Chapter 12
Expendable-Use Mold Casting Processes

Before you begin: Turn on the sound on your computer. There is audio to accompany this presentation.

Casting Processes

Materials Processing

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Chapters 20-27
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Chapters 30-33
Expendable Mold Casting

- Permanent molds are usually made from metal.
- Expendable molds are formed using:
  - Sand, plaster, ceramics or other refractory materials, and
  - Binders.

Commonly cast materials:
- Iron*
- Steel and stainless steel
- Aluminum alloys*
- Brass, bronze and other copper alloys
- Magnesium alloys
- Certain zinc alloys
- Nickel-based superalloys

* Most common due to low cost, good fluidity, adaptability to casting processes and wide range of product properties.

Sand Casting

- The most common and most versatile of the casting processes accounting for over 90% of all metal casting.
- Uses granular refractory material (sand) combined with clay and water.
- Sand is actually just crushed rock of a certain size.
- Rock examples are silica, zircon, olivine, and chromite sand.
Sand Casting

Figure 12-1. Sequential steps in making a sand casting.

(a) A pattern is placed between the bottom (drag) and top (cope) halves of the flask with the bottom side up.

(b) Sand is then packed into the bottom half or drag half of the mold.

(c) A bottom board is positioned on the top of the packed sand, and the mold is turned over, showing the top (cope) half of the pattern with sprue and riser pins in place.

(d) The upper or cope half of the mold is then packed with sand.

(e) The mold is opened, the pattern board is drawn (removed), and the runner and gate are cut into the bottom parting surface of the sand.

(e') The parting surface of the upper or cope half of the mold is also shown with the pattern and pins removed.
Sand Casting

Figure 12-1. Sequential steps in making a sand casting.

(f) The mold is reassembled with the pattern board removed, and the molten metal is poured through the sprue.

(g) The contents are shaken from the flask and the metal segment is separated from the sand, ready for further processing.

Patterns for Sand Casting

- Patterns can be made from wood, metal, or hard plastics such as urethanes.
- Pattern material depends on how many times the pattern will be used, the finish needed on the casting, and the cost of making the pattern.
- Wood is cheap, has ok surface finish, but warps easily with moisture and can only be used for low production runs due to wear.

Types of Patterns

- Many types of patterns are also used in the sand casting process – again dependent on the number of casting being made and dependent on the design of the final cast shape:
  - One-piece or solid patterns
  - Split patterns
  - Match-plate patterns
  - Cope and drag patterns
  - Loose-piece patterns
Types of Patterns

- **One-piece or solid patterns** – essentially a duplicate of the part to be cast with allowances for shrinkage, etc. added.

- **Follow board** – forms the parting surface for solid patterns.

  Figure 12-2 Single piece pattern for a pinion gear.

- **Split patterns** – pattern divided into two segments along the parting line.

  Figure 12-4 Split pattern, showing the two sections together and separated. The light-colored portions are core prints.

- **Match-plate patterns** – cope and drag segments are attached to opposite sides of match-plate with gates, runners and risers.

  Figure 12-5 Match-plate pattern used to produce two identical parts in single flask. (Left) Cope-side; (right) drag side. (Note: The views are opposite sides of a single-pattern board.)
Types of Patterns

- Cope and drag patterns – cope and drag portions of pattern attached to separate pattern boards allowing independent mold half preparation – used in high production environment.

![Cope and drag pattern](image)

Figure 12-6 Cope and drag pattern for producing two heavy parts. (Left) Cope section; (right) drag section. (Note: these are two separate pattern boards.)

Types of Patterns


![Loose-piece pattern](image)

Figure 12-7 Loose-piece pattern for molding a large worm gear. After sufficient sand has been packed around the pattern to hold the pieces in position, the wooden pins are withdrawn. The mold is then completed, after which the pieces of the pattern can be removed in a designated sequence.

Sand and its Properties

- Sand is obviously very important in the sand casting process.
- Good quality sand must have 4 important characteristics:
  - Refractoriness – ability to withstand heat.
  - Cohesiveness – ability to stick together.
  - Permeability – ability to allow gases to escape.
  - Collapsibility – ability to release casting.
Sand and its Properties

- Refractoriness is provided by the basic nature of sand.
- Cohesiveness is improved by adding binders such as clay that become cohesive when moistened.
- Permeability is a function of grain size and shape.
- Collapsibility can be improved by adding materials such as cereals or other organic material that burn away during the pour.
- Good molding sand is always a compromise between competing factors.

Muller serves to knead, stir and roll sand into a consistent mixture.

Typical green sand (never fired or cured) mixture:

- 88% Silica sand.
- 9% Clay
- 3% Water/Oil

Figure 12-8 Schematic diagram of a continuous (left) and batch-type (right) muller.
Sand Testing

Quality control of sand characteristics is also very important.

Sand testing is used to ensure the properties of the sand are consistent and where expected:

- Grain size
- Moisture content
- Clay content
- Permeability
- Compressive strength
- Hardness
- Compactability

**TABLE 12-1 Desirable Properties of a Sand-Based Molding Material**

1. Is temperate in bulk quantities
2. Retains properties through transportation and storage
3. Uniformly fills a flask or container
4. Can be compacted or set by simple methods
5. Has sufficient sphericity to remain undamaged during pattern withdrawal
6. Can withstand high temperatures and maintains its dimensions until the metal has solidified
7. Is sufficiently permeable to allow the escape of gases
8. Is sufficiently dense to prevent metal penetration
9. Is sufficiently cohesive to prevent wash-out of mold material into the pour stream
10. Is chemically inert to the metal being cast
11. Can yield to solidification and thermal shrinkage, thereby preventing hot tears and cracks
12. Has good collapsibility to permit easy removal and separation of the casting
13. Can be recycled

Sand Related Defects

Some casting defects are directly related to sand characteristics:

- Sand expansion defects – inability of sand to expand near metal interface causes buckles.
- Voids or blows – inability of sand to allow gas escape.
- Penetration – mold material imbedded in surface of casting can be caused by high-permeability sands.
- Hot tears – due to casting restrained by mold and lack of collapsibility.
Making of Sand Molds

- Hand ramming – molds are made by hand.
- Sand slinging – centrifugal force slings sand into flask.
- Jolting – lifts flask and drops multiple times.
- Squeezing – uses pneumatic pressure to compress sand.
- Jolting and squeezing – combination of above.
- Automated molding machines – up to 300 molds/hr.
- Vertically parted flaskless molding – makes an entire mold in one cycle.
- Stack molding – molds piled vertically with one sprue.

Figure 12-12 Jolting a mold section. (Note: The pattern is on the bottom, where the greatest packing is expected.)

Figure 12-13 Squeezing a sand-filled mold section. While the pattern is on the bottom, the highest packing will be directly under the squeeze head.

Making of Sand Molds

Jolt-squeeze machines.
Making of Sand Molds

Figure 12-15 Activity sequence for automatic match-plate molding.

Making of Sand Molds

Figure 12-16 Vertically parted flaskless molding with insert cores. Note how one mold block now contains both the cope and drag impressions.

Types of Sand Molds

- Green-sand – most common for both ferrous and non-ferrous materials.
- Dry-sand – green-sand mold heated to drive off moisture. Strengthens molds and overcomes problems with moisture by completely drying mold.
- Skin-dried – compromise between green-sand and dry-sand since only area near pattern is dried.
**Types of Sand Molds**

- Sodium Silicate molding (aka: waterglass) – waterglass remains soft and moldable until exposed to carbon dioxide (CO₂), then hardens quickly.
- Chemically bonded sands (aka no-bake or air-set) – chemical bonding additive reacts with air to cure or harden the mold.
- Vacuum molding (aka: V-process) – uses vacuum to create mold with loose sand.

**Types of Sand Molds**

- Shell molding – chemically bonded, sets with heat, produces thin shell. Steps in shell molding:
  - Grains of sand coated with thermosetting, phenolic resin.
  - Sand shot into metal pattern that has been preheated.
  - Pattern and sand mixture inverted to remove loose sand.
  - Pattern and shell placed in oven to complete curing.
  - Shell stripped from the pattern.
  - Two or more shells clamped together to form the mold.
  - Shell mold placed in a metal jacket for additional support.

![Diagram of Shell Molding Process](image)
Types of Sand Molds

Figure 12-19 (Top) Two halves of a shell mold pattern. (Bottom) The two shells before clamping, and the final shell-mold casting with attached pouring basin, runner and riser.

Types of Sand Molds

Pouring a shell mold. Note the sand used to support the shell mold.

Shell mold for crankshafts.

Cores

- Cores allow complex internal geometries.
- Reduce the amount of machining required later.

Figure 12-22 Four methods of making a hole in a cast pulley. Three involve the use of a core.
Cores

- Cores can be made with the same processes as used to make molds (except v-process).
- Core types include:
  - Green-sand – core formed as part of the molding process. Low strength.
  - Dry-sand – sand and binder mixed and packed into core box. Core is cured and assembled if necessary.

Cores

- Core processes include:
  - Split cores

Figure 12-21 V-8 engine block (bottom center) and the five dry-sand cores that are used in the construction of its mold.

Figure 12-23 (Upper right) A dump-type core box; (bottom) two core halves ready for baking; and (upper left) a completed core made by gluing two opposing halves together.
Cores

- Other core processes/variations include:
  - Single-piece cores – made in a split core box.
  - Core extrusion – used for uniform cross-section core geometries.
  - Core-oil process – binder of oil used in conjunction with heat curing to produce higher strength cores.

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Cores

- Other core processes/variations include:
  - Hot-box method – heat activated systems using a thermosetting binder and catalyst.
  - Cold-box method – gas or vaporized catalyst blow through permeable sand to polymerize the resin.
  - Air-set, no-bake and shell molding also commonly used to produce cores.

Characteristics of Cores

- Good strength in green condition.
- Good strength and hardness after baking to withstand force of molten metal.
- Permeability.
- Collapsibility.
- Refractoriness.
- Smooth surface.
- Minimum generation of gases.
Cores

- Core mounting methods include:
  - Core prints – recesses in mold cavity to support and orient cores.
  - Chaplets – small metal supports.

![Figure 12-24 (Left)](Typical chaplets. (Right) Method of supporting a core by use of chaplets.)

Example – Core Design

Example – Engine Mold

- Core prints for cylinders.
- Core print for end of block.
- Core box for rear block internal geometry.
Example – Engine Mold

Core box for cam follower.

Core box for cylinders and water jacket.

Core boxes for inside of crankcase.

Pattern mounted in molding box with sprue, runners and gates added.

Expendable Mold Processes

Multiple-Use Pattern Processes:

- Plaster mold casting – uses plaster of paris:
  - Fine detail and accuracy.
  - Limited to low-melting temperature non-ferrous alloys.
- Ceramic mold casting – ceramic slurry capable of higher-temperatures used.
- Expendable graphite methods – uses powdered graphite for materials (e.g. titanium) that react with other molding materials.
- Rubber mold casting – Limited to low-melting temperature materials.
Expendable Mold Processes

Single-Use Pattern Processes:
- Investment casting – pattern destroyed during molding process.
  - Counter-gravity investment casting – vacuum used to draw metal up into the cavity.
- Evaporation pattern – pattern destroyed during pouring process:
  - Full mold casting – uses green-sand to support the pattern.
  - Lost foam casting – uses ceramic coating and unbonded sand.

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Expendable Mold Processes

- Investment casting – used for complex shapes. Uses same ceramic aggregate as ceramic molding process.

Process:
- Produce a master pattern.
- Produce a master die.
- Produce wax patterns.
- Assemble wax patterns onto a common wax sprue.

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Expendable Mold Processes

- Investment casting – Process (continued):
  - Coat cluster or tree with investment material – watery slurry of finely ground refractory material.
  - Form additional layers of ceramic material and allow to harden.
  - Remove wax by melting or dissolving.
  - Heat mold to prepare for pouring.
  - Pour molten metal.
  - Remove solidified casting.
Expendable Mold Processes

Dipping wax patterns into refractory slurry.

Investment molds ready for pour.

Pouring investment castings.
Expendable Mold Processes

Evaporation pattern – pattern destroyed during pouring process:

- Uses expanded polystyrene (EPS) or expanded polymethylmethacrylate (EPMMA).
- During pour, pattern melts and burns.
- Small quantities of patterns can be produced by hand.
- Dies can be used to produce large quantities of patterns.

Expendable Mold Processes

- Full mold casting – uses green-sand or chemically bonded sand to support the pattern.

Figure 12-31 Schematic of the full-mold process. (Left) An uncoated EP pattern is surrounded by bonded sand to produce a mold. (Right) Hot metal progressively vaporizes the EP pattern and fills the resulting cavity.

Expendable Mold Processes

- Lost foam casting – uses ceramic coating and unbonded sand.

Figure 12-32 Schematic of the lost-foam process. In this process the EP pattern is dipped in a ceramic slurry, and the coated pattern is then surrounded with loose, unbonded sand.
Expendable Mold Processes

Figure 12-33: The stages of lost-foam casting, proceeding counterclockwise from the lower left: polystyrene beads → EP pellets → three foam pattern segments → an assembled and dipped polystyrene pattern → a finished metal casting that is a duplicate of the polystyrene pattern.

CAE - Simulation

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