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

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

(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
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

Plaster Mold Casting

Similar to sand casting except mold is made of plaster of Paris (gypsum - CaSO₄·2H₂O)

• 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 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
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
Molds for Die Casting

- Usually made of tool steel, or mold 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 melting 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
(a) Semicentrifugal Casting  
(b) Centrifuge Casting

(a) Crystal Pulling  
(b) Floating-zone Method
Melt Spinning