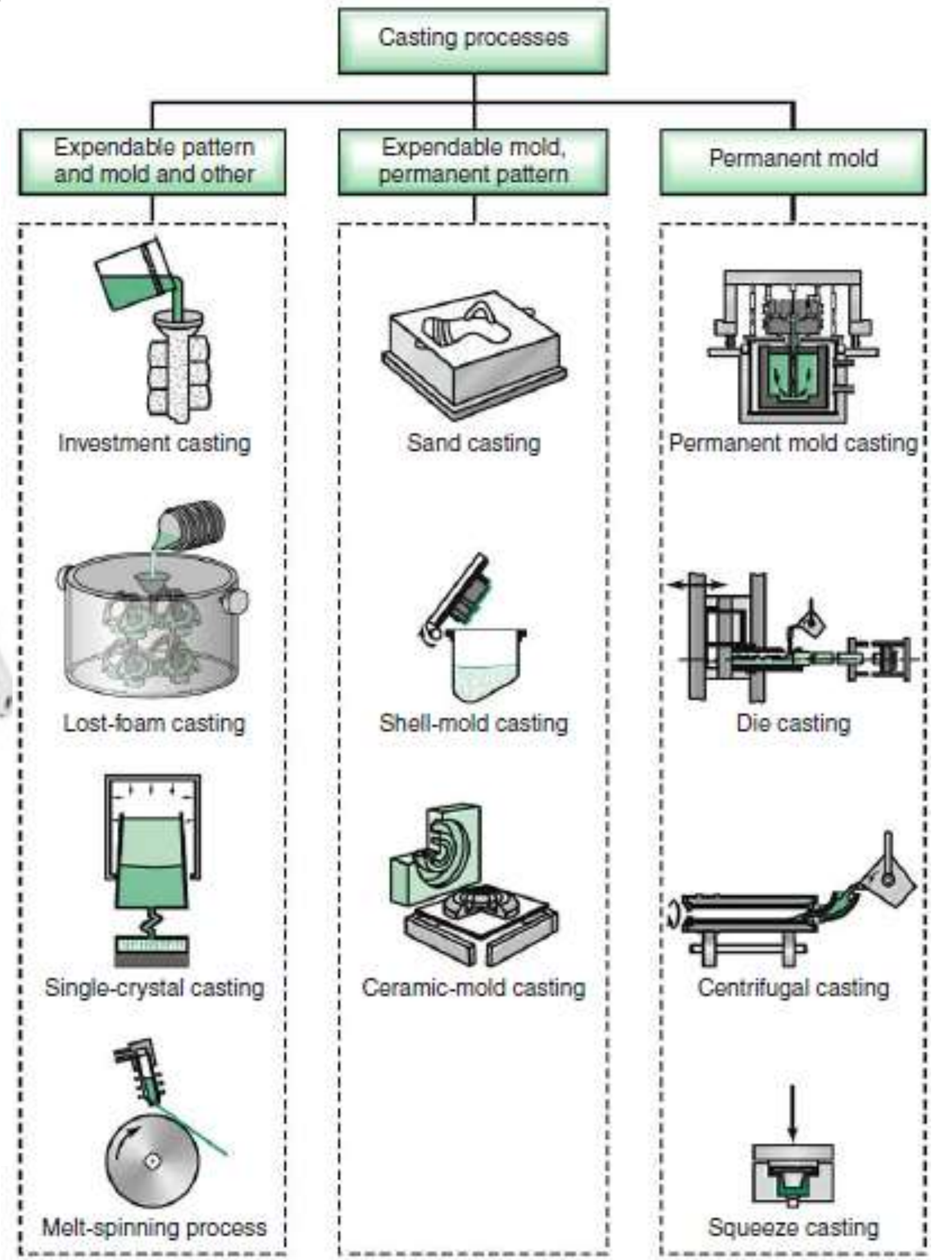
Casting Processes

(a) Melting of metal in a furnace,

(b) Flow of molten metal into a mold cavity,

(c) Solidification and cooling of metal in mold,



Factors affecting events taking place during the solidification of the metal & its cooling to ambient temperature →
① Type of metal
② Thermal properties of metal + mold
③ geometric relationship b/w volume + surface area of casting
④ shape of mould.

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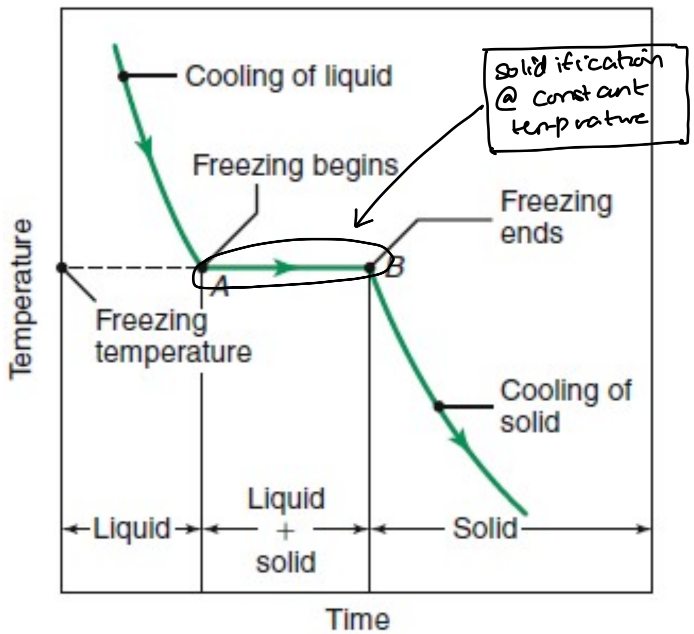
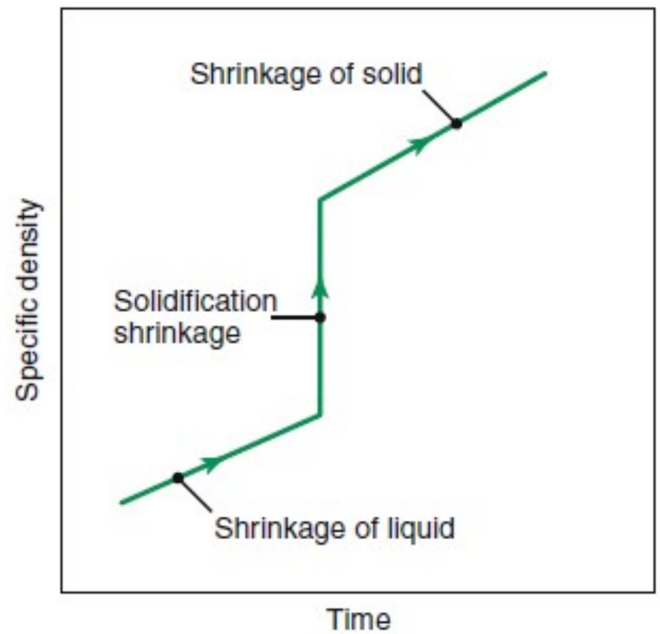
Casting Processes – Solidification – Pure Metal





(a) Pure metal solidifies at a fixed temp. (e.g. Al – 660 C; Fe – 1537 C; W – 3410 C)

(b) At freezing temperature, latent heat of fusion is given off,

(c) Solidification front (solid – liquid interface) moves through the molten metal from the mold wall towards the center,

(d) Once solidified, the cast is taken out of mold.

(e) Metal also shrinks as it solidifies and cools to room temperature.

→ shrinkage in metals can lead to micro cracks and associated porosity, which may compromise mechanical properties of casting.

Solidification Structure – Pure Metal

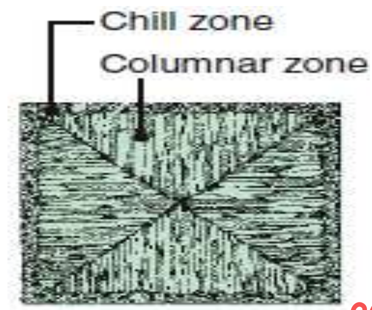
Mold wall is much cooler – so. molten metal cools rapidly and produces a solidified skin of fine equiaxed zone,

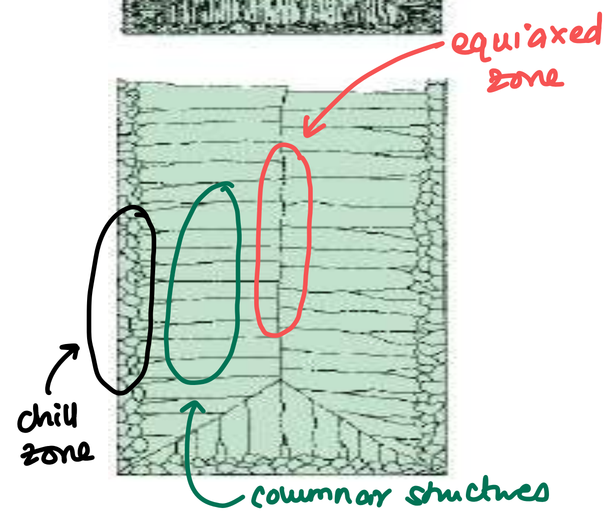
Grains grow in a direction opposite to that of the heat transfer through the mold – **columnar grains**,

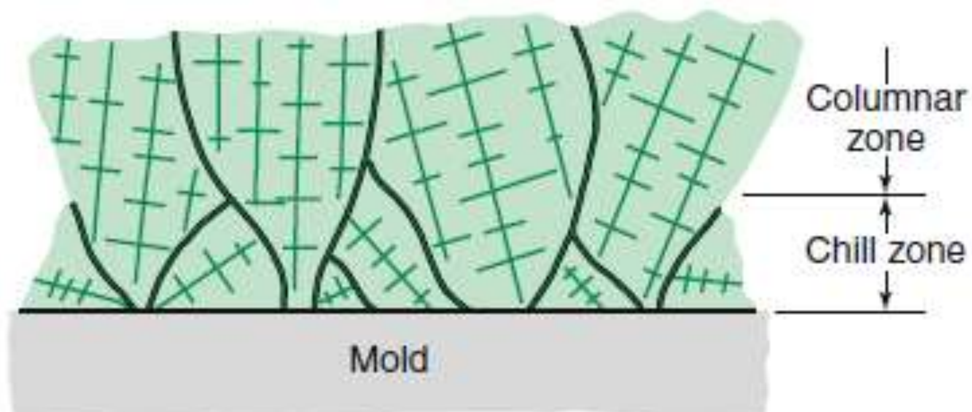
Grains with favorable orientation grow as **columnar grains** but those with different orientation are blocked

As temperature gradient reduces away from mold wall, grains are equiazed and coarse,

This is **homogeneous nucleation** – i.e. grains (crystals) grow upon themselves, starting @ the mold walls.







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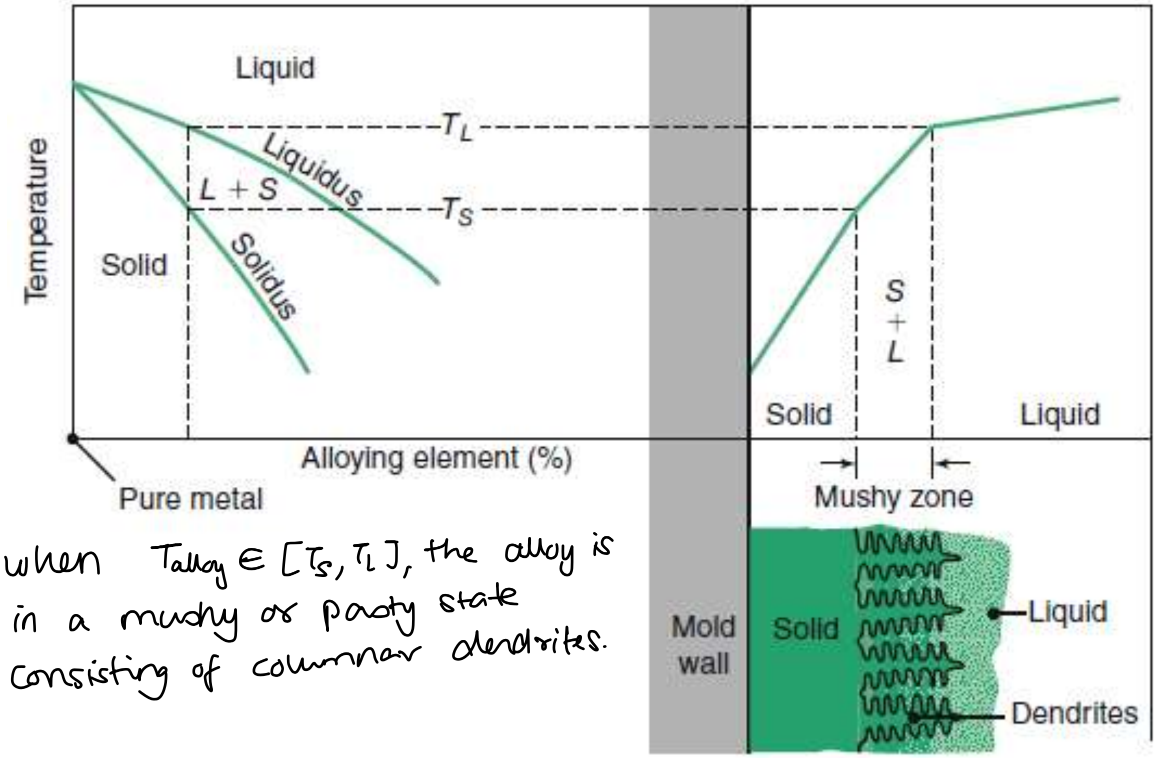
Solidification Structure – Alloys



→ when $T_{alloy} \in [T_S, T_L]$, the alloy is in a mushy or pasty state consisting of columnar dendrites.

Solidification in alloys begins when temperature drops below T_L, and is complete when it reaches T_S.

Between (T_L and T_S), the alloy remains in a mushy state consisting of **columnar dendrites**.

Dendritic Structure is bad as the dendrite arms entrap eutectic liquid.

Dendritic Structure also contribute to several other detrimental factors such as compositional variation, segregation and microporosity in a cast part.
① ② ③

(width of mushy zone)

(Freezing Range $= T_L - T_S$)

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⇒ Eutectics solidify similar to pure metals with an essentially plane solidification front.

⇒ Type of structure after solidification depends upon eutectic composition
→ symmetrical phase diagram alloys: LAMELLAR
→ volume fraction of minor phase <25% : FIBROUS.

Effects of cooling rates

① Slow Cooling Rates (10^2 K/s) → coarse dendritic structures with large spacing b/w dendritic arms.

② higher cooling Rates (10^4 K/s) → finer structure with smaller dendrite arm spacing.

③ Still higher cooling rates (10^6–10^8 K/s) → amorphous structures

---

Grain Size Vs Properties

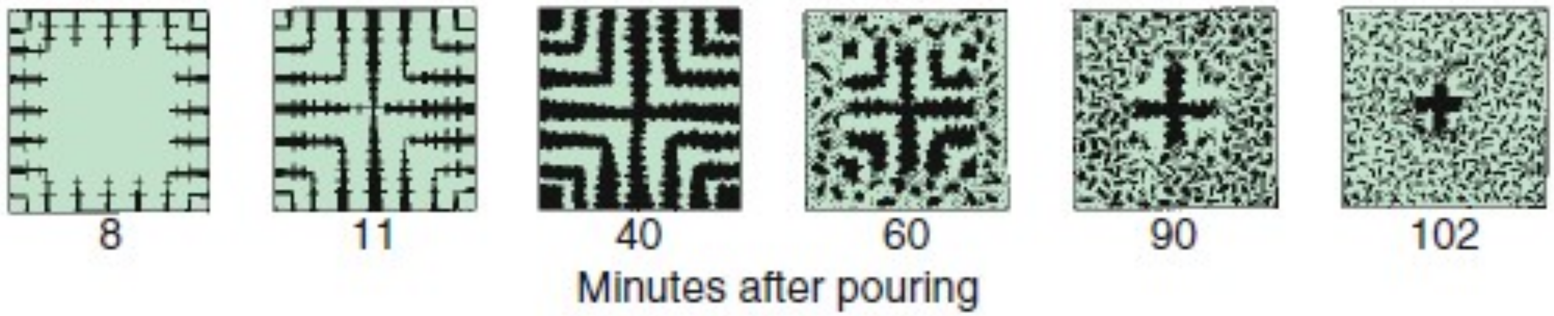
Decrease in grain size ⟹ Strength and Ductility of cast alloy increase

Decrease in grain size ⟹ interdendritic shrinkage voids or microporosity decreases

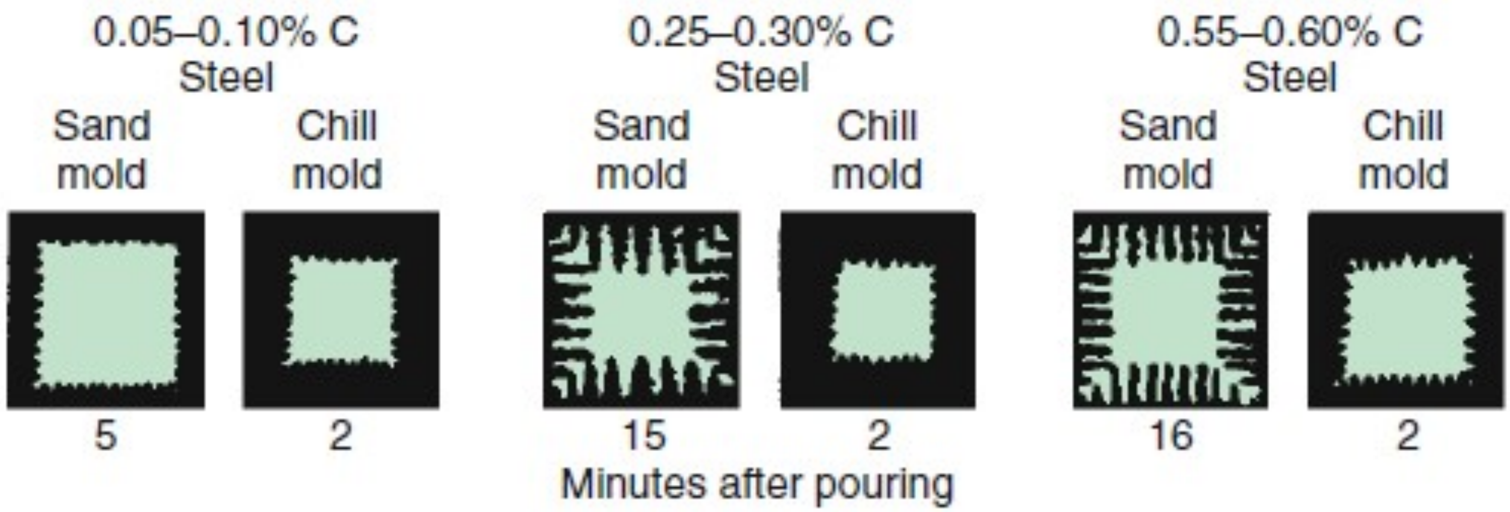
Decrease in grain size ⟹ tendency of casting to crack during solidification (hot tear) decreases.

Lack of uniformity in grain size and grain distribution results in casting with anisotropic properties.

Solidification Structure – Alloys



Solidification pattern for gray cast iron in a 180 mm square cast – takes almost 2 hrs for complete solidification – however, dendrites reach each other after even 11 s.



Heat transfer conditions of mold walls and chemical composition of alloys can influence the solidification structure and final property of the cast significantly.

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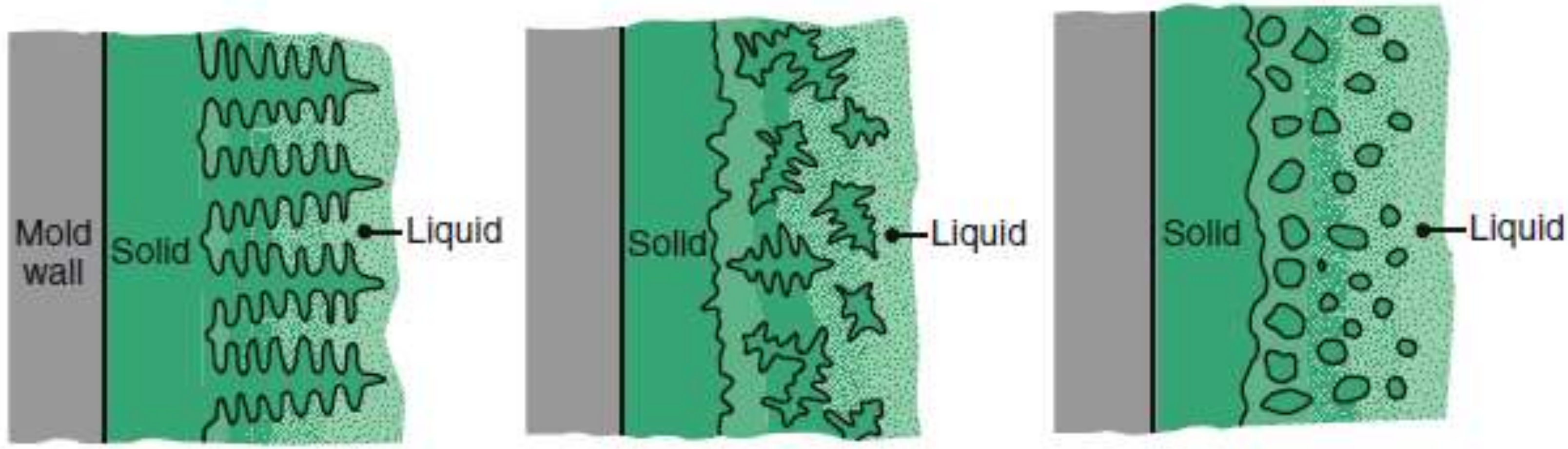
Solidification Structure and Property – Alloys



Morphology of dendrites and **Concentration** of alloys can vary widely in different regions of the cast resulting in variation in properties within the cast.

A very slow cooling can allow dendrites to form uniform composition. But, a little fast cooling, which usually happen in reality, form **cored dendrites** (surface has higher concentration of alloying elements than the core - **microsegregation**).

Concentration Gradient: Surface composition of cored dendrites is different from that @ their centers.

Mac**rosegregation** is another challenge. This refers to compositional difference thru' the cast. For example, low melting point constituents in the solidified alloy are driven towards the center (**normal segregation**).

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Cause of Microsegregation: solute rejection from the core toward the surface during solidification of the dendrite.

Segregation

① Microsegregation

- → takes place in formation of dendrites as surface of cored dendrites leads to surface having higher concentration of alloying elements than the core.
- → caused due to solute rejection from the core towards the surface during solidification of the dendrite.

② Macrosegregation

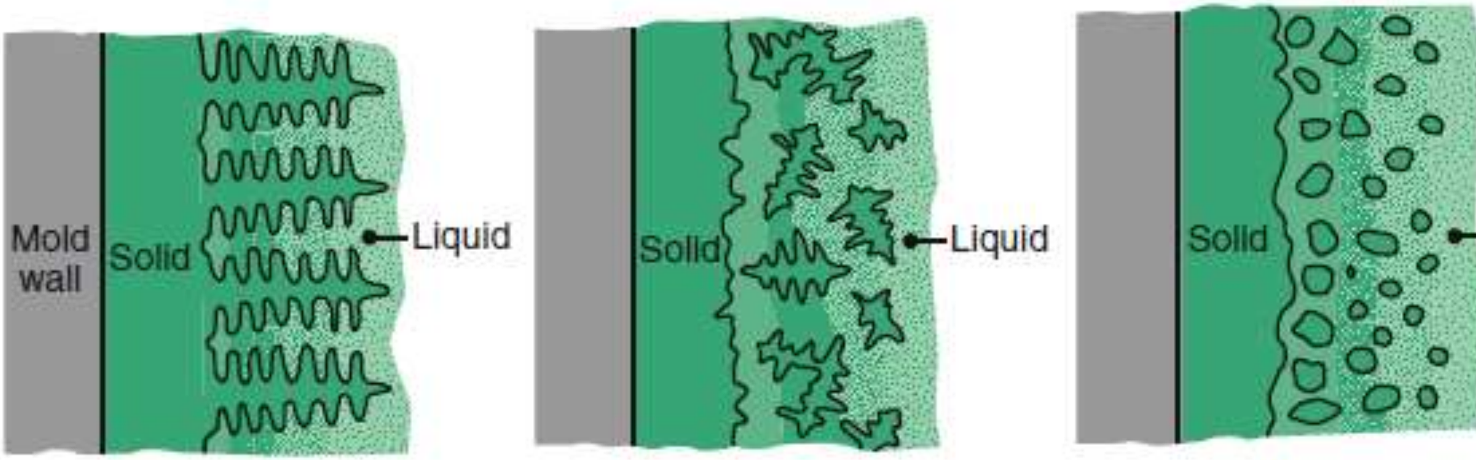
- → compositional differences throughout the casting.
  - → **Normal segregation**: when solidification front moves away from the surface of a casting as a plane, lower melting point constituents in the solidifying alloy are driven towards the center and hence the concentration of alloying elements is higher @ center than surface.
  - → **Inverse segregation**: In dendritic structures of solid solution alloys, the center has lower concentration of alloying elements than at the surface. This is because liquid metals enters the cavities developed from solidification shrinkage in the dendrite arms, which have solidified sooner.

③ Gravity segregation

High density inclusions/compound sink and lighter elements (Pb – Sn) float to surface.

Because of presence of thermal gradients in a solidifying mass of liquid metal and due to gravity and resulting density differences, CONVECTION plays a huge role on types of structures developed.

Solidification Structure and Property – Alloys



Convection promote formation of outer chill zone, refines grain size and accelerates transition from columnar to equiaxed grains.

The structure in the middle can be influenced by increasing convection in the liquid. A bit of convection can help separation of dendrite arms and transition from columnar to equiaxed (**CTE**) structure. (Dendrite Multiplication ⇒ increase convection)
(reducing convection ⇒ coarser + longer columnar dendritic grains)

advantages of mechanical agitation

Dendrite arms can also be broken in the early stages of solidification (rheocasting, semisolid processing, etc.) by agitation or mechanical vibration producing equiaxed non-dendritic structure (**top – right**). This results in finer grain size with equiaxed non-dendritic grains distributed more uniformly throughout the casting. Another advantage is THIXOTROPY → improved castability due to reduced viscosity when the liquid metal is agitated.

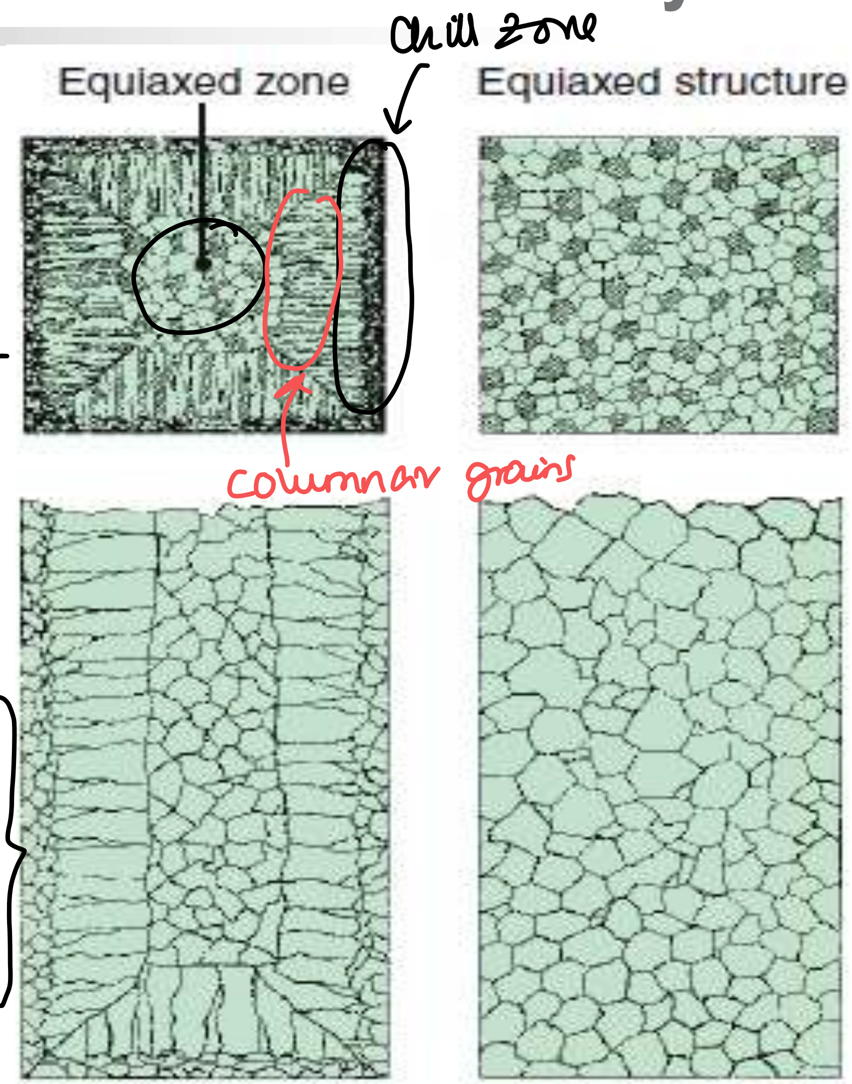
Solidification Structure – Solid Solution Alloys

A typical cast structure of a solid-solution alloy with an inner zone of equiaxed grains.

The inner zone can be extended all through the cast by adding an inoculant (nucleating agent) to the alloy. The inoculant induces nucleation of the grains through out the liquid – this is called **heterogeneous nucleation.**

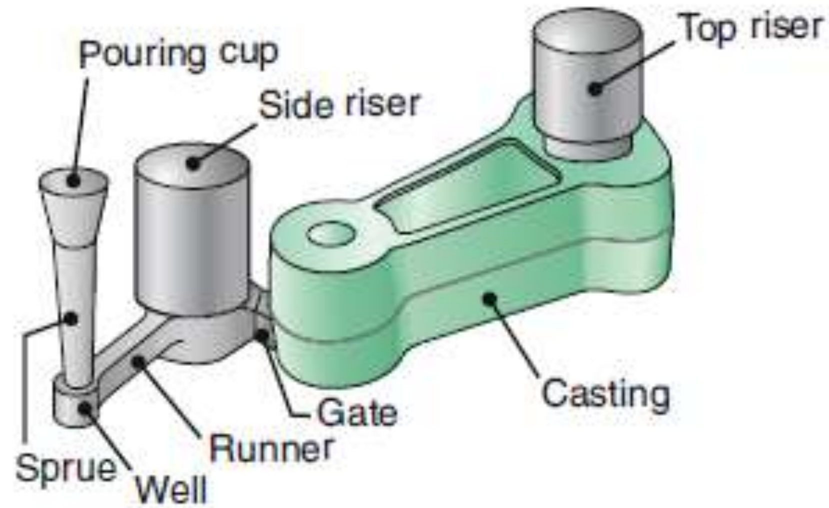
Another form of segregation of alloys is due to gravity, which allows higher density inclusions and compounds to sink and lighter elements to float on the surface. This is referred to as the gravity segregation.

(gravity - based segregation)



Flow of Molten Metal

Molten metal is poured through a pouring basin and it then flows through the gating system (sprue, runner and gates) to mold cavity.



③ Risers or feeders act as reservoirs of molten metal, which will be supplied (if required) to prevent porosity due to shrinkage during solidification.

④ Gating system : in sand casting, it is used to trap oxide contaminants and remove them from molten metals by having them adhere to the walls of the gating system, thereby preventing them to reach the mould cavity.

① Sprue : tapered vertical channel through which molten metal flows downward.

② Runners : channels that carry molten metal from sprue to the gate.

As molten metal enters into the actual mold, it must be handled carefully to avoid formation of oxides. It should not cool before reaching to the mold cavity, and do not entrap any gas.

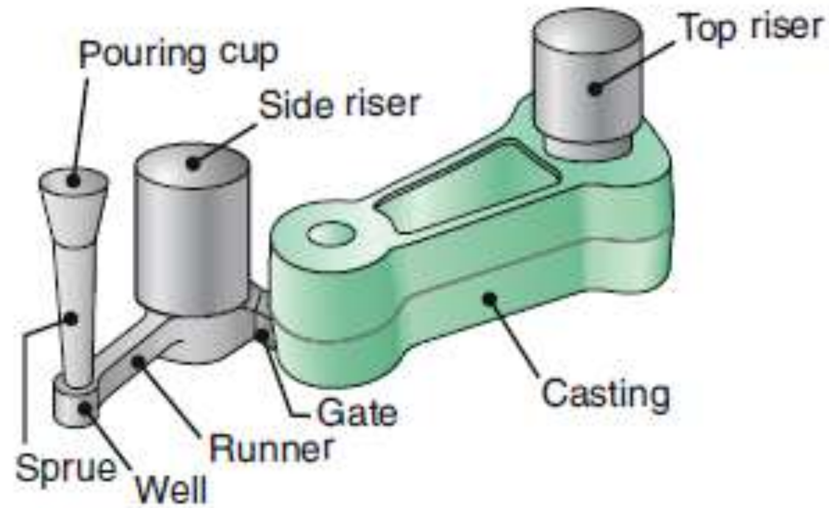
← succesful design requires control of solidification to ensure adequate fluid flow.

Properly designed gating system helps avoid
① premature cooling
② turbulence
③ gas entrapment

Flow of Molten Metal

$$h + \frac{p}{\rho g} + \frac{v^2}{2g} = \text{constant},$$

h is elevation above a certain level, *p* is pressure at that elevation, *v* is the velocity of the liquid at that elevation, ρ is density of liquid (assuming that it is incompressible) and *g* is the gravitational constant.



$$h_1 + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} = h_2 + \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + f,$$

f is the friction loss.

$$Q = A_1 v_1 = A_2 v_2,$$

Continuity of Mass: *For incompressible fluids and in a system with impermeable walls, the rate of flow is constant*

Q is volume rate of flow, A is cross-sectional area of liquid stream and v is the average velocity of the liquid in that cross-section.

A constant permeability of mold wall is very important. Otherwise, some liquid will escape through the mold wall and flow rate will decrease as the liquid stream will move thru' the mold.

Q: why is const. permeability of mold wall crucial?

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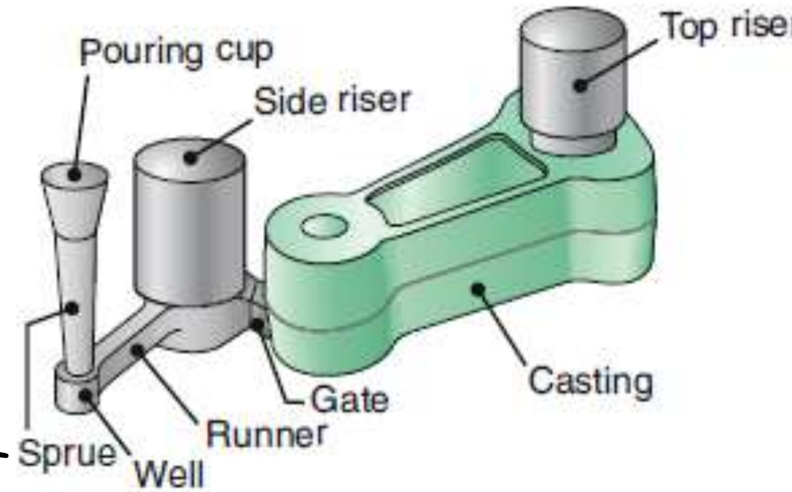
Flow of Molten Metal – Sprue Design

For a free falling liquid (such as water from a faucet), the cross-section area of the stream decreases as the liquid gains velocity downward.

So, if we design a sprue with constant cross-section, regions can develop where liquid loses contact with sprue wall. As a result, **ASPIRATION** (**a process whereby air is sucked in or entrapped in the liquid**) may take place.



A tapered sprue is an alternative and its specific shape can be determined as

$$\frac{A_1}{A_2} = \sqrt{\frac{h_2}{h_1}},$$

← to avoid "ASPIRATION"

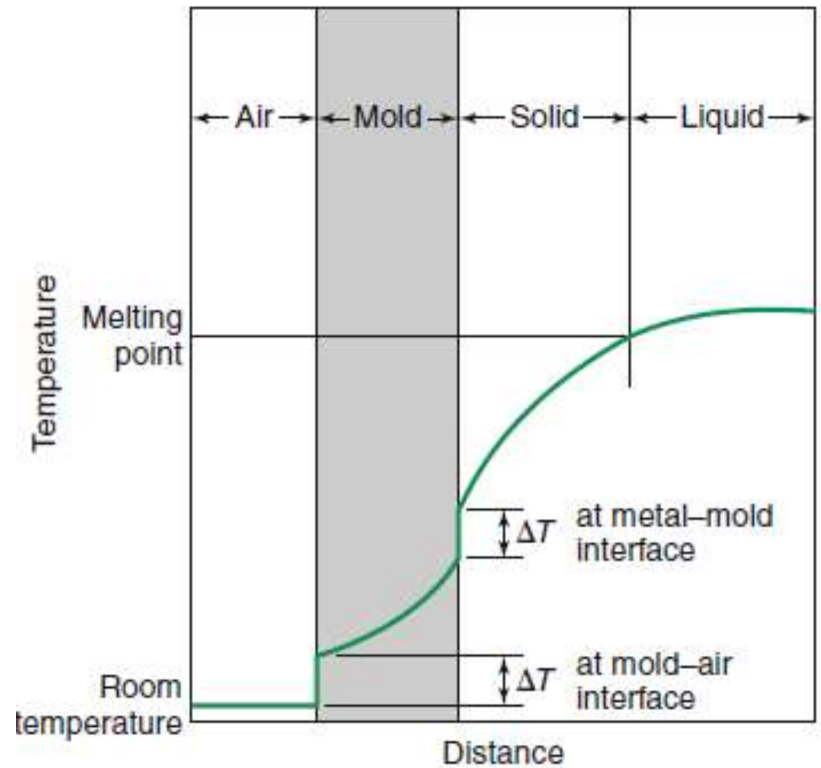
Assuming no frictional loss encountered by the liquid stream.

cube & sphere of same volume ⟶ cube solidifies faster

Flow of Molten Metal – Solidification Time

Heat transfer from pouring to solidification to cooling to room temperature is very important.

Heat from the liquid metal is given off thru' the mold wall and to the surrounding air. The temperature drop at the air-mold and mold-metal interfaces is caused by the presence of the boundary layers and imperfect contact at these interfaces.



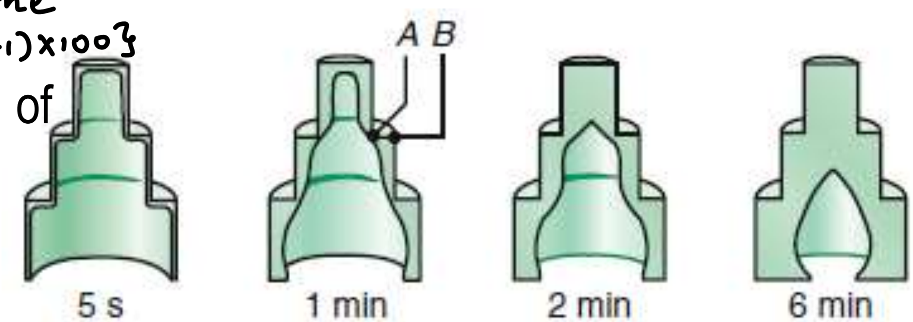
During the early stages, a thin skin begins to form at the relatively cool mold walls. As time passes, the thickness of the ski increases. **With a flat mold wall, this thickness is almost proportional to the square root of time.** Doubling the time makes the skin 41% thicker $\{(\sqrt{2}-1)\times 100\}$

The solidification time is a function of the volume of a casting and its surface area (*Chvorinov's rule*).

$$\text{Solidification time} = C\left(\frac{\text{Volume}}{\text{Surface area}}\right)^{n}$$

$\boxed{n \in [1.5, 2]}$

reflects → (a) mold material, (b) metal properties, (c) temperature



Typical slush casting with molten metal being poured out after the indicated times.

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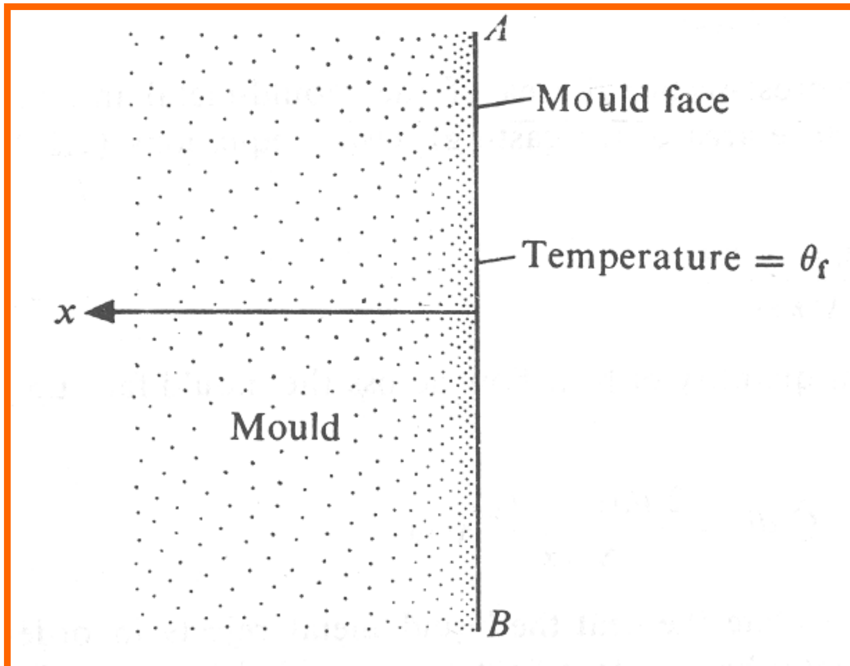
Flow of Molten Metal – Solidification Time

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \Rightarrow T_x(t) = T_0 + (T_f - T_0)\left[1 - \operatorname{erf}\frac{x}{2\sqrt{\alpha t}}\right]; \quad \operatorname{erf}(z) = \frac{2}{\sqrt{\pi}}\int_0^z e^{-x^2}\,dx$$

$$\dot{Q} = -kA\left.\frac{\partial T}{\partial x}\right|_{x=0} = \frac{kA(T_f - T_0)}{\sqrt{\pi\alpha t}}$$

$$Q_{t_0} = \int_0^{t_0}\dot{Q}\,dt = \frac{2kA(T_f - T_0)}{\sqrt{\pi\alpha}}\sqrt{t_0}$$

$$Q_R = \rho_m V[L + C_m(T_p - T_f)]$$



$$t_s = \gamma\left(\frac{V}{A}\right)^2 \quad \text{where} \quad \gamma = \left(\frac{\rho_m\sqrt{\pi\alpha}\,[L + C_m(T_p - T_f)]}{2k(T_f - T_0)}\right)$$

$\Leftarrow$ Chvorinov's rule

Flow of Molten Metal – Filling of Mold Cavity

Instantaneous Filling

Pressure Die Casting, Centrifugal Casting, Injection Molding

Slow Filling

Sand Casting, Investment Casting, Shell Molding, Gravity Die Casting

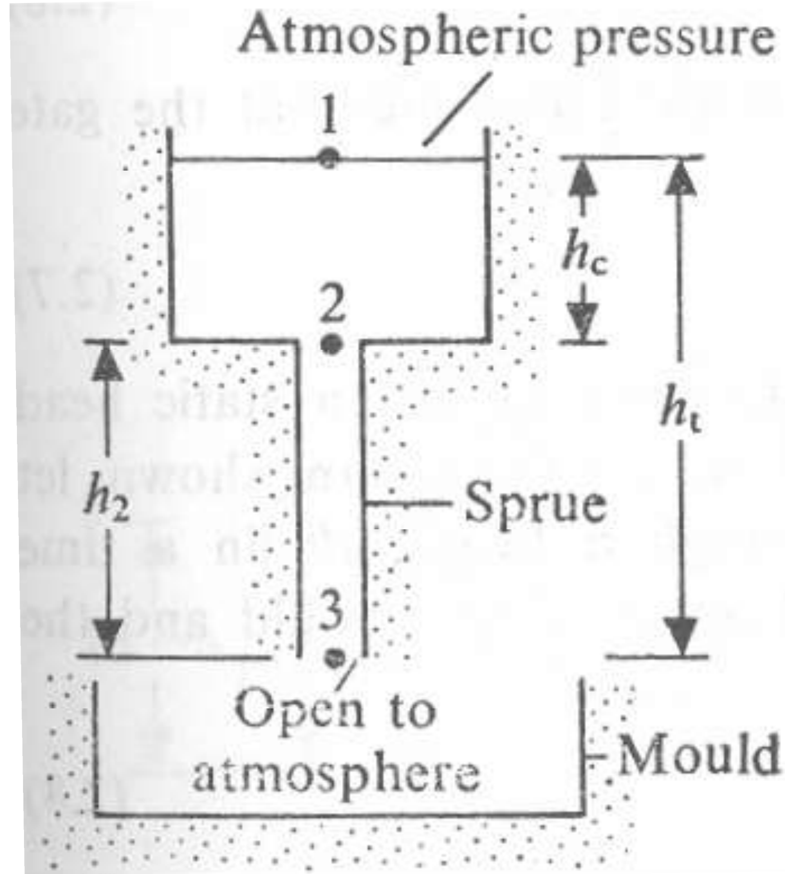
Sand Casting

Top Gating, Bottom Gating, Horizontal Gating

Time to fill a Mold Cavity – Sand Mold

Energy Balance

$$\frac{v_3^2}{2} + \frac{p_3}{\rho_m} + g \cdot 0 = \frac{v_1^2}{2} + \frac{p_1}{\rho_m} + gh_t$$



Time to fill, t_f

$$t_f = \frac{V}{A_g v_3}$$

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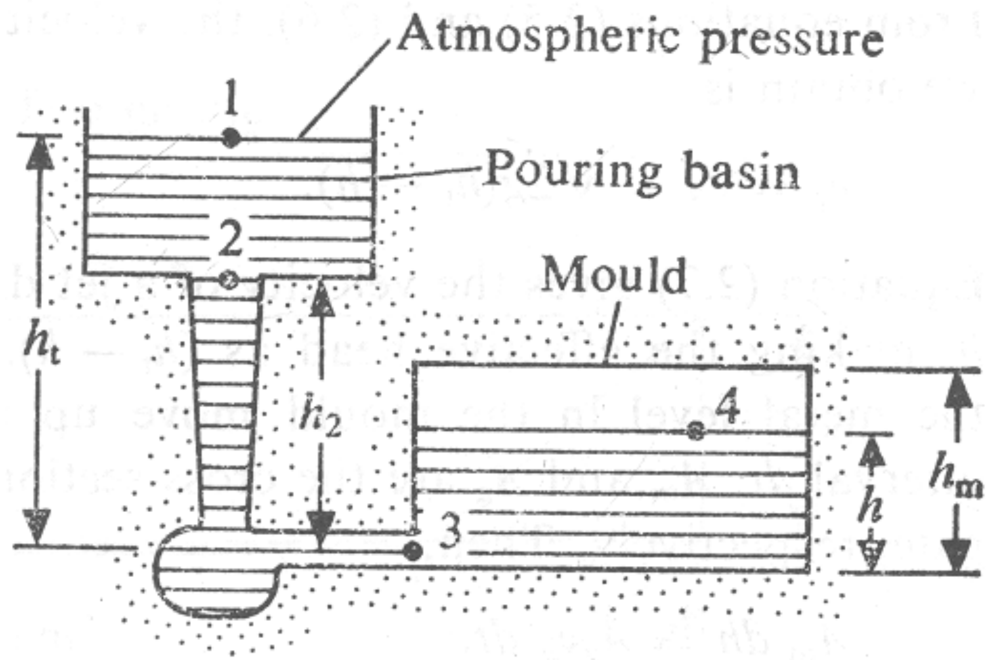
Time to fill a Mold Cavity – Sand Mold (Bottom Gating)

Energy Balance

$$\frac{v_3^2}{2}+\frac{p_3}{\rho_m}+g\cdot 0=\frac{v_1^2}{2}+\frac{p_1}{\rho_m}+gh_t$$

$$\frac{v_4^2}{2}+\frac{p_4}{\rho_m}+gh=\frac{v_3^2}{2}+\frac{p_3}{\rho_m}+g\cdot 0$$



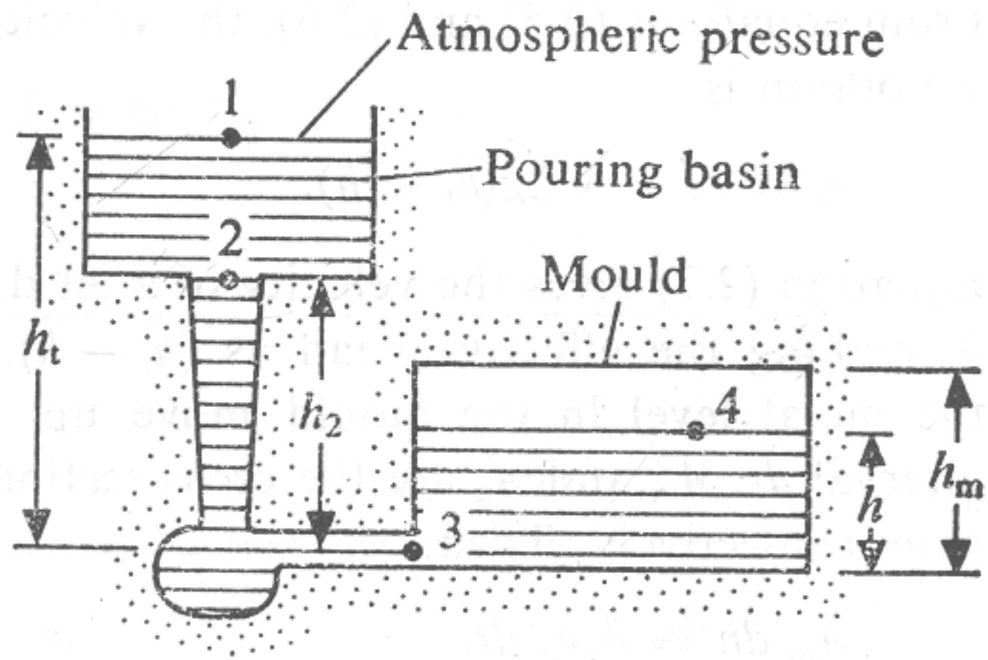
$$\Rightarrow \quad v_g=v_3=\sqrt{2g(h_t-h)}$$

Time to fill a Mold Cavity – Sand Mold (Bottom Gating)

Mass conservation

$$A_m dh = A_g v_g dt$$

$$\frac{1}{\sqrt{2g}}\frac{dh}{\sqrt{h_t - h}} = \frac{A_g}{A_m} dt$$



Time to Fill, t_f

$$\frac{1}{\sqrt{2g}}\int_0^{h_m}\frac{dh}{\sqrt{h_t - h}} = \frac{A_g}{A_m}\int_0^{t_f} dt$$

$$t_f = \frac{A_m}{A_g}\frac{1}{\sqrt{2g}}2\left(\sqrt{h_t} - \sqrt{(h_t - h_m)}\right)$$

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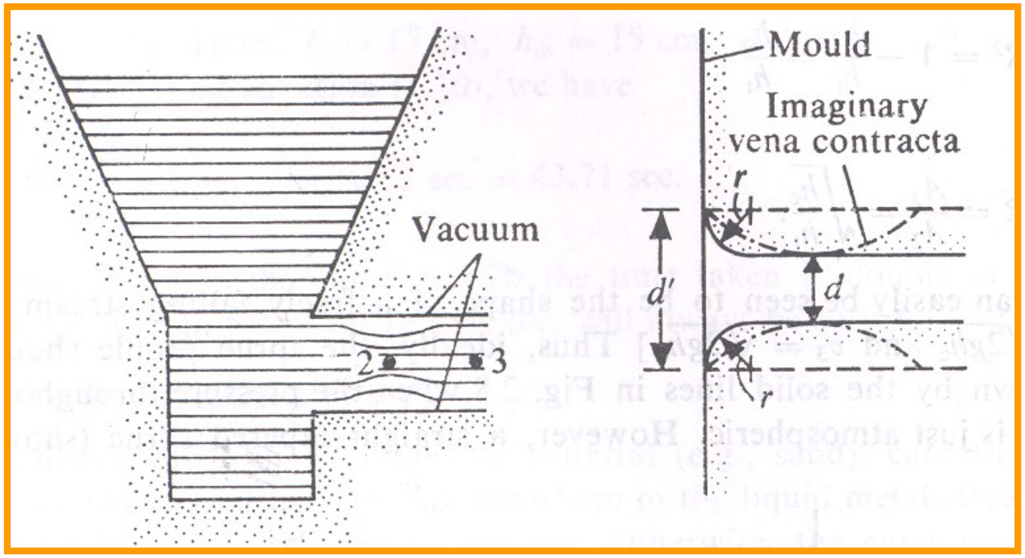
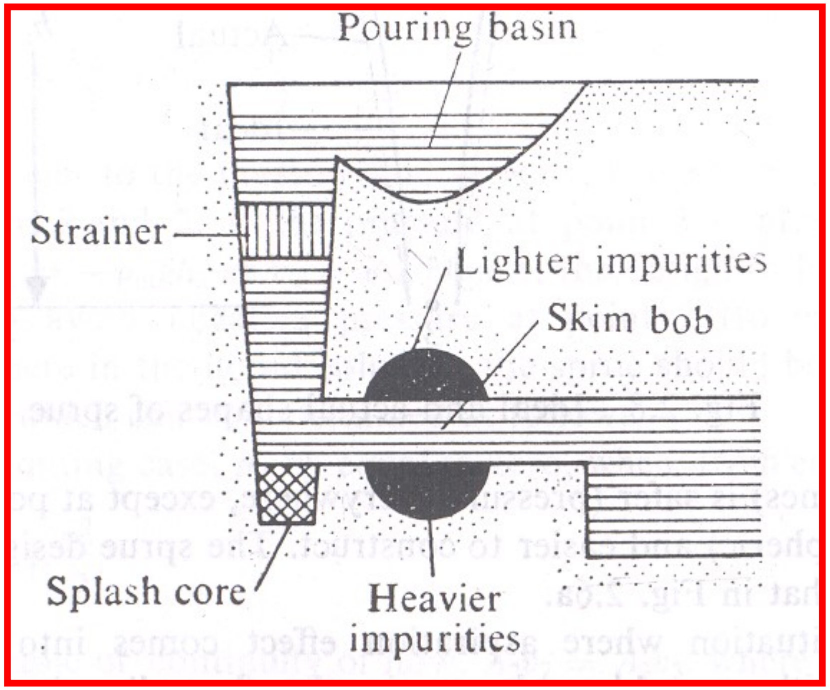
Gating Design is very important





Shrinkage

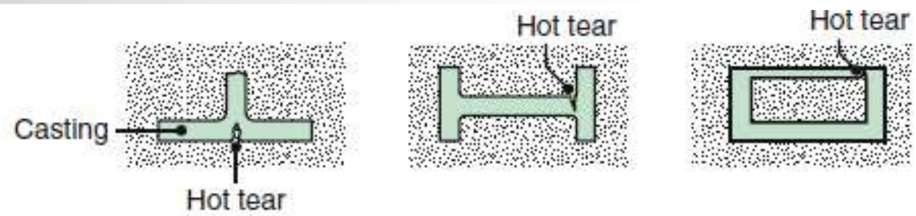
→ Because of their thermal expansion characteristics, metals usually shrink upon and during solidification. Shrinkage, which causes dimensional changes, warping and cracking is a result of :

1. contraction of molten metal prior to its solidification.
2. contraction of metal during phase change from $L \to S$.
3. contraction of solidified metal (casting) as $T \to T_{ambient}$

Largest shrinkage occurs during step 3

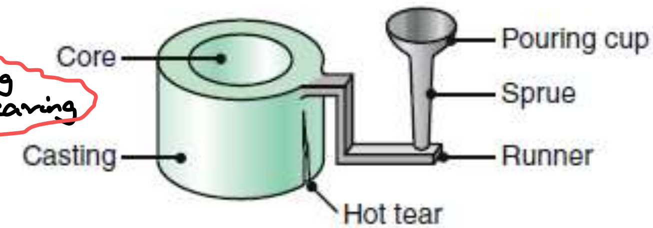
Common defects in Casting

1. **Metallic Projections –** consisting of fins, flash, or projections such as swells & rough surfaces.



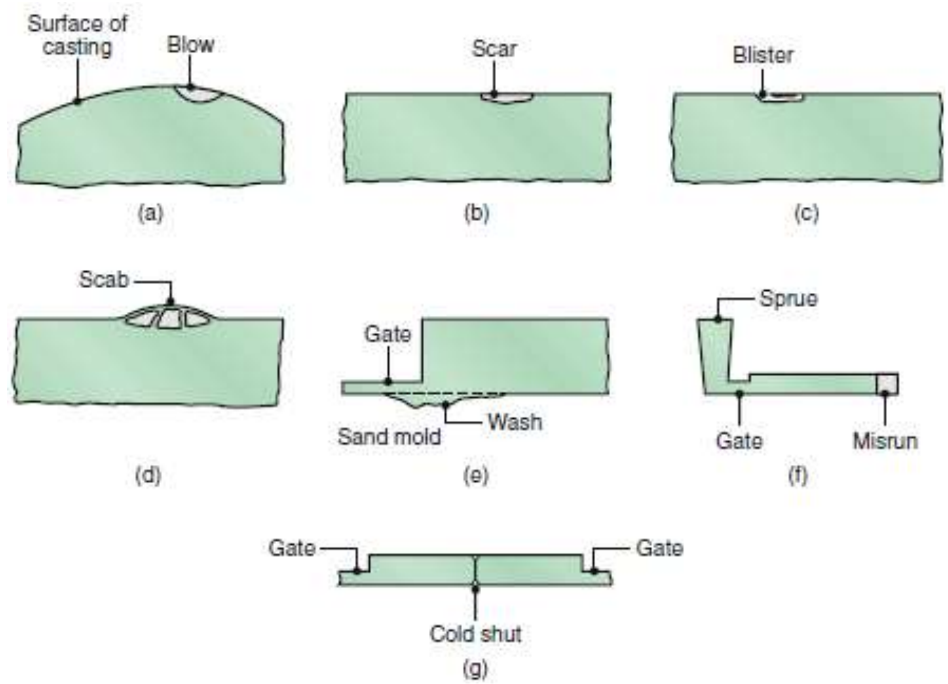
2. **Cavities –** rounded or rough internal or exposed cavities including blowholes, pinholes and shrinkage cavities.

tendency of casting to crack during tearing



3. **Discontinuities –** cracks, cold or hot tearing, and cold shuts. If solidifying metal is constrained from free shrinkage, cracking and tearing may occur. **Cold shut** is an interface that lacks complete fusion because of meeting of two liquid streams from different gates.

4. **Defective surface –** surface folds, laps, scars, adhering sand layers and oxide scale.



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- Reason for hot tearing : casting cannot shrink freely during cooling
- How to avoid hot tearing → exothermic padding may be used to control cooling @ critical sections.

Common defects in Casting

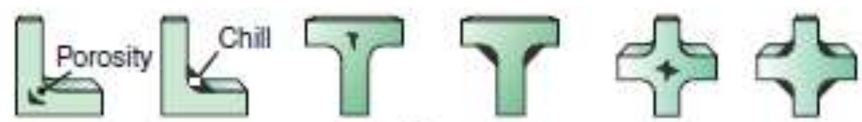
(5) **Incomplete casting –** misrun due to premature solidification and insufficient volume of metal poured, and runout due to loss of metal from the mold after pouring.

(6) **Incorrect dimension or shape –** due to improper shrinkage allowance, pattern-mounting error, irregular contraction, deformed pattern, warped casting….. .

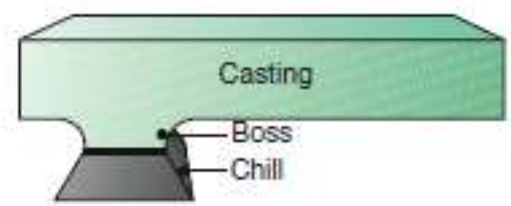
(7) **Inclusions –** generally nonmetallic and forms during melting, solidification and molding. These are harmful as they arc as stress raisers and reduce the impact strength and ductility of the casting.

(8) **Porosity –** can form due to shrinkage, or dissolved gases or both. Microporosity can develop when liquid metal soldifies and shrinks between dendrtes and between dendrite branches.

(a)



(b)



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Porosity

→ may be caused by shrinkage, entrapped gases or both. Porous regions can develop in castings because of shrinkage of the solidified metal. Thin sections in a casting solidify sooner than thicker regions: as a result, molten metal flows into thicker regions that haven't yet solidified.

→ Microporosity : liquid metal solidifies and shrinks b/w dendrites and dendrite branches.

→ Porosity is detrimental to ductility of casting and surface finish. It makes the cast permeable and affects the pressure tightness of the cast pressure vessel.

→ Methods to eliminate porosity caused by shrinkage:

① provide adequate liquid metal to avoid cavity formation
② Internal / External chills as in sand casting. They increase the rate of solidification in critical regions.
③ Alloy - porosity may be reduced by steep temp. gradient.
④ Hot Isostatic Pressing applied to the casting.

10.2 : Differences b/w solidification of pure metals v/s alloys?

→ Pure metal solidify @ their characteristic freezing temperature

→ Alloys solidify in a temperature range extending from solidus – liquidus region. (exception. Eutectics – they transform to one or more solid after eutectic point)

Casting Processes - Classifications

Casting processes are generally categorized as **permanent mold** and **expendable mold** processes. **Expendable mold** processes are further categorized as **permanent mold** and **expendable pattern** processes..

Expendable molds: made of sand, plaster, ceramics, and similar refractory materials. These are mixed with various binders for improved properties. A typical sand mold consists of 90% sand, 7% clay, and 3% water.

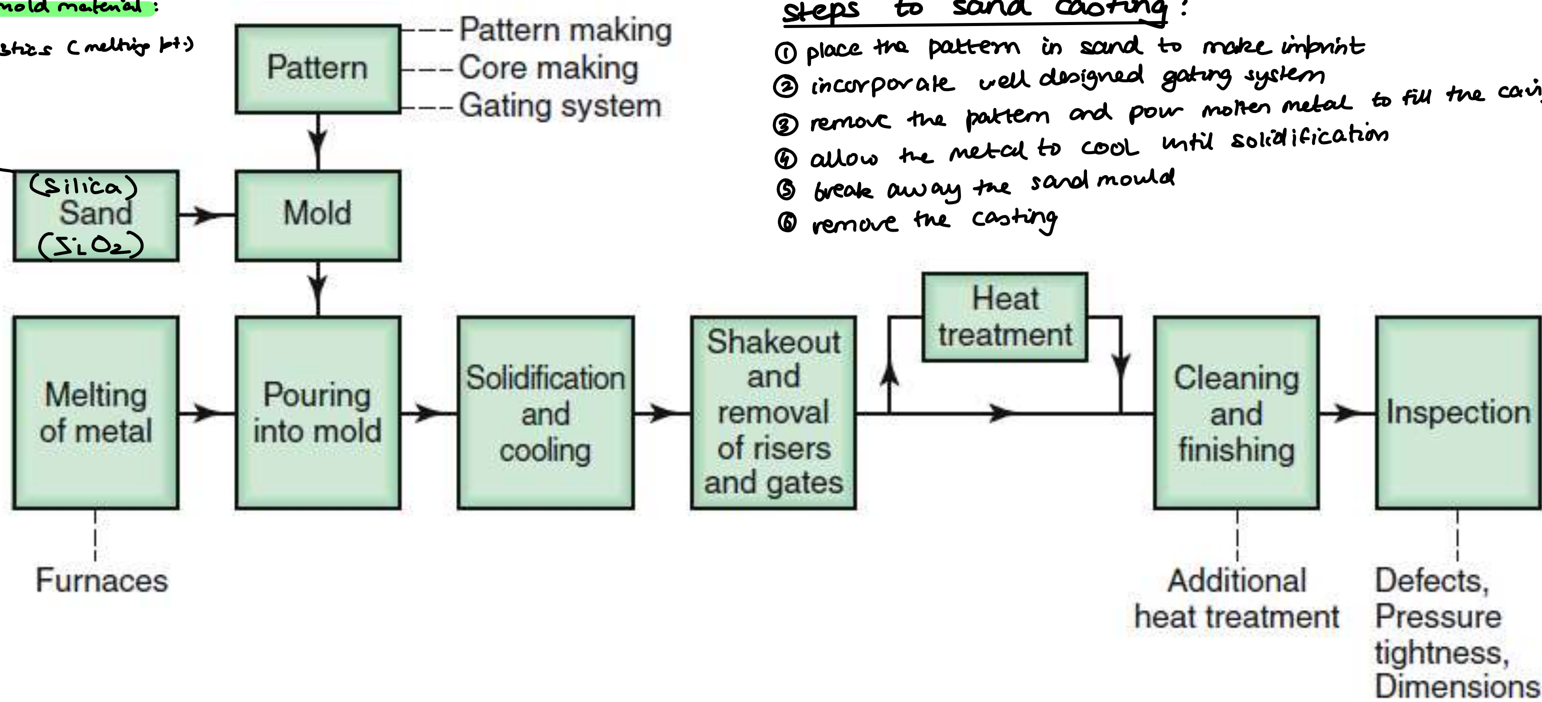
In **sand and shell casting**, the mold is produced from a pattern, which can be reused - so, **expendable-mold, permanent-pattern processes**.

But, **investment casting** consumes a pattern for each mold produced - so, **expendable-mold, expendable pattern** process.

Permanent mold :: made of metals that maintain their strength at high temperatures. These are made for repeated use with a facility for easy removal of cast.

Expendable Mold Permanent Pattern Casting

Sand is suitable as mold material:
① inexpensive
② high temp. characteristics (melting pt.)



Steps to sand casting:
① place the pattern in sand to make imprint
② incorporate well designed gating system
③ remove the pattern and pour molten metal to fill the cavity
④ allow the metal to cool until solidification
⑤ break away the sand mould
⑥ remove the casting

Naturally bonded (bank sand) and **synthetic (lake sand)** - two types of sand are generally used. **Synthetic sand** is used as its composition can be controlled more accurately. For proper functioning, mould sand must be fresh, clean and preferably new.

Sand particles should be **fine, rounded and uniformly distributed** to form a smooth mold surface. Fine grained sand enhances mold strength but lowers mold permeability. The mold also should have **good collapsibility** to allow the casting to shrink while cooling and, thus, to avoid defects in the casting, such as hot tearing and cracking.

(cracking/break in cast during solidification)

Types of Sand Mold

Green Sand, **Cold-Box** and **No-bake** – three basic types of sand molds are common. The most common mold material is **Green Molding Sand**, which is **a mixture oft sand, clay and water.** The word "green" refers to the fact that the sand in the mold is moist or damp while molten metal is being poured in it. It is the least expensive method ⟹ sand may be recycled.

Skin Dried Method: mold surfaces are dried by storing in air or with torches. These are used in larger castings due to high strength.

In **cold-box mold** process, various organic and inorganic binders are blended into the sane to bond the grains chemically for greater strength. Such molds produce more dimensionally accurate parts. In the **no-bake mold**, a synthetic liquid resin is mixed with the sand and the sand hardens at room temperature.

aka (COLD SETTING PROCESSES)

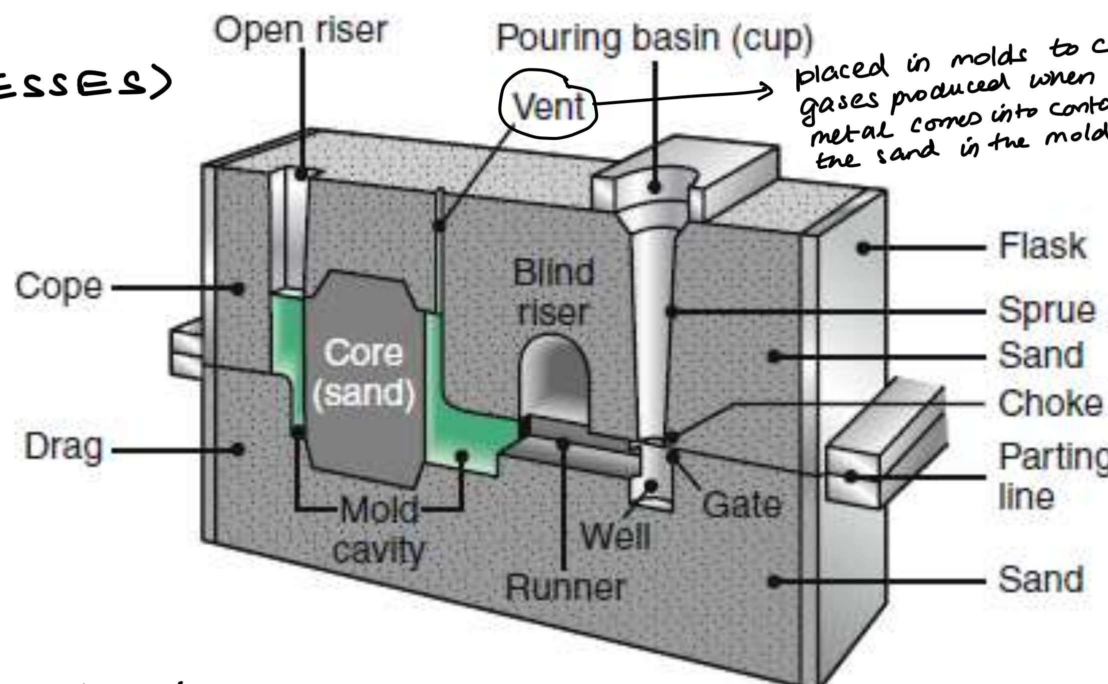
Oven Dried Sand Moulds

Advantages:

1. stronger than green sand molds
2. impart better dimensional accuracy & surface finish

Disadvantages:

1. distortion of mold is greater
2. casting are more susceptible to hot tearing because of the lower collapsability of the mould.
3. lower production rate as drying time required is higher.



Vent: placed in molds to carry off gases produced when molten metal comes into contact with the sand in the mold & the core.

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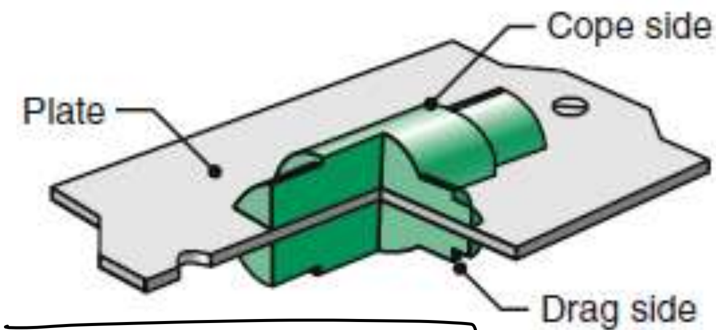
Cores: inserts made from sand placed in the mold to form hollow regions or otherwise define the interior surface of the casting. Cores may be used outside the casting to form lettering on surface or deep external pockets.

#Patterns are usually provided with PARTING AGENT to facilitate removal of casting from the moulds.

Types of Patterns



Match plate Pattern

cope & drag made together and not seperately

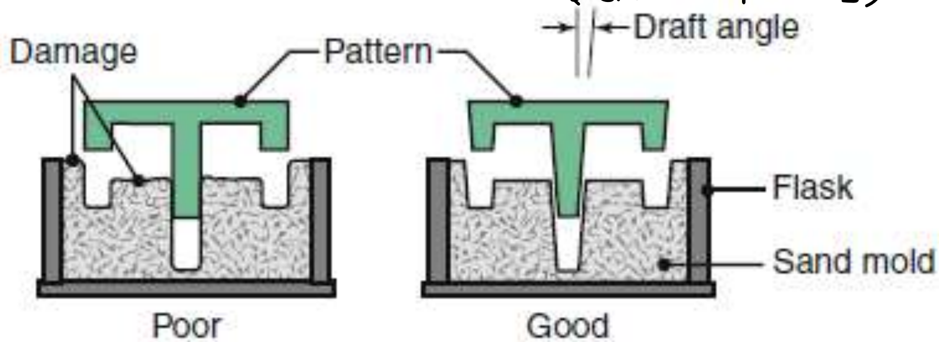
Different types of patterns are used such as – **One Piece** pattern, **Split** patterns and **Match Plate** patterns.

① One Piece Pattern: simpler shapes, low quantity produced, inexpensive, made of wood.

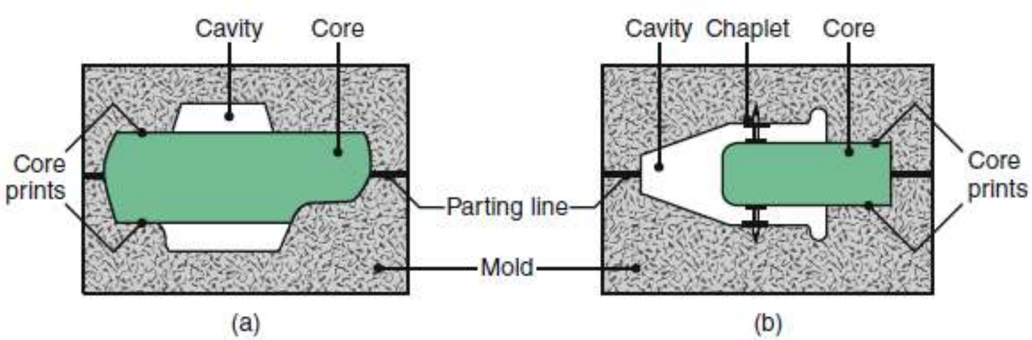
② Split Patterns: (2-piece) — each part forms portion of cavity for the casting.

Patterns must include shrinkage & machining allowance.

③ Match Plate Patterns: 2 piece patterns are constructed by securing each half of one or more split patterns to the opp. side of single plate.



Patterns must provide a draft for their easy removal from the mold.



Sand Cores and **Core Prints** and **Chaplets** to support the cores.

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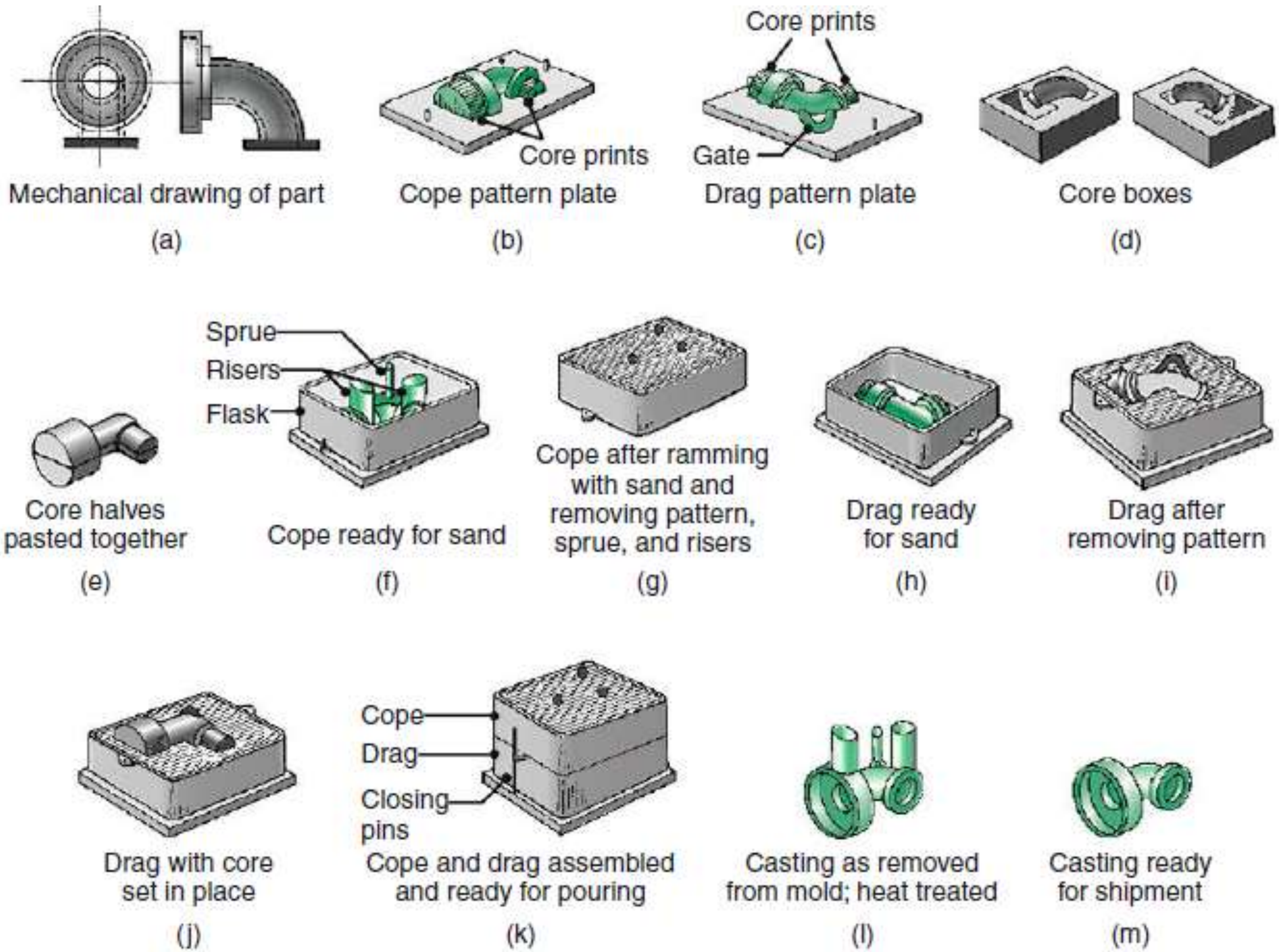
Sequence of Operations – Sand Casting



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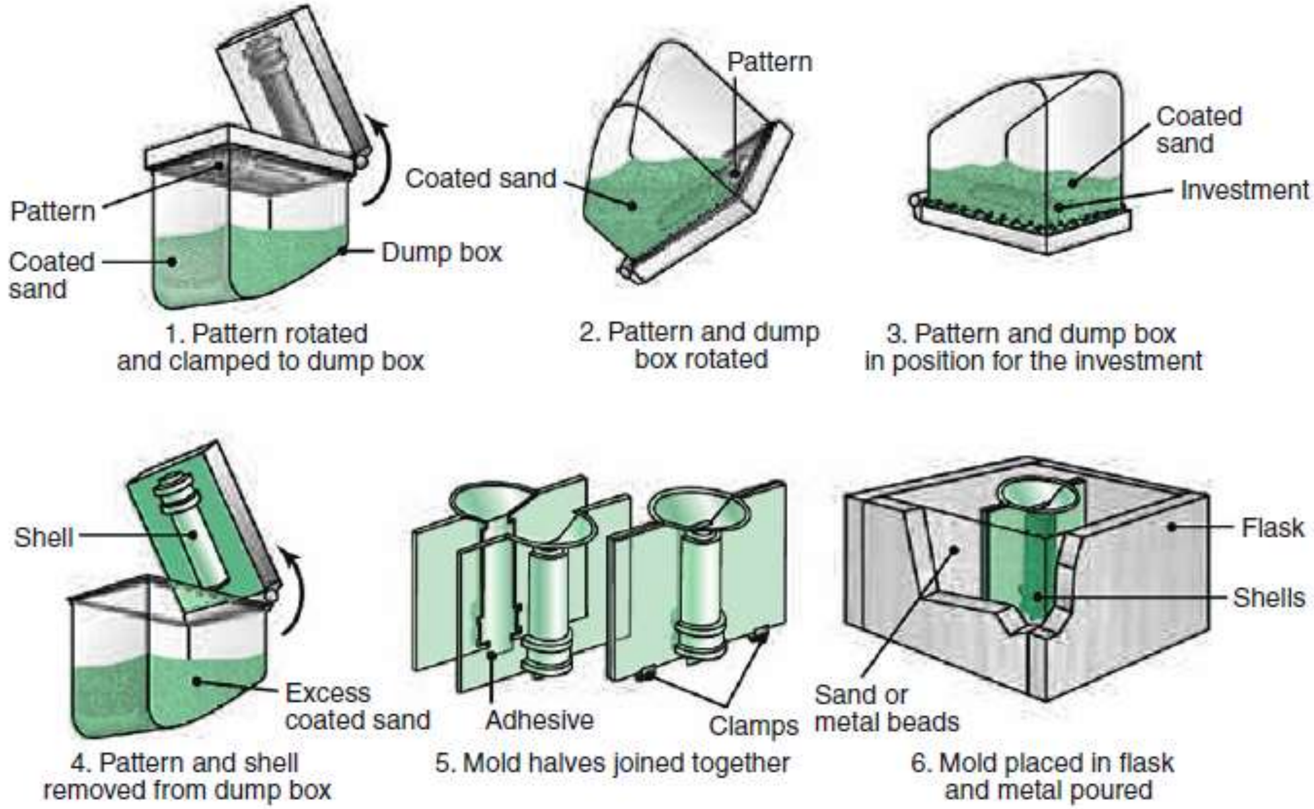
Shell Molding Process :

Advantages
1. produces many types of castings
2. good dimensional tolerances
3. inexpensive — low cost
4. good surface finish



Steps to shell Moulding
1. Mounted pattern (Fe, Al) heated to 175–370°C
2. Coated with PARTING Agent like silicone
3. clamped to box/chamber containing fine sand mixed with 2.5–4% of a thermo-setting resin binder that coats sand particles.
4. Box is rotated or sand mixture is blown over pattern allowing it to form a coating.
5. Assembly placed in an oven for a short period of time to complete curing of resin.
6. 2 half shells are made & clamped to form a mold.

A heated (175 to 370 C) metallic pattern (steel or aluminium) is coated with a parting agent (such as silicone) and placed in a box containing a fine sand mixed with 2.5 to 4% thermosetting resin. The box is rotated or the sand mixture is blown over the pattern to form the coating. The assembly is then overn-heated to complete the curing of the resin.

Shell sand has much lower permeability. Decomposition of resin yields lots of gas and it is a challenge..
(as compared to green sand)

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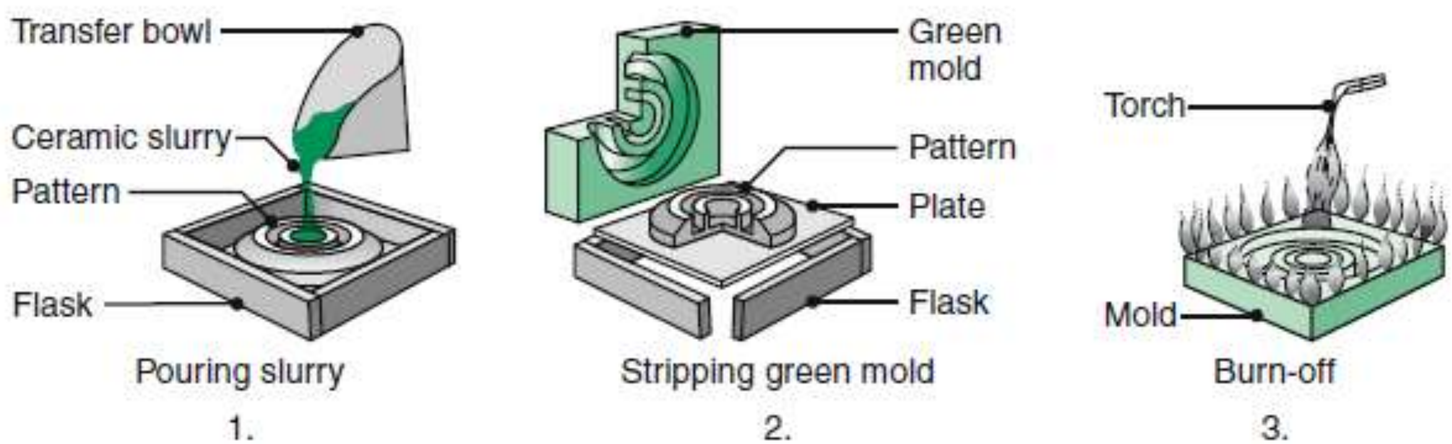
(PRECISION CASTING → plaster-mold, ceramic-mold, investment casting)

Plaster-mold and Ceramic-mold

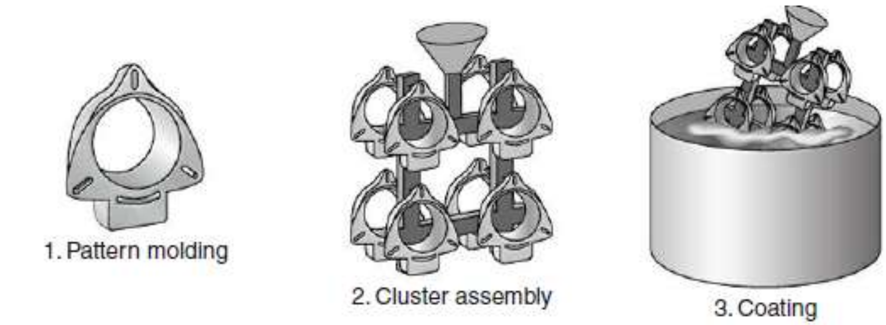
In the **plaster-molding process**, the mold is made of plaster of paris (gypsum or calcium sulfate) with the addition of talc and silica flour to improve strength and to control the time required for the plaster to set. These components are mixed with water, and the resulting slurry is poured over the pattern.

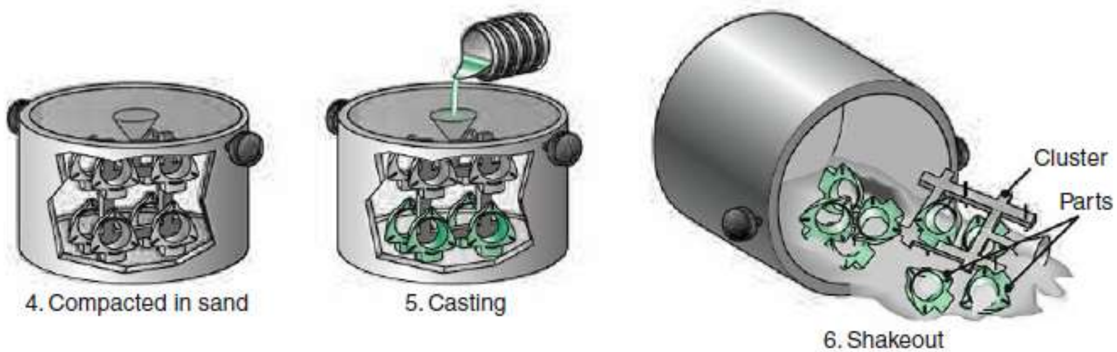
After the plaster sets (usually within 15 minutes), it is removed, and the mold is dried at a temperature range of 120 to 260 C. The mold halves are assembled to form the mold cavity and are preheated to about 120 C The molten metal is then poured into the mold. A metallic or thermoset polymer pattern is used.



The ceramic-mold casting process (also called cope-and-drag investment casting) is similar to the plaster-mold process, except that it uses refractory mold materials suitable for high-temperature applications. The slurry is a mixture of fine-grained zircon ($ZrSiO_4$) aluminum oxide, and fused silica, which are mixed with bonding agents and poured over the pattern, which is placed in a flask.

Expendable-mold Expendable-Pattern Casting





Lost-foam or **evaporative-pattern** casting process involves use of polystyrene beads with 5 to 8% pentane (volatile hydrocarbon) that are placed in a preheated aluminium die.

As the die is heated, polystyrene expands and takes the shape of the die cavity. Additional heat is supplied to fuse and bond the beads together. Die is then opened and polystyrene pattern is removed.

The pattern is coated with a water-based refractory slurry, dried, and placed in a flask. The flask is then filled with loose, fine sand, which surrounds and supports the pattern.

The sand is compacted periodically, without removing the polystyrene pattern; then the molten metal is poured into the mold. The molten metal vaporizes the pattern and fills the mold cavity, completely replacing the space previously occupied by the polystyrene. Any degradation products from the polystyrene are vented into the surrounding sand.

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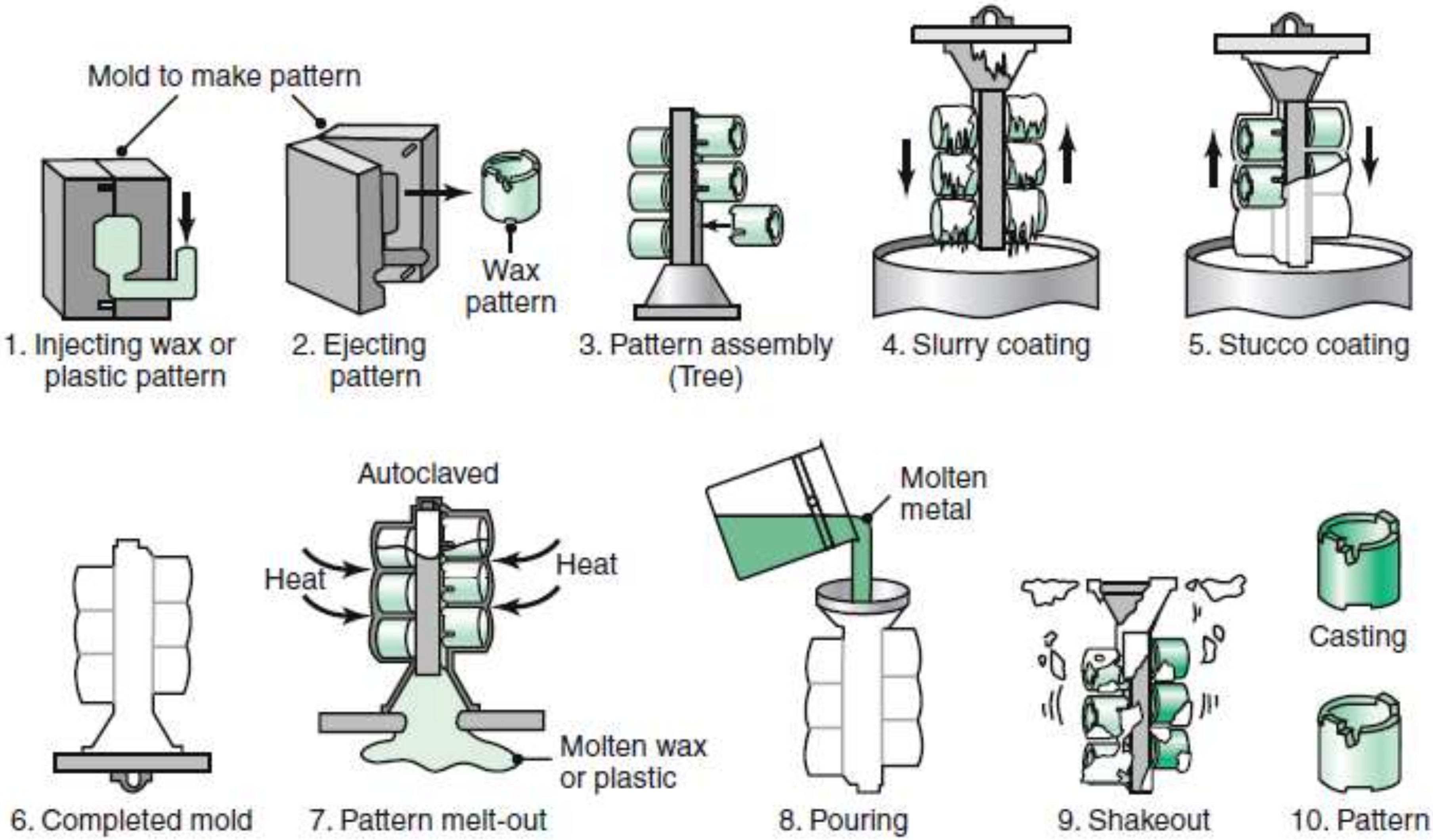
Advantages of lost foam:
1. simple process, no design required for cores, risers, parting lines, etc.
2. inexpensive (flasks + polystyrene)
3. minimal finishing + cleaning operations required
4. economical + process may be automated easily.

Investment Casting (lost-wax process)



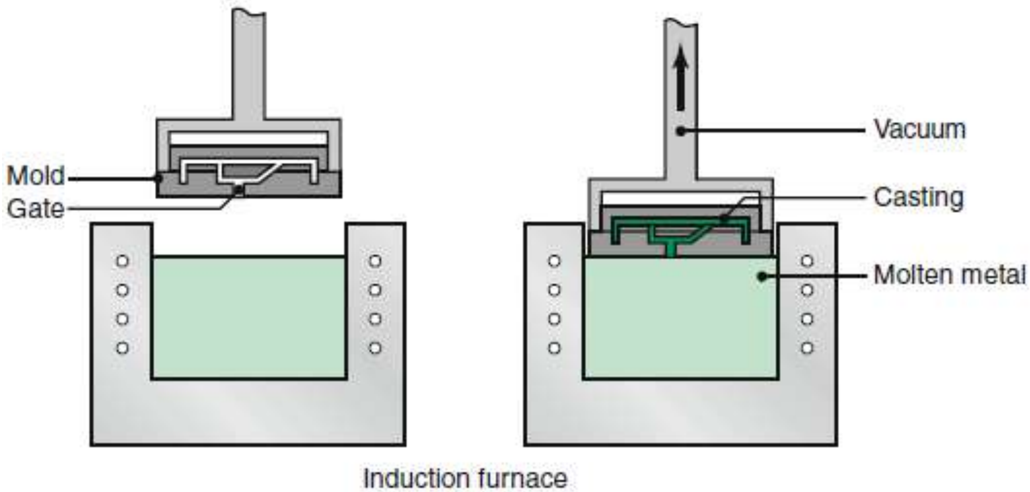
Advantages :
1. suitable for casting high melting point alloys
2. good surface finish + close dimensional tolerance
3. few/no finishing operations
4. produces intricate shapes

Disadvantages: expensive

Investment Casting / Lost - Wax Process

- pattern is made of wax or plastic (polystyrene)
- pattern is dipped into slurry of refractory materials
- multiple coatings are done to increase thickness for better strngth.
- initial coating requires smaller particles for better surface finish.
- Pattern is INVESTED (surrounded) by refractory material.
- The one piece mold is then dried in air and heated and held in vertical position to remove the wax. Its heated further to remove residual wax/water of crystallisation.
- After solidification, mold is broken and casting is removed.

Permanent Mold Casting – Vacuum Casting



Vacuum-casting process, or countergravity low pressure (CL) process is an alternative to investment, shell-mold, and green-sand casting and is suitable particularly for thin-walled (~ 0.75 mm) complex shapes with uniform properties. Typical parts made are superalloy gas-turbine components with walls as thin as 0.5 mm..

A mixture of fine sand and urethane is molded over metal dies and cured with amine vapor. The mold is then held with a robot arm and immersed partially into molten metal held in an induction furnace. The metal is melted in air (CLA process) or in a vacuum (CLV process).

The vacuum reduces the air pressure inside the mold to about two-thirds of atmospheric pressure, thus drawing the molten metal into the mold cavities through a gate in the bottom of the mold. The metal in the furnace is usually at a temperature of 55 C above the liquidus temperature of the alloy. Consequently, it begins to solidify within a very short time. After the mold is filled, it is withdrawn from the molten metal.