METAL CASTING

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1.1 OVERVIEW OF CASTING TECHNOLOGY

Definitions
Casting is a process in which molten metal flows into a mold where it solidifies in the shape of the mold cavity. The part produced is also called casting.

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Casting technology involves the next steps:
Mold preparation → Metal heating → Pouring → Cooling → Processing

Casting nomenclature
The figure in the right shows the nomenclature of mold and castings in sand casting.

Selection of castings of various materials, shapes, and sizes
The pouring cup, downsprue, runners, etc., are known as the *mold gating system*, which serves to deliver the molten metal to all sections of the mold cavity.

### Heating and pouring

#### Heating

The total heat required is estimated as the sum of

1. Heat to raise the temperature to the melting point
2. Heat of fusion
3. Heat to raise the molten metal temperature to the temperature of pouring

#### Pouring

Major factors affecting the pouring action

1. Pouring temperature
2. Pouring rate
3. Turbulence

Some important equations in pouring:

- Velocity of the liquid metal at the base of the sprue: \( v = \sqrt{\frac{2gh}{\text{Sprue height}}} \)
- Volumetric flow rate: \( Q = vA \)
- Mold filling time: \( MFT = \frac{V}{Q} \)

### Fluidity

Fluidity is a measure of the capability of a metal to flow into and to fill the mold before freezing. It defines to the great extend the quality of casting.

Factors affecting fluidity:

1. Pouring temperature
2. Metal composition
3. Heat transfer to the surroundings
4. Viscosity of the liquid metal

In the foundry practice, test for fluidity is carried out for each ladle just before pouring the molten metal into the mold.
Solidification and cooling

Solidification of metals

*Pure metals* solidify at a constant temperature equal to their freezing point

**Chvorinov's rule**

$$TST = C_m \left( \frac{V}{A} \right)^n$$

- \(TST\) — total solidification time
- \(C_m\) — mold constant
- \(V\) — volume of the casting
- \(A\) — surface area of the casting
- \(n\) — constant, usually \(n=2\)

Most alloys freeze over a temperature range

Example:

Calculate the total solidification time for a 10/100/200-mm steel plate if \(C_m = 0.2 \text{ min/mm}^2\)

Solution:
Shrinkage

Shrinkage of a cylindrical casting during solidification and cooling: (0) starting level of molten metal immediately after pouring; (1) reduction in level caused by liquid contraction during cooling; (2) reduction in height and formation of shrinkage cavity caused by solidification shrinkage; and (3) further reduction in height and diameter due to thermal contraction during cooling of the solid metal. Dimensional reductions are exaggerated for clarity in our sketches.

Directional solidification

1. By a proper design of the casting
2. By external and internal chills

Riser design

Several riser designs are used in practice as shown in the figure. The riser must remain molten until after the casting solidifies. The Chvorinov’s Rule is used to calculate the riser’s dimensions.
1.2 CASTING PROCESSES

EXPENDABLE MOLD CASTING

In expendable mold casting, the mold is destroyed to remove the casting and a new mold is required for each new casting.

Sand Casting

The next figure illustrates the basic production steps in sand casting:

Patterns

Patterns in sand casting are used to form the mold cavity. One major requirement is that patterns (and therefore the mold cavity) must be oversized (i) to account for shrinkage in cooling and solidification, and (ii) to provide enough metal for the subsequent machining operation(s).

Types of patterns used in sand casting:

(a) solid pattern, (b) split pattern, (c) match-plate pattern, and (d) cope-and-drag pattern

Split pattern showing the two sections together and separated. Light-colored portions are core prints.

Solid pattern for a pinion gear
Cores

Cores serve to produce internal surfaces in castings. In some cases, they have to be supported by *chaplets* for more stable positioning:

![Diagram of core setup]

(a) Core held in place in the mold cavity by chaplets, (b) chaplet design, (c) casting with internal cavity

Cores are made of foundry sand with addition of some resin for strength by means of *core boxes*:

![Core box images]

Core box, two core halves ready for baking, and the complete core made by gluing the two halves together

**Foundry sands**

The typical foundry sand is a mixture of fresh and recycled sand, which contains 90% silica (\(\text{SiO}_2\)), 3% water, and 7% clay. The *grain size* and *grain shape* are very important as they define the surface quality of casting and the major mold parameters such as strength and permeability:

- Bigger grain size results in a worse surface finish
- Irregular grain shapes produce stronger mold
- Larger grain size ensures better permeability
Mixing of foundry sands

Schematics of continuous (left) and batch-type (right) sand muller. Plow blades move the sand and the muller wheels mix the components.

Mold making

1. Hand packing
2. Machine packing
3. Automated methods

Shell molding

Steps in shell molding

Advantages:

- Good surface finish (up to 2.5 mm)
- Good dimensional accuracy (±0.25 mm)
- Suitable for mass production

Disadvantages:

- Expensive metal pattern

Area of application:

- Mass production of steel casting of less than 10 kg

Two halves of a shell mold pattern
Investment casting (lost wax casting)

In investment casting, the pattern is made of wax, which melts after making the mold to produce the mold cavity. Production steps in investment casting are illustrated in the figure:

Steps in investment casting: (1) wax patterns are produced; (2) several patterns are attached to a sprue to form a pattern tree; (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; (5) the mold is held in an inverted position and heated to melt the wax and permit it to drip out of the cavity; (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 and (7) the mold is broken away from the finished casting. Parts are separated from the sprue.

Advantages:
- Arbitrary complexity of castings
- Good dimensional accuracy
- Good surface finish
- No or little additional machining (net, or near-net process)
- Wax can be reused

Disadvantages:
- Very expensive process
- Requires skilled labor

Area of application:
- Small in size, complex parts such as art pieces, jewelry, dental fixtures from all types of metals.
- Used to produce machine elements such as gas turbine blades, pinion gears, etc. which do not require or require only little subsequent machining.
PERMANENT MOLD CASTING PROCESSES

In contrary to sand casting, in permanent mold casting the mold is used to produce not a single but many castings.

Steps in permanent mold casting

Steps in permanent mold casting: (1) mold is preheated and coated with lubricant for easier separation of the casting; (2) cores (if used) are inserted and mold is closed; (3) molten metal is poured into the mold; and (4) mold is opened and finished part removed. Finished part is shown in (5).

Advantages:
Good dimensional accuracy
Good surface finish
Finer grain structure (stronger casting)
Possibility for automation

Disadvantages:
Only for metals with low melting point
Castings with simple geometry

Area of application:
Mass production of non-ferrous alloys and cast iron
Die casting

Hot-chamber die-casting
In hot chamber die-casting, the metal is melted in a container attached to the machine, and a piston is used to inject the liquid metal under high pressure into the die.

![Schematics of hot-chamber die-casting](image1.png)

**Advantages:**
- High productivity (up to 500 parts per hour)
- Close tolerances
- Good surface finish

**Disadvantages:**
- The injection system is submerged in the molten metal
- Only simple shapes

**Area of application:**
- Mass production of non-ferrous alloys with very low melting point (zinc, tin, lead)

Cold chamber die casting

In cold-chamber die-casting, molten metal is poured into the chamber from an external melting container, and a piston is used to inject the metal under high pressure into the die cavity.

![Schematics of cold-chamber die-casting](image2.png)

**Advantages:**
- Same as in hot chamber die-casting, but less productivity.

**Disadvantages:**
- Only simple shapes

**Area of application:**
- Mass production of aluminium and magnesium alloys, and brass
Centrifugal casting

True centrifugal casting

In true centrifugal casting, molten metal is poured into a rotating mold to produce tubular parts such as pipes, tubes, and rings.

Semi-centrifugal casting

In this method, centrifugal force is used to produce solid castings rather than tubular parts. Density of the metal in the final casting is greater in the outer sections than at the center of rotation. The process is used on parts in which the center of the casting is machined away, such as wheels and pulleys.

1.3 CASTING QUALITY

There are numerous opportunities in the casting operation for different defects to appear in the cast product. Some of them are common to all casting processes:

Misruns: Casting solidifies before completely fill the mold. Reasons are low pouring temperature, slow pouring or thin cross section of casting.

Cold shut: Two portions flow together but without fusion between them. Causes are similar to those of a misrun.

Cold shots: When splattering occurs during pouring, solid globules of metal are entrapped in the casting. Proper gating system designs could avoid this defect.
**Shrinkage cavity:** Voids resulting from shrinkage. The problem can often be solved by proper riser design but may require some changes in the part design as well.

**Microporosity:** Network of small voids distributed throughout the casting. The defect occurs more often in alloys, because of the manner they solidify.

**Hot tearing:** Cracks caused by low mold collapsibility. They occur when the material is restrained from contraction during solidification. A proper mold design can solve the problem.

Some common defects in casting

Some defects are typical only for some particular casting processes, for instance, many defects occur in sand casting as a result of interaction between the sand mold and the molten metal. Defect found primarily in sand casting are gas cavities, rough surface areas, shift of the two halves of the mold, or shift of the core, etc.