Manufacturing Processes - classification -

**CASTING**

**Casting** A manufacturing process that pours a liquid material into a hollow mold until the material cools into a solidified shape.

**FORMING**

**Forming** operations change the geometry of the starting material without cutting it.

**MATERIAL REMOVAL**

**Material removal** or machining processes remove a part of the starting material using a tool to get the desired geometry.

**JOINING**

**Combining** processes join two materials or deposit material onto the exterior surface of the starting material.
CASTING - Basics -

A material in a liquid or semisolid form is poured or forced to flow into a die cavity and allowed to solidify, thus taking the solid shape of the cavity.

The process can be applied on metals and plastics.

The term casting is commonly used for metals and the term molding is used for plastics.

Examples: door handles, locks, the outer casing or housing for motors, pumps, etc., wheels of many cars. Casting is also heavily used in the toy industry to make parts, e.g. toy cars, planes, etc.

Advantages of casting:

(a) Casting can produce very complex geometry parts with internal cavities.

(b) It can be used to make small (few hundred grams) to very large size parts (thousands of kilograms).

(c) It is economical, with very little wastage: the extra metal in each casting is re-melted and re-used.

(d) Cast metal is isotropic. It has the same physical and mechanical properties along any direction.
Sand casting is a method involving pouring a molten metal into a sand mold.
The set of channels through which a molten metal flows to the mold cavity is called **gating system**.

Typical gating system consists of a **pouring cup** and a **sprue** receiving the poured melt, **runner** – a channel through which the melt is supplied to the **gates** through which the molten metal enters the mold cavity.
A gating system may include a riser (feed head) – a cavity connected to the gating system feeding the casting when it is shrinking.

Air within the mold cavity and gases formed when a molten metal contacts the mold surface are removed through the vents.

The interior cavities of a casting are formed by a separate inserts called cores. Cores are usually made of sand and baked.

A mold frame (flask) consists of two parts: cope (the upper part) and drag (the lower part).

A mold cavity is formed in the process of pattern molding, when the pattern (commonly wooden) is embedded in sand in the flask forming an impression of the casting.
After the sand packing the pattern is removed from the flask and the cores and the gating system are arranged. Cores, runner and gates are arranged in the drag; pouring cap and sprue are placed in the cope. Then the two parts of the mold are assembled and poured. After the metal has solidified and cooled to a desired temperature, the casting is removed from the mold by the process called shakeout.

**SAND CASTING**

(Description...)

**SAND CASTING**

(Advantages/Disadvantages)

- **Advantages**
  - Inexpensive mold
  - Complex geometry
  - All alloys
  - Unlimited size
  - Economical in low quantities

- **Disadvantages**
  - Labor intensive
  - Slower production rate
  - Rough surface finish
  - Loose tolerances
  - Requires relatively thick walls (>3mm)
(a) How do we make the pattern?

Usually craftsmen will carve the part shape by hand and machines to the exact size.

(b) Why is the pattern not exactly identical to the part shape?

- you only need to make the outer surfaces with the pattern; the inner surfaces are made by the core
- you need to allow for the shrinkage of the casting after the metal solidifies

(c) Why the surfaces in the original part design are slightly inclined?

In order to avoid damaging the surface of the mould when removing the pattern and the wood-pieces for the vents, pouring cup and sprue, risers etc., it is important to incline the vertical surfaces of the part geometry. This (slight) inclination is called a taper.
SAND CASTING (VIDEO)

http://www.designinsite.dk/htmsider/pb0211wmv.htm

or

Video of sand casting

CD (sand casting)

SHELL-MOLD CASTING (Description)
SHELL-MOLD CASTING
(Sequential Operations)

(a) A heated pattern is placed over a dump box containing a sand and resin mixture.

(b) The box is inverted and a shell partially cures around the pattern.
(c) The box is righted, the top is removed, and placed in an oven to further cure the shell.

(d) The shell is stripped from the pattern.
(e) Matched shells are then joined and supported in a flask ready for pouring.
**SHELL-MOLD CASTING**
(Advantages/Disadvantages)

- **Advantages**
  - Better accuracy
  - Finish
  - Higher production rate

- **Disadvantages**
  - Limited part size

**EXPENDABLE-MOLD CASTING**
(Description)
EXPENDABLE -MOLD CASTING
(Description)

The pattern used in this process is made from polystyrene (this is the light, white packaging material which is used to pack electronics inside the boxes). Polystyrene foam is 95% air bubbles, and the material itself evaporates when the liquid metal is poured on it.

The pattern itself is made by molding – the polystyrene beads and pentane are put inside an aluminum mold, and heated; it expands to fill the mold, and takes the shape of the cavity.

EXPENDABLE -MOLD CASTING
(Advantages/Disadvantages)

- **Advantages**
  - Very cheap
  - Good surface finish
  - Complex geometry
  - Simple design process

- **Disadvantages**
  - Patterns have low strength
Investment (lost wax) casting is an ancient method of precision casting complex near-net-shape details. The investment casting process uses expendable patterns made of investment casting wax.

(a) Wax patterns are produced by injection molding

(b) Multiple patterns are assembled to a central wax sprue
INVESTMENT CASTING (Description)

(c) A shell is built by immersing the assembly in a liquid ceramic slurry and then into a bed of extremely fine sand. Several layers may be required.

(d) The ceramic is dried; the wax is melted out; ceramic is fired to burn all wax.

INVESTMENT CASTING (Description)

(e) The shell is filled with molten metal by gravity pouring. On solidification, the parts, gates, sprue and pouring cup become one solid casting.

(f) After metal solidifies, the ceramic shell is broken off by vibration or water blasting.
INVESTMENT CASTING (Description)

(g) The parts are cut away from the sprue using a high speed friction saw. Minor finishing gives final part.

INVESTMENT CASTING (Advantages/Disadvantages)

- **Advantages**
  - Good dimensional accuracy
  - Relatively inexpensive mold
  - Rapid production rates possible
  - Complex shapes

- **Disadvantages**
  - Long production cycle
  - Mold is not reusable
INVESTMENT CASTING
(VIDEO)

Investment casting (RLS)

CD Video of investment casting

PERMANENT MOLD CASTING
(Description)

Permanent mold casting is a casting process involving pouring a molten metal by gravity into a steel (or cast iron) mold.
3 Steps in permanent mold casting:

Step 1: mold is preheated and coated

Step 2: cores (if used) are inserted and mold is closed.
**PERMANENT MOLD CASTING** (Description)

**Steps in permanent mold casting:**

Step 3: molten metal is poured into the mold, where it solidifies.

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**PERMANENT MOLD CASTING** (Description)

The permanent mold casting is similar to the sand casting process. In distinction from sand molds which are broken after each casting, a permanent mold may be used for pouring of at least one thousand and up to 100,000 casting cycles.

Manufacturing metal mold is much more expensive than manufacturing sand molds or investment casting process mold. Minimum number of castings for profitable use of a permanent mold is dependent on the complexity of its shape.

Ferrous and no-ferrous metals and alloys are cast by the permanent mold casting process.
Permanent Mold Casting: Aluminum piston

Permanently Mold Casting: Aluminum piston

As cast After machining

Kalpakjian

PERMANENT MOLD CASTING
(Advantages/Disadvantages)

- Advantages
  - Better mechanical properties;
  - Homogeneous grain structure and chemical composition;
  - Low shrinkage and gas porosity;
  - Good surface quality;
  - Low dimensions tolerances

- Disadvantages
  - Costly mold,
  - Simpler shapes only
Die casting is a permanent mold casting process in which the molten metal is injected into the mold cavity at an increased pressure. The mold used in the die casting process is called a die. The molten metal injection is carried out by a machine called the casting machine.
DIE CASTING (Description)

- Pressure is maintained during solidification, then mold is opened and part is removed
- 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

**Cycle in hot-chamber casting:**

1. With die closed and plunger withdrawn, molten metal flows into the chamber
**Hot-Chamber Die Casting**

**Cycle in hot-chamber casting:**
(2) plunger forces metal in chamber to flow into die, maintaining pressure during cooling and solidification.

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**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)
Cold-Chamber Die Casting

Cycle in cold-chamber casting:
(1) with die closed and ram withdrawn, molten metal is poured into the chamber

Cold-Chamber Die Casting

Cycle in cold-chamber casting:
(2) ram forces metal to flow into die, maintaining pressure during cooling and solidification.
Advantages

- Die casting is a highly productive method of casting parts with low dimensions tolerance and high surface quality

Disadvantages

- Expensive die
- Small parts
- Complex and large machinery: expensive
**CENTRIFUGAL CASTING** (Description)

*Centrifugal casting* is a method of casting parts having axial symmetry. The method involves pouring molten metal into a cylindrical mold spinning about its axis of symmetry. The mold is kept rotating till the metal has **solidified**.

As the mold material *steels, Cast irons, Graphite* may be used.

A centrifugal casting machine is schematically presented in the picture:
Centrifugal casting is carried out as follows:

• The mold wall is coated by a refractory ceramic coating
• Starting rotation of the mold at a predetermined speed.
• Pouring a molten metal directly into the mold
• The mold is stopped after the casting has solidified.
• Extraction of the casting from the mold.

Centrifugal casting (animation)

Horizontal centrifugal casting video
Vertical centrifugal casting video
Vertical centrifugal casting is more suitable for cylinders with a ring geometry (diameter > length).

Horizontal centrifugal casting is more suitable for tube geometries (diameter < length).
CENTRIFUGAL CASTING
(Advantages/Disadvantages)

**Advantages**
- Large cylindrical parts
- Good quality

**Disadvantages**
- Expensive
- Limited shapes

**CENTRIFUGAL CASTING - Products**
Centrifugal casting technology is widely used for manufacturing of iron pipes, bushings, wheels, pulleys bi-metal steel-bronze bearings and other parts possessing axial symmetry.
In this case, the material is sucked upwards into the mold by a vacuum pump. The mold in an inverted position from the usual casting process, is lowered into the flask with the molten metal.

(a) Before and (b) after immersion of the mold into the molten metal.

One advantage of vacuum casting is that by releasing the pressure a short time after the mold is filled, we can release the un-solidified metal back into the flask. This allows us to create **hollow castings**. Since most of the heat is conducted away from the surface between the mold and the metal, therefore the portion of the metal closest to the mold surface always solidifies first; the solid front travels inwards into the cavity. Thus, if the liquid is drained a very short time after the filling, then we get a very thin walled hollow object, (see Figure):
**Solidification Time**

Total solidification time $T_{TS}$ is the time required for casting to solidify after pouring.

- $T_{TS}$ depends on size and shape of casting by relationship known as *Chvorinov’s Rule*

\[
T_{ST} = C_m \left(\frac{V}{A}\right)^n
\]

where,
- $T_{ST}$ = total solidification time;
- $V$ = volume of the casting;
- $A$ = surface area of casting;
- $n$ = exponent with typical value = 2;
- $C_m$ is *mold constant*.

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**Mold Constant in Chvorinov’s Rule**

- Mold constant $C_m$ depends on:
  - Mold material
  - Thermal properties of casting metal
  - Pouring temperature relative to melting point

- Value of $C_m$ for a given casting operation can be based on experimental data from previous operations carried out using same mold material, metal, and pouring temperature, even though the shape of the part may be quite different.
Casting Defects are discontinuities in castings that exhibit a size, shape, orientation, or location that makes them detrimental to the useful service life of the casting.

Some casting defects are remedied by minor repair or refurbishing techniques.

Other casting defects are cause for rejection of the casting.

1. Metallic projections
2. Cavities
3. Discontinuities
4. Defective Surfaces
5. Inclusions
CASTING DEFECTS

1. Metallic projections

**Fins** are excessive amounts of metal created by solidification into the parting line of the mold. Fins are removed by grinding or sandblasting.

**Swells** are excessive amounts of metal in the vicinity of gates or beneath the sprue.

**Scabs** are surface slivers caused by splashing and rapid solidification of the metal when it is first poured and strikes the mold wall.

CASTING DEFECTS

2. Cavities

**Blowholes and pinholes** are holes formed by gas entrapped during solidification.

**Shrinkage cavities** are cavities that have a rougher shape and sometimes penetrate deep into the casting. Shrinkage cavities are caused by lack of proper feeding or non-progressive solidification.

**Porosity** is pockets of gas inside the metal caused by micro-shrinkage, e.g. dendritic shrinkage during solidification.
CASTING DEFECTS

3. Discontinuities

A hot tear is a fracture formed during solidification because of hindered contraction.

A hot crack is a crack formed during cooling after solidification because of internal stresses developed in the casting.

Lack of fusion is a discontinuity caused when two streams of liquid in the solidifying casting meet but fail to unite.

CASTING DEFECTS

4. Defective Surfaces

Casting surface irregularities that are caused by incipient freezing from too low a casting temperature.

Wrinkles, depressions, and adhering sand particles.
5. Inclusions

Particles of foreign material in the metal matrix.

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