Module 5. Casting

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Casting was used during the bronze age to produce swords and other tools, and today it remains essential to manufacturing of objects such as jewelry, automotive engine blocks, complex pipe fittings, turbine blades for jet engines, and many other parts.





Swords, 17th-century BC., Bronze Statue (323 BC), A complex Jewellery, Bugatti Veyron engine block, pipe

Casting involves solidification of a molten metal to take the shape of a mold. It is versatile to many types of metals, cost effective, and can be used for a wide range of sizes (from millimetre (Jewelry) to meter (large pipes)). Casting is used to make large, near net-shape parts having complex internal features or geometries that are not possible to machine as a single piece.


Ferrari F12berlietta: *Wheelhouses by Sand Casting, Frame Components by Die Casting*
https://auto.ferrari.com/en_EN/sports-cars-models/past-models/f12-berlinetta/

Inlet-outlet cover of a valve for a nuclear power station produced using investment casting (https://en.wikipedia.org/wiki/File:Nuclear_valve_01.jpg)

Turbocharger rotor, made by investment casting https://en.wikipedia.org/wiki/Investment_casting

Module Objective:

Casting process general steps are - Mold making -Melting -Mold filling -Cooling and solidification -Removal of the part. In this module you will learn:

1. The principles and applications of casting processes; and the classification of casting methods: Sand casting, Die casting, and Investment casting
2. How to apply basic engineering analysis to estimate the solidification time for a casting process and shrinkage.
3. Design guidelines
4. Review of "Engine Block Manufacturing Process" as an example

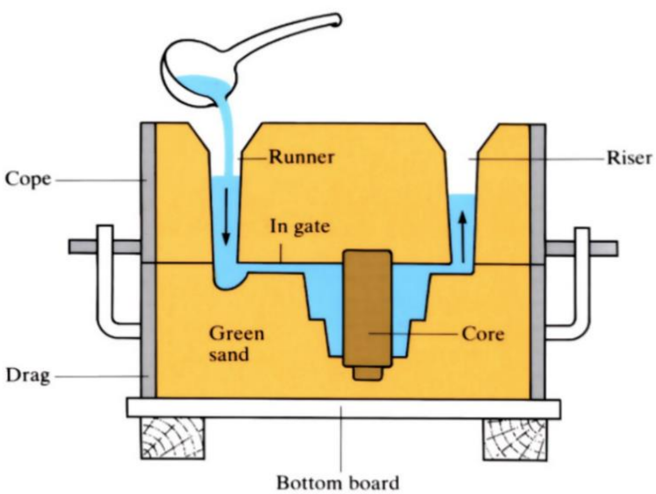
 Casting is labor intensive, to get an idea, be patient and watch this video:

Casting methods:

1. Sand casting,
2. Die casting,
3. Investment casting

Sand Casting:

Sand casting is one of the oldest, and still the most common form of casting. Due to the refractive nature of the sand mold, sand casting (unlike die casting) has a longer solidification time. Sand casting can be used to manufacturing anything from pipefittings, medallions, and cast-iron skillets, to large diesel engines and propellers. Sand casting parts have low surface quality and machining is often required for some of surfaces. It is relatively labor-intensive process. In sand casting, mold filling is driven by gravity; therefore, it requires meticulous attention to flow and shrinkage.
The following figure shows the schematic of a sand-casting process. Here we have the two mold halves which are called the cope and the drag. There is a pathway by which your molten metal is poured into the mold and flows into the cavity that is represented by the pattern to which the sand is molded during the mold making process. The riser is sort of reservoirs of metal that are there to counteract shrinkage. As the metal cools, it shrinks, so the excess metal in the riser and the pressure had created by the riser helps counteract shrinkage.



www.open.edu/openlearn

Mold cavity is made by packing sand around a pattern. Sand used for mold is usually 90% sand, and 10% clay plus water. The interior geometry is created by a core. Then the pattern is removed, and the cavity gets the desired form.

Read more here: https://www.open.edu/openlearn/science-maths-technology/engineering-technology/manupedia/sand-casting

Sand is moulded by hand or machined, around a wooden or metal pattern that can be withdrawn to leave a cavity of the required shape in the sand. Access to the mould cavity for molten metal entry is provided via a pouring basin sprue, runner, riser and in-gate system moulded in the top and bottom halves of the mould. Cores are used to form holes in the castings.

Most metals and alloys (except the reactive and refractory (extraordinarily resistant to heat and wear) metals such as titanium and tungsten), can be sand cast in air. Cast irons, the biggest group of casting alloys are cast at 1200–1500 ˚C. Because of their higher melting point, steels are not favoured as casting alloys. The second biggest group of casting alloys are the aluminium based alloys. A major problem with aluminium castings is the relatively high shrinkage that occurs during solidification. Copper-based alloys are sand cast with additions of zinc, tin and lead, which has a large application for Babbitt bearing. (examples of circular saw guide pads are shown in the class).

Die Casting:

Die casting, involves a reusable mold set. In some ways, die casting is analogous to injection molding yet for metals rather than polymers. Die casting is a metal casting process that is characterized by forcing molten metal under high pressure into a mold cavity. The mold cavity is created using two hardened tool steel dies which have been machined into shape and work similarly to an injection mold during the process. Most die castings parts are made from non-ferrous metals, specifically zinc, copper, aluminium, magnesium, lead, pewter, and tin-based alloys. Several automobile components are manufactured using die casting, including pistons, cylinder heads, and engine blocks. Other common die cast parts include propellers, gears, bushings, pumps, and valves. There are two methods, and hence, two main types of die casting machines - hot chamber machines (used for alloys with low melting temperatures, such as zinc) and cold chamber machines (used for alloys with higher melting temperatures, such as aluminum).

Hot Chamber method:

(click on the images for the video link)

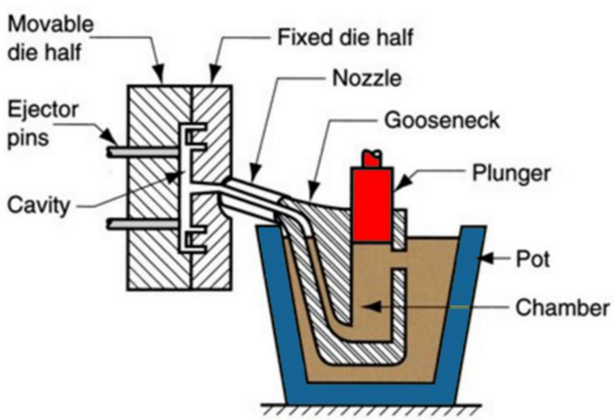


Image source: https://www.cwmdiecast.com/blog/2016/05/24/die-casting-101-hot-chamber-vs-cold-chamber/

Cold Chamber method:

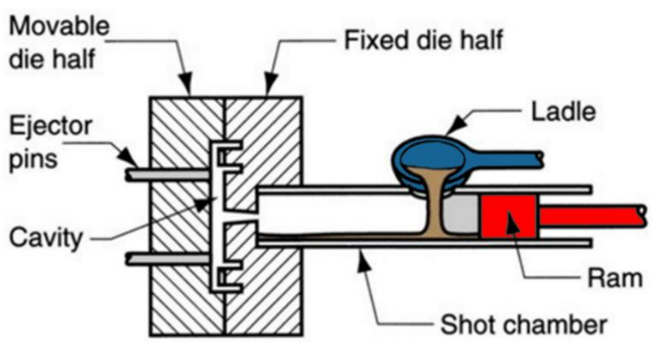


Image source: https://www.cwmdiecast.com/blog/2016/05/24/die-casting-101-hot-chamber-vs-cold-chamber/

The main reason for choosing cold chamber die casting over hot chamber is the metal which you are casting is corrosive.

Compared to sand casting, die casting requres higher pressure for mold filling, required pressure is in a range of 1000 MPa. Cycle time is faster than sand casting, it is usually about 10-15 seconds. It uses permananet molds, dies must be made from tool-grade steel or other special material, due to heat which may induce cracking and corrosion. Compared with sand casting, it has a better surface finish. In general, die casting has the following advantages and disadvantages:

Die casting advantages:

- High dimensional accuracy is achievable
- Fast production rate
- Thinner walls are achievable when compared to investment casting (0.6mm -0.8mm)
- Wide range of possible shapes
- Good finish (1 µm - 2.5 µm) (depending on purpose not all parts will require extra finishing)

Die casting disadvantages:

- High initial cost (Cost of molds and machine set up). Therefore, a large production volume is required to make the process cost effective
- Some porosity is common with die casting
- Die casting is limited to high fluidity metals (Zinc, Aluminium, Magnesium, Copper, Lead and Tin)

The process cycle for die casting consists of five main stages.

1. **Clamping**
   - The first step is the preparation and Each die half is first cleaned from the previous injection and then lubricated to facilitate the ejection of the next part, then the two halves of the die are clamped.

2. **Injection**
   - The molten metal, which is maintained at a set temperature in the furnace, is transferred into a chamber where it can be injected into the die.

3. **Cooling**
   - The molten metal that is injected into the die will begin to cool and solidify once it enters the die cavity. When the entire cavity is filled and the molten metal solidifies, the final shape of the casting is formed.

4. **Ejection**
   - After the predetermined cooling time has passed, the die halves can be opened and an ejection mechanism can push the casting out of the die cavity.

5. **Trimming**
   - During cooling, the material in the channels of the die will solidify attached to the casting. This excess material, along with any flash that has occurred are trimmed from the casting by cutting or sawing, or using a trimming press.

Study more from these two links

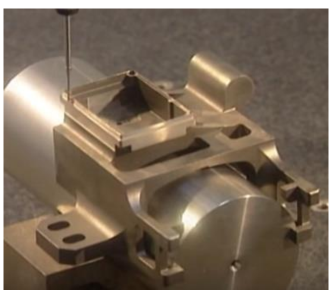
https://www.custompartnet.com/wu/die-casting

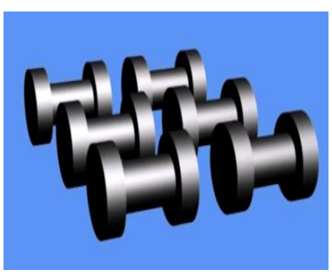
https://www.cwmdiecast.com/blog/2016/05/24/die-casting-101-hot-chamber-vs-cold-chamber/

Investment Casting (also known as: Lost Wax Casting):

Investment casting was developed over 5000 years ago and can trace its roots back to ancient Egypt and China. Parts manufactured in industry by this process include dental fixtures, gears, cams, ratchets, jewelry, turbine blades, machinery components and other parts of complex geometry. Investment casting is used to create complex geometries such as jewelry and aircraft turbine blades. Parts made by investment casting typically have high quality surfaces due to the use of a wax template. The ceramic shell allows investment casting to be used for high melting point metals.

Investment casting is a manufacturing process in which a wax pattern is coated with a ceramic material. Once the ceramic material is hardened its internal geometry takes the shape of the casting. The wax is melted out and molten metal is poured into the cavity where the wax pattern was. The metal solidifies within the ceramic mold and then the metal casting is broken out, using vibration. This manufacturing technique is also known as the lost wax process.

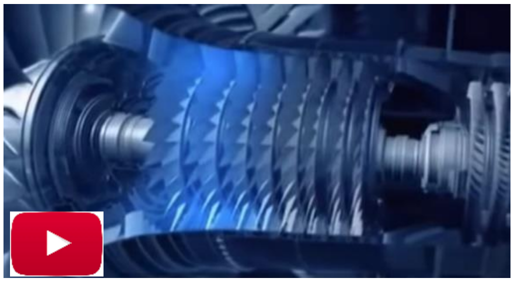




Use of wax template enables good surface finish. The ceramic shell enables casting of high melting point metals. It is very labor intensive. It is suitable for complex geometry, high tolerance and fine features, like Jewelry. It is also used when we need smooth surface finish, which obtaining by machining is not possible, such as Jet engine parts. This process is compatible with high temperature alloys, like Jet engine parts. Investment casting makes production of very complex geometry possible (we can use 3D printing of Wax to create the initial wax geometry)

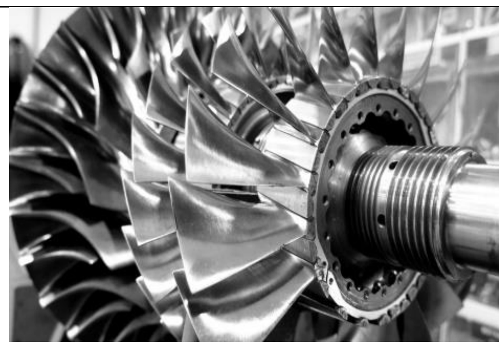
Reading more on Investment Casting Wax Models ***(click for the link)***

Jet engines spin at very high speeds, operate at very high temperatures. At the hot section of the engine, which is basically the center, you have the highest temperature turban blades. And for these turban blades to be so reliable, they need to maintain their strength under an incredibly large number of cycles of rotation at high temperature. Investment casting is used to create these blades out of special high temperature alloys, called super alloys, which titanium is often a component of these alloys. Careful control of solidification can result in single crystal blades with very high strength under cyclic load and high temperature. A single crystal turbine blade is produced by carefully controlling the solidification pathway. The process is designed to ensure that only a single crystal persists during the entire solidification process. Here you can watch a video, turbine blades from Rolls Royce:



Which process, sand, die, or investment casting to choose?

Application of Sand, Die, and Investment Castings:

Sand casting	Large parts, rough surface finish	
Die casting	Smaller parts, precision features, good surface finish	
Investment casting	Complex curves, good surface finish, complex internal cavities, higher melting point materials,	

Comparing the attributes:

	Cost	**Rate**	**Quality**	**Flexibility**
Sand Casting	Low	Low	Low	Medium
Die Casting	High	High	Medium	Low
Investment Casting	High	Low	High	Medium

Engineering Analysis:

Key parameters in casting is the required time for solidification and shrinkage.

Melting point:

3000℃

Tungsten

Silicon Carbide

Alumina Al_2O_3

2000℃

Platinum, Titanium

1500℃ **Steel, Iron**

1000℃ **Copper, Bronze, Brass**

Aluminium

500℃ **Zinc, Tin**

Solidification time:

Chvorinov's rule:

Sand: $t_{solidify} = B.(\frac{V}{A})^2$

Die: $t_{solidify} = B.(\frac{V}{A})$

V: volume of the casting

A: Surface area of the casting

B: mold constant (It depends on the properties of the metal, such as density, heat capacity, heat of fusion and superheat, and the mold, such as initial temperature, density, thermal conductivity, heat capacity and wall thickness.)

B can be calculated from this formula:

$$B = \left(\frac{\rho_m L}{T_m - T_0}\right)^2 \left(\frac{\pi}{4k\rho C_p}\right)\left(1 + \left(\frac{C_m(T_{pour} - T_m)}{L}\right)^2\right)^2$$

T_m = Melting temperature of the liquid (in kelvins),
T_0 = Initial temperature of the mold (in kelvins),
ΔTs = $T_{pour} - T_m$ = superheat (in kelvins),
L = Latent heat of fusion (in [J·kg−1]),
k = thermal conductivity of the mold (in [W·m−1·K−1)]),
ρ = density of the mold (in [kg·m−3]),
C_p = specific heat of the mold (in [J·kg−1·K−1]),
ρ_m = density of the metal (in [kg·m−3]),
C_m = specific heat of the metal (in [J·kg−1·K−1]).

Shrinkage:

The size and shape of the pattern must take into account the relative amount of shrinkage and the change in shape that can occur on solidification. Here is an approximation of different metals shrinkage range:

No	Metal	Shrinkage (%)
1	Gray cast iron	1
2	White cast iron	2
3	Aluminium Alloys	1.3
4	Magnesium Alloys	1.3
5	Copper Alloys	1.3
6	Brass	1.5
7	Phosphor Bronze	1.5
8	Aluminium Bronze	2
9	Steel	2.5

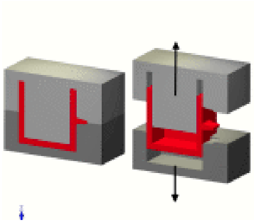
Source: Manufacturing Engineering and Technology, by Kalpakiian and Schmid

Defects:

The common defect in casting is Void and cavity. Air may enter into casting and causes turbulent flow. As a result, the bubbles may be trapped into the casting leading to voids. Also, oxygen will react with the molten metal causing defects. Also, a misrun is the phenomenon of solidification of the molten metal before the mold is completely filled. This would result in a void in the part.

Design Consideration:

Study from this link:



https://www.custompartnet.com/wu/die-casting

Example for study:

Read from this link: Engine Block Manufacturing Process