Metals Forming

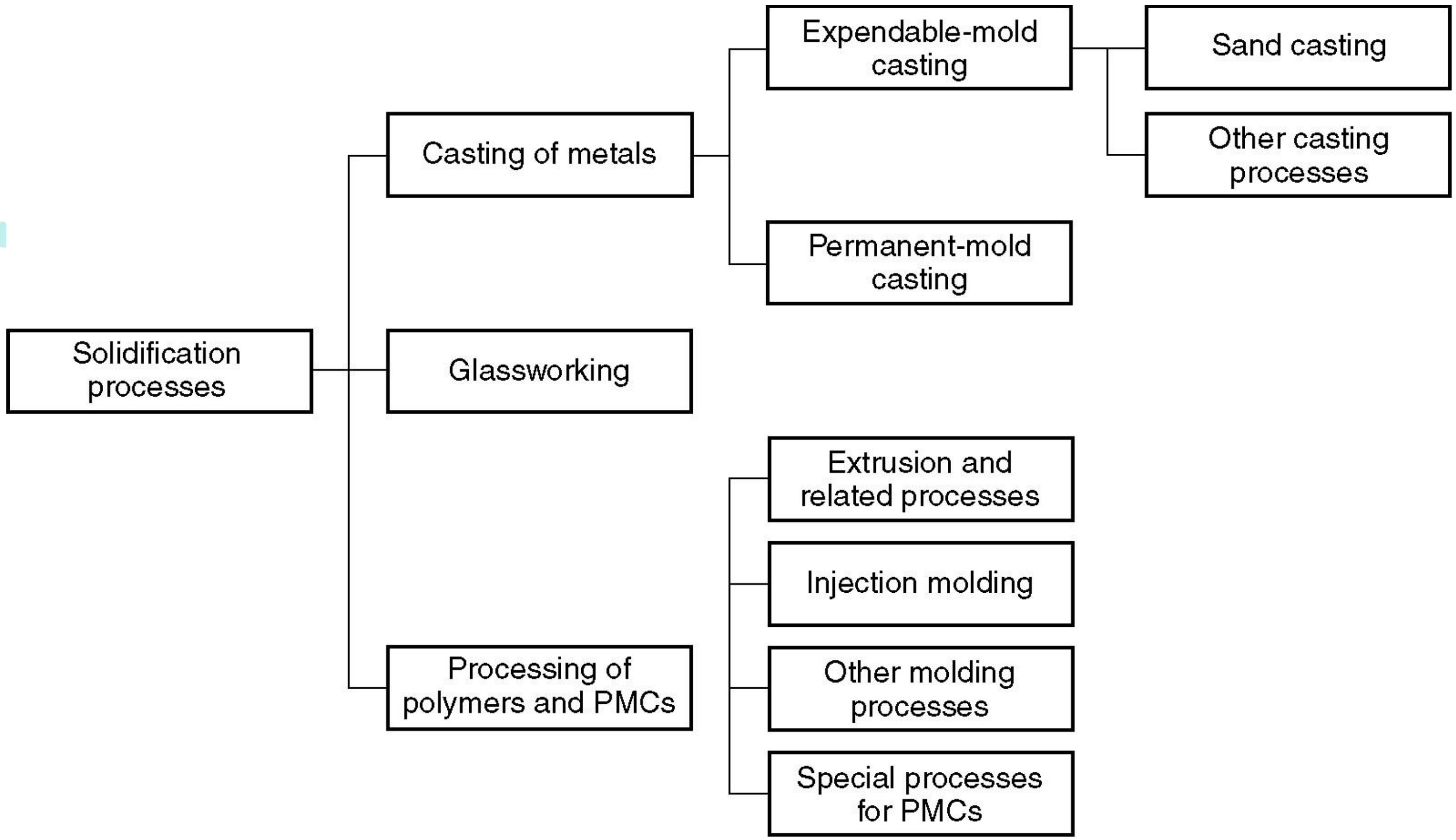
METAL CASTING

Contents

Solidification Processes

We consider starting work material is either a liquid or is in a highly plastic condition, and a part is created through solidification of the material

- Solidification processes can be classified according to engineering material processed:
  - Metals
  - Ceramics, specifically glasses
  - Polymers and polymer matrix composites



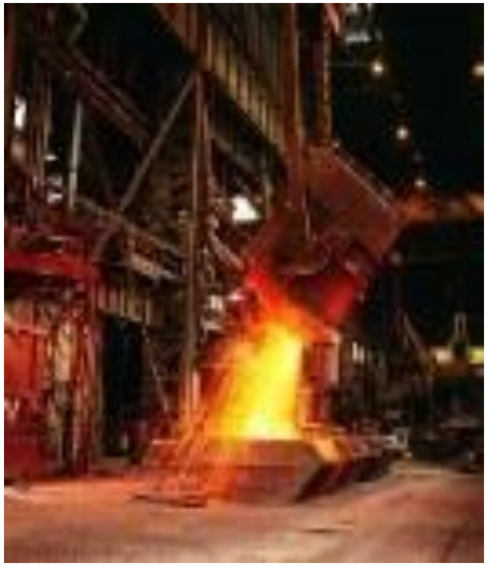
Classification of solidification processes.

Casting

Casting definition:-

Process in which molten metal flows by gravity or other force into a mold where it solidifies in the shape of the mold cavity

- The term *casting* also applies to the part made in the process



Steps of casting:-

1. Melt the metal
2. Pour it into a mold
3. Let it freeze

Advantages of Casting

1- Can create complex part geometries that can not be made by any other process.

2- Can create both external and internal shapes.

3- Some casting processes are *net shape;* others are *near net shape.*

4- Can produce very large parts (with weight more than 100 tons).

5- Casting can be applied to shape any metal that can melt.

6- Some casting methods are suited to mass production.

7- Can also be applied on polymers and ceramics.

Disadvantages of Casting

Different disadvantages for different casting processes:

1- Limitations on mechanical properties.

2- Poor dimensional accuracy and surface finish for some processes; e.g., sand casting.

3- Safety hazards to workers due to hot molten metals.

4- Environmental problems.

Parts Made by Casting

- <u>Big parts</u>
  - Engine blocks and heads for automotive vehicles, wood burning stoves, machine frames, railway wheels, pipes, bells, pump housings

- <u>Small parts</u>
  - Dental crowns, jewelry, small statues, frying pans

- <u>All varieties of metals can be cast - ferrous and nonferrous</u>

Overview of Casting Technology

- Casting is usually performed in a foundry.

Foundry = factory equipped for

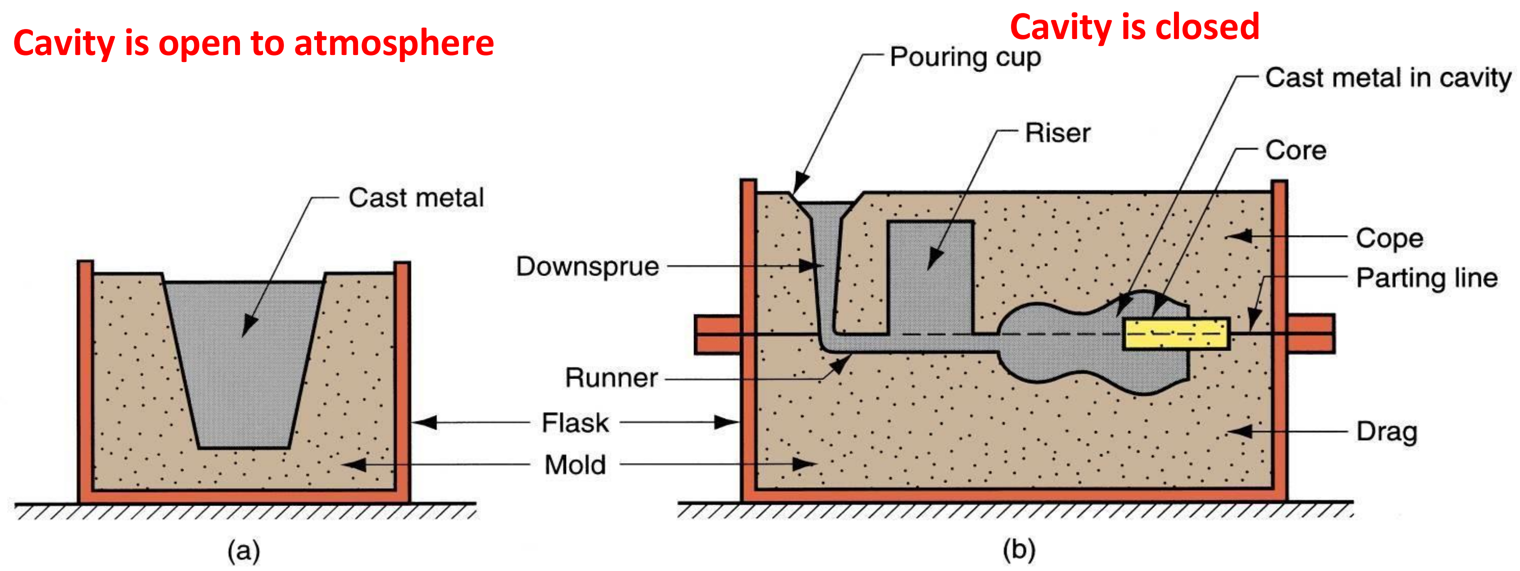
- Making molds.
- Melting and handling molten metal.
- Performing the casting process.
- Cleaning the finished casting.

- Workers who perform casting are called foundrymen

1- The Mold in Casting

- Mold is a container with cavity whose geometry determines part shape.
  - Actual size and shape of cavity must be slightly oversized to allow for shrinkage of metal during solidification and cooling.
  - Mold materials:- Molds are made of a variety of materials, including sand, plaster, ceramic, and metal.

Open Molds and Closed Molds



*** Two forms of mold:-**

(a) [open mold] simply a container in the shape of the desired part.

(b) [closed mold] in which the mold geometry is more complex and requires a gating system (passageway) leading into the cavity.

Two Categories of Casting Processes

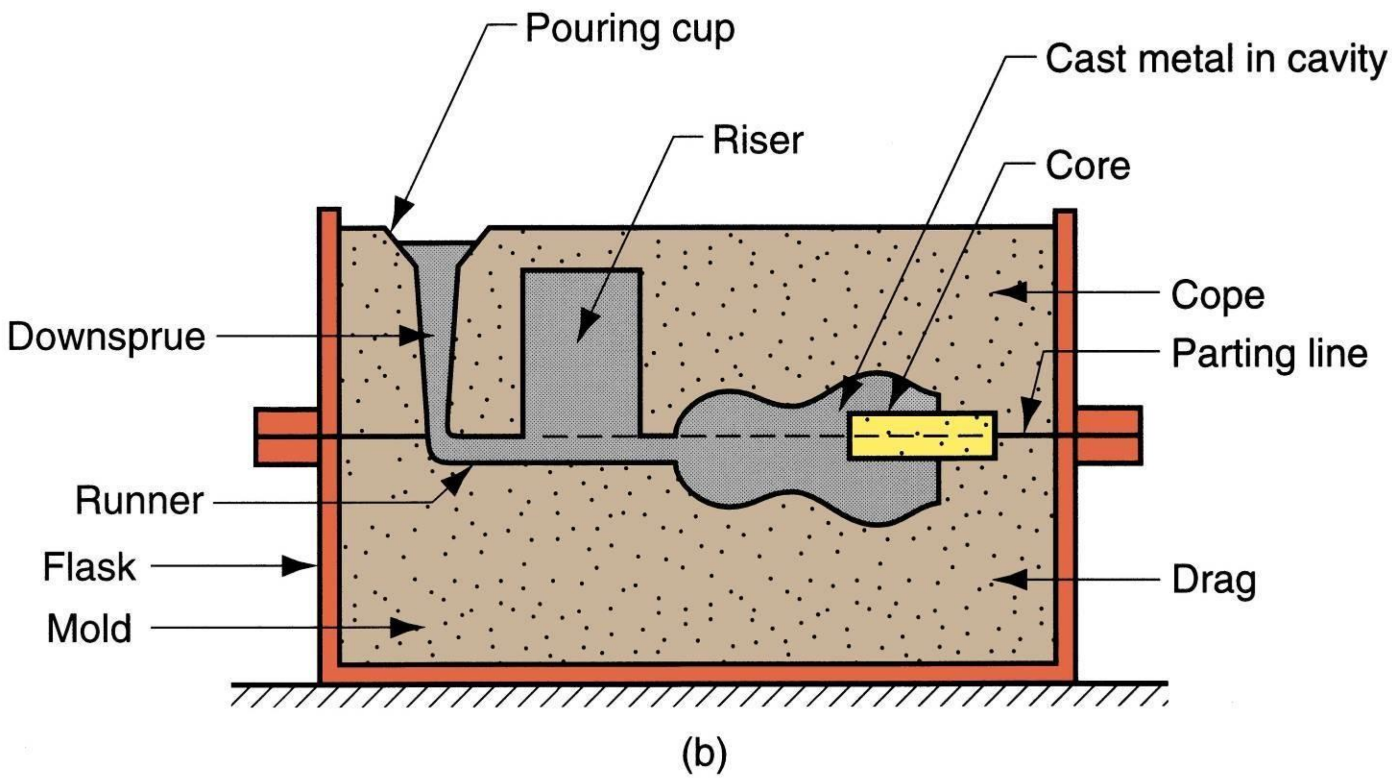
1. **Expendable mold processes:-** uses an expendable mold which must be destroyed to remove casting.

   - **Mold materials:-** sand, plaster, and similar materials, plus binders

2. **Permanent mold processes:-** uses a permanent mold which can be used over and over to produce many castings.

   - **Mold materials:-** Made of metal (or, less commonly, a ceramic refractory material)

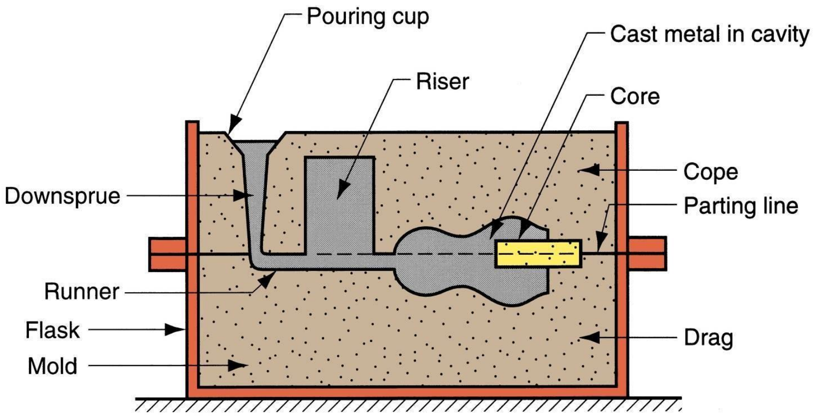
Sand Casting Mold



Sand casting mold.

Sand Casting Mold Terms

- <u>Mold consists of two halves:-</u>
  - **<u>Cope</u>** = upper half of mold
  - **<u>Drag</u>** = bottom half
- Mold halves are contained in a box, called **<u>a flask.</u>**
- The two halves separate at the **<u>parting line.</u>**



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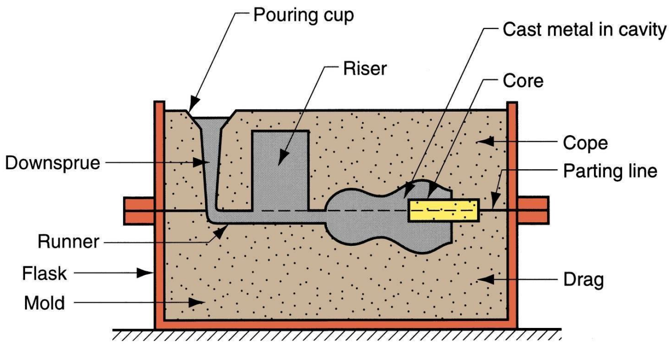
Forming the Mold Cavity

* **[Cavity]** is inverse of final shape with shrinkage allowance.
* **[Pattern]** is model of final shape with shrinkage allowance.
* **[Wet sand]** is made by adding binder in the sand.

- Mold cavity is formed by packing sand around a **pattern.**

When the pattern is removed, the remaining cavity of the packed sand has desired shape of cast part.

- The pattern is usually oversized to allow for shrinkage of metal during solidification and cooling.



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2- Use of a Core in the Mold Cavity

- **[Cavity]** provides the external features of the cast part.

- **[Core]** provides internal features of the part.

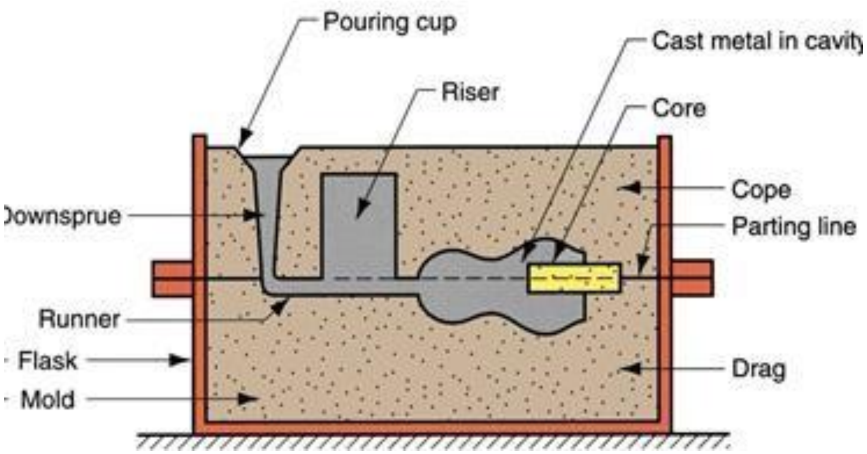
- **It is** placed inside the mold cavity with some support.
- In sand casting, cores are generally made of sand

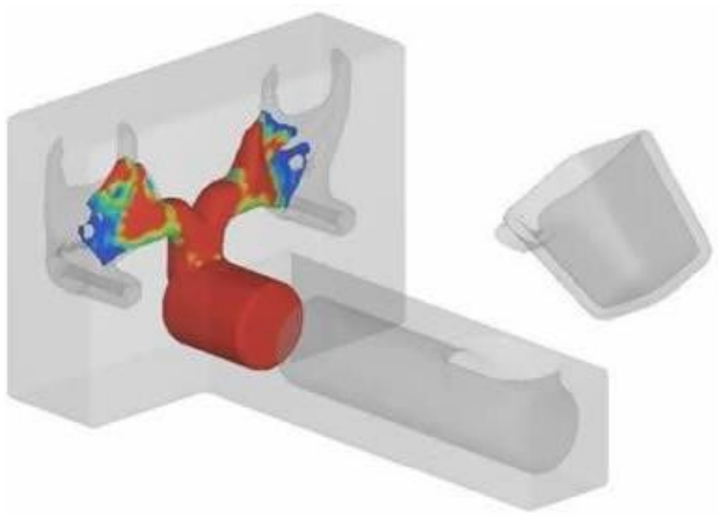
Difference between cavity & core ?

3- Gating System

* It is channel through which molten metal flows into cavity from outside of mold.

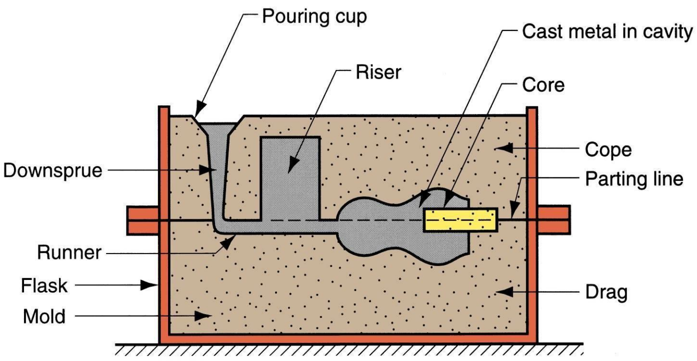
- Consists of a **down-sprue**, through which metal enters a **runner** leading to the main cavity.
- At the top of down-sprue, a **pouring cup** is often used to minimize splash and turbulence as the metal flows into down-sprue.





4- Riser

* It is a reservoir in the mold which is a source of liquid metal to compensate for shrinkage of the part during solidification.
* Most metals are less dense as a liquid than as a solid so castings shrink upon cooling, which can leave a void at the last point to solidify. Risers prevent this by providing molten metal to the casting as it solidifies, so that the cavity forms in the riser and not in the casting.



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5- Heating the Metal

- Heating furnaces are used to heat the metal to molten temperature sufficient for casting.

- The heat required is the sum of :-

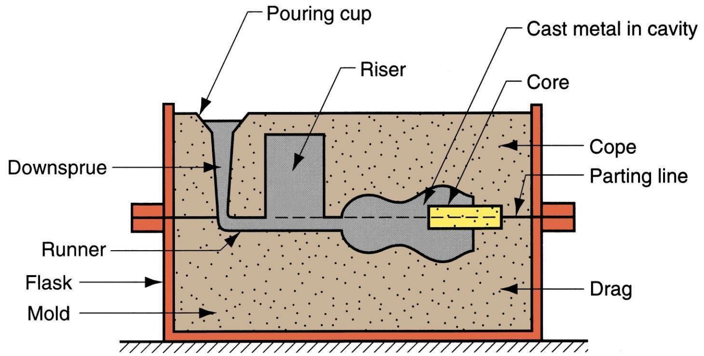
1. Heat to raise temperature to melting point.
2. Heat to raise molten metal to desired temperature for pouring.

6- Pouring the Molten Metal

- For this step to be successful, metal must flow into all regions of the mold, most importantly the main cavity, before solidifying.
- Factors that determine the success of pouring process:-

  1- Pouring temperature 2- Pouring rate 3- Turbulence

1- Pouring temperature:- should be sufficiently high in order to prevent the molten metal to start solidifying on its way to the cavity.



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Pouring the Molten Metal

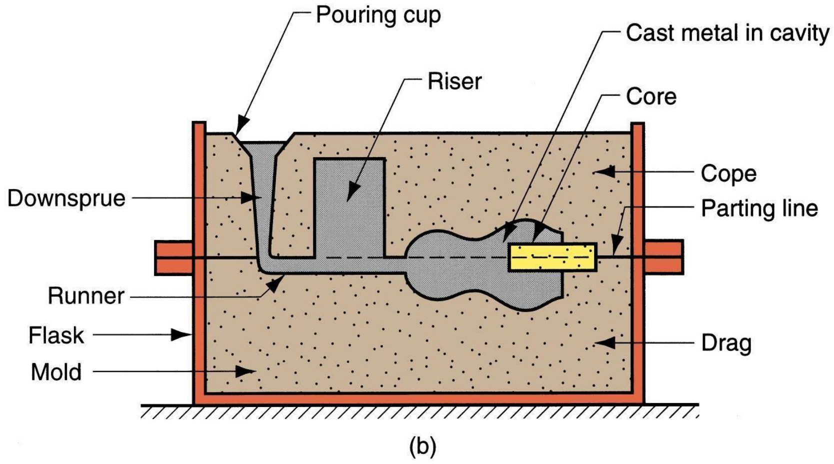
2- Pouring rate:- Should neither be high (may stuck the runner – should match viscosity of the metal) nor very low that may start solidifying on its way to the cavity.

3- Turbulence:- Should be kept to a minimum in order to ensure smooth flow and to avoid mold damage and entrapment of foreign materials. Also, turbulence causes oxidation at the inner surface of cavity. This results in cavity damage and poor surface quality of casting.

Engineering Analysis of Pouring

- Flow Velocity: $v = \sqrt{2gh}$ (From Bernoulli's Eqn)
- Vol. Flow Rate: $Q= v_1A_1=v_2A_2$ (Continuity Law)
- Time to Fill Mold Cavity: $T_{MF}= V/Q$

1. **[v] velocity of liquid metal at base of sprue in cm/sec.**
   [g] 981cm/sec.sec.
   [h] height of sprue in cm
2. **[v_1] velocity at section of area A_1.**
   [v_2] velocity at section of area A_2.
3. **[V] volume of mold cavity**



Calculation of Pouring Parameters: Example

- Height of sprue (h) = 20cm; X-sectional area at sprue base = 2.5cm2; Vol. of cavity (V)= 1560cm3

a. Velocity of molten metal (v):

$v = \sqrt{2gh} = \sqrt{2(981)(20)}$ 198.1cm/s

b. Volumetric flow rate (Q):

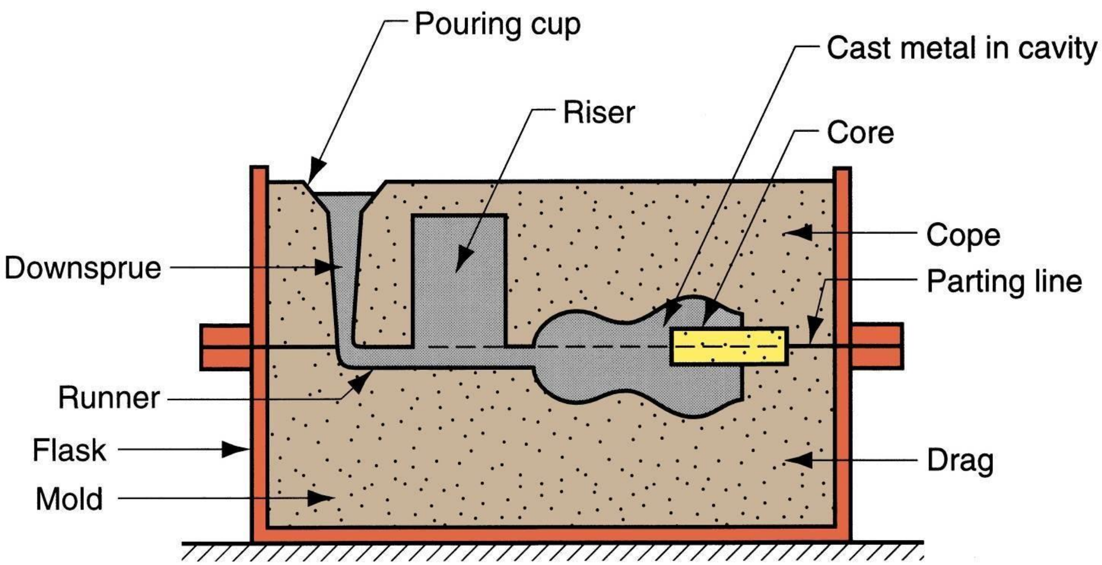
Q= vA= (198.1)(2.5)= 495 cm3/s

c. Time required to fill mold cavity (T_{MF}):

T_{MF}= V/Q= 1560/495= 3.2s

1. If sprue area at its entrance is 5cm2, compute metal velocity at sprue entrance.
2. Calculate velocity & flow rate of metal when metal is in the midway of sprue

Why Sprue X-section is kept taper ??



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- In order to keep volume flow rate (Q=VA) constant. In case, x-section is fixed, increased fluid velocity due to gravity will increase flow rate. This can cause air entrapment into liquid metal.

Fluidity

A measure of the capability of the metal to flow into and fill the mold before freezing.

- Fluidity is the inverse of viscosity (resistance to flow).

Factors affecting fluidity are:-

1- Pouring temperature relative to melting point.

2- Metal composition.

3- Viscosity of the liquid metal.

4- Heat transfer to surrounding.

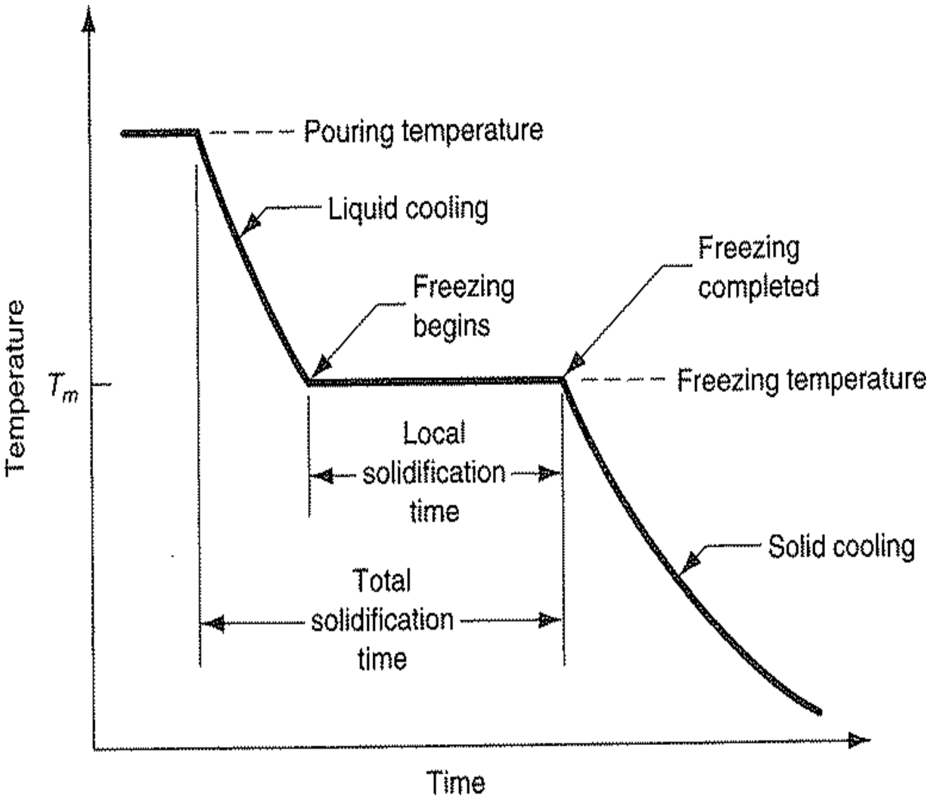
Solidification of Metals

It is the transformation of molten metal back into solid state.

- Solidification differs depending on whether the metal is
  - A pure element.
  - An alloy.
  - A Eutectic alloy.

Solidification: Pure Metals

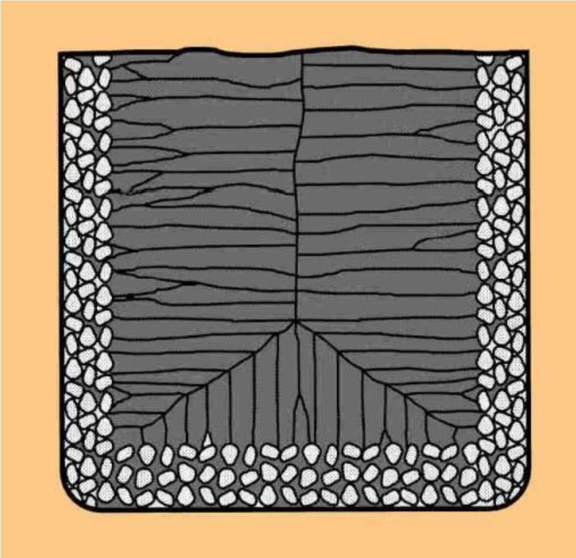
- Pure metal solidifies at a constant temperature equal to its freezing point (same as melting point).
- Local freezing time= Time from freezing begins and completed.
- Total freezing time= Time from pouring to freezing completed.
- After freezing is completed, the solid continues to cool at a rate indicated by downward slope of curve



Cooling curve for a pure metal during casting

Solidification: Pure Metals

- Because of the chilling action of the mold wall, a thin skin of solid metal is initially formed at interface immediately after pouring.
- The skin formed initially has equi-iaxed, fine grained and randomly oriented structure. This is because of rapid cooling.
- As freezing proceeds, the grains grow inwardly, away from heat flow direction, as needles or spine of solid metal.



Characteristic grain structure in a casting of a pure metal, showing randomly oriented grains of small size near the mold wall and large columnar grains oriented toward the center of the casting

Solidification: Pure Metals

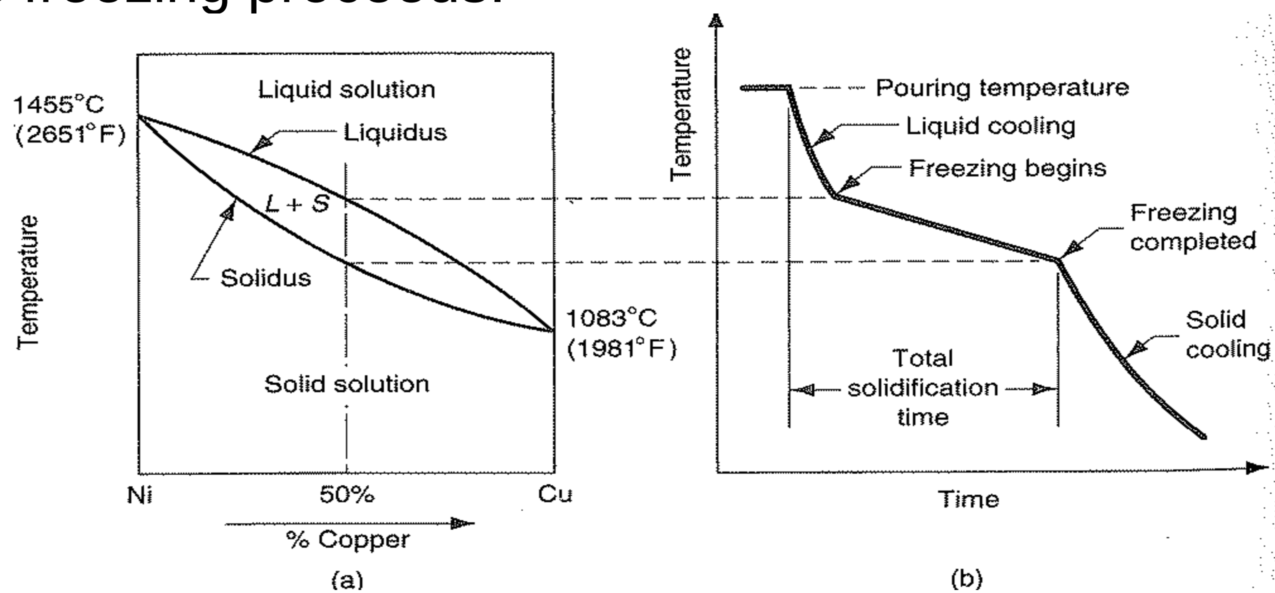
- On further growth of spine, lateral branches are formed, and as these branches grow further branches are formed at right angle to the first branches. This type of growth is called **dendritic growth**.

- The dendritic grains are coarse, columnar and aligned towards the center of casting.

Solidification: Most Alloys

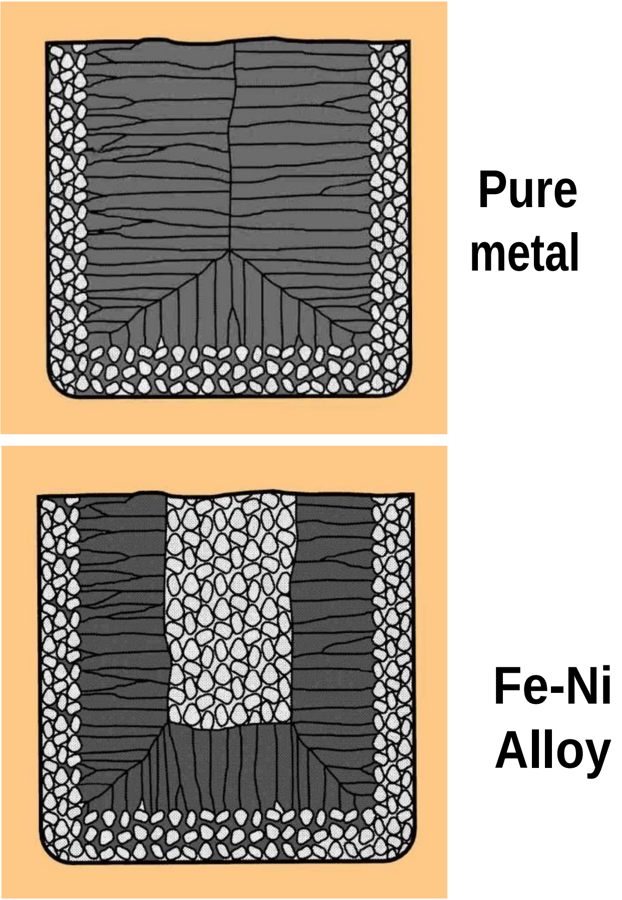
- Most alloys freeze at range of temperature rather than at a single temperature.
- Freezing begins from liquidus temperature and completes at solidus temperature.
- The cooling begins in the same manner as that in pure metals; a thin skin is formed at the interface of mold and makes shell as freezing proceeds.

(a) phase diagram for a Cu-Ni alloy system and (b) associated cooling curve for a 50%Ni-50% Cu composition during casting.



Solidification: Most Alloys

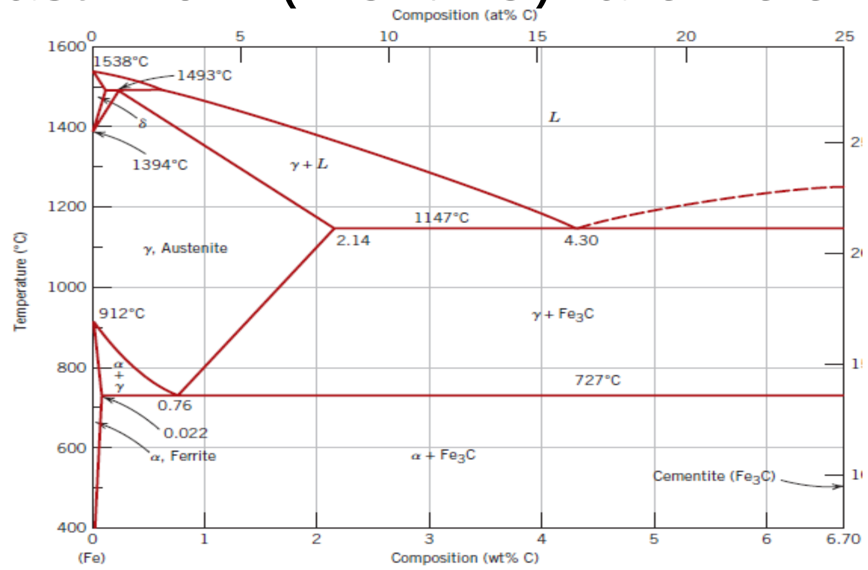
- The dendrites begin to form with freezing. However, due to large temperature spread between solidus and liquidus, the earlier portion of dendritic grains extract higher % of elements from liquid solution than the portion of grain formed later.
- As a result, the molten metal in the center of mold cavity depletes from the elements and hence forms a different structure.



Characteristic grain structure in an alloy casting, showing segregation of alloying components in the center of casting.

Solidification: Eutectic Alloys

- Eutectic alloys solidify similar to pure metals.
- Eutectic point on phase diagram is a point at which the liquid, on cooling, completely converts into solid at one temp. No intermediate phase (L+S) exists.
- Al-Si (11.6% Si) and Cast Iron (4.3% C) are relevant casting eutectic alloys.



Solidification Time & Chorinov's Rule

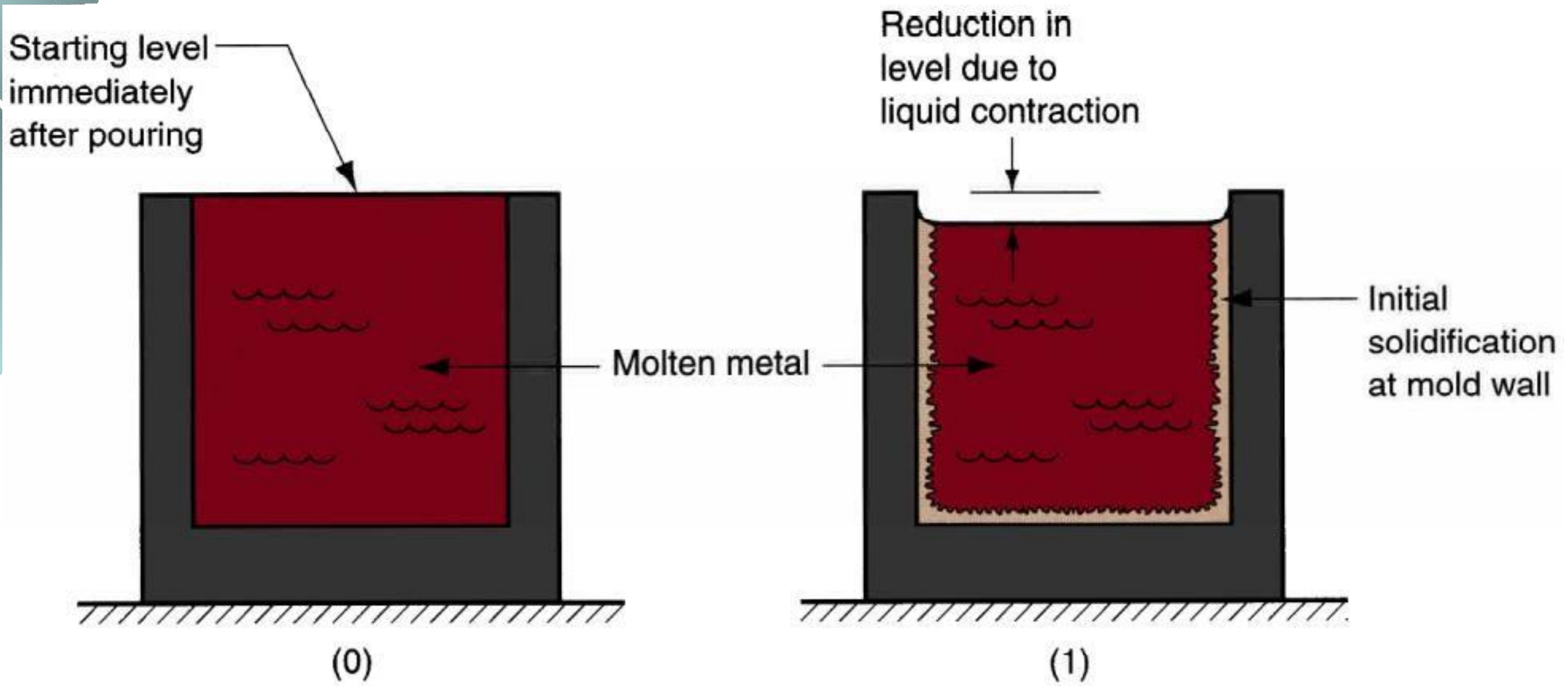
- $T_{TS} = Cm(\frac{V}{A})^n$

T_{TS} Total solidification time in min; V: volume of casting cm3; A: surface area of casting in cm2; n: exponent having value 2; Cm is mold constant min/cm2.

- This is basically an empirical formula

- The relation shows that higher volume to surface area ratio will lead to higher cooling time
- The above formula is helpful in designing riser. T_{TS} for riser should be higher than T_{TS} for main casting so that molten metal can in riser can compensate for shrinkage in casting before the metal .

Shrinkage in Solidification and Cooling



Shrinkage of a cylindrical casting during solidification and cooling: (0) starting level of molten metal immediately after pouring; (1) reduction in level caused by liquid contraction during cooling (dimensional reductions are exaggerated for clarity in sketches)

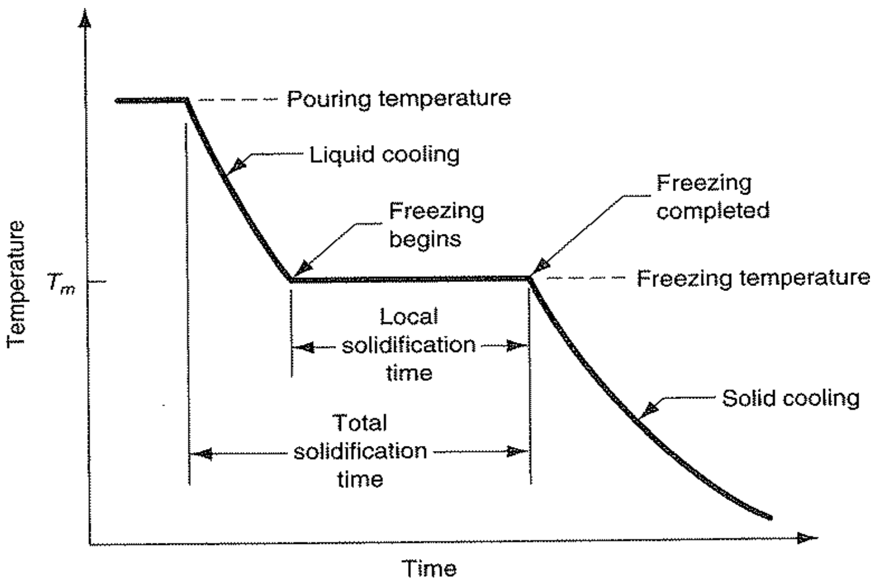
Shrinkage in Solidification and Cooling

Shrinkage occurs in 3 steps:-

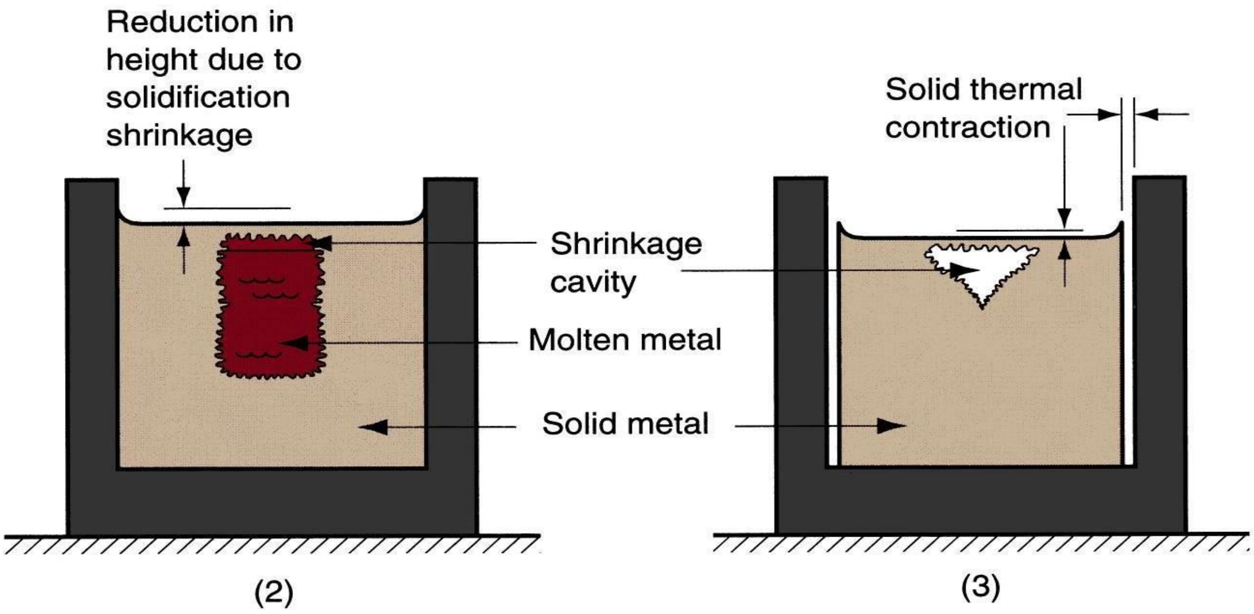
[a] While cooling of metal in liquid form (liquid contraction).

[b] During phase transformation from liquid to solid (solidification shrinkage).

[c] While solidified metal is cooled down to room temperature (solid thermal contraction).



Shrinkage in Solidification and Cooling



(2) Reduction in height and formation of shrinkage cavity caused by solidification shrinkage.

(3) Further reduction in height and diameter due to thermal contraction during cooling of solid metal (dimensional reductions are exaggerated for clarity).

Solidification Shrinkage (Liquid –Solid transformation)

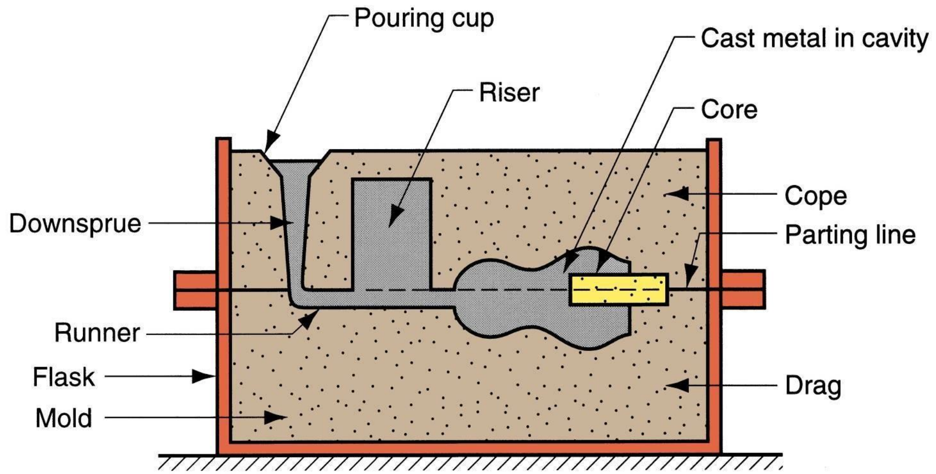
- Occurs in nearly all metals because the solid phase has a higher density than the liquid phase.
- Thus, solidification causes a reduction in volume per unit mass of metal.
- **Exception:-** cast iron with high C content.
  - Graphitization during final stages of freezing causes expansion that counteracts volumetric decrease associated with phase change.

Shrinkage Allowance

- Patternmakers account for solidification shrinkage and thermal contraction by making mold cavity oversized.
- Amount by which mold is made larger relative to final casting size is called pattern shrinkage allowance.
- Casting dimensions are expressed linearly, so allowances are applied accordingly.

Directional Solidification- Design Optimization

- In order to minimize the damaging effects of shrinkage, it is desirable that the regions far from the riser (metal supply) should solidify earlier than those near the riser in order to ensure metal flow to distant regions to compensate shrinkage.
- So, casting and mold design should be optimal: riser should be kept far from the regions of casting having low V/A ratio.



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Directional Solidification- Use of Chills

- The chills increase the heat extraction.
- Internal and external chills can also be used for directional cooling.
- For thick sections, small metal parts, with same material as that of casting, are put inside the cavity. The metal solidifies around these pieces as it is poured into cavity.
- For thin long sections, external chills are used. Vent holes are made in the cavity walls or metal pieces are put in cavity wall.

Riser Design

- Riser is used to compensate for shrinkage of part during solidification and later it is separated from the casting and re-melted to make more castings

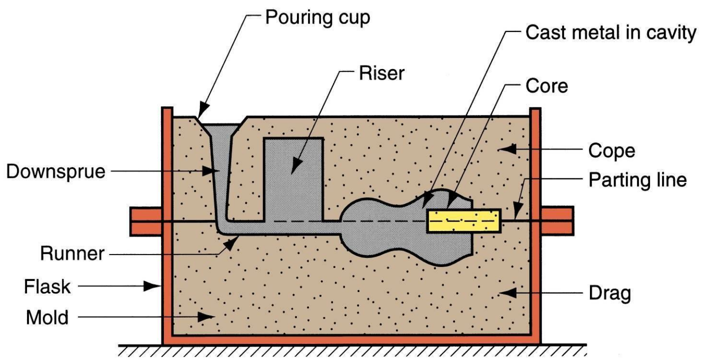
There could be different designs of riser:-

1- Side riser:- Attached to the side of casting through a channel

2- Top riser:- Connected to the top surface of the casting

3- Open riser:- Exposed to the outside at the top surface of cope- Disadvantage of allowing of more heat to escape promoting faster solidification.

4- Blind riser:- Entirely enclosed within the mold.



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