



**Important considerations for casting:**

(a) How do we make the pattern.

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

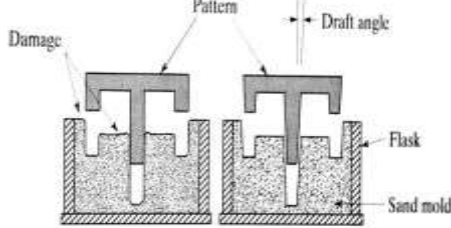
(b) Why is the pattern not exactly identical to the part shape?

- you only need to make the outer surfaces with the pattern; the inner surfaces are made by the core

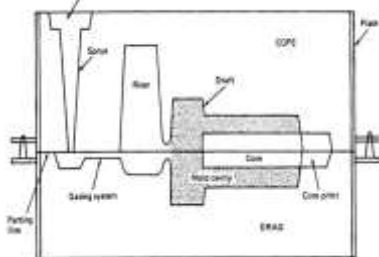
- you need to allow for the shrinkage of the casting after the metal solidifies

(c) If you intersect the plane formed by the mating surfaces of the drag and cope with the cast part, you will get a cross-section of the part. The outer part of the outline of this cross section is called the parting line. The design of the mold is done by first determining the parting line (why ?)

(d) 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. If you know that your part will be made by casting, you should taper the surfaces in the original part design.



**Figure 3. Taper in design**



**Figure 4. Design components of a mold showing chaplets**

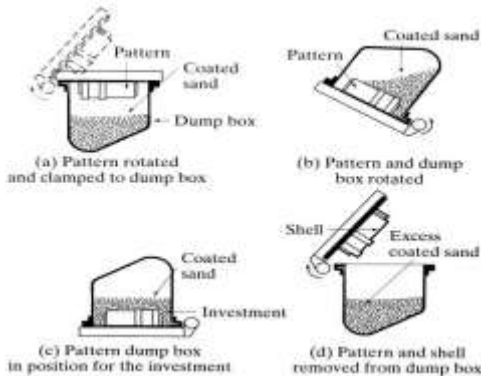
**Shell-mold casting**

- Each heated half-pattern is covered with a mixture of sand and a thermoset resin/epoxy binder. The binder glues a layer of sand to the pattern, forming a shell. The process may be repeated to get a thicker shell.

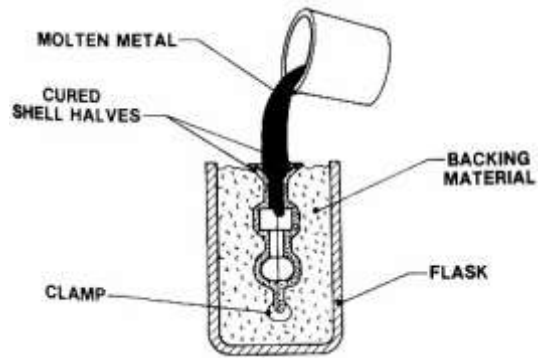
- The assembly is baked to cure it.

- The patterns are removed, and the two half-shells joined together to form the mold; metal is poured into the mold.

- When the metal solidifies, the shell is broken to get the part.



**Figure 5. Making the shell-mold**



**Figure 6. Shell mold casting**

**Expendable-pattern casting (lost foam process)**

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. The pattern is removed, and used for the casting process, as follows:

- The pattern is dipped in a slurry of water and clay (or other refractory grains); it is dried to get a hard shell around the pattern.

- The shell-covered pattern is placed in a container with sand for support, and liquid metal is poured from a hole on top.

- The foam evaporates as the metal fills the shell; upon cooling and solidification, the part is removed by breaking the shell.

The process is useful since it is very cheap, and yields good surface finish and complex geometry. There are no runners, risers, gating or parting lines – thus the design process is simplified. The process is used to manufacture crank-shafts for engines, aluminum engine blocks, manifolds etc. polystyrenepatternpatternssupportsandmoltenmetalpolystyreneburns;gas

escapespolystyrenepatternpatternssupportsandmoltenmetalpolystyreneburns;escapes

**Plaster-mold casting**

The mold is made by mixing *plaster of paris* (CaSO<sub>4</sub>) with talc and silica flour; this is a fine white powder, which, when mixed with water gets a clay-like consistency and can be shaped around the pattern (it is the same material used to make casts for people if they fracture a bone). The plaster cast can be finished to yield very good surface finish and dimensional accuracy. However, it is relatively soft and not strong enough at temperature above 1200°C, so this method is mainly used to make castings from non-ferrous metals, e.g. zinc, copper, aluminum, and magnesium.

Since plaster has lower thermal conductivity, the casting cools slowly, and therefore has more uniform grain structure (i.e. less warpage, less residual stresses).

**Ceramic mold casting**

Similar to plaster-mold casting, except that ceramic material is used (e.g. silica or powdered Zircon ZrSiO<sub>4</sub>). Ceramics are refractory (e.g. the clay hotpot used in Chinese restaurants to cook some dishes), and also have higher strength than plaster.

- The ceramic slurry forms a shell over the pattern;

- It is dried in a low temperature oven, and the pattern is removed

- Then it is backed by clay for strength, and baked in a high temperature oven to burn off any volatile substances.

- The metal is cast same as in plaster casting.

This process can be used to make very good quality castings of steel or even stainless steel; it is used for parts such as impeller blades (for turbines, pumps, or rotors for motor-boats).

#### **Investment casting (lost wax process)**

This is an old process, and has been used since ancient times to make jewellery – therefore it is of great importance to HK. It is also used to make other small (few grams, though it can be used for parts up to a few kilograms). The steps of this process are shown in the figure 10 below.

An advantage of this process is that the wax can carry very fine details – so the process not only gives good dimensional tolerances, but also excellent surface finish; in fact, almost any surface texture as well as logos etc. can be reproduced with very high level of detail.

#### **Vacuum casting**

This process is also called counter-gravity casting. It is basically the same process as investment casting, except for the step of filling the mold (step (e) above). In this case, the material is sucked upwards into the mould by a vacuum pump. The figure 9 below shows the basic idea – notice how the mold appears in an inverted position from the usual casting process, and is lowered into the flask with 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, etc. (see Figure 10)

#### **Permanent mold casting**

Here, the two halves of the mold are made of metal, usually cast iron, steel, or refractory alloys. The cavity, including the runners and gating system are machined into the mold halves. For hollow parts, either permanent cores (made of metal) or sand-bonded ones may be used, depending on whether the core can be extracted from the part without damage after casting. The surface of the mold is coated with clay or other hard refractory material – this improves the life of the mold. Before molding, the surface is covered with a spray of graphite or silica, which acts as a lubricant. This has two purposes – it improves the flow of the liquid metal, and it allows the cast part to be withdrawn from the mold more easily. The process can be automated, and therefore yields high throughput rates. Also, it produces very good tolerance and surface finish. It is commonly used for producing pistons used in car engines, gear blanks, cylinder heads, and other parts made of low melting point metals, e.g. copper, bronze, aluminum, magnesium, etc.

#### **Die casting**

Die casting is a very commonly used type of permanent mold casting process. It is used for producing many components of home appliances (e.g. rice cookers, stoves, fans, washing and drying machines, fridges), motors, toys and hand-tools – since Pearl river delta is a largest manufacturer of such products in the world, this technology is used by many HK-based companies. Surface finish and tolerance of die cast parts is so good that there is almost no post-processing required. Die casting molds are expensive, and require significant lead time to fabricate; they are commonly called dies. There are two common types of die casting: hot- and cold-chamber die casting.

- In a *hot chamber process* (used for Zinc alloys, magnesium) the pressure chamber connected to the die cavity is filled permanently in the molten metal. The basic cycle of operation is as follows: (i) die is closed and gooseneck cylinder is filled with molten metal; (ii) plunger pushes molten metal through gooseneck passage and nozzle and into the die cavity; metal is held under pressure until it solidifies; (iii) die opens and cores, if any, are retracted; casting stays in ejector die; plunger returns, pulling molten metal back through nozzle and gooseneck; (iv) ejector pins push casting out of ejector die. As plunger uncovers inlet hole, molten metal refills gooseneck cylinder. The hot chamber process is used for metals that (a) have low melting points and (b) do not alloy with the die material, steel; common examples are tin, zinc, and lead.

- In a *cold chamber process*, the molten metal is poured into the cold chamber in each cycle. The operating cycle is (i) Die is closed and molten metal is ladled into the cold chamber cylinder; (ii) plunger pushes molten metal into die cavity; the metal is held under high pressure until it solidifies; (iii) die opens and plunger follows to push the solidified slug from the cylinder, if there are cores, they are retracted away; (iv) ejector pins push casting off ejector die and plunger returns to original position. This process is particularly useful for high melting point metals such as Aluminum, and Copper (and its alloys).

#### **Centrifugal casting**

Centrifugal casting uses a permanent mold that is rotated about its axis at a speed between 300 to 3000 rpm as the molten metal is poured. Centrifugal forces cause the metal to be pushed out towards the mold walls, where it solidifies after cooling. Parts cast in this method have a fine grain microstructure, which is resistant to atmospheric corrosion; hence this method has been used to manufacture pipes. Since metal is heavier than impurities, most of the impurities and inclusions are closer to the inner diameter and can be machined away. surface finish along the inner diameter is also much worse than along the outer surface.

Figure 12. Centrifugal casting schematic [source: Kalpakjian & Schmid]

#### **Casting design and quality**

Several factors affect the quality/performance of cast parts – therefore the design of parts that must be produced by casting, as well as the design of casting molds and dies, must account for these. You may think of these as design guidelines, and their scientific basis lies in the analysis – the strength and behavior of materials.

#### **Corners, angles and section thickness**

Many casting processes lead to small surface defects (e.g. blisters, scars, scabs or blows), or tiny holes/impurities in the interior (e.g. inclusions, cold-shuts, shrinkage cavities). These defects are a problem if the part with such a defect is subject of varying loads during use. Under such conditions, it is likely that the defects act like cracks, which propagate under repeated stress causing fatigue failure. Another possibility is that internal holes act as stress concentrators and reduce the actual strength of the part below the expected strength of the design. Figure 14 shows the variation of stress in the presence of holes to illustrate the problem.

#### **To avoid these problems**

- (a) sharp corners should be avoided (these behave like cracks and cause stress concentration)
- (b) Section changes should be blended smoothly using fillets

(c) Rapid changes in cross-section areas should be avoided; if unavoidable, the mold must be designed to ensure that metal can flow to all regions and mechanism is provided for uniform and rapid cooling during solidification. This can be achieved by the use of chills or incorporating fluid-cooled tubes in the mold.

**These principles are illustrated in the figures below.**

It is not good for a casting to have surfaces whose normal is perpendicular to the direction along which the part will be ejected from the mold. This can cause the part to stick in the mold and forceful ejection will cause damage to the part (and mold, if the mold is re-usable). Therefore all such surfaces are tilted by a small angle (between  $0.5^\circ$  and  $2^\circ$ ) so as to allow easy ejection. Draft angles on the inner surfaces of the part are higher, since the cast part also shrinks a little bit towards the core during solidification and cooling.

### Conclusion

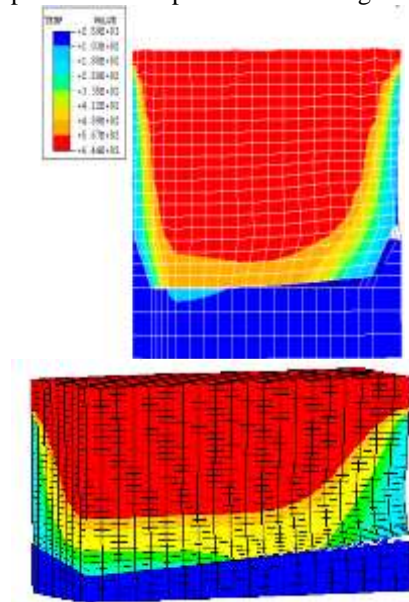
The development and increased accuracy of simulation tools will provide the casting designers the ability to consider the manufacturing and material selection conditions at early stages in the design process. The benefits of this kind of simulations are, beside optimizing the casting process and predicting the mechanical performance of complex components, the cost effectiveness and the shorter time to market.

Additionally, it should be mentioned that this simulation tool is still under development and comprises only Si levels up to 12%, Cu up to 4%, Mg levels up to 0.5% and Fe up to 0.7%. The iron level will be extended up to  $\sim 1-1.5\%$ , which are levels found in high pressure die cast components.

More research should be devoted to developing means to understand and model to role of micro-, and macro porosity, the

iron rich constituents and other impurities on the mechanical properties of these kinds of engineering alloys.

The thermal profile of workpiece shows in Figs.7



**Fig.7. Thermal profile of workpiece**

### Reference

- Magnus Wessén, Ingvar L Svensson, Salem Seifeddine, Jörgen Olsson, Wilfried Schäfer, MCWASP, (2006).  
 Campbell J, Castings, 2nd Ed, Butterworth- Heinemann Ltd, Oxford (2003), ISBN 0 7506 4790 6.  
 P. Kumar, J.L. Gaidhar, AFS Transaction, (1997), pp. 635-638.