CHAPTER 11

Metal-Casting Processes and Equipment
11.40: the Blank for the spool ..... 
11.42: In sand casting, it is important that the cope-mold half ....
There will be a quiz on immediately after the submission of the homework
Major Categories of Casting Processes

1. Expendable molds
   - made of sand, plaster, ceramics, and similar materials.
   - are generally mixed with various binders, or bonding agents.
   - These materials are refractory.
   - After the casting has solidified, the mold in these processes is broken up to remove the casting.

2. Permanent molds, made of metals that maintain their strength at high temperatures.

3. Composite molds
   - made of two or more different materials, such as sand, graphite, and metal, combining the advantages of each material.
   - are used in various casting processes to improve mold strength, control the cooling rates, and optimize the overall economics of the process.
   - Table 11.1: Summary of casting processes
   - Table 11.2: General Characteristics of Casting Processes
Expendable-mold, Permanent Casting Processes – Sand Casting

- Sand casting consists of:
  - Placing a pattern having the shape of the desired casting in sand to make an imprint
  - A gating system
  - Filling the resulting cavity with molten metal
  - Allowing the metal to cool until it solidifies
  - Breaking away the sand mold
  - Removing the casting (Fig. 11.4).
Expendable-mold, Permanent Casting Processes – Sand Casting-Figure 11.4

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Expendable-mold, Permanent Casting Processes – Sand Casting, Sands

- Silica sand (SiO$_2$)
- Two general types of sand:
  1. naturally bonded (bank sand)
  2. synthetic (lake sand)
- Several factors affect the selection of sand for molds.
  - Sand having fine, round grains can be closely packed and forms a smooth mold surface.
  - Although fine-grained sand enhances mold strength, the fine grains also lower mold permeability.
  - Good permeability of molds and cores allows gases and steam evolved during casting to escape easily.
  - The mold should have good collapsibility (to allow for the casting to shrink while cooling to avoid defects in the casting, such as hot tearing and cracking.)
Expendable-mold, Permanent Casting Processes – Sand Casting, Sands

- Mulling machines are used to uniformly and thoroughly mix sand with additives.

- Clay (bentonite) is used as a cohesive agent to bond sand particles, giving the sand strength.

- Zircon (ZrSiO$_4$), Olivine (Mg$_2$SiO$_4$), and Iron Silicate (Fe$_2$SiO$_4$) sands are often used in steel foundries for their low thermal expansion.

- Chromite (FeCr$_2$O$_4$) is used for its high heat-transfer characteristics.
Expendable-mold, Permanent Casting Processes – Sand Casting, Types of Sand Molds

1. Green-sand
2. Cold-box
3. No-bake molds
Green molding sand:
- is a mixture of sand, clay, and water.
  - least expensive method of making molds
  - In the skin-dried method, the mold surfaces are dried, either by storing the mold in air or by using torches.
  - Sand molds are also oven dried prior to pouring the molten metal, they are stronger than green-sand molds and impart better dimensional accuracy and surface finish to the casting. However, distortion of the mold is greater; the castings are more susceptible to hot treating because of the lower collapsibility of the mold; and the production rate is slower because of the drying time required.
2. Cold-box Mold Process

- Various organic and inorganic binders are blended into the sand to bond the grains chemically for greater strength.
- These molds are dimensionally more accurate than green-sand molds but are more expensive.

2. The No-bake Mold Process

- A synthetic liquid resin is mixed with the sand; the mixture hardens at room temperature
Expendable-mold, Permanent Casting Processes – Sand Casting

Major components of sand molds:

1. The mold itself, which is supported by a flask. Two-piece molds consist of a cope on top and a drag on bottom
2. A pouring basin or cup
3. A sprue
4. The runner system
5. Risers
6. Cores
7. Vents
Expendable-mold, Permanent Casting Processes – Sand Casting

- Figure 11.5: Outline of production steps in a typical sand-casting operation.
Expendable-mold, Permanent Casting Processes – Sand Casting - Patterns

- May be made of wood, plastic, or metal.
- Patterns are usually coated with a parting agent to facilitate their removal from the molds.

1. One-piece patterns:
   - used for simple shapes and low-quantity production.
   - are generally made of wood and are inexpensive.
Expendable-mold, Permanent Casting Processes – Sand Casting - Patterns

2. Split patterns:
   - Two-piece patterns made such that each part forms a portion of the cavity for the casting.
Expendable-mold, Permanent Casting Processes – Sand Casting - Patterns

3. Match-plate patterns:

- Two-piece patterns are constructed by securing each half of one or more split patterns to the opposite sides of a single plate.
- The gating system can be mounted on the drag side of the pattern.
Expendable-mold, Permanent Casting Processes – Sand Casting - Patterns

The design should provide for metal shrinkage, ease of removal from the sand by means of a taper or draft (Fig. 11.7), and proper metal flow in the mold cavity.
Expendable-mold, Permanent Casting Processes – Sand Casting - Cores

- The core is anchored by core prints, which support the core and provide vents for the escape of gases.
- Chaplets
- Figure 11.8 Examples of sand cores showing core prints and chaplets to support cores.
Expendable-mold, Permanent Casting Processes – Sand Casting - Molding Machines

- The flask, molding sand, and pattern are first placed on a pattern plate mounted on an anvil, and then jolted upward by air pressure at rapid intervals.
- The inertial forces compact the sand around the pattern.
- Jolting produces the highest compaction at the horizontal parting line.
- In squeezing, compaction is highest at the squeezing head.
- Thus, more uniform compaction can be obtained by combining squeezing and jolting.
Expendable-mold, Permanent Casting Processes – Sand Casting - Molding Machines

Figure 11.9 Various designs of squeeze heads for mold making:

- a) Conventional
- b) profile head
- c) equalizing squeeze pistons
- d) Flexible diaphragm
Expendable-mold, Permanent Casting Processes – Sand Casting - Molding Machines

Impact molding

- The sand is compacted by controlled explosion or instantaneous release of compressed gases.
- This method produces molds with uniform strength and good permeability.
Expendable-mold, Permanent Casting Processes – Sand Casting - Vertical Flaskless Molding

• The halves of the pattern form a vertical chamber wall against which sand is blown and compacted (Fig. 11.10).
• Then, the mold halves are packed horizontally, with the parting line oriented vertically and moved along a pouring conveyor.
• This operation is simple and eliminates the need to handle flasks, allowing for very high production rates.
Expendable-mold, Permanent Casting Processes – Sand Casting - Vertical Flaskless Molding

(a)

Box

Sand

Ram force

Pattern

(b) Metal poured here

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Expendable-mold, Permanent Casting Processes – Sand Casting - Sequence of Operations

(a) Mechanical drawing of part

(b) Cope pattern plate
Core prints

(c) Gate
Drag pattern plate
Core prints

(d) Core boxes

(e) Core halves pasted together

(f) Risers
Sprue
Core ready for sand

Flask
Expendable-mold, Permanent Casting Processes – Sand Casting - Sequence of Operations

(g) Cope after ramming with sand and removing pattern, sprue, and risers

(h) Drag ready for sand

(i) Drag after removing pattern

(j) Drag with core set in place

(k) Cope and drag assembled ready for pouring

(l) Casting as removed from mold; heat treated

(m) Casting ready for shipment
Expendable-mold, Permanent Casting

Processes — Sand Casting - sequence of operations

1. A mechanical drawing of part is used to generate a design for pattern. Considerations such as: shrinkage and draft.
2. Patterns mounted on plate equipped with pins for alignment, with core prints to hold the core in place.
3. Core boxes produce core halves, which are pasted together.
4. Cope half of mold is assembled by securing cope pattern plate to flask with aligning pins, and attaching inserts to form the sprue and risers.
5. Flask is rammed with sand and the plate and inserts are removed.
6. Drag half is produced in a similar manner, with the pattern inserted. A bottom board is placed below the drag and aligned with pins.
7. The pattern, flask, and bottom board are inverted, and the pattern is withdrawn, leaving the appropriate imprint.
8. Core is set in place within the drag cavity.
9. Mold is closed by placing cope on top of drag and securing the assembly with pins.
10. Flasks are then subjected to pressure to counteract buoyant forces in the liquid
11. After metal solidifies, the casting is removed from the mold.
12. The sprue and risers are cut off and recycled, and the casting is cleaned, inspected, and heat treated.
Expendable-mold, Permanent Casting Processes – Sand Casting - Vacuum molding

- The pattern is covered tightly by a thin sheet of plastic.
- A flask is placed over the coated pattern and is filled with dry binderless sand.
- A second sheet of plastic is then placed on top of the sand, and a vacuum action hardens the sand so that the pattern can be withdrawn. Both halves of the mold are made this way and assembled.
- During pouring, the mold remains under a vacuum but the casting cavity does not.
- When the metal has solidified, the vacuum is turned off and the sand falls away, releasing the casting.
- Vacuum molding produces casting with high-quality detail and dimensional accuracy.
- It is especially well suited for large, relatively flat castings.

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### Expendable-mold, Permanent Casting Processes — Sand Casting

**Figure 11.12:** Surface roughness in casting and other metalworking processes. See also Figs. 22.14 and 26.4 for comparison with other manufacturing processes.

<table>
<thead>
<tr>
<th>Process</th>
<th>Roughness ($R_a$)</th>
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<tr>
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<td>$m$ 50</td>
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<td></td>
<td>$\mu$ 2000</td>
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<tr>
<td>Sand casting</td>
<td>Average application</td>
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<td>Hot rolling</td>
<td>Less frequent application</td>
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<td>Forging</td>
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<td>Permanent mold casting</td>
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<td>Investment casting</td>
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<td>Extruding</td>
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<td>Cold rolling, drawing</td>
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<td>Die casting</td>
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Expendable-mold, Permanent Casting Processes — Shell-mold Casting

- A mounted pattern made of a ferrous metal or aluminum is heated to 175°C – 370°C.
- Coated with a parting agent such as silicone.
- Clamped to a box that contains fine sand, mixed with 2.5% - 4% thermosetting resin binder (such as phenol-formaldehyde).
- The box is either rotated upside down or the sand mixture is blown over the pattern, to coat the pattern.
- The assembly is then placed in an oven for a short period of time to complete the curing of the resin.
- The shell hardens around the pattern and is removed from the pattern using built-in ejector pins.
- Two half-shells are made in this manner and are bonded or clamped together in preparation for pouring.
Expendable-mold, Permanent Casting Processes — Shell-mold Casting

(a) Pattern rotated and clamped to dump box
(b) Pattern and dump box rotated
(c) Pattern dump box in position for the investment
(d) Pattern and shell removed from dump box

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Expendable-mold, Permanent Casting Processes – Shell-mold Characteristics

- The shells are light and thin (5-10 mm).
- Shell sand has a much lower permeability than sand used for green-sand molding, fine sand is used.
- The decomposition of the shell-sand binder produces a high volume of gas; unless the molds are properly vented, trapped air and gas can cause serious problems in shell molding of ferrous castings.
- The walls of the mold are relatively smooth, offering low resistance to flow of the molten metal and producing casting with sharper corners, thinner sections, and smaller projections than are possible in green-sand molds.
Expendable-mold, Permanent Casting Processes - Ceramic Molding

- Figure 11.16 Sequence of operations in making a ceramic mold.
EXPENDABLE-PATTERN CASTING (LOST FOAM)

- Uses a polystyrene pattern, which evaporates upon contact with molten metal to form a cavity for the casting.
- Raw expendable polystyrene (EPS) beads, containing 5% to 8% pentane (a volatile hydrocarbon), are placed in a preheated die which is usually made of aluminum.
- The polystyrene expands and takes the shape of the die cavity.
- Additional heat is applied to fuse and bond the beads together.
- The die is then cooled and opened, and the polystyrene pattern is removed.
- The pattern is coated with water-based refractory slurry, dried, and placed in a flask.
- The flask is filled with loose fine sand, which surrounds and supports the pattern and may be dried or mixed with bonding agents to give it additional strength.
- The sand is periodically compacted.
- Without removing the polystyrene pattern, the molten metal is poured into the mold.
EXPENDABLE-PATTERN CASTING (LOST FOAM)

(a) Polystyrene blank
(b) Support sand
(c) Flask

Molten metal
EXPENDABLE-PATTERN CASTING (LOST FOAM) - Notes

- Flow velocity in the mold depends on the rate of degradation of the polymer.
- With Re = 400 to 3000, The velocity of the molten metal at the metal-polymer pattern front is estimated to be in the range of 0.1 m/s – 1.0 m/s.
- Velocity can be controlled by producing pattern with cavities or hollow sections.
EXPENDABLE-PATTERN CASTING (LOST FOAM) - Advantages

- Relatively simple because there are no parting lines, cores, or riser systems, hence it has design flexibility.
- Inexpensive flasks are sufficient for the process.
- Polysterene is inexpensive and can be easily processed into patterns having complex shapes, various sizes, and fine surface detail.
- The casting requires minimum finishing and cleaning operation.
- The process can be automated and is economical for long production runs.
EXPENDABLE-PATTERN CASTING

Replicast C-S process

- In a modification of the evaporative-pattern process, a polystyrene pattern is surrounded by a ceramic shell.
- The pattern is burned out prior to pouring the molten metal into the mold.
- Its principal advantage over investment casting is that carbon pickup into the metal is entirely avoided.
EXPENDABLE-PATTERN CASTING

Investment Casting

It is suitable for casting high-melting-point alloys with good surface finish and close dimensional tolerances.

1. The pattern is made of wax or of a plastic (such as polystyrene) by molding or rapid prototyping techniques.
2. The pattern is then dipped into a slurry of refractory material such as very fine silica and binders, including water, ethyl silicate, and acids.
3. After this initial coating has dried, the pattern is coated repeatedly to increase its thickness.
4. The mold is dried in air and heated to a temp. of 90°C–175°C, while held in an inverted position for about 12 hours to melt out the wax.
5. The mold is then fired to 650°C–1050°C for about 4 hours, to drive off the water of crystallization and burn off any residual wax.
6. After the metal has been poured and has solidified, the mold is broken up and the casting is removed.
EXPENDABLE-PATTERN CASTING

Investment Casting

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EXPENDABLE-PATTERN CASTING

Investment Casting

- Figure 11.19: Investment casting of an integrally cast rotor for a gas turbine.
  a) Wax pattern assembly.
  b) Ceramic shell around wax pattern.
  c) Wax is melted out and the mold is filled, under a vacuum, with molten superalloy.
  d) The cast rotor, produced to net or near-net shape.
Vacuum Casting Process
PERMANENT-MOLD CASTING

- Two halves of a mold are made from materials such as cast iron, steel, bronze, graphite, or refractory metal alloys.
- To produce castings with internal cavities, cores made of metal, or sand aggregate are placed in the mold prior to casting.
- The surfaces of the mold cavity are usually coated with a refractory slurry (such as sodium silicate and clay) or sprayed with graphite every few castings. These coatings also serve as parting agents and as thermal barriers, controlling the rate of cooling of the casting.
- Mechanical ejectors may be needed for removal of complex castings.
- The molds are clamped together by mechanical means and heated to about 150°C – 200°C.
PERMANENT-MOLD CASTING

Process Characteristics

- Used mostly for aluminum, magnesium, copper alloys, and gray iron because of their generally lower melting points.
- Steels can also be cast using graphite or heat-resistant metal molds.
- This process produces - at high production rates – casting with:
  - good surface finish
  - close dimensional tolerances
  - uniform and good mechanical properties.
DIE CASTING

- The molten metal is forced into the die cavity at pressures ranging from 0.7 MPa–700 MPa.
- The weight of most casting ranges from less than 90g to about 25 kg.
- Two basic types of die-casting machines:
  1. hot-chamber
  2. cold-chamber.
DIE CASTING
Hot-Chamber Process

- Involves the use of a piston, which traps a certain volume of molten metal and forces it into the die cavity through a gooseneck and nozzle.
- The metal is held under pressure (up to 35 MPa) until it solidifies in the die.
- To improve die life and to aid in rapid metal cooling, dies are usually cooled by circulating water or oil through various passageways in the die block.
DIE CASTING

800-ton hot-chamber die-casting machine
DIE CASTING
Cold-Chamber Process

- Molten metal is poured into the injection cylinder.
- The shot chamber is not heated, hence the term cold chamber.
- The metal is forced into the die cavity at pressures usually ranging from 20 to 70 MPa.
DIE CASTING
Cold-Chamber Machine
DIE CASTING

Process Capabilities and Machine Selection

- Machines are rated according to the clamping force needed to keep the dies closed.
- Capacities range: 25 to 3000 tons.
- Other factors involved in the selection of die-casting machines are die size, piston stroke, shot pressure and cost.
- Ratio of die weight to part weight is 1000 to 1
- Dies are usually made of hot-work die steels or mold steels.
- Die design includes draft to allow removal of the casting.
- Die casting has the capability for rapid production of strong, high-quality parts with complex shapes.
- It also produces good dimensional accuracy and surface details, (net-shape forming).
- Because of the high pressures involved, walls as thin as 0.38 mm are produced. Ejector marks remain.
DIE CASTING

Process Capabilities and Machine Selection

- Because the molten metal chills rapidly at the die walls, the casting has a fine-grained, hard skin with higher strength.
- Strength-to-weight ratio of die-cast parts increases with decreasing wall thickness.
- Components such as pins, shafts, and threaded fasteners can be die cast integrally. Called insert molding.
- For good interfacial strength, inserts may be knurled, grooved, or splined.
- In selecting insert materials, the possibility of galvanic corrosion should be taken into account.
  - If galvanic corrosion is a potential problem, the insert can be insulated, plated, or surface-treated.
- Equipment costs, particularly the cost of dies, are somewhat high, but labor costs are generally low.
- Die casting is economical for large production runs.
DIE CASTING

Figure 11.25: Various types of cavities in a die-casting die

(a) Single-cavity die  (b) Multiple-cavity die  (c) Combination die  (d) Unit die
DIE CASTING

Figure 11.26 Examples of cast-in-place inserts in die casting.

a) Knurled bushings.
b) Grooved
c) threaded rod.
Centrifugal Casting

True centrifugal Casting

- Molds are made of steel, iron, or graphite, and may be coated with a refractory lining to increase mold life.
- The mold surfaces can be shaped so that pipes with various outer shapes, including square or polygonal, can be cast.
- Cylindrical parts ranging from 13 mm to 3 m in diameter and 16 m long can be cast centrifugally, with wall thicknesses ranging from 6 mm to 125 mm.
- Castings of good quality, dimensional accuracy, and external surface detail are obtained by this process.
Centrifugal Casting
True centrifugal Casting

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Centrifugal Casting
Semicentrifugal casting
Centrifugal Casting

Centrifuging

- Mold cavities of any shape are placed at a certain distance from the axis of rotation.
- The molten metal is poured from the center and is forced into the mold by centrifugal forces.
SQUEEZE-CASTING

- This process combines the advantages of casting and forging.
Melt Spinning

- Gas
- Crucible
- Induction coil
- Melt
- Strip
- Copper disk

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INSPECTION OF CASTINGS

- Inspected visually or optically for surface defects.
- Subsurface and internal defects are investigated using various nondestructive techniques.
- In destructive testing, test specimens are removed from various sections of a casting to test for strength, ductility, and other mechanical properties, and to determine the presence and location of porosity and any other defects.
- Pressure tightness of cast components (valves, pumps, and pipes) is usually determined by sealing the openings in the casting and pressurizing it with water, oil, or air.
- For extreme leak tightness requirements, pressurized helium or specially scented gases with detectors are used.
Fluxes are inorganic compounds that refine the molten metal by removing dissolved gases and various impurities.

Fluxes have several functions, depending on the metal.

For example, for aluminum alloys there are:
- cover fluxes (to form a barrier to oxidation)
- cleaning fluxes
- drossing fluxes
- refining fluxes
- wall-cleaning fluxes.

Fluxes may be added manually or can be injected automatically into the molten metal.

To protect the surface of the molten metal against atmospheric reaction and contamination, and to refine the melt, the metal must be insulated against heat loss.

Insulation is usually provided by covering the surface or mixing the melt with compounds that form a slag. In casting steels, the composition of the slag includes CaO, SiO₂, MnO, and FeO.
Melting Furnaces
Electric Arc Furnaces

• High rate of melting
• Much less pollution than other types of furnaces,
• Ability to hold the molten metal for alloying purposes.
Melting Furnaces

Induction Furnaces

1. The coreless induction furnace:
   - consists of a crucible completely surrounded with a water-cooled copper coil through which high frequency current passes.
   - Because there is a strong electromagnetic stirring action during induction heating, this type of furnace has excellent mixing characteristics for alloying and adding new charge of metal.

2. Core or channel furnace:
   - uses low frequency (as low as 60 Hz) and has a coil that surrounds only a small portion of the unit.
   - commonly used in nonferrous foundries and is particularly suitable for superheating to improve fluidity, holding, and duplexing (using two furnaces to, for instance, melt the metal in one furnace and transfer it to another).
Melting Furnaces

- Crucible furnaces
- **Cupolas**: refractory-lined vertical steel vessels charged with alternating layers of metal. Coke, and flux. Cupolas operate continuously, have high melting rates, and produce large amounts of molten metal.
Furnace Selection

- Economic considerations.
- Composition and melting point of the alloy to be cast as well as the ease of controlling its chemistry.
- Control of the furnace atmosphere to avoid contamination of the metal.
- Capacity and rate of melting required.
- Environmental consideration.
- Power supply and its availability and cost of fuels.
- Ease of superheating the metal.
- Type of charge material that can be used.