Lecture 4: Casting II

1. Sand casting
2. Other expendable-mold casting processes
3. Permanent-mold casting processes
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
- Castings range in size from small to very large
Sand Casting Production Sequence

1. Core making (if needed)
2. Pattern making
3. Mold making
4. Preparation of sand
5. Melting
6. Pouring
7. Solidification and cooling
8. Removal of sand mold
9. Cleaning and inspection
10. Finished casting
Types of Patterns

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

- (a) Core held in place in the mold cavity by chaplets,
- (b) possible chaplet design
- (c) casting
- (d) higher melting point than casting metal
Desirable Mold Properties

- 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 Sand

Silica (SiO$_2$) or silica mixed with other minerals

- Good refractory properties - for high temperatures
- Small grain size for better surface finish on cast part
- Large grain size is more permeable, allowing gases to escape during pouring
- Irregular grain shapes strengthen molds due to interlocking, compared to round grains
  - Disadvantage: interlocking reduces permeability
Binders Used with Foundry Sand

- 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 increase 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
  - 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
Shell Molding

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

- (1) A metal pattern is heated and placed over a box containing sand mixed with thermosetting resin
- (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
Steps in Shell Molding

- (3) Box is repositioned so loose uncured particles drop away
- (4) Sand shell is heated in oven for several minutes to complete curing
- (5) Shell mold is stripped from pattern
- (6) Two halves of the shell mold are assembled, supported by sand or metal shot in a box, and pouring is accomplished
- (7) Finished casting with sprue removed

http://www.youtube.com/watch?v=5Kkv8udoLYI
Shell Molding: Advantages and Disadvantages

• Advantages:
  – Smoother cavity surface permits easier flow of molten metal and better surface finish
  – Good dimensional accuracy
  – Mold collapsibility minimizes cracks in casting
  – Can be mechanized for mass production

• Disadvantages:
  – More expensive metal pattern
  – Difficult to justify for small quantities
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
Steps in Expanded Polystyrene Process

1. Polystyrene foam pattern is coated with refractory compound
2. Foam pattern is placed in mold box, and sand is compacted around the pattern
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 filling the mold cavity
Expanded Polystyrene Process: Advantages and Disadvantages

• Advantages of expanded polystyrene process:
  – Pattern need not be removed from the mold
  – Simplifies and speeds up mold-making, because two mold halves 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:
  – Mass production of castings for automobile engines
  – Automated and integrated manufacturing systems are used to
    1. Mold the polystyrene foam patterns and then
    2. Feed them to the downstream casting operation
Investment Casting
(a.k.a. Lost Wax Process)

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

- "Investment" comes from a less familiar definition of "invest" - "to cover completely," which refers to coating of refractory material around wax pattern.
- It is a precision casting process
  - Capable of producing castings of high accuracy and intricate detail.
Steps in Investment Casting

- (1) Wax patterns are produced
- (2) Several patterns are attached to a sprue to form a pattern tree
- (3) Pattern tree is coated with a thin layer of refractory material
- (4) Full mold is formed by covering the coated tree with sufficient refractory material to make it rigid
Steps in Investment Casting

• (5) Mold is held in an inverted position and heated to melt the wax and permit it to drip out of the cavity
• (6) Mold is preheated to a high temperature, the molten metal is poured, and it solidifies
• (7) Mold is broken away from the finished casting and the parts are separated from the sprue
One-piece compressor stator with 108 separate airfoils made by 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
  - This is a net shape process
    - Additional machining is not normally required

- **Disadvantages:**
  - Many processing steps are required
  - Relatively expensive process

The biggest problem is inclusions. They're hard to prevent and even harder to track to their source. 
.....pour in vacuum environments —Andrew Johnson, Doncasters, Alabama (2015 graduate)

http://www.youtube.com/watch?v=tyrXq_u1OH0
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
Steps in Permanent Mold Casting

- (1) Mold is preheated and coated for lubrication and heat dissipation
- (2) Cores (if any are used) are inserted and mold is closed
- (3) Molten metal is poured into the mold, where it solidifies
Permanent Mold Casting: Advantages and Limitations

• Advantages of permanent mold casting:
  – Good dimensional control and surface finish
  – Rapid solidification caused by metal mold results in a finer grain structure, so castings are stronger

• Limitations:
  – Generally limited to metals of lower melting point
  – Simpler part geometries compared to sand casting because of need to open the mold
  – High cost of mold
Applications and Metals for 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.
  – Uns suited to steels because of very high pouring temperatures.

Quiz: why steel has higher pouring $T$?
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
- 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
Hot-Chamber Die Casting

- Hot-chamber die casting cycle: (1) with die closed and plunger withdrawn, molten metal flows into the chamber
- (2) plunger forces metal in chamber to flow into die, maintaining pressure during cooling and solidification.
- (3) Plunger is withdrawn, die is opened, and casting is ejected
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
Cold-Chamber Die Casting Cycle

- (1) With die closed and ram withdrawn, molten metal is poured into the chamber.
- (2) Ram forces metal to flow into die, maintaining pressure during cooling and solidification.
- (3) Ram is withdrawn, die is opened, and part is ejected.

http://www.youtube.com/watch?v=Pj_mjjUQad8
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
• In comparison, hot-chamber process favors is used on lower melting-point alloys (zinc, tin, lead)
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 onto cavity surfaces to prevent sticking
Die Casting:
Advantages and Limitations

• Advantages:
  – Economical for large production quantities
  – Good accuracy and surface finish
  – Thin sections possible
  – Rapid cooling means small grain size and good strength in casting

• Disadvantages:
  – Generally limited to metals with low melting points
  – Part geometry must allow removal from die
Squeeze Casting

Combination of casting and forging in which a molten metal is poured into a preheated lower die, and the upper die is closed to create the mold cavity after solidification begins

• Differs from usual closed-mold casting processes in which die halves are closed before introduction of the molten metal
• Compared to conventional forging, pressures are less and finer surface details can be achieved
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

[Diagram of True Centrifugal Casting process]
HW Assignment

• Read Chapter 6
• Review Questions: 6.1, 6.3, 6.4, 6.6, 6.7

• Quiz for online students: None