MME **345**, Lecture **A:03**

Moulding and Casting Methods

1. General methods of moulding and casting

Ref:

[1] Heine, Loper & Rosenthal, Principles of Metal Casting, McGraw-Hill, 1976
[2] Beeley, Foundry Technology, Butterworth-Heinemann, 2001

Topics to discuss today …

1. Moulding and casting methods
2. Sand system
3. Non-sand system
4. Comparative study

1. Moulding and casting methods

- Good castings cannot be made without good moulds.
- Because of the importance of the mould, casting processes often described by the materials and methods employed in moulding.
- Moulding process – methods of making mould and the material used.
- Casting methods – moulding process, method of introducing liquid metal into the mould cavity, and other processes used in making the casting.

- Moulding methods and materials encompass a wide range of options
  - **expendable mould, permanent mould, etc.**
  - **sand mould, graphite mould, ceramic mould, plaster mould, metal mould, etc.**

- The selection of the correct one to use in a specific casting application depends on
  1. **the alloy,**
  2. **the dimensional tolerances and degree of precision desired,**
  3. **the quality of the casting, and**
  4. **the price the customer is willing to pay.**

1.1 Classification of moulding and casting methods

- Based on the moulding medium
  1. **sand mould,**
  2. **ceramic mould,**
  3. **metal mould, etc.**

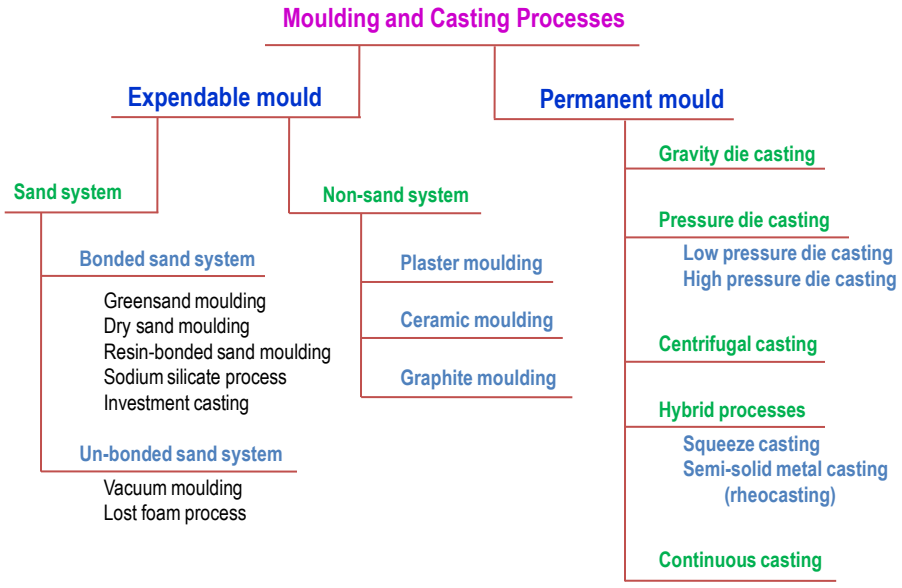
- Based on the type of mould
  1. **expendable –** destroyed after each casting (sand casting)
  2. **permanent –** reused many times (die casting)

- Based on the type of pattern
  1. **expendable –** destroyed for each mould (investment casting, foam casting)
  2. **permanent** – reused many times (wood/metal for sand casting)

- Based on the type of liquid filling (metal flow in mould)
  1. **gravity –** sand casting, gravity die casting
  2. **pressure –** low and high pressure die casting
  3. **vacuum –** vacuum investment casting

- Most metals and alloys can be cast using any of the methods. There are, however, limitations in some cases.

Classification system for foundry processes based on mould type



Metal processed by casting

- Sand casting – 60%
- Investment casting – 7%
- Shell mould casting – 6%
- Permanent mould casting – 11%
- (Pressure) Die casting – 9%
- Centrifugal casting – 7%

2. Sand-based moulding and casting methods

- The use of permanent metal moulds or dies for shaped components is subject to certain major limitations:

  mould (die) life, melting point of liquid, die cost

- Silica sand, either bonded or unbonded, still remains the most popular moulding media.

- Common advantages:
  - **widely available**
  - **inexpensive**
  - **ability to withstand elevated temperatures**
  - **does not react with most metals and alloys**
  - **permeable for escaping air, moisture and other mould gases**
  - **easily recycled**

- Sand-based moulding processes have certain features in common:
  - **the use of pattern and/or core boxes**
  - **an aggregate mixture, comprising a granular refractory material and binder**
  - **a means of forming the aggregate mixture around the pattern**
  - **hardening of the aggregate (or developing bond) while in contact with the pattern**
  - **withdrawal of pattern from the hardened aggregate mould**
  - **assembly of mould and core pieces to make a complete mould to pour the liquid metal**

- The various sand moulding processes differ primarily in
  - **the method of forming the mould,**
  - **the type of granular refractory material, and**
  - **the method of bonding the granular refractory material**

2.1 Bonded sand moulding methods

- In bonded sand moulds, the sand particles are held together with electrostatic/chemical bonds.
- The bonds that are developed must be broken easily when the casting is solid so that the casting can be removed from the mould.
- Common bonded sand moulding processes
  1. **Greensand moulding**
  2. **Dry sand moulding**
  3. **Resin boned sand moulding**
  4. **Sodium silicate bonded sand moulding (a.k.a. CO_2 process)**
  5. **Cement bonded sand moulding process**
  6. **Investment (or precision) casting processes**
  7. **Shell moulding process**

2.2 Un-bonded sand moulding methods

- It is not always necessary to use a binder with sand.
- In un-bonded sand moulds, the pattern is held either by the pattern itself during pouring, or by the use of a vacuum.
- Use of un-bonded sand moulds is advantageous because they need no binders, mulling equipment, or mould additives.
- Common un-bonded sand moulding processes
  1. **Lost foam moulding**
  2. **Vacuum moulding**

Greensand moulding process

- It is the most widely used of all sand moulds for small to medium-sized metal castings.
- Made of natural silica sand, bonded by a mixture of clay and water.
- Other materials may be added to control its strength and prevent metal penetration.
- The sand mixture is compacted in a removable flask that is attached to the pattern. After the sand is compacted, the pattern is removed revealing a cavity in the sand mould.
- It is called "green sand" because of the presence of moisture in it and is not baked or fired. Its actual colour is usually black.

- Principal advantages of greensand system
  - **Flexible; can be reused**
  - **Rapid and repetitive**
  - **Can be mechanized**
  - **Cheaper**
- Disadvantages of greensand system
  - **Single-time use of mould**
  - **Create defects**
  - **Bad dimensional accuracy and surface finish**
  - **Some casting designs** (e.g., large castings; castings having thin, long sections; intricate designs, etc.) **cannot be made**

Dry sand mould

- Made with moulding sand in green condition, but thoroughly dried at about 200-300 °C (in oven or using heated air) to remove all moisture.
- Sand mixture is modified somewhat (more clay and moisture; use of pitch, molasses, dextrin, glutrin or other forms of organic binders) to obtain high strength and hardness, which make it suitable for castings of the largest dimensions and provide high standards of accuracy.
- Castings of large or medium size, and of complex configuration such as frames, engine cylinders, rolls, large gears and housings are made using this process.

- More dimensional accuracy and smoother finish
- Reduced venting problem, as moisture content in mould is reduced/eliminated
- Reduced chilling problem, facilitating mould filling in thin sections
- Reduced metal penetration, as more finer sand or mould coat can be used

- Time consuming, causes problems during mould heating
- Expensive

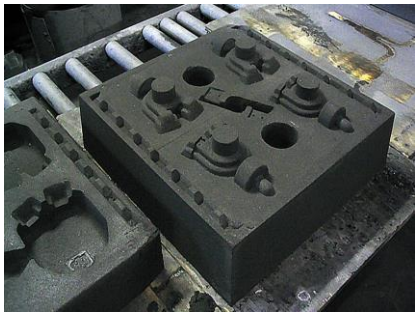
- Effect of dry sand moulding may be partially obtained in skin-dried mould by drying the mould surface to some depth (1/4 – 1 inch) by torch, infrared lamp or electric heating.

Resin-bonded sand mould

- 1 – 2 wt.% chemical binder (polymer resin) and dry sand are mixed together and formed around a pattern or placed in a core box.
- Curing (for bonding) of mould is necessary. It is done either at room temperature, or by heat. To accelerate the curing, solid/liquid/gaseous catalysts may be added.

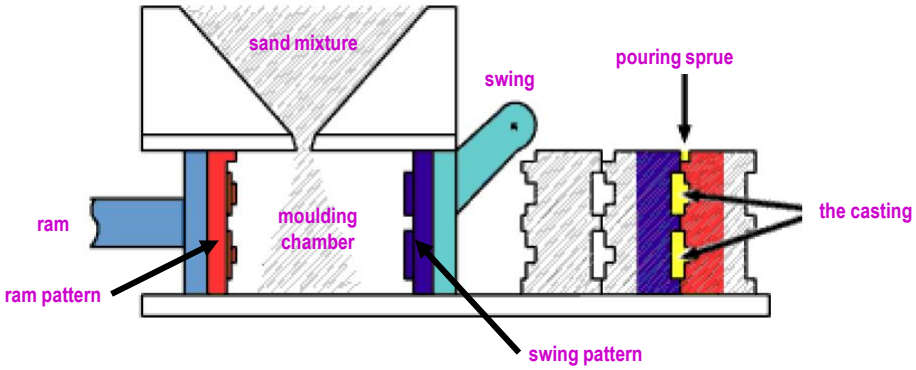
- **Good surface finish**
- **Greater longevity** and **higher strength** of the mould
- **Limited bench life** due to water absorption

Advancement in mould making



flaskless molding

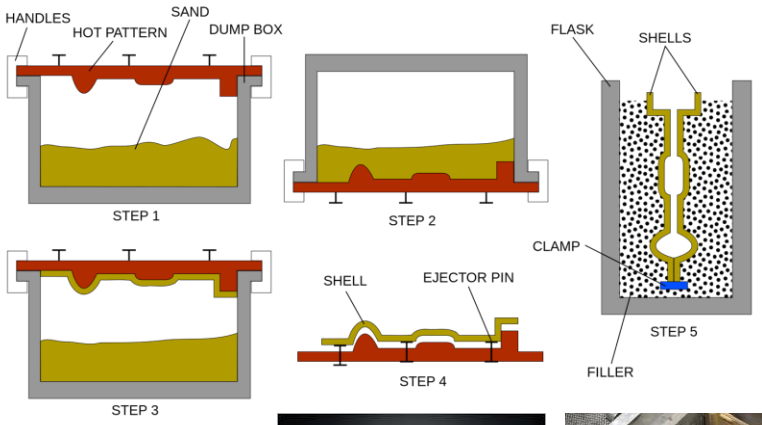
- instead of using "tight" individual flasks for each mould produced, the master flask is contained as an integral unit of the totally mechanized mould producing system.
- both vertical and horizontal partings can be used.
- reduced labour costs because the molding operation is entirely automatic.



disamatic moulding

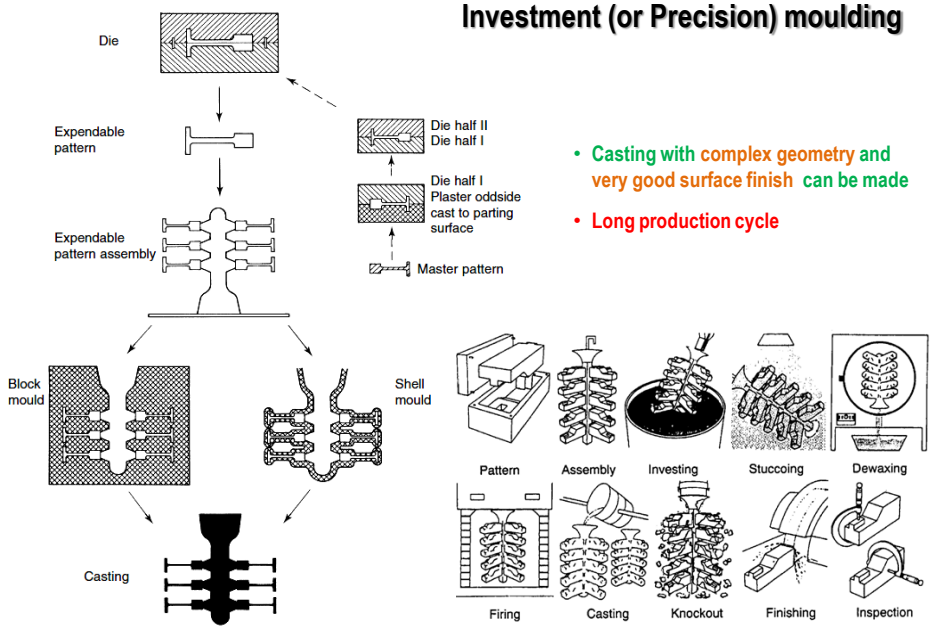
- highly efficient means of rapidly and automatically creating a string of flaskless moulds.
- built for vertical casting and are created in a vertical moulding environment

Shell moulding process



- very fine sand coated with a thermosetting resin placed in contact with a heated pattern to produce a shell of only about 10 mm thick
- produces an excellent surface finish

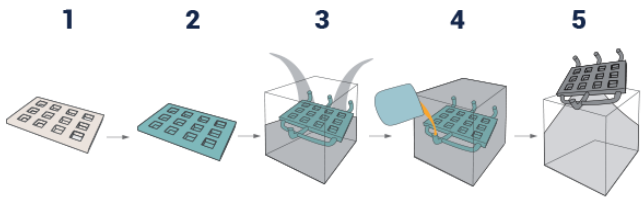
Investment (or Precision) moulding

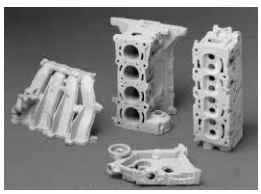


- Casting with complex geometry and very good surface finish can be made
- Long production cycle

Figure 9.14 Production sequence in investment casting (expendable pattern technique) showing casting production (centre) and steps in fusible metal die manufacture (top right)

Lost foam or full mould casting





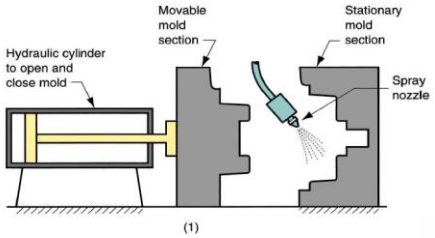
- eliminates the use of sand binders, additives, and cores
- capable of making some shapes that could be made no other way
- care must be taken in gating lost foam parts so that, the molten metal flows through the pattern in one direction

2. Permanent moulding and casting methods

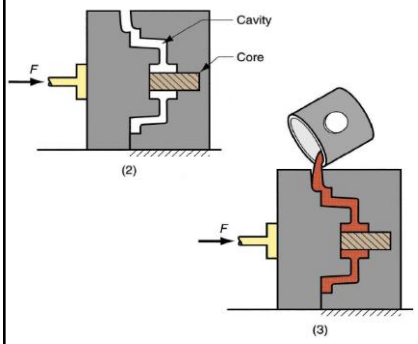
- Use of permanent, metal moulds (made of grey iron, steel, bronze); Moulds used **many times.**
- Liquid poured directly (under gravity) or injected under pressure
- Mould cavity and gating system are machined; generate very good surface finish and dimensional accuracy in casting.
- Common alloys to cast:
  - **Al-, Mg-, Zn-, Pb-, Cu-base alloys, and cast irons;**
  - **most steel casting not suitable due to high temperature (and mould erosion).**
- Limited to relatively simple shapes and volume production only; automation used to obtain a continuous cycle.

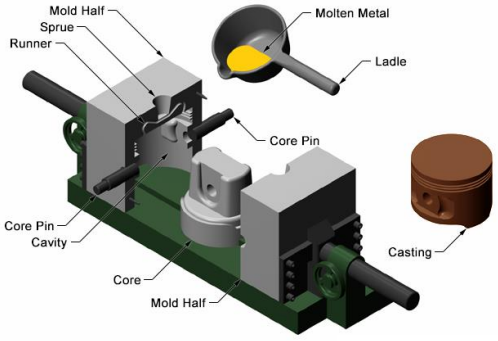
- Short mould life. Common modes of die failure:
  (1) Thermal fatigue, and (2) Mould erosion
- Mould life is extended and ejection made easier by using mould coat (carbon shoot, refractories suspended in liquids).
- **Gravity die (or, permanent mould) casting processes**
  - metal fed by gravity, or by air pressure of 3 to 10 psi.
- **Pressure die (or, simply die) casting processes**
  - processes molten metal is forced into mould cavity under high pressures
  - **low-pressure** (1000 – 2000 psi) or hot chamber die casting process
  - **high-pressure** (10,000 – 30,000 psi) or cold chamber die casting processes
- **Centrifugal casting**

Permanent mould (or, Gravity die) casting process



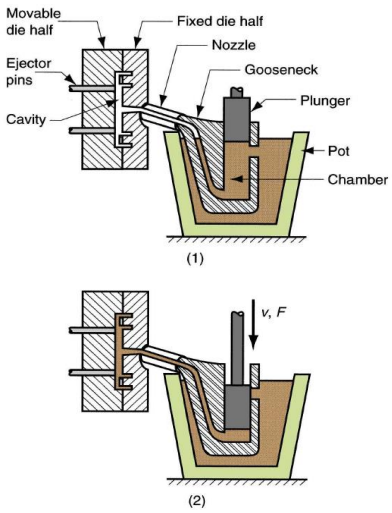
- better mechanical properties
- homogeneous structure and composition
- low shrinkage and gas porosity
- better surface finish and dimensional accuracy
- low-melting-point alloys
- simple-shaped casting
- high mould cost



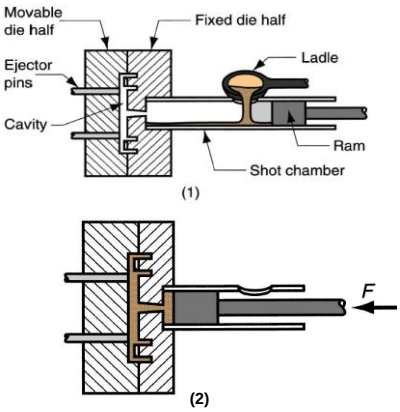


(Pressure) Die casting process

- highly productive method of simple-shaped casting with low dimensions tolerance and high surface quality
- expensive die
- simple-shaped small castings
- complex and large expensive machinery



hot-chamber process

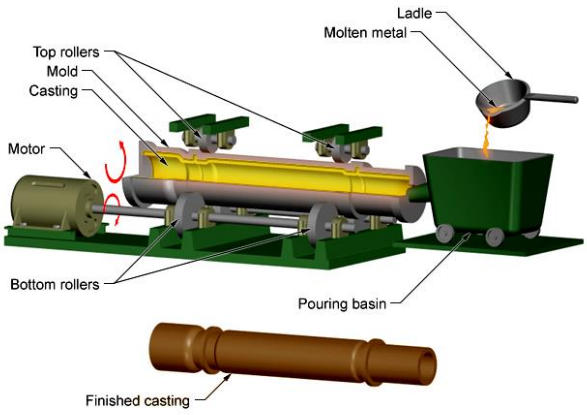


cold-chamber process

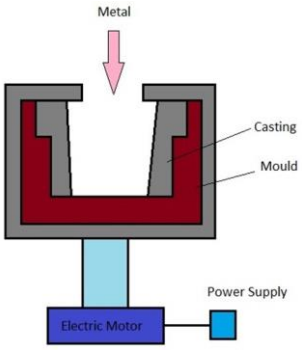
Centrifugal casting

- large cylindrical parts
- good quality

- expensive
- limited design



horizontal centrifugal casting



vertical centrifugal casting

4. Comparative study

	Process
Sand casting	Sand moulds are produced around a permanent pattern that is withdrawn to leave a cavity. Molten metal is poured into the mould and solidifies. Mould (and core) is broken up to retrieve the casting.
Investment casting	A ceramic shell (investment) is slip cast around a wax pattern. Wax is melted and molten metal cast into the investment that is broken up to remove the casting.
Permanent mould casting	Molten metal poured into a metallic mould where it solidifies.
Pressure die casting	Molten metal is forced into a water-coated metal mould (die) through a system of sprues and runners. The metal solidifies rapidly and the casting is removed with its sprue and runners.
Centrifugal casting	Molten metal is introduced into a sand- or copper-lined, cylindrical steel mould that is rotated about its long axis, distributing the metal over its inner surface.
Full mould casting	A refractory coating is applied to a volatile or combustible pattern that is used in a sand mould. The pattern is destroyed by the molten metal.

	Shape	Material
Sand casting	Mainly solid components but complex internal shapes produced using friable cores. Very large and small castings possible but thin sections difficult.	All metals excluding refractory and reactive alloys (e.g. titanium).
Investment casting	Best for relatively small, complex 3D components. Re-entrant angles possible.	Suitable for most metals. Reactive metals can be cast under vacuum.
Permanent mould casting	Mostly used for small, simple shapes with only simple coring.	Mainly used for light alloys. Steels and cast irons also possible.
Pressure die casting	Used for complex shapes and thin sections. Cores must be simple and retractable.	High fluidity requirement means low melting temperature eutectics usually used (e.g. Al-Si). Hot chamber method restricted to very low melting temperature alloys (e.g. Mg and Zn).
Centrifugal casting	Technique used to produce relatively long, hollow objects (e.g. pipes) without the need for cores.	Metals excluding refractory and reactive metals.
Full mould casting	Very complex 3D shapes possible.	Non-refractory metals with casting temperatures high enough to vaporise the pattern.

	Cycle time	Quality
Sand casting	Usually long as limited by rate of heat transfer out of the casting. Use of multiple moulds increases production rate.	Surface texture poor. Porosity endemic. Non-metallic inclusions difficult to control.
Investment casting	Limited by rate of heat transfer out of the casting. Production rates low because of process complexity. Increased by using multiple moulds and patterns.	Surface texture good. Higher mould temperatures decrease porosity but produce coarse microstructures.
Permanent mould casting	Limited by rate of heat transfer across the interface. Production rates can be increased by using multiple moulds.	Surface texture is good. Porosity unavoidable but can be minimized by slower mould filling to reduce turbulence.
Pressure die casting	Solidification time is typically < 1 s so cycle is controlled by time taken to fill mould and remove casting.	Good surface texture but tolerable mould filling produces high degree of internal porosity.
Centrifugal casting	Determined by the rate of introduction of metal into the mould and the rate of solidification of the metal. The latter is lowered for sand-lined moulds.	Porosity and non-metallic inclusions migrate towards the inner surface because of their low density, giving a high quality outer surface.
Full mould casting	Long due to process complexity. Multiple moulds increase production rate.	Normal sand casting defects. Surface texture similar to that of pattern.

	Flexibility	Material utilisation	Operating cost
Sand casting	Patterns cheap and easy to make.	Up to 50% of casting in runners and feeders. Both mould and scrap metal can be directly recycled.	Very low as pattern costs are low and making is relatively easy.
Investment casting	Moderately high because of the ease of production patterns.	Near net shape process with little material contained in feeding systems. Wax recycled, investment lost.	Equipment costs can be high especially where reactive alloys are concerned. Labour costs are high due to the many stages in the process.
Permanent mould casting	Negligible setting up time for manual operation. Mould making relatively difficult.	Rarely better than 60% utilization. Scrap in the runners and feeders can be directly recycled.	Equipment cost can be limited to mould and melt preparation apparatus.
Pressure die casting	Tooling dictated so limited by machine setting up time.	Near net shape process but some scrap in sprues, runners and flash which can be directly recycled.	High, since machine and moulds are expensive.
Centrifugal casting	Setting up times are relatively short.	Absence of runners and risers leads to near 100% use of material.	Equipment is relatively simple and can cost a little. Increased complexity of water-cooled copper-lined moulds more costly.
Full mould casting	Ideal for manufacturing one-offs.	Pattern material entirely wasted. Metal usage poor.	All equipment involved is rudimentary and process is very cheap to operate.

	Advantage	Disadvantage
Sand casting	Almost any metal is cast; no limit on size, shape or weight; low tooling cost.	Some finishing required; somewhat coarse finish; wide tolerances.
Investment casting	Intricate shapes; excellent surface finish and accuracy; almost any metal cast.	Part size limited; expensive patterns, moulds and labour.
Permanent mould casting	Good surface finish and dimensional accuracy; low porosity; high production rate	High mould cost; limited shape and intricacy; not suitable for refractory metals.
Pressure die casting	Excellent dimensional accuracy and surface finish; high production rate.	Die and machine cost high; part size limited; usually limited to non-ferrous alloys; long lead time
Centrifugal casting	Small and large cylindrical parts with good quality; high production rate.	Equipment is expensive; part shape limited.
Full mould casting	Most metal cast with no limit on size; complex shapes.	Patterns have low strength; can be costly for low quantities

	Typical material cast	Weight (kg)		Typical surface finish (μm)
		Minimum	Maximum	
Sand casting	All	0.05	No limit	5-25
Investment casting	All (high melting points)	0.005	100+	1-3
Permanent mould casting	All	0.5	300	2-3
Pressure die casting	Nonferrous (Al, Mg, Zn, Cu)	<0.05	50	1-2
Centrifugal casting	All	--	5000+	2-10
Full mould casting	All	0.05	No limit	5-20

	Porosity	Shape complexity	Dimensional accuracy	Section thickness (mm)	
				Minimum	Maximum
Sand casting	4	1-2	3	3	No limit
Investment casting	3	1	1	1	75
Permanent mould casting	2-3	3-4	1	2	50
Pressure die casting	1-2	3-4	1	0.5	12
Centrifugal casting	1-2	3-4	3	2	100
Full mould casting	4	1	2	2	No limit

Relative rating: 1 – best, 5 – worst;
These ratings are only general; significant variations can occur depending on the methods used.

	Cost			Production rate (Pc/hr)
	Die	Equipment	Labour	
Sand casting	L	L	L-M	<20
Investment casting	M-H	L-M	H	<1000
Permanent mould casting	M	M	L-M	<60
Pressure die casting	H	H	L-M	<200
Centrifugal casting	M	H	L-M	<50
Full mould casting	--	--	M-H	<50

L – Low; M – Medium; H – High

Next Class

MME **345**, Lecture **A:04**

Moulding and Casting Methods

2. Greensand moulding process