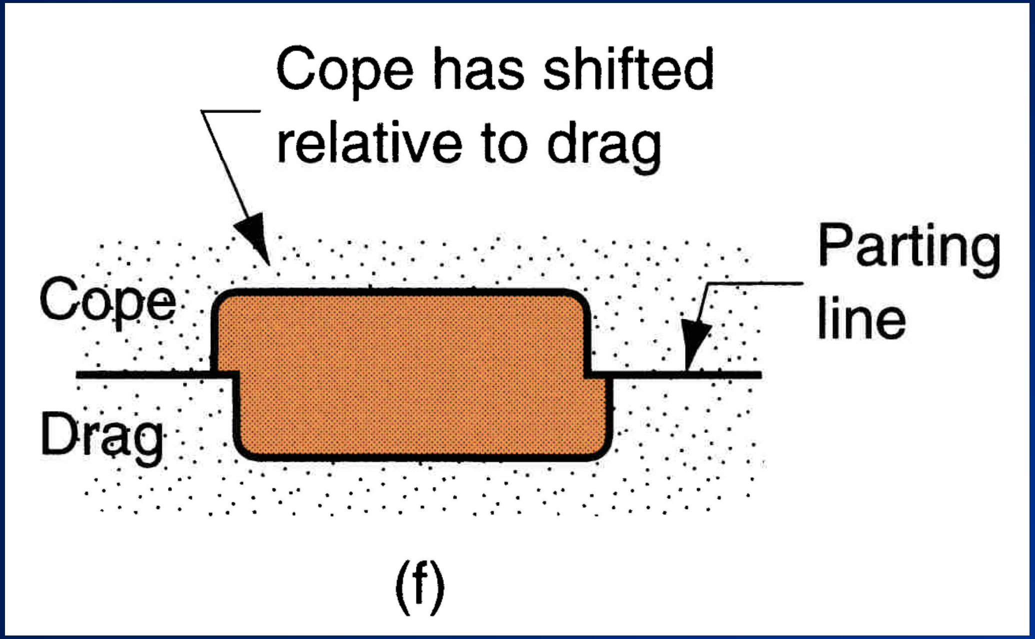


Figure 11.23 - Common defects in sand castings: (f) mold shift

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

Metals for Casting

- Most commercial castings are made of alloys rather than pure metals
  - Alloys are generally easier to cast, and properties of product are better
- Casting alloys can be classified as:
  - Ferrous
  - Nonferrous

Ferrous Casting Alloys: Cast Iron

- Most important of all casting alloys
- Tonnage of cast iron castings is several times that of all other metals combined
- Several types: (1) gray cast iron, (2) nodular iron, (3) white cast iron, (4) malleable iron, and (5) alloy cast irons
- Typical pouring temperatures ~ 1400°C (2500°F), depending on composition

Ferrous Casting Alloys: Steel

- The mechanical properties of steel make it an attractive engineering material
- The capability to create complex geometries makes casting an attractive shaping process
- Difficulties faced by the foundry working with steel:
  - Pouring temperature of steel is higher than for most other casting metals ~ 1650°C (3000°F)
  - At these temperatures, steel readily oxidizes, so molten metal must be isolated from air
  - Molten steel has relatively poor fluidity

Nonferrous Casting Alloys: Aluminum

- Generally considered to be very castable
- Pouring temperatures low – melting temperature of aluminum T_m = 660°C (1220°F)
- Properties:
  - Light weight
  - Range of strength properties by heat treatment
  - Ease of machining

Nonferrous Casting Alloys: Copper Alloys

- Includes bronze, brass, and aluminum bronze
- Properties:
  - Corrosion resistance
  - Attractive appearance
  - Good bearing qualities
- Limitation: high cost of copper
- Applications: pipe fittings, marine propeller blades, pump components, ornamental jewelry

Nonferrous Casting Alloys: Zinc Alloys

- Highly castable, commonly used in die casting
- Low melting point – melting point of zinc T_m = 419°C (786°F)
- Good fluidity for ease of casting
- Properties:
  - Low creep strength, so castings cannot be subjected to prolonged high stresses

Product Design Considerations: Geometric Simplicity

- Although casting can be used to produce complex part geometries, simplifying the part design will improve castability
- Avoiding unnecessary complexities:
  - Simplifies mold-making
  - Reduces the need for cores
  - Improves the strength of the casting

Product Design Considerations: Corners

- Sharp corners and angles should be avoided, since they are sources of stress concentrations and may cause hot tearing and cracks
- Generous fillets should be designed on inside corners and sharp edges should be blended

Product Design Considerations: Draft Guidelines

- In expendable mold casting, purpose of draft is to facilitate removal of pattern from mold (1° for sand casting)
- In permanent mold casting, purpose is to aid in removal of the part from the mold (2° to 3° for permanent mold processes)
- Similar tapers should be allowed if solid cores are used

- Minor changes in part design can reduce need for coring

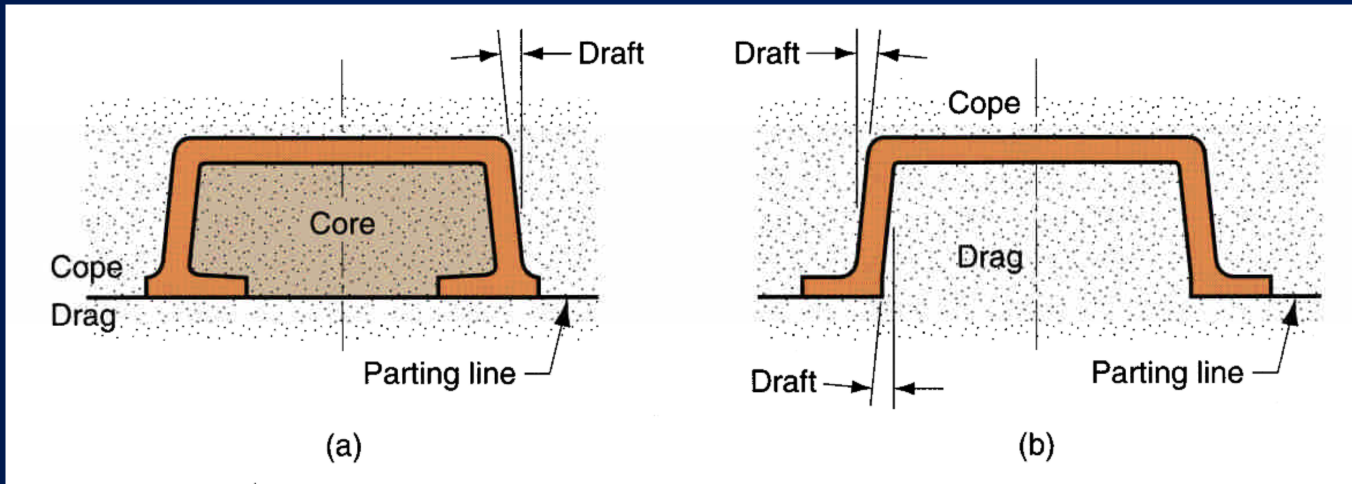


Figure 11.25 – Design change to eliminate the need for using a core: (a) original design, and (b) redesign

Product Design Considerations: Dimensional Tolerances and Surface Finish

Significant differences in dimensional accuracies and finishes can be achieved in castings, depending on process:

- Poor dimensional accuracies and finish for sand casting
- Good dimensional accuracies and finish for die casting and investment casting

Product Design Considerations: Machining Allowances

- Almost all sand castings must be machined to achieve the required dimensions and part features
- Additional material, called the *machining allowance*, must be left on the casting in those surfaces where machining is necessary
- Typical machining allowances for sand castings are around 1.5 and 3 mm (1/16 and 1/4 in)