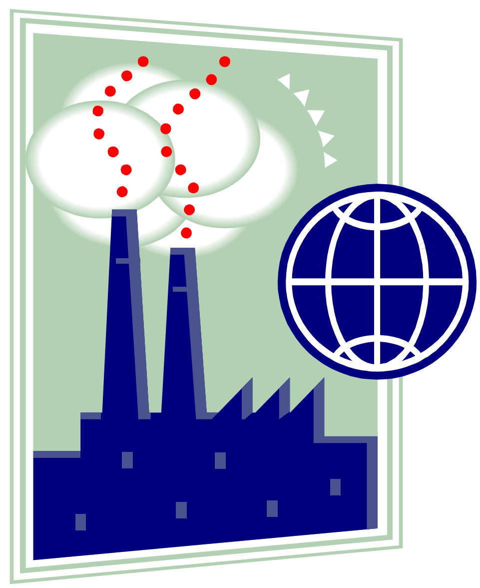
SMJ 3703

MANUFACTURING PROCESSES

CHAPTER 4

CASTING



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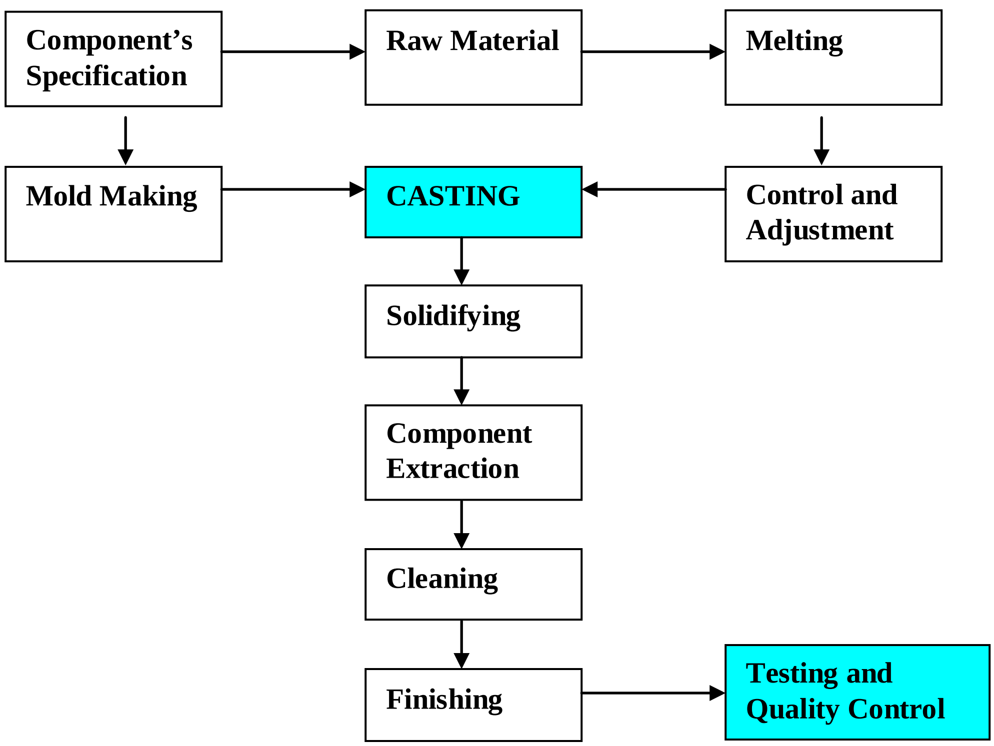
1.0 INTRODUCTION

Casting process basically involves pouring a molten metal into a mold patterned after the part to be manufactured, allowing it to cool, and then removing the shaped metal from the mold. As with all other manufacturing processes, an understanding of the fundamentals is essential, both for the production of good quality and economical castings, and also to establish proper techniques for mold design and casting practice.

It is one of the oldest methods of manufacturing process which first used in 4000 B.C. This process is able to produce from simple to complicated design products, and, small to big size products. For example, engine block, shaft, piston, valve, wheel of train, and etc. Below show the complete flow chart of the whole casting process.



So, why do we need to consider using casting process? The reason is;

- **Ability to produce complicated shape design's product.**
- **Some metals are more suitable to be cast than any other processes.**
- **Project development can be made easy, due to only one part is being formed.**
- **Ability to cast some very hard to process material.**
- **Ability to produce bulk and heavy component.**
- **Ability to obtain good product characteristics.**
- **Economical.**

There are 6 basic factors involved in the casting process, they are;

- **Mold cavity**
- **Melting process**
- **Pouring technique**
- **Solidification process**
- **Part removal process**
- **Post processing**

2.0 MELTING

The selection of melting process has to take into account for casting in a few of the area below;

- **Cost (Equipment, and heating sources),**
- **Suitability with materials,**
- **Quantity and melting rate required,**
- **Melting point of metals, and**
- **Environmental factor.**

There are a few types of melting equipment (furnace), they are;

- **Cupola,**
- **Open-Hearth furnace,**
- **Rotary furnace,**
- **Crucible furnace,**
- **Arc furnace,**
- **Induction furnace, and**
- **Resistance furnace.**

3.0 MOLD AND CASTING STEPS

3.1 Types of mold;

3.1.1 Permanent mold;

It is made of metal that maintain their strength at high temperature. They are used repeatedly and is designed to suit repeating application. Because metal mold are better heat conductor, the solidifying is subjected to a higher rate of cooling which affect the microstructure and grain size. Material used for making the mold can be cast iron, alloy, graphite, bronze and etc.

3.1.2 Non-Permanent mold/Expendable mold;

It is normally made of sand, plaster, ceramics and similar material. It is generally mixed with various binders, or bonding agents. It is capable of withstanding high temperature of molten metal. After the molten is solidified, the mold is broken up to obtain the finish goods.

3.2 Types of pattern;

3.2.1 Permanent pattern;

This kind of pattern can be used repetitively in producing numbers of mold. The mold produced requires a parting line to extract the mold.

3.2.2 Non-Permanent pattern/Expendable pattern;

Each and every pattern only will be able to produce one mold. So, this type of mold doesn't require any parting line. Pattern of this type is generally removed through heating.

3.3 Pattern's function is to produce mold, other function which includes; Provide gating system, Used as core, Determined the parting line, Determined the component location, and Minimize defects in casting. Pattern allowed a mold to be made around it. It acts as a duplication of the component to be produced. Pattern size determined the casting size, however, the pattern size is to be modified so to cope with the few conditions such as; Shrinkage (Normally, metal will somehow shrink to a certain degree after they cooled down. For example, carbon alloy will shrink 11.8% after cooling down.), Machine tolerance, Tapered, Flowing systems, and Core formation.

4.0 PATTERN

Pattern in used to mold the sand mixture into the shape of the casting. They may be made of wood, plastic or metal. The selection of a pattern material depending on the size and shape of the casting, the dimensional accuracy, the quantity of casting required, and also the molding process. Because pattern are used repeatedly to make molds, the strength and durability of the material selected for patterns must reflect the number of castings that the mold will produce. They may be made of a combination of materials to reduce wear in critical regions. Patterns are usually coated with a parting agent to facilitate their removal from the molds. Pattern also can be designed with a variety of features to fit application and economic requirements, such as; Split pattern, Follow board pattern, Loose piece pattern, Match plate pattern, and Cope and drag pattern.

5.0 PATTERN MATERIAL

5.1 Wood

This is one of the mostly used materials for pattern. Type of wood normally used is white pine, ork, shisham, maple, cherry, mahagony, birch, and etc.

5.1.1 Advantages

- **Low cost,**
- **Easily obtained,**
- **Easily produced and joined,**
- **Light weight, and**
- **Easily repaired.**

5.1.2 Disadvantages

- **Easily spoiled,**
- **Low wear resistance, and**
- **Absorb moisture, easily change size and shape.**

5.2 Metal

Metal is selected when repeating casting is desired. Types of metal normally used includes, aluminum and its alloy, cast iron, copper, zinc, and etc.

5.2.1 Advantages

- **Resistance to moisture absorption,**
- **Higher strength,**
- **Tougher,**
- **Close tolerance can be obtained easily, and**
- **Stability against the environment.**

5.2.2 Disadvantages

- **Hard to repair,**
- **Heavier if compared to wood,**
- **Easily rusted, and**
- **High cost.**

5.3 Plastic

It is used normally for small size and complicated pattern. The type of plastic normally used includes, epoxy and polystyrene.

5.3.1 Advantages

- Resistance to moisture absorption,
- Light weight,
- Corrosion resistance and chemical attack resistance, and
- Non-sticking to mold thus can be removed from mold easily.

5.3.2 Disadvantages

- Easily broken
- Poor shock resistance.

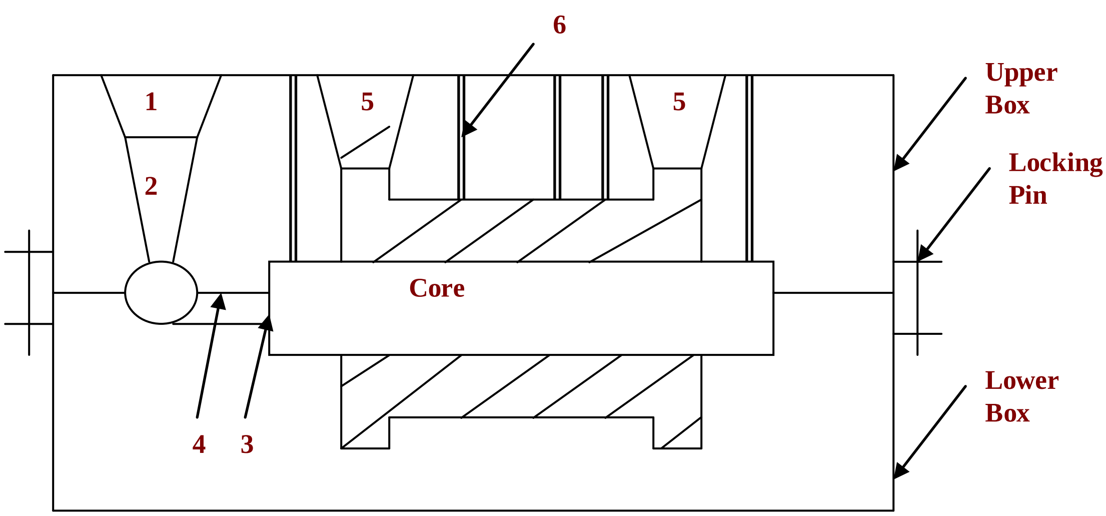
5.4 Wax

It is used specially for lost wax casting. Its advantages include;

- Ability to produce good surface finishing goods,
- Ability to produce close tolerance goods, and
- Pattern can be join together easily.

6.0 GATING SYSTEM

The objective of the gating system is to allow metal to be poured into the mold, and also to allow the molten metal to fill the mold at the suitable rate and temperature. Other requirement is to; Avoid oxidation, Avoid air trap, Avoid mold wear, Reduce the casting temperature, Allow flow of molten metal, and Minimize the usage of metal. Below shown an example of gating system in casting,



1 –Pouring Basin - Allow molten metal to be poured.

2 –Sprue - Main pouring tunnel, avoiding air trap.

3 –Gate - Final stage of runner before molten metal entered the mold.

4 –Runner - A flow path between sprue and gate.

5 –Riser - Avoid effect of shrinkage, allow air, steam and gas to escape, and giving sign that there is already enough molten metal.

6 –Venting Hole - Allow air and gas to escape.

7.0 SOLIDIFICATION OF METALS

After the molten metal is poured into a mold, a series of events takes place during the solidification of the casting and its cooling to ambient temperature. These events greatly influence the size, shape, uniformity, and chemical composition of the grains formed throughout the casting which in turn will influence its overall properties. The significant factors affecting these events are the type of metal; thermal properties of both the metal and also the mold; the geometric relationship between volume and surface area of the casting; and finally the shape of the mold.

8.0 TYPES OF CASTING PROCESSES

8.1 Sand casting,

- **Green sand mold,**
- **Baked sand mold,**
- **CO_2 process,**
- **Shell molding,**
- **Evaporative pattern casting.**

8.2 Permanent mold casting,

- **Gravity die casting,**
- **Squeezing casting,**
- **Compression molding,**
- **Slush casting.**

8.3 Refractory aggregate processes,

- **Plaster casting,**
- **Shaw casting,**
- **Investment casting. (A.K.A. lost wax process)**

8.4 Others.

- **Centrifugal casting.**
- **Continuous casting.**

9.0 PROCESS FACTORS

9.1 Molten Metal Problems

Reaction of the metal and its environment can lead to poor quality castings. Oxygen and molten metal react to form "slag" or "dross." These impurities can become trapped in castings to impair surface finish, machinability, or reduce the mechanical properties of the castings.

9.2 Fluidity

Molten metal must flow then freeze into the desired shape. Incorrect flow characteristics can result in "short" shots, incorrect part tolerances, cracks in castings, voids, etc.

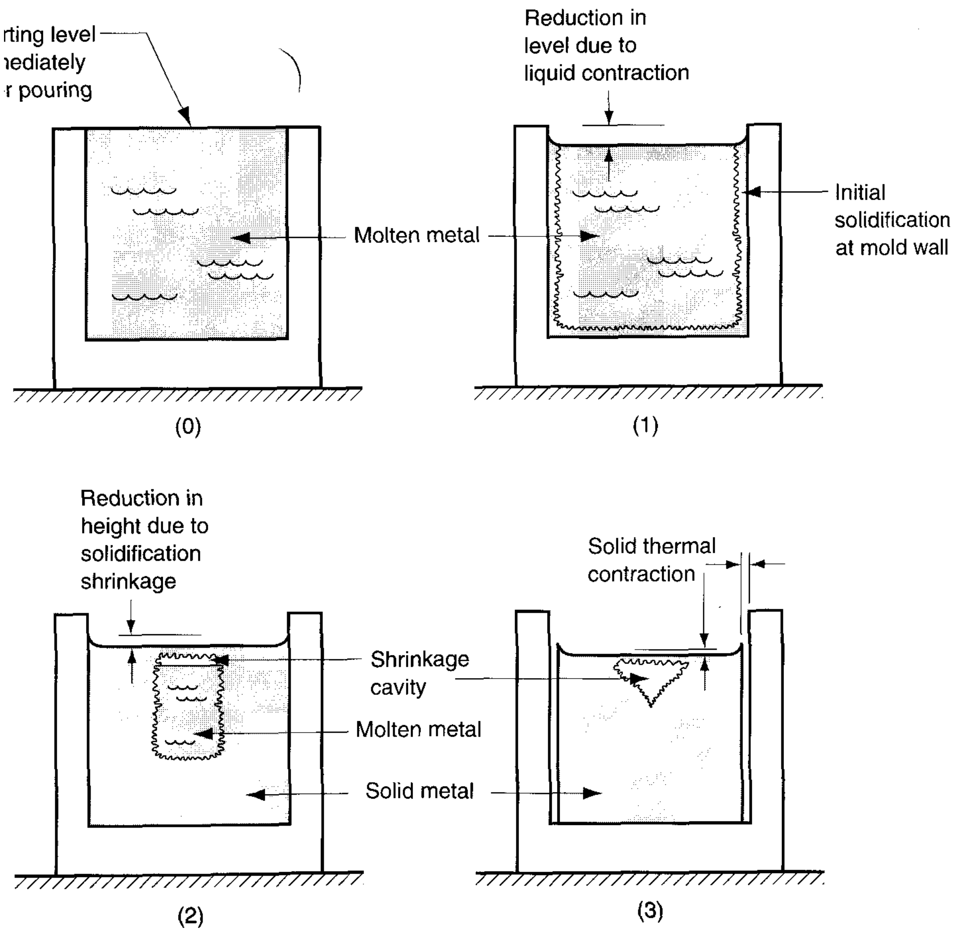
9.3 Gating System

Correct design of the gating system is a must. Gating system controls the speed, rate, and delivery of molten material into the mold cavity.

9.4 Patterns

- **Shrinkage allowance**
  - **Cast Iron = 1/10 - 1/8 in/ft**
  - **Aluminum = 1/8 - 5/32 in/ft**
  - **Brass = 3/16 in/ft**
- **Amount of draft**
- **Finish material allowance**
- **Final dimensional accuracy of the casting**

10.0 SHRINKAGE



Because of the thermal expansion characteristics, metal shrink (contract during solidification and cooling. Shrinkage, which causes dimensional changes and, sometimes, cracking, is the result of the following three events;

- **Contraction of the molten metal as it cools prior to its solidification,**
- **Contraction of the metal during phase change from liquid to solid (latent heat of fusion), and**
- **Contraction of the solidified metal (the casting) as its temperature drops to ambient temperature.**

The largest amount of shrinkage occurs during cooling of the casting. The amount of contraction during solidification of various metal is shown below,

Metal	Volumetric contraction due to: Solidification shrinkage, %	Solid thermal contraction, %
Aluminum	7.0	5.6
Aluminum alloy (typical)	7.0	5.0
Gray cast iron	1.8	3.0
Gray cast iron, high carbon	0	3.0
Low carbon cast steel	3.0	7.2
Copper	4.5	7.5
Bronze (Cu–Sn)	5.5	6.0

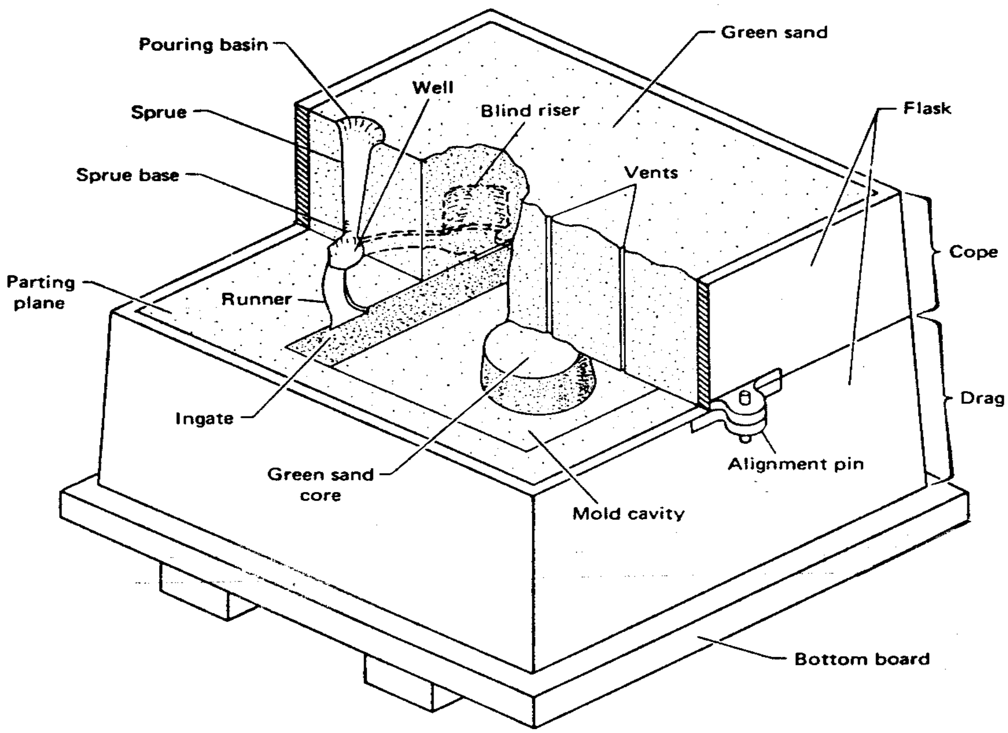
To avoid cracking of the casting, there should be allowance for shrinkage during solidification. In casting with intersecting ribs, the tensile stresses can be reduced by staggering the ribs or by changing the intersection geometry. Pattern dimensions should also provide for shrinkage of the metal during solidification and cooling. Allowances for shrinkage, also known as patternmaker's shrinkage allowances, usually range from 10 mm/m to 20 mm/m.

Normal Shrinkage Allowance for Some Metals Cast in Sand Molds

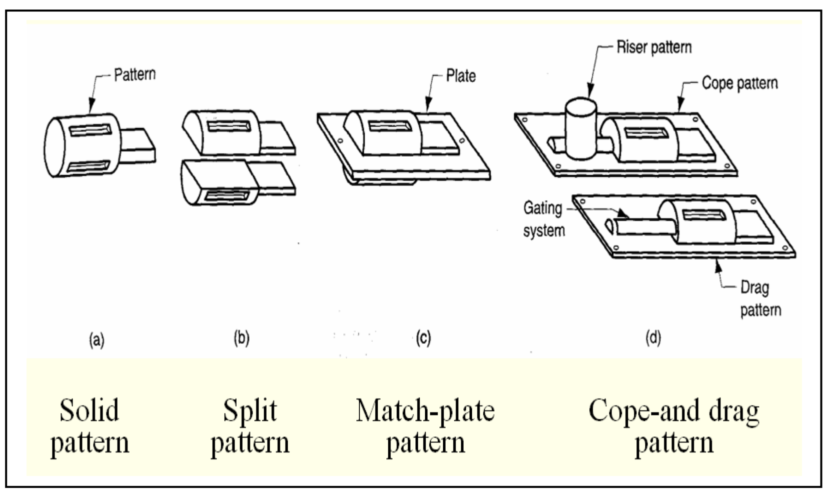
Metal	Percent
Gray cast iron	0.83-1.3
White cast iron	2.1
Malleable cast iron	0.78-1.0
Aluminium alloys	1.3
Magnesium alloys	1.3
Yellow brass	1.3-1.6
Phosphor bronze	1.0-1.6
Aluminium bronze	2.1
High-manganese steel	2.6

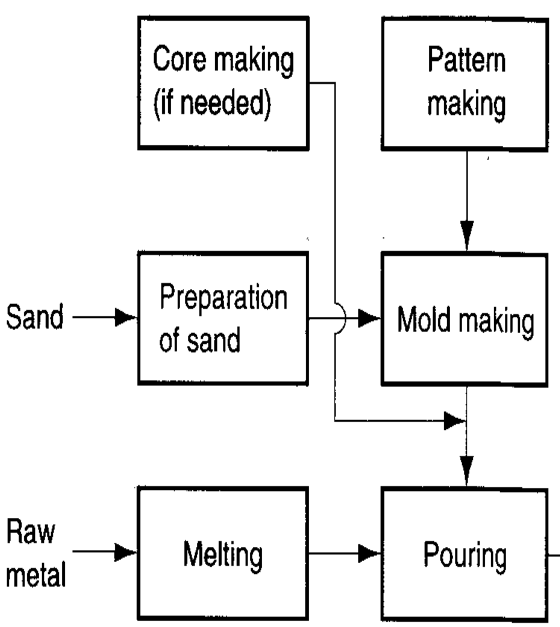
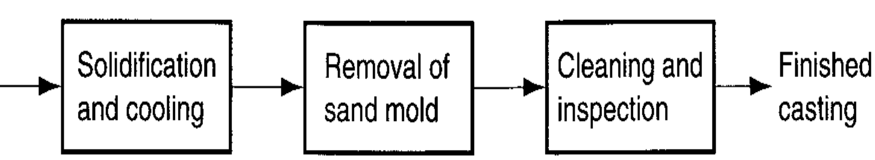
11.0 SAND CASTING

11.1 Sand casting configuration



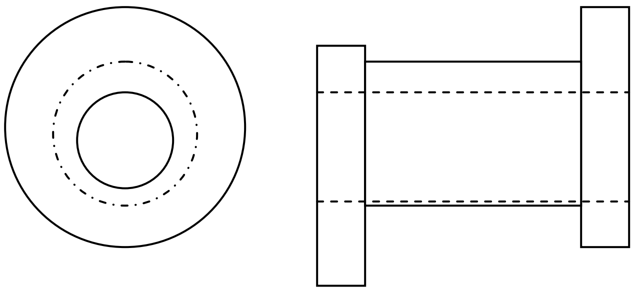
11.2 Sand casting processing



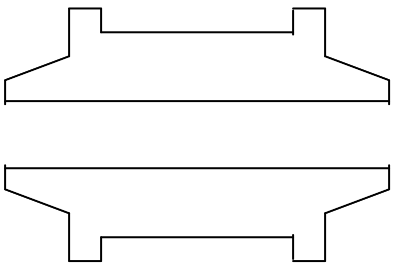



11.3 Sand casting mold making process

- **Producing Pattern and core according to the component drawing,**



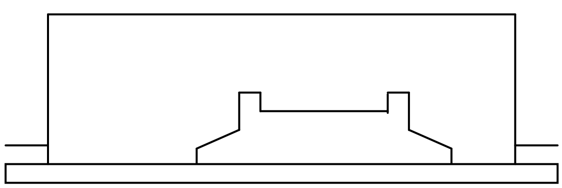
Component drawing



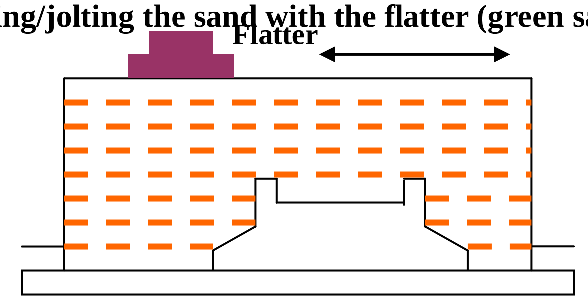
Split pattern

Core

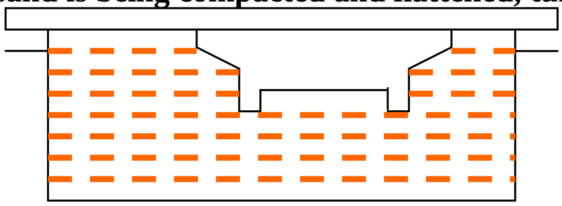
- **A flask is put in an up-side-down position, then place on the plate or something flat,**
- **Put in the lower part of the split pattern, pouring some splitting powder to ease the mold separation later on,**



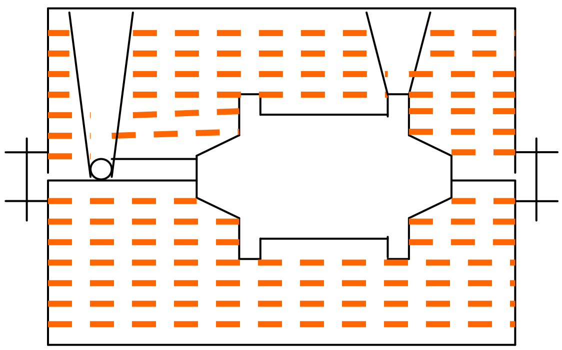
- **Pouring sand mixture into the flask, beginning with find sand and then course sand, compacting/jolting the sand with the flatter (green sand, skin dried or, loam mold),**



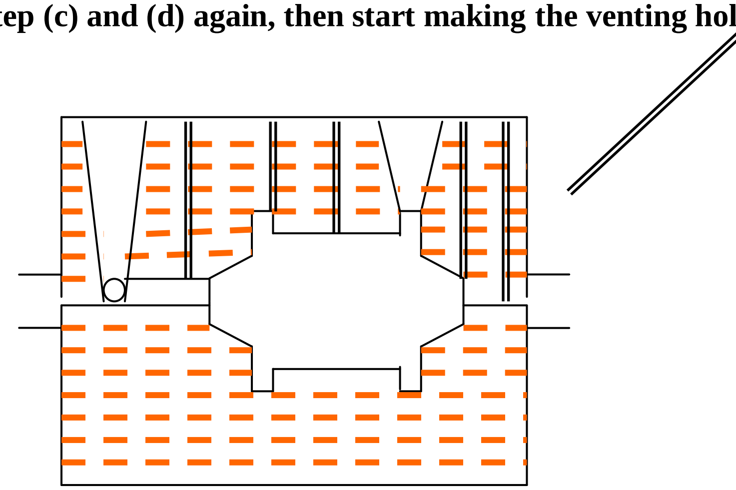
- After the sand is being compacted and flattened, turn the mold up-side down again,



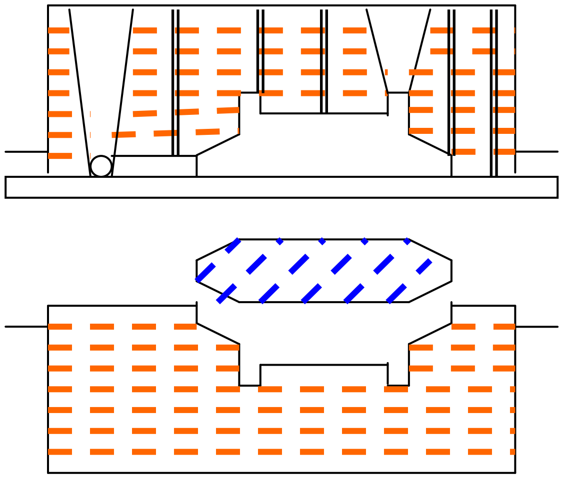
- The upper mold is being made the same way as mentioned from (a) to (d). Pouring basin, sprue, riser, gate, and runner are added to the upper mold. After the upper mold and lower mold is done, match both of them together,



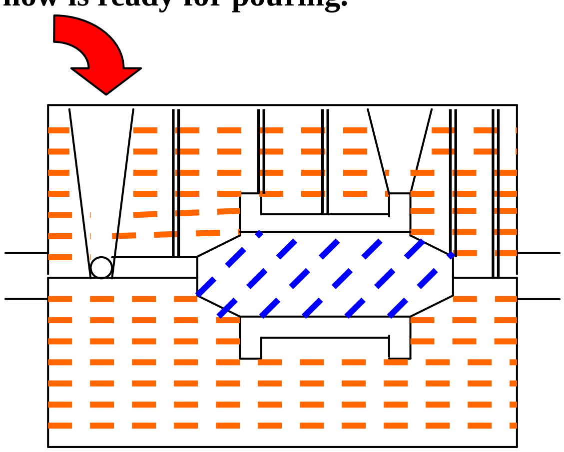
- Repeat step (c) and (d) again, then start making the venting holes using some tiny long metal rod.



- **Take off the upper mold flask again, clean off the dropping sand, inserting the core to its correct location,**



- **The mold now is ready for pouring.**



11.4 Sand casting material

- **Applicable for most metals, some difficulty in encountered in casting include materials like, lead, tin and zinc, also refractory alloys, beryllium, titanium, and zirconium alloys.**

11.5 Process variation

- **Green sand casting: the most common and the cheapest. Associated problems are that the mould has low strength and high moisture content.**
- **Dry sand: core boxes are used instead of patterns. Expensive and time consuming.**
- **Skin-dried sand: the mould is dried to a certain depth. Used in the casting of steels.**

11.6 Types of application

- **Engine blocks,**
- **Manifolds,**
- **Machine tool bases,**
- **Pump housings,**
- **Cylinder heads.**

11.7 Pattern

One piece solid patterns are cheapest to make; split patterns for moderate quantities; match plate patterns for high volume production.

- **Wooden patterns: low volume production only.**
- **Metal patterns: for medium to high volume production.**
- **Hard plastics are increasingly being used.**

11.8 Economic consideration

- **Production rates of 1-60 pieces/hour, but dependent on size.**
- **Lead time ranges from days to several weeks depending on complexity and size of casting.**
- **Material utilization is low to moderate - 20-50% of material lost in runners and risers.**
- **Both mould material and runners and risers may he recycled.**
- **Patterns are easy to make and set, and are reusable.**
- **Pattern material dependent on the number of castings required.**
- **Easy to change design during production. Economical for low production runs. Can be used for one-offs.**
- **Tooling costs are low.**
- **Equipment costs are low. Direct labour costs are moderate to high. Can be labour intensive.**
- **Finishing costs can be high. Cleaning and fettling are important before secondary processing.**

11.9 Design aspects

- **High degree of shape complexity possible. Limited only by the pattern.**
- **Loose piece patterns can be used for holes and protrusions.**
- **All intersecting surfaces must be filleted: prevents shrinkage cracks and eliminates stress concentrations.**
- **Design of gating system for delivery of molten metal into mould cavity important.**
- **Placing of parting line important, i.e. avoid placement across critical dimensions.**
- **Bosses, undercuts and inserts are all possible at low added cost.**
- **Machining allowances are usually in the range 1.5-6 mm.**
- **Draft angle ranges from 1 to 5'.**
- **Minimum section typically 3 mm for light alloys and 6 mm for ferrous alloys.**
- **Sizes range from 20 g to 400 t in weight.**

11.10 Quality issue

- **Moulding sand must be carefully conditioned and controlled.**
- **Most casting defects can be traced to and rectified by sand content.**
- **Casting shrinkage and distortion during cooling governed by shape, especially when one dimension is much larger than the other two.**
- **Extensive flat surfaces are prone to sand expansion defects.**
- **Inspection of castings is important.**
- **High porosity and inclusion levels are common in castings.**
- **Defects in castings may be filled with weld material.**
- **Castings generally have rough grainy surfaces.**
- **Material strength is inherently poor.**
- **Castings have good bearing and damping properties.**
- **If production volumes warrant the cost of a die, close tolerances may be achieved.**
- **Surface detail fair to moderate.**
- **Surface roughness is a function of the materials used in making the mould and is in the range from 3.2 to 50 mm Ra.**
- **Not suitable for close specification of tolerances without secondary processing.**
- **Process capability charts showing the achievable dimensional tolerances using various materials are given below. Allowances of ±0.5 to ±2 mm should be added for dimensions across the parting line.**

11.11 Sand casting advantages and disadvantages in general

11.11.1 Disadvantages

- Part tolerances +/- .01 - .015”
- Poor surface finish
- Limited design freedom
- In hand ramming, process can be labor intensive
- Single use of mold
- Porosity
- Poor dimensional control for some processes
- Poor surface finish for some processes
- Limitation on mechanical properties
- Safety hazard
- Environmental hazard

11.11.2 Advantages

- General tooling costs are low
- Sand in most cases can be reused in some form
- Can handle a wide variety of metals
- Relatively easy process to obtain net shape or near-net shape
- Produce parts with complex geometries, both internally and externally.
- Possible to net shape with no further manufacturing required.
- Large parts can be produced.
- Wide choice of metals.
- Suitable for mass production.

11.12 Green sand mold

It is one of the low cost processes. It is widely used for small and medium component. It is also suitable for big and heavy component. Example of products, machine base, engine block, agricultural equipment, valve, pump, gear, and, piping assembly component.

- Advantages
  - Economic even for low quantity production,
  - Low equipment cost,
  - Suitable for ferrous and non ferrous metal,
  - Moderate worker cost,
  - No size limitation.

- Disadvantages
  - Mold can't be kept for a long time,
  - Course surface finishing, and
  - Wider range of tolerance in finish goods.
  - Mold is not too strong, easily spoiled even when lifted,
  - Ease in mold wearing,
  - Moisture in sand will produced defects,

11.13 BAKED SAND MOLD

The method of preparing a baked sand mold is exactly the same with green sand mold, except the mold produced is dried in an oven/furnace for 1-1.5 hours at a temperature of 200^0C to 300^0C. The product can be produced is exactly the same with green sand mold too. The drying of mold can increase the strength of mold, reduce wearing and cracking of mold.

- Advantages
  - Strong mold, can be removed easily,
  - Mold can be kept for sometimes,
  - Mold is basically harder, better wear
  - Better surface finish,
  - No defects caused by moisture of mold.

- Disadvantages
  - Require additional equipment, i.e. oven/furnace,
  - Extra working cost,
  - Smaller in mold size because mold required to be baked.

11.14 CARBON DIOXIDE PROCESS

Mold materials consist of the mixture of sand with 1.5-6% of Natrium Silicate (Na_2SiO_3) as a bonding agent. Other mixing material includes charcoal and graphite is also being used. Besides being used to produce mold, it has the capability to produce CORE. The mold making steps are more or less similar with green sand molding. After the sand is being compressed, a few venting hole is produced, CO_2 is blow in for 20-30 seconds. Natrium Silicate will react with CO_2 to form a layer of hard silica gel.

- Advantages
  - Better accuracy,
  - Mold can be kept for a long time,
  - Easy in processing.

- **Disadvantages**
  - **Sand is hard to re-use,**
  - **Mold can be exposed to ambient heat for too long,**
  - **Na_2SiO_3 will react with some metal,**
  - **The sand is hard to remove (due to its bonded).**

12.0 INVESTMENT CASTING

12.1 This is also called the lost wax process, mold material consists of fine silica and bonding agent includes water ethyl silicate and acid. Pattern is made from wax or plastic. Pattern is produced by injecting the melted pattern material into the metal mold. The pattern produced is attached to a series of runner and raiser, which is also made by wax or plastic, to form a pattern cluster, also called a tree. Ceramic slurry is cast around the wax pattern, the wax melted out and the metal cast in the ceramic mould. The mould is then destroyed to remove the casting.

12.2 Materials - All metals, including precious, reactive and radioactive alloys (cast in vacuum).

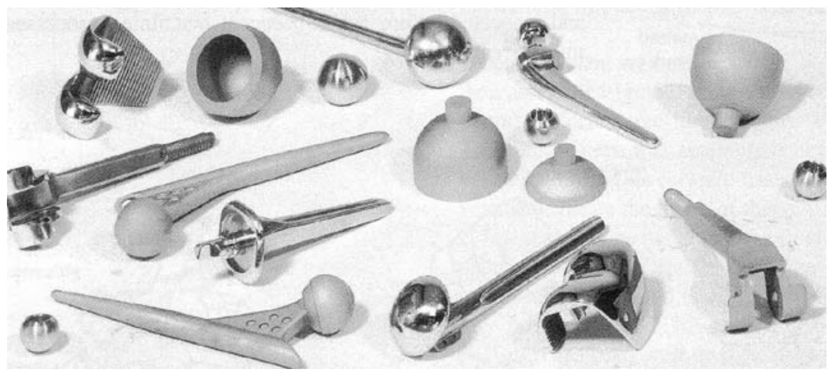
12.3 Economic consideration

- **Production rates of up to 1000 pieces/hour, depending on size.**
- **Lead times are usually several weeks, but can be shorter.**
- **Best suited to metals having high melting temperatures, and/or which are difficult to machine or which have a high cost.**
- **Material utilisation is high.**
- **Pattern costs can be high for low quantities.**
- **Ceramic and wax cores allow complex internal configurations to be produced, but increase the cost significantly.**
- **Wax or plastic patterns can be injection moulded for high production runs.**

12.4 Economics

- **A 'tree' of wax patterns enables many small castings to be handled together.**
- **Suitable for small batches (10-1000) and high volume production.**
- **Tooling costs moderate, but dependent on complexity.**
- **Equipment costs are low to moderate (high when processing reactive materials).**
- **Labour costs are high. Can be labour intensive as many hand operations required.**
- **Low finishing costs. Gates and feeders are removed by machining and the piece may he cleaned by sand/bead blasting.**

12.5 Application



- **Turbine blades.**
- **Machine tool parts.**
- **Aero-engine components.**
- **Pump casings.**
- **Automotive engine components.**
- **Figurines.**
- **Jewellery.**
- **Hip prosthesis**

12.6 Design aspects

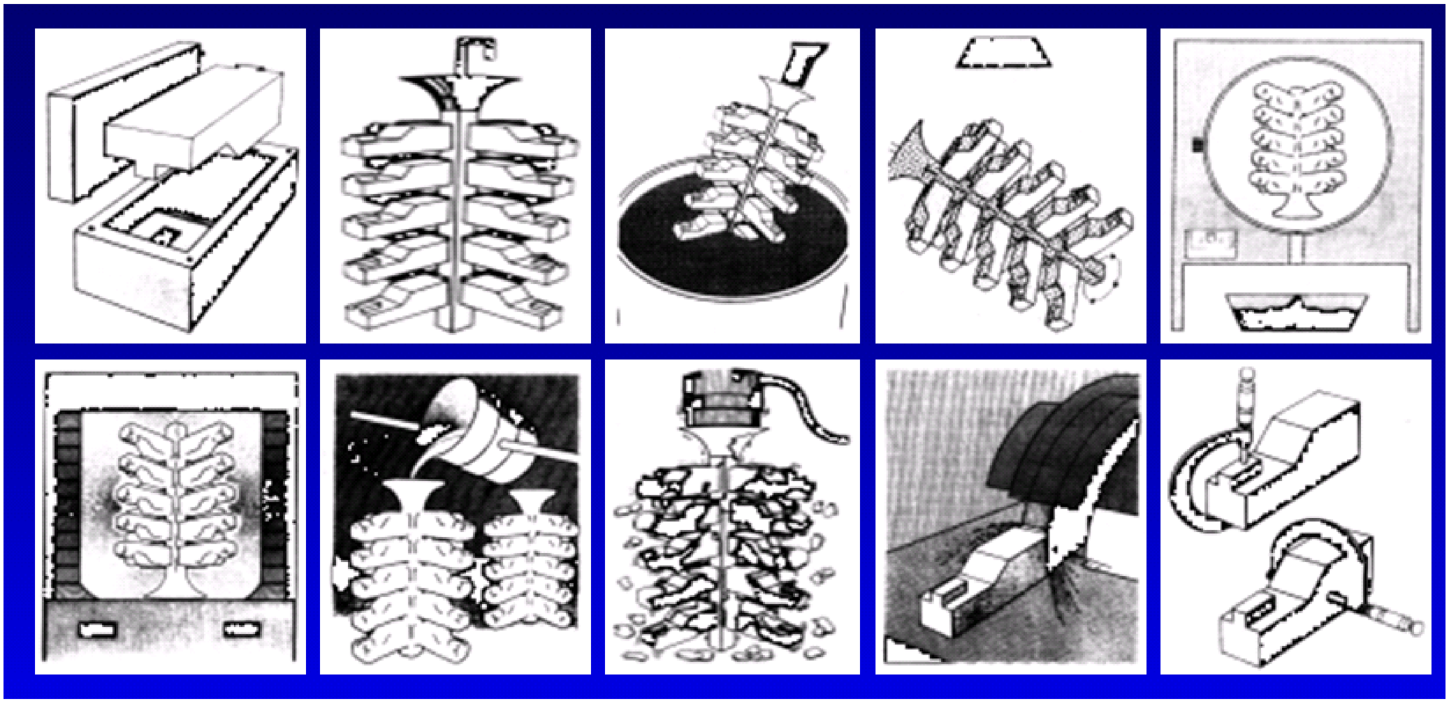
- **Very complex castings with unusual internal configurations possible.**
- **Wax pattern must be easily removable from its mould.**
- **Complex shapes may be assembled from several simpler shapes.**
- **Practical way of producing threads in hard to machine materials, or where thread design is unusual.**
- **Uniform sections are preferred. Abrupt changes should be gradually blended in or designed out.**
- **Fillets should be as generous as possible.**
- **Holes, both blind and through are possible. Length to diameter ratio for blind holes is typically 4:1.**
- **Bosses and undercuts are possible with added cost.**
- **Inserts are not possible.**
- **Machining allowance usually between 0.3 and 2 min, depending on size.**
- **Draft angle usually zero, but 0.5 to 1' desirable on long extended surfaces, or if mould cavity is deep.**
- **Minimum section ranges from 0.25 to 1 min, depending on material cast.**
- **Maximum section is approximately 75 min.**
- **Sizes range from 0.5 g to 100 kg in weight, but best for parts <5 kg.**

12.7 Quality issues

- **Moderate porosity.**
- **High strength castings are produced.**
- **Grain growth more pronounced in longer sections which may limit the toughness and fatigue life of the part.**
- **Good to excellent surface detail possible. Surface roughness in the range 0.4 to 6.3 mm Ra can be achieved.**
- **A process capability chart showing the achievable dimensional tolerances is given below.**
- **No parting line on casting.**

12.8 Processing steps

- **Produce master pattern of desired casting**
- **Produce master die**
- **Produce wax patterns**
- **Assemble wax patterns on a common sprue sometimes called a tree**
- **Coat "tree" with an initial investment material**
- **Vibrate to remove air and settle material around patterns**
- **Finish coat**
- **Allow investment to harden**
- **Fire investment to finish hardening process and melt our wax patterns**
- **Preheat mold**
- **Pour molten metal into mold cavity**
- **Allow metal to solidify**
- **Remove castings**
- **Post processing**



Wax or plastic is injected into die to make a pattern. Then the pattern is gated to a central sprue. Pattern clusters are dipped in ceramic slurry, this is repeated for several times to gain desired shell thickness. After mold material has set and dried, the patterns are melted out from the mold. Hot molds are filled with molten metal. Then the mold material is broken from casting to obtain the desirable products.

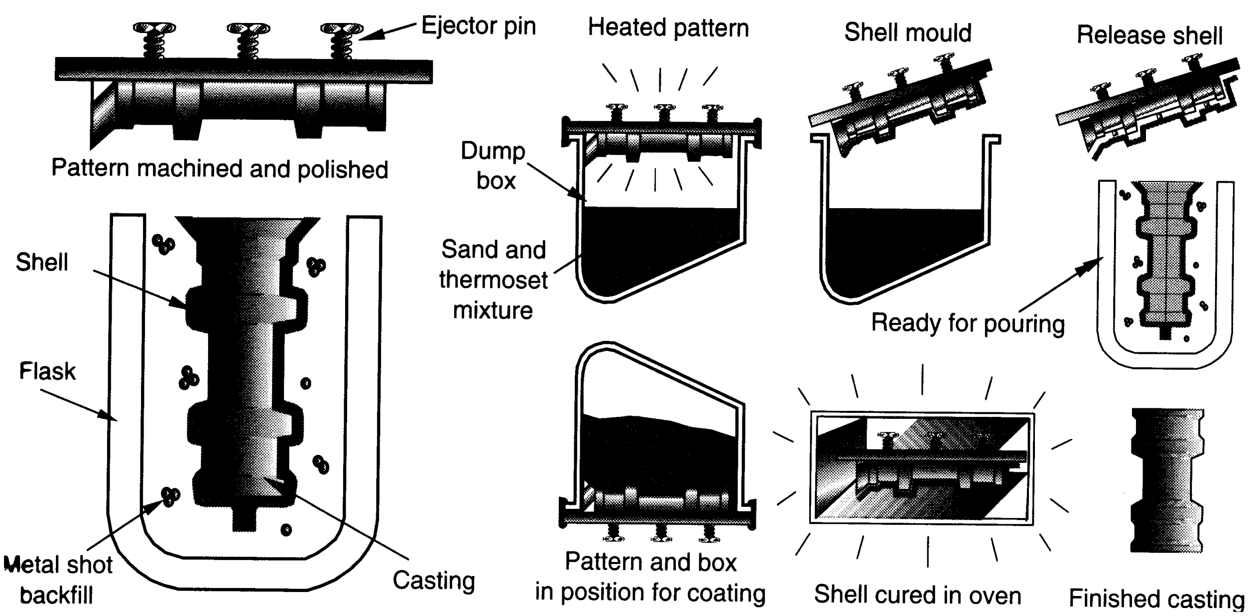
12.9 Advantages & Disadvantages

- Advantages
  - Wide variety of metals can be cast including high temperature alloys,
  - Excellent surface finish,
  - Good dimensional accuracy (+/- .003" up to ¼"),
  - Tooling cost average,
  - Complex shapes are possible,
  - Wax or plastic used can be recycled.
- Disadvantages
  - Price per unit costs can be high,
  - The processing required a longer time,
  - Worker cost is high,
  - Not suitable for big, heavy products,
  - One mold per batch.

13.0 SHELL MOULDING

13.1 General

This is a sand casting process that uses thin, resin-coated sand shells instead of moulding boxes to produce the casting envelope. It requires a upper mold and lower mold. The pattern used in this process is normally made from metal. Mold material consists of fine sand and 2.5-4% of thermoset (e.g. phenol formaldehyde) as the bonding agent. The pattern is heated to 175-370^{o}C and then coated with splitting agent (e.g. silicon). The box contains fine sand, mixed with 2.5-4% of thermosetting resin binder that coats the sand particles. The box is either rotated upside down or the sand mixture is blown over the pattern, allowing it to coat the pattern. The assembly is then placed in an oven for a short period of time to complete the curing of resin. In most shell molding machines the oven is a metal box with gas-fired burners that swing over the shell mold to cure it. The shell hardens around the pattern and is removed from the pattern using built-in ejector pins. Two half-shells are made in this manner and are bonded or clamped together in preparation for pouring.



13.2 Advantages and disadvantages

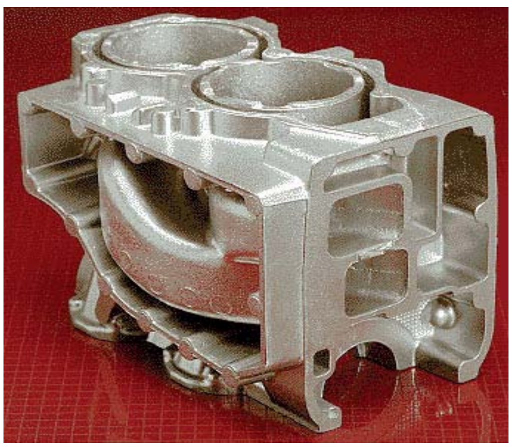
- **Advantages**
  - **Higher accuracy can be achieved,**
  - **Good surface finishing,**
  - **Thickness of shell can be controlled,**
  - **Flowing of molten material is made easy due to the smooth surface,**

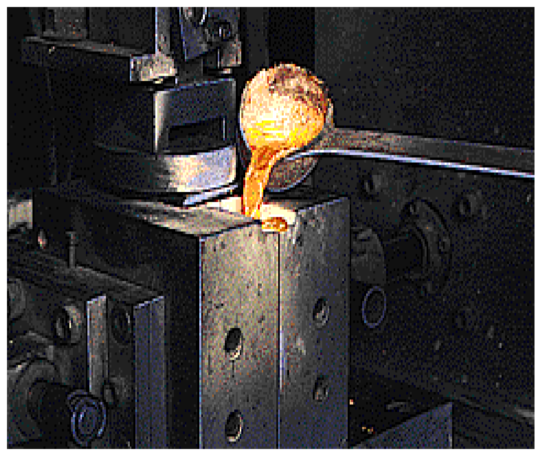
- **Process automation is made possible,**
- **Suitable for ferrous and non ferrous materials**

- **Disadvantages**
  - **Heating of binder produces gases, and a good venting path is required to avoid defects,**
  - **Higher pattern cost, thus production rate has to be high,**
  - **High binder cost,**
  - **Not suitable for heavy products.**

14.0 GRAVITY DIE CASTING

This is the simplest of the die casting processes. The molten metal is poured under gravity into the pre-heated metallic, graphite or refractory die where it solidifies. The die is then opened and the casting is ejected.





14.1 The tool

Molds are machined from tool steels and can have metal retractable cores

14.2 The Process

- **Lubrication of dies**
- **Closing and locking of dies**
- **Molten metal is forced into the die cavity**
- **Held under pressure until it solidifies**
- **Die opens**
- **Casting is ejected**

14.3 Process parameters

- **Normal Minimum Section Thickness:**

  Al: .03" Small Parts: .06" Medium Parts; Mg: .03" Small Parts: .045" Medium Parts; Zinc: .025" Small Parts: .040" Medium Parts; Copper Base: .060"; Ferrous: 3/16" for small areas, 1/4" normal.

- **Tolerances:**

  Al and Mg ± .002"/in.; Zinc ± .0015"/in.; Brass ± .005"/in.; +/- .012” first inch (add .002” per inch); Wall section .125”.

- **Materials**

  Usually non-ferrous metals, for example: copper, aluminium, magnesium, but sometimes iron, lead, nickel, tin and zinc alloys. Carbon steel can be cast with graphite dies.

14.4 Machine

- **Hot Chamber**
  - **15 cycles per minute**
  - **Direct transfer of molten metal into die cavity**
  - **Used primarily with zinc and zinc alloys**
- **Cold Chamber**
  - **Higher temperature alloys (aluminum and magnesium)**
  - **Metal is melted in a separate furnace and transported to the machine**
  - **Measured quantity of metal is forced into the mold by a hydraulic or mechanical plunger (can be a double plunger system for productivity)**

14.5 Process variations

- **Low pressure die casting - uses low pressure air to force the molten metal into the die cavity. Less popular than gravity and tends to be used purely for the production of car wheels.**

14.6 Economic consideration

- **Production rates of 5-100 pieces/hour common, but dependent on size.**
- **Lead times can be many weeks.**
- **Material utilization is high.**
- **There is little scrap generated.**
- **If accuracy and surface finish is not an issue, can use sand cores instead of metallic or graphite for greater economy.**

- **Production volumes of 500-1000 may be viable.**
- **Suited to high volume production.**
- **Tooling costs are moderate.**
- **Equipment costs are moderate.**
- **Labour costs are low to moderate.**
- **Finishing cots are low to moderate.**
- **Typical applications**
- **Cylinder heads.**
- **Connecting rods.**
- **Pistons.**
- **Gear and die blanks.**

14.7 Design aspects

- **Shape complexity limited by that obtained in die halves.**
- **Undercuts are possible with large added cost.**
- **Inserts are possible with small added cost.**
- **Machining allowances in the range from 0.8 to 1.5 mm.**
- **Placing of parting line important, i.e. avoid placement across critical dimensions.**
- **Draft angle ranges from 0.1º to 3º.**
- **Maximum section = 50 mm.**
- **Minimum section = 2 mm.**
- **Sizes range from 100 g to 300 kg in weight. Commonly used for castings <5 kg.**

14.8 Quality issue

- **Little porosity and inclusions.**
- **Redressing of the dies may be required after several thousand castings.**
- **Collapsible cores improve extraction difficulties on cooling.**
- **'Chilling' effect of cold metallic dies on the surface of the solidifying metals needs to be controlled by pre-heating at correct temperature.**
- **Large castings sometimes require that the die is tilted as molten metal is being poured in to reduce turbulence.**
- **Mechanical properties are fair to good.**
- **Surface detail good.**

- Surface roughness in the range 0.8 to 6.3 mm Ra can be achieved.
- Process capability charts showing the achievable dimensional tolerances using various materials are given on the next page. Allowances of ±0.25 to ±0.75 mm should be added for dimensions across the parting line.

14.9 Advantages and disadvantages

- Advantages
  - Fine section detail (.003”),
  - Excellent dimensional accuracy (+/- 0.002”),
  - High production rates,
  - Mold is reusable,
  - Excellent surface finish,
  - Control of processing temperatures extended mold life (about 25000 cycles) and limited part defects,
- Disadvantages
  - Majority of molds use low-melt alloys,
  - Mold costs can be high,
  - Low complexity of mold and fine section detail may be limited,
  - Limited part size of up to 25 lbs.

15.0 PRESSURE DIE CASTING

This is a process where molten metal is inserted into a metallic mould under pressure where it solidifies. The die is then opened and the casing is ejected.

15.1 Process variations

- Cold-chamber die casting is used for high melting temperature metals.
- Hot-chamber die casting is used for low melting temperature metals due to the erosive nature of molten metal. Can be either plunger or goose-neck type.

15.2 Materials

- Limited to non-ferrous metals, i.e. zinc, aluminium, magnesium, lead, tin and copper alloys.
- Zinc and aluminium alloys tend to be the most popular.
- High temperature metals, e.g. copper alloys, reduce die life.
- Iron based materials for casting are under development.

15.3 Economics

- Rapid production rates possible, up to 200 pieces/hour.
- Lead time could run into months.
- Material utilisation is high.
- Gates, sprues, etc., can be re-melted.

- **High initial die costs due to high complexity and difficulty to process.**
- **Production quantities of >10,000 are economical.**
- **Tooling costs are high.**
- **Equipment costs are high.**
- **Direct labour costs are low to moderate.**
- **Finishing costs are low. Little more than trimming operations required to remove flash, etc.**

15.4 Applocations

- **Transmission cases.**
- **Engine parts.**
- **Pump components.**
- **Electrical boxes,**
- **Domestic appliances.**
- **Toy parts.**

15.5 Design aspects

- **Shape complexity can be high. Limited by design of movable cores.**
- **Bosses are possible with added costs.**
- **Undercuts and inserts are possible with added costs and reduced production rates.**
- **Wall thickness should be as uniform as possible; transitions should be gradual.**
- **Sharp corners, or corners without proper radii should be avoided. (Pressure die casting permits smaller radii because metal flow is aided.)**
- **Placing of parting line important, i.e. avoid placement across critical dimensions.**
- **Holes perpendicular to the parting line can be cast.**
- **Casting holes for subsequent tapping is generally more economical than drilling.**
- **Machining allowance is normally in the range from 0.25 to 0.8 mm.**
- **Draft angle ranges from 0.5 to 3º.**
- **Maximum section = 12 mm.**
- **Minimum section ranges from 0.4 to 1.5 mm depending on material used.**
- **Sizes range from 10 g to 50 kg. Castings up to 100 kg have been made in zinc. Copper, tin and lead castings are normally less than 5 kg.**

15.6 Quality issues

- **Very low porosity.**
- **Particularly suited where casting requires high mechanical properties or absence of creep.**
- **The high melting temperature of some metals can cause significant processing difficulties and die wear.**

- Difficulty is experienced in obtaining sound castings in the larger capacities due to gas entrapment.
- Close control of temperature, pressure and cooling times important in obtaining consistent quality castings.
- Mechanical properties are good.
- Surface detail excellent.
- Surface roughness in the range 0.4 to 3.2 mm Ra can be achieved.
- Process capability charts showing the achievable dimensional tolerances using various materials are given below. Allowances of ±0.05 to ±0.35 mm should be added for dimensions across the parting line.

15.7 Advantages and disadvantages

- Advantages
  - Excellent dimensional accuracy (+/- 0.001”),
  - High production rates,
  - Excellent surface finish,
  - Ability to produce thin cross-section products.

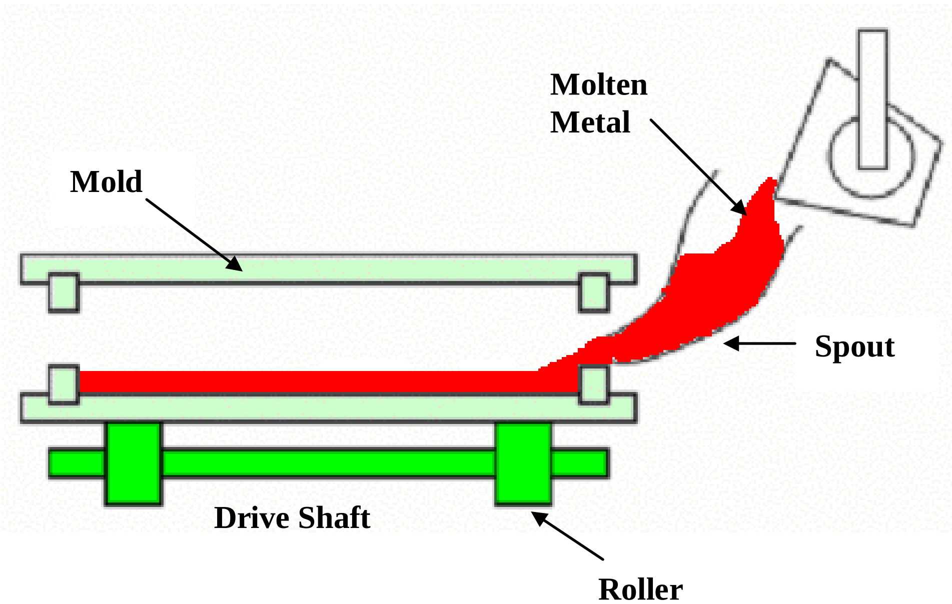
- Disadvantages
  - High mold and tooling cost,
  - Melting temperature is limited to <850^{o}C,
  - Chilling happened easily,
  - Limited component size.

16.0 CENTRIFUGAL CASTING

As its name implies, the centrifugal casting process utilizes the inertial forces caused by rotation to distribute the molten metal into the mold cavities. This method was first suggested in the early 1800s. There are three types of centrifugal casting, that is;

16.1 True centrifugal casting,

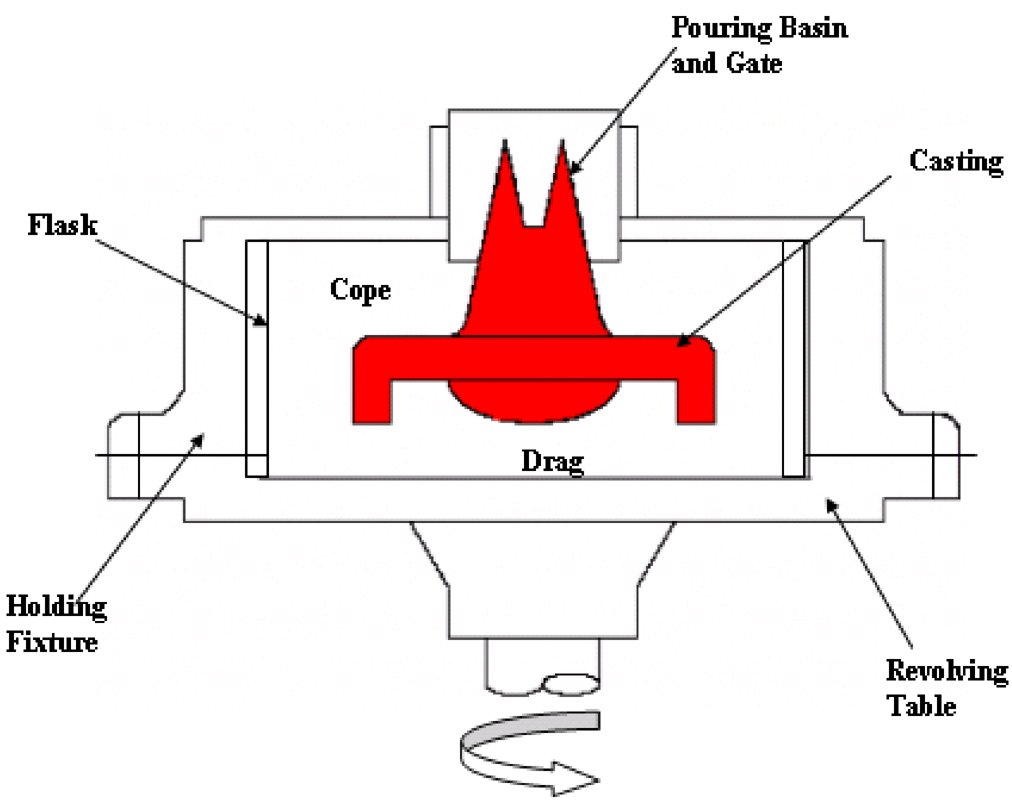
In true centrifugal casting, hollow cylindrical parts, such as pipes, gun barrels, and streetlamp posts, are produced in which molten metal is poured into a rotation mold. The axis of rotation is usually horizontal but can be vertical for short workpieces. Molds are made of steel, iron, or graphite, and may be coated with a refractory lining to increase mold life.



The mold surfaces can be shaped so that pipes with various outer shapes, including square or polygonal, can be cast. The inner surface of the casting remains cylindrical because the molten metal is uniformly distributed by centrifugal forces. However, because of density differences, lighter elements such as dross, impurities, and pieces of the refractory lining tend to collect on the inner surface of the casting. Cylindrical parts ranging from 13 mm (0.5 in.) to 3 m (10 ft) in diameter and 16 m (50 ft) long can be cast centrifugally, with wall thickness ranging force is high, as much as 150 g's and such high pressure is necessary for casting thick-walled parts. Castings of good quality, dimensional accuracy, and external surface detail are obtained by this process. In addition to pipes, typical parts made are bushings, engine cylinder liners, and bearing ring with or without flanges.

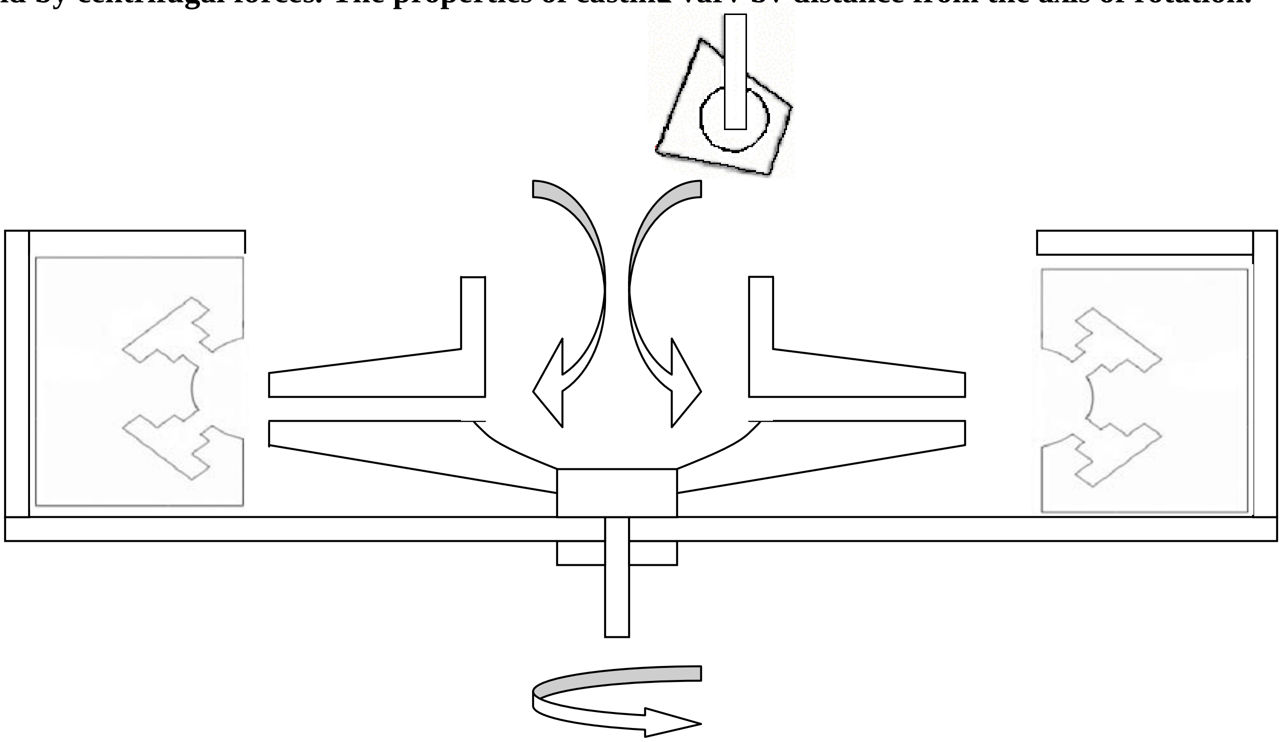
16.2 Semi-centrifugal casting,

This method is used to cast parts with rotational symmetry such as wheel with spokes.



16.3 Centrifuging.

In centrifuging, also called centrifuge casting, mold cavities of any shape are placed at a certain distance from the axis of rotation. The molten metal is poured from the center and is forced into the mold by centrifugal forces. The properties of casting vary by distance from the axis of rotation.



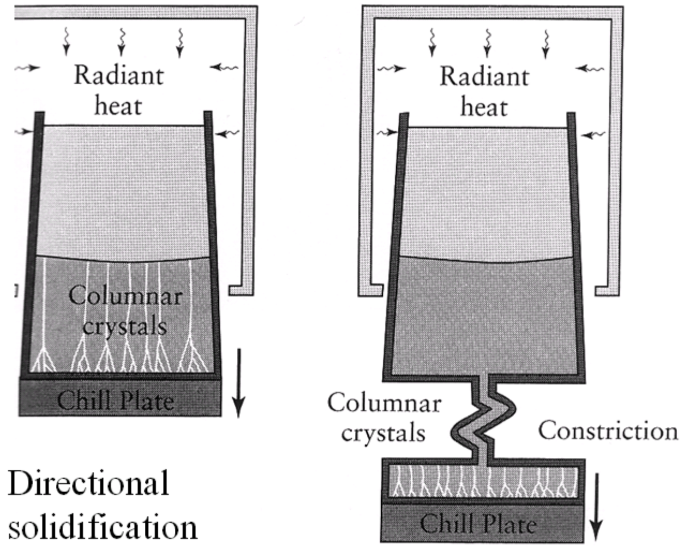
16.4 Materials : Most metals, also glass plastics and ceramics.

16.5 Applications

- **Pipes; Brake drums; Pulley wheels; Gun barrels; Bushes and gears; Engine cylinder liners; pressure vessels.**

17.0 CASTING TECHNIQUES FOR SINGLE CRYSTAL COMPONENTS

The process is used to cast single-crystal components such as gas turbine blades, which is generally made of nickel-based super-alloy and used in the hot stages of the engine. The procedures involved can also be used for other alloys and components.



17.1 Conventional casting of turbine blades,

The conventional casting process uses a ceramic mold. The molten metal is poured into the mold and begins to solidify at the ceramic walls. The grain structure develops is polycrystalline and is similar to that shown in the figure A below. The presence of grain boundaries makes this structure susceptible to creep and cracking along the boundaries under centrifugal forces and elevated temperatures commonly encountered in an operating gas turbine.

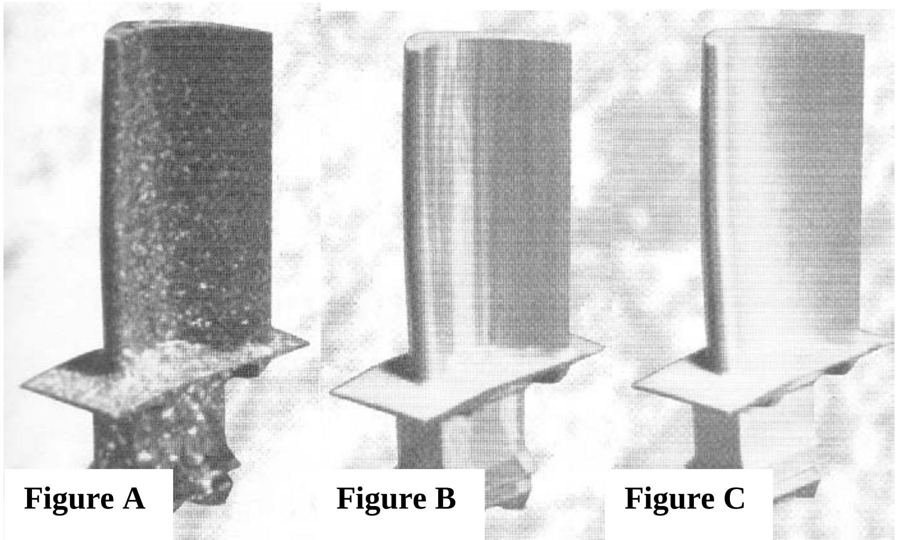
17.2 Directionally solidified blades

In the directional solidification process, first developed in the 1960, the ceramic mold is preheated by radiant heating. The mold is supported by a water-cooled chill plate. After the metal is poured into the mold, the assembly is slowly lowered. Crystals begin to grow at the chill-plate surface and upward, like columnar grains shown in figure B below. The blade is thus directionally solidified, with longitudinal but no transverse grain boundaries. Consequence, the blade is stronger in the direction of centrifugal forces developed in the gas turbine.

17.3 Single-crystal blades

In crystal growing, developed in 1967, the mold has a constriction in the shape of a corkscrew or helix, the cross-section of which is so small that it allows only one crystal to fir through. The mechanism of crystal growth is such that only the most favorably oriented crystal are able to grow through the helix because all others are intercepted by the walls of the helical passage. As the assembly is lowered slowly, a single crystal grows upwards through the constriction and began to grow in the mold. Strict control of the rate of movement is necessary. The solidified mass in the mold is a single-crystal blade.

Although these blades are more expensive than other types, the lack of grain boundaries make them resistant to creep and thermal shock, so that have a longer and more reliable service life.

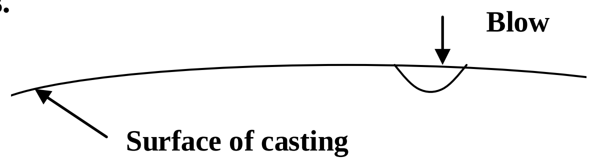


18.0 DEFECTS

Various defects can be developed in casting processes, depending on the factors such as materials, part design, and processing techniques. While some defects affect only the appearance of parts, other can have major adverse on the structural integrity of the parts made. Several defects can developed in castings, the International Committee of Foundry Technical Associations has developed a standardized nomenclature consisting of 7basic categories of casting defects such as shown below, they are;

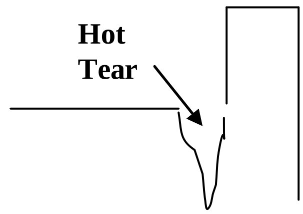
- **Cavities**

  It is consisting of rounded or rough internal or exposed cavities, including blowing holes, pinholes, and shrinkage cavities.



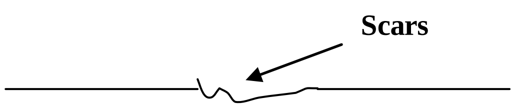
- **Discontinuities**

  It is consisting of cracks, cold or hot tearing and cold shuts. If the solidifying metal is constrained from shrinking freely, cracking and tearing can occur. Although many factors are involving in tearing, coarse grain size and the presence of low melting point segregates along the grain boundaries increase the tendency for hot tearing. Cold shut is an interface in a casting that lacks complete fusion because of the meeting of two streams of liquid metal from different gates.



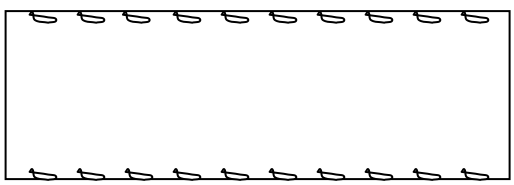
- **Defective surface**

  It is consisting of surface folds, laps, scars, adhering sand layers and also oxide scale.



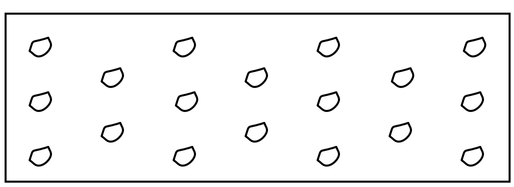
- **Pin holes**

  Small holes defects normally happened beneath or underneath the casting surface.



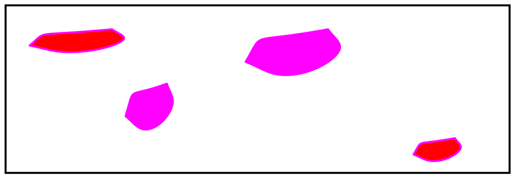
- **Porosity**

  It consists of fine hole, normally caused by gas or shrinkages.



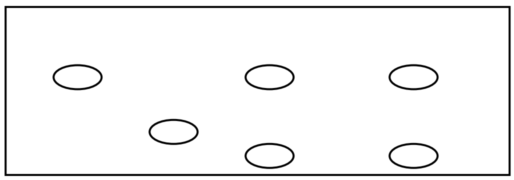
- **Inclusion**

It consists of non-metal, oxidants, or inter-metallic mixture.



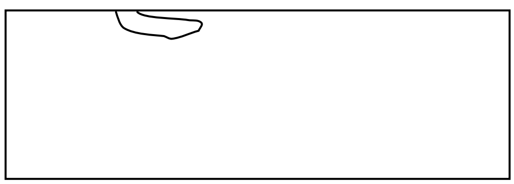
- **Gas holes**

Holes produced inside the casting, almost sphere in shape, normally is caused by the chemical reaction with mold.



- **Blister**

Just like a scar, but the outer layer is covered with thin metal.

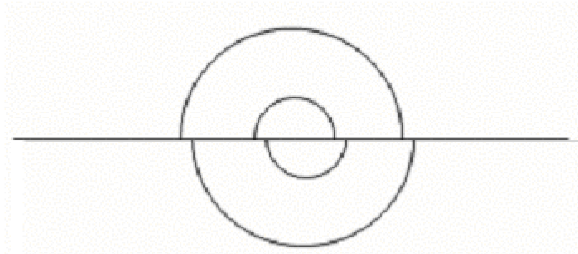


- **Misrun**

Caused by imperfect flow of molten metal into the mold.

- **Shifting**

Misalignment of mold will cause shifting in the casting.



Notes: There are still a lot more information about this topic, so, for more information, do refer to more books.

-THE END-

SAND CASTING

CASTING 1

PROCESS

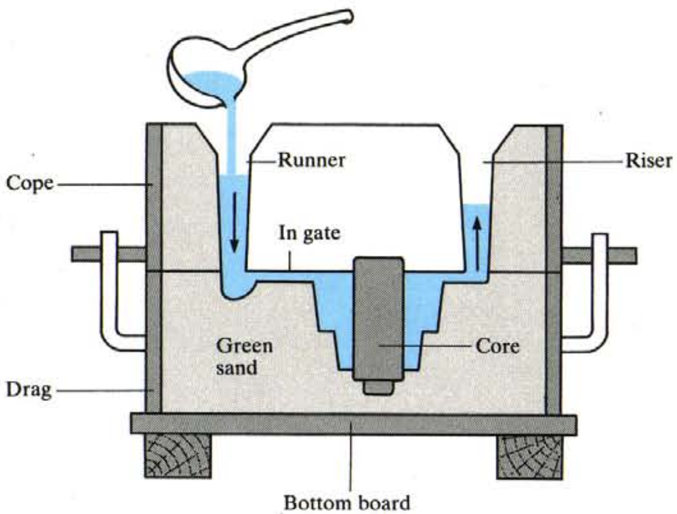
Permanent pattern
Sand moulds are produced around a pattern which is withdrawn to leave a cavity. Molten metal is poured into the mould and solidifies. Mould is broken up to retrieve the casting.

SHAPE

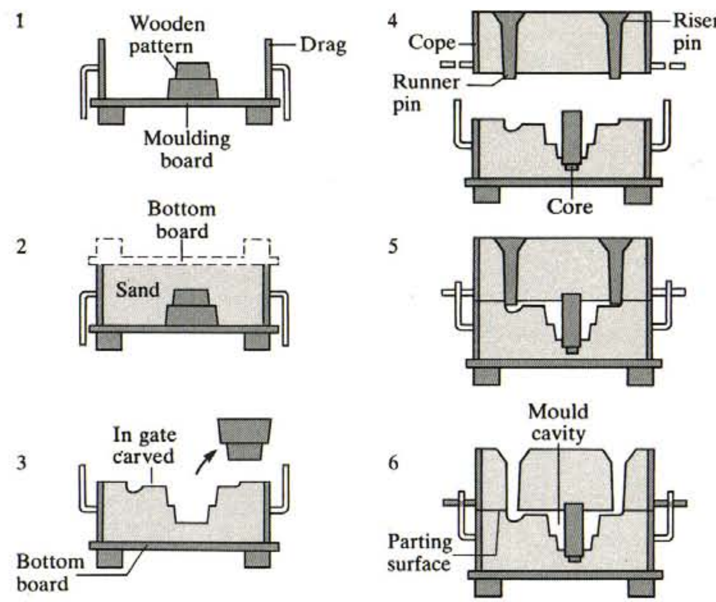
3D
Mainly solid components but complex internal shapes produced using friable cores. Thin sections difficult.

MATERIALS

Metals
Metals excluding refractory and reactive alloys (e.g. Ti).



Sectional view of a casting mould



Stages in the production of the mould shown on the left

CYCLE TIME

Usually long as limited by rate of heat transfer out of the casting. Use of multiple moulds increases production rate.

RATING 2

QUALITY

Surface texture poor. Porosity endemic. Nonmetallic inclusions difficult to control.

RATING 1

FLEXIBILITY

Patterns cheap and easy to make.

RATING 5

MATERIALS UTILIZATION

Up to 50% of casting in runners and risers. Both mould and scrap metal can be directly recycled.

RATING 2

OPERATING COST

Very low as pattern costs are low and mould making is relatively easy.

RATING 5

INVESTMENT CASTING

CASTING 3

PROCESS

Expendable mould and pattern

A ceramic shell (investment) is slip cast around a wax pattern. Wax is melted and molten metal cast into the investment which is broken up to remove the casting.

SHAPE

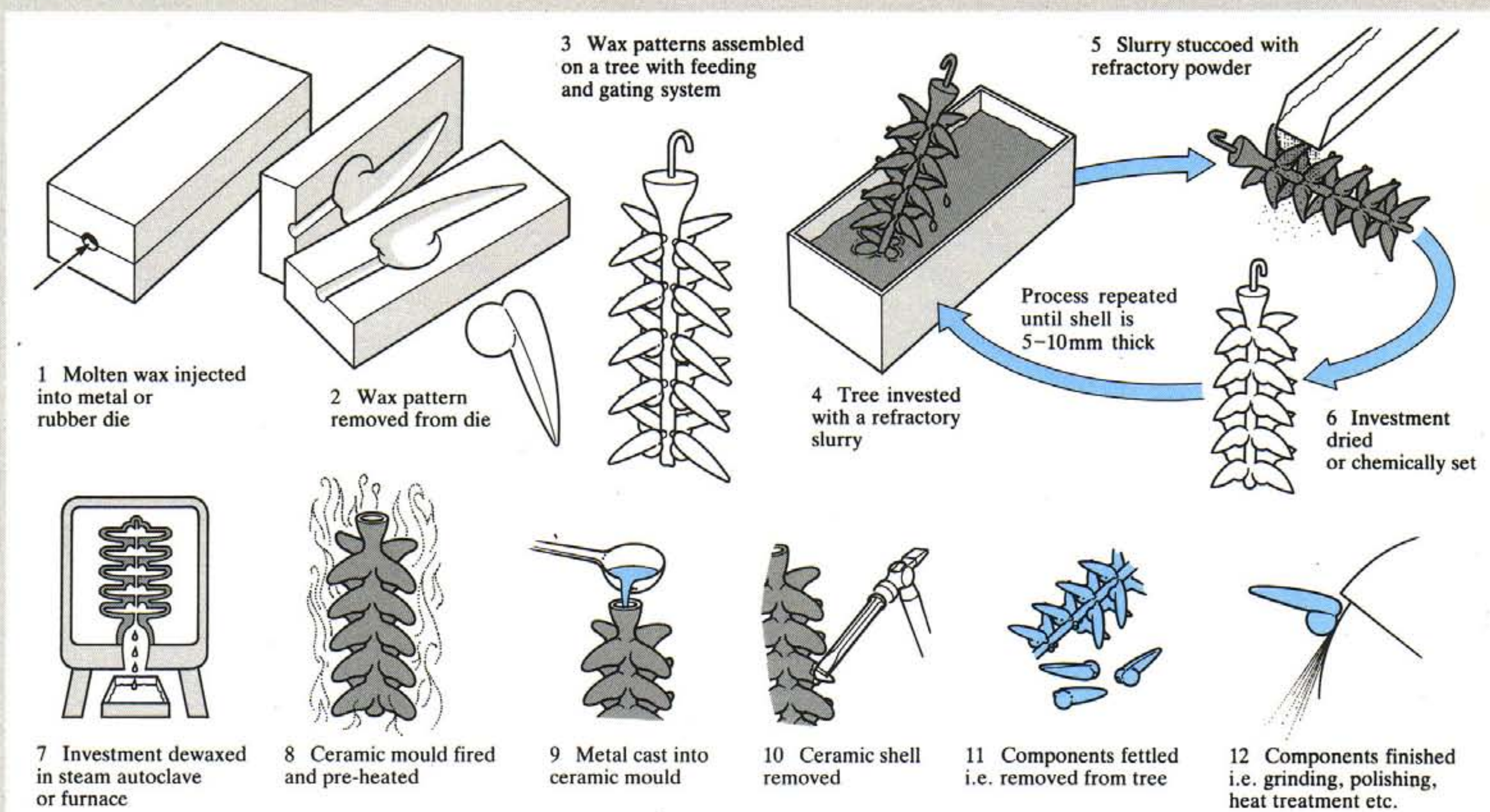
3D

Best for relatively small, complex 3D components. Re-entrant angles possible.

MATERIALS

Metals

Suitable for most metals. Reactive metals can be cast under vacuum.



CYCLE TIME

Limited by rate of heat transfer out of the casting. Production rates low because of process complexity. Increased by using multiple moulds and patterns.

RATING 2

QUALITY

Surface texture good. Higher mould temperatures decrease porosity but produce coarse microstructures.

RATING 4

FLEXIBILITY

Moderately high because of the ease of production of patterns.

RATING 4

MATERIALS UTILIZATION

Near net shape process with little material contained in feeding systems. Wax recycled, investment lost.

RATING 4

OPERATING COST

Equipment costs can be high especially where reactive alloys are concerned. Labour costs are high due to the many stages in the process.

RATING 3

FULL MOULD (EVAPORATIVE PATTERN) CASTING

CASTING 2

PROCESS

Expendable mould and pattern

A refractory coating is applied to a volatile or combustible pattern which is used in a sand mould. The pattern is destroyed by the molten metal.

SHAPE

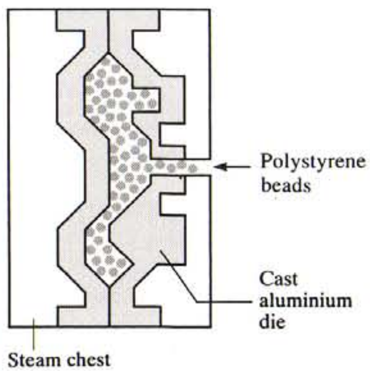
3D

Very complex shapes possible.

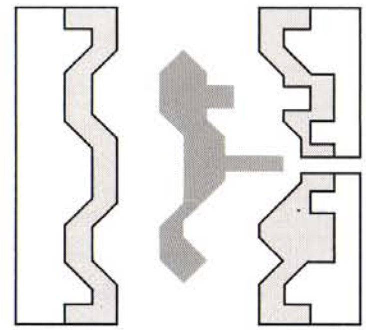
MATERIALS

Metals

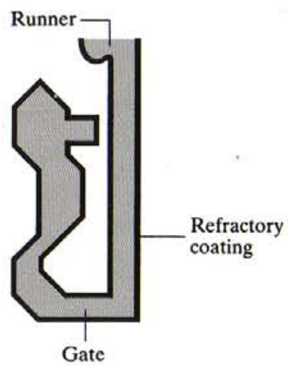
Nonrefractory metals with casting temperatures high enough to vaporize the pattern.



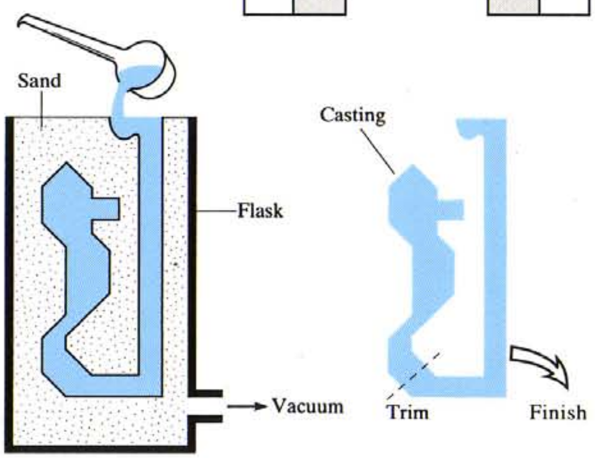
1. Inject polystyrene beads into a heated aluminium die. Pass steam through mould to fuse and expand polystyrene beads to form solid pattern.



2. Cool die, open to eject pattern.



3. Glue on additional runners and risers where necessary. Cover pattern with refractory slurry and dry to form a refractory coating.



4. Place pattern in a 'flask' of loose dry unbonded sand and consolidate by vibration. Apply vacuum to flask and pour metal. Cool, remove casting and recycle sand.

CYCLE TIME	QUALITY	FLEXIBILITY	MATERIALS UTILIZATION	OPERATING COST
Long due to process complexity. Multiple moulds increase production rate.	Normal sand casting defects. Surface texture similar to that of pattern.	Ideal for the manufacture of one-offs.	Pattern material entirely wasted. Metal usage poor due to runners etc.	All equipment involved is rudimentary and process is very cheap to operate.
RATING 1	RATING 2	RATING 5	RATING 2	RATING 4

GRAVITY DIE CASTING

PROCESS

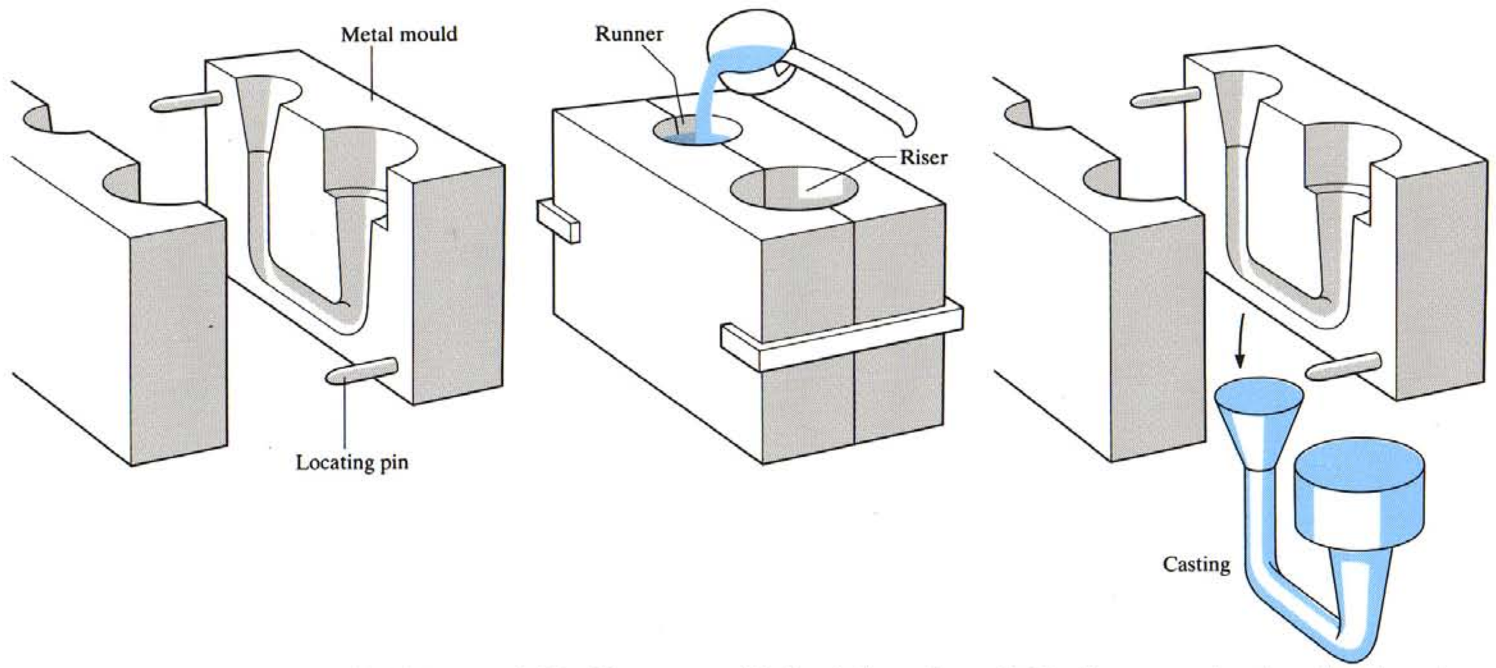
Permanent mould
Molten metal is poured into a metallic mould where it solidifies.

SHAPE

3D
Mostly used for small, simple shapes with only simple coring.

MATERIALS

Ferrous alloys, light alloys
Mainly used for light alloys. Steels and cast irons also possible.



1. Mould and cores (where applicable) sprayed with coating. Mould heated using gas burners and lubricant sprayed on.

2. Mould parts assembled and clamped. Metal poured into runner.

3. Mould set opened and casting ejected, finished and heat treated (when necessary).

CYCLE TIME

Limited by rate of heat transfer across the interface. Production rates can be increased by using multiple moulds or multiple cavities.

RATING 4

QUALITY

Surface texture is good. Porosity unavoidable but can be minimized by slower mould filling to reduce turbulence.

RATING 3

FLEXIBILITY

Negligible setting up time for manual operation. Mould making relatively difficult.

RATING 2

MATERIALS UTILIZATION

Rarely better than 60% utilization. Scrap in the runners and risers can be directly recycled.

RATING 2

OPERATING COST

Equipment cost can be limited to mould and melt preparation apparatus.

RATING 2

PRESSURE DIE CASTING

PROCESS

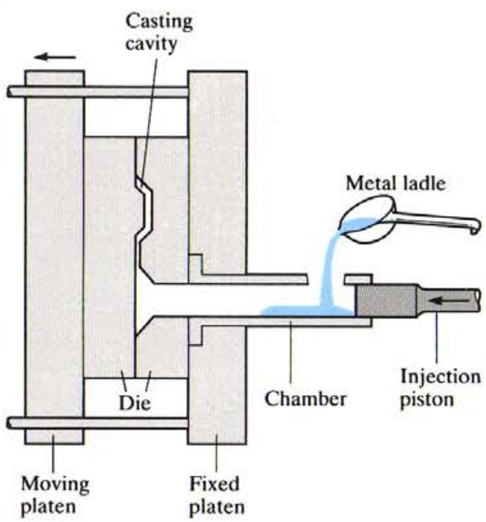
Permanent mould
Molten metal is forced into a water-cooled metal mould (die) through a system of sprues and runners. The metal solidifies rapidly and the casting is removed with its sprues and runners.

SHAPE

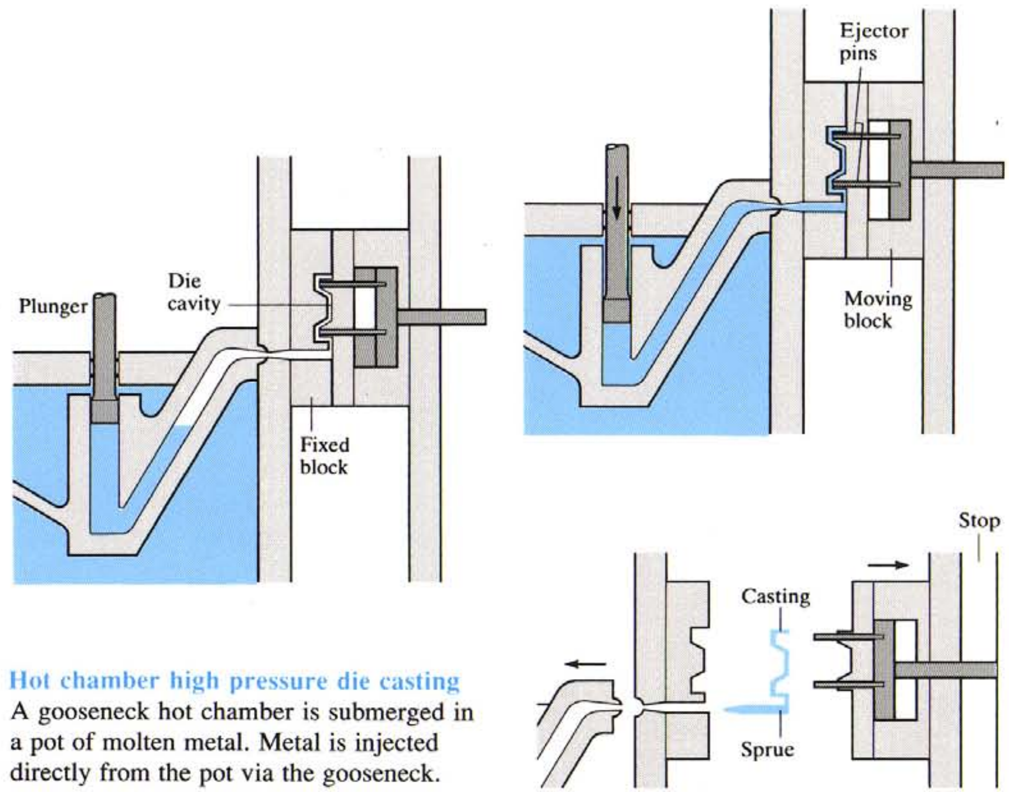
3D solid
Used for complex shapes and thin sections. Cores must be simple and retractable.

MATERIALS

Light alloys
High fluidity requirement means low melting temperature eutectics usually used. Hot chamber method restricted to very low melting temperature alloys (e.g. Mg and Zn).



Cold-chamber high pressure die casting
Molten metal is poured into a cold shot chamber. A high pressure plunger forces metal into the single or multi-die cavity.



Hot chamber high pressure die casting
A gooseneck hot chamber is submerged in a pot of molten metal. Metal is injected directly from the pot via the gooseneck.

CYCLE TIME

Solidification time is typically < 1 s so cycle is controlled by time taken to fill mould and remove casting.

RATING 5

QUALITY

Good surface texture but turbulent mould filling produces high degree of internal porosity.

RATING 2

FLEXIBILITY

Tooling dedicated so limited by machine setting up time.

RATING 1

MATERIALS UTILIZATION

Near net shape process but some scrap in sprues, runners and flash which can be directly recycled.

RATING 4

OPERATING COST

High, since machine and moulds are expensive.

RATING 1

CENTRIFUGAL CASTING

PROCESS

Permanent mould

Molten metal is introduced into a sand- or copper-lined, cylindrical steel mould which is rotated about its long axis, distributing the metal over its inner surface.

SHAPE

3D hollow

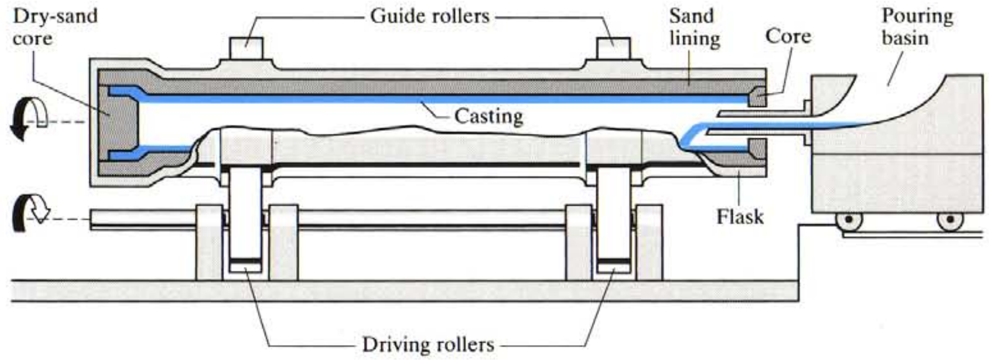
Technique used to produce relatively long, hollow objects without the need for cores.

MATERIALS

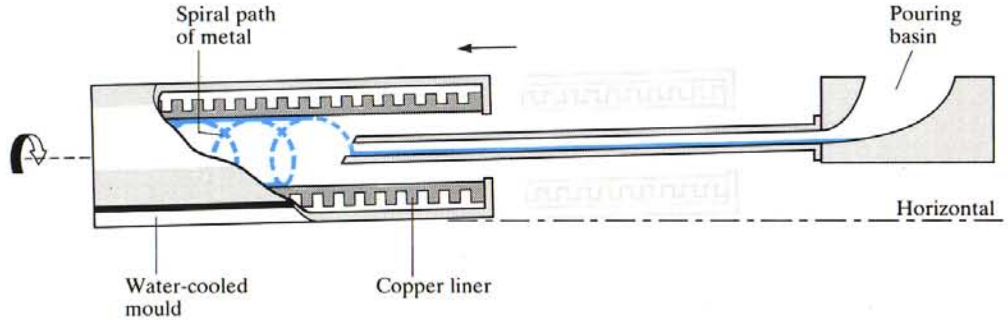
Metals

Metals excluding refractory and reactive metals.

Sand mould casting



Metal mould casting



CYCLE TIME

Determined by the rate of introduction of metal into the mould and the rate of solidification of the metal. The latter is lower for sand-lined moulds.

RATING 2

QUALITY

Porosity and nonmetallic inclusions migrate towards the inner surface because of their lower density, giving a high quality outer surface.

RATING 3

FLEXIBILITY

Setting up times are relatively short.

RATING 3

MATERIALS UTILIZATION

Absence of runners and risers leads to near 100% use of material.

RATING 5

OPERATING COST

Equipment is relatively simple and can cost little. Increased complexity of water-cooled copper-lined moulds more costly.

RATING 3