Casting Intro

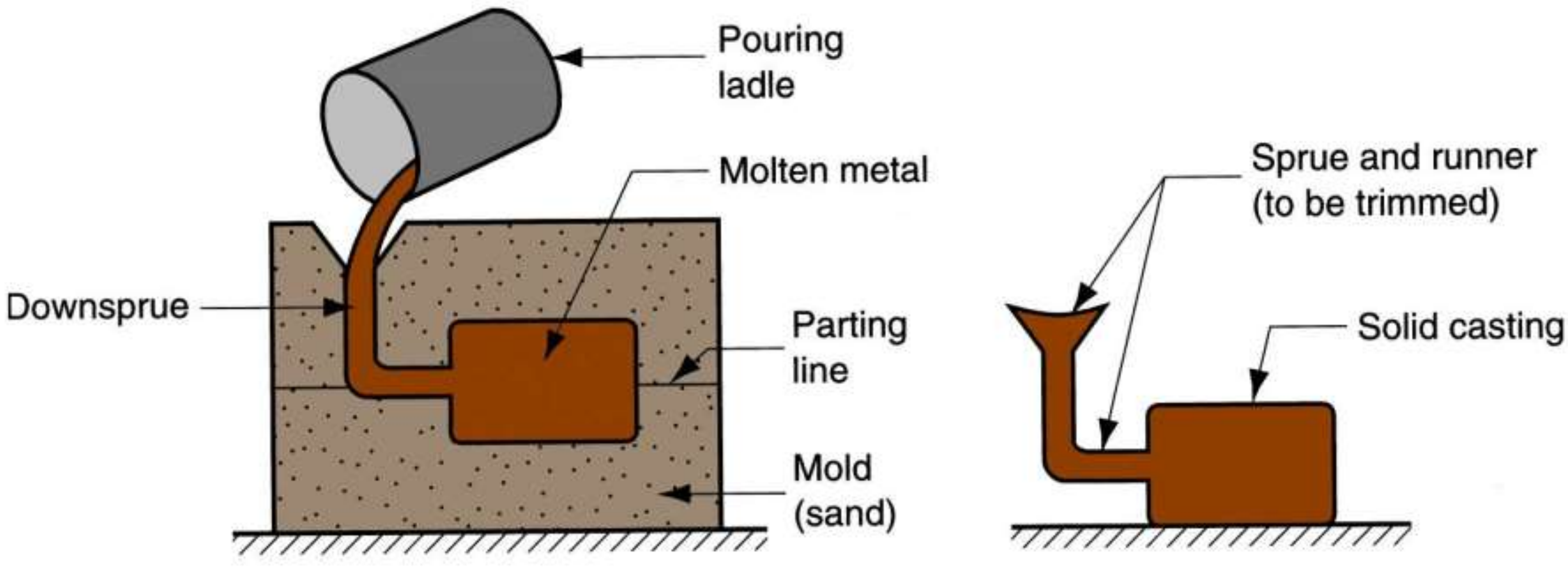
Casting

- In the ***casting processes***, a material is first melted, heated to proper temperature, and then poured into a ***cavity or mold*** that holds it in the desired shape during cool-down and solidification.

Casting

- ***Casting*** is a 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 is also applied to the part that is made by this process.***
- It is one of the ***oldest*** shaping processes, dating back ***6000 years.***
- The variety of casting processes use different ***pouring*** methods ***(gravity, vacuum, low pressure, or high pressure)***

Casting


Pouring ladle
Molten metal
Downsprue
Parting line
Mold (sand)
Sprue and runner (to be trimmed)
Solid casting

Capabilities and Advantages of Casting

- Can create ***complex part geometries***
- Can create both ***external and internal*** shapes
- Some casting processes are ***net shape;*** others are *near net shape*
- Can produce very ***large parts***
- Some casting methods are suited to ***mass production***

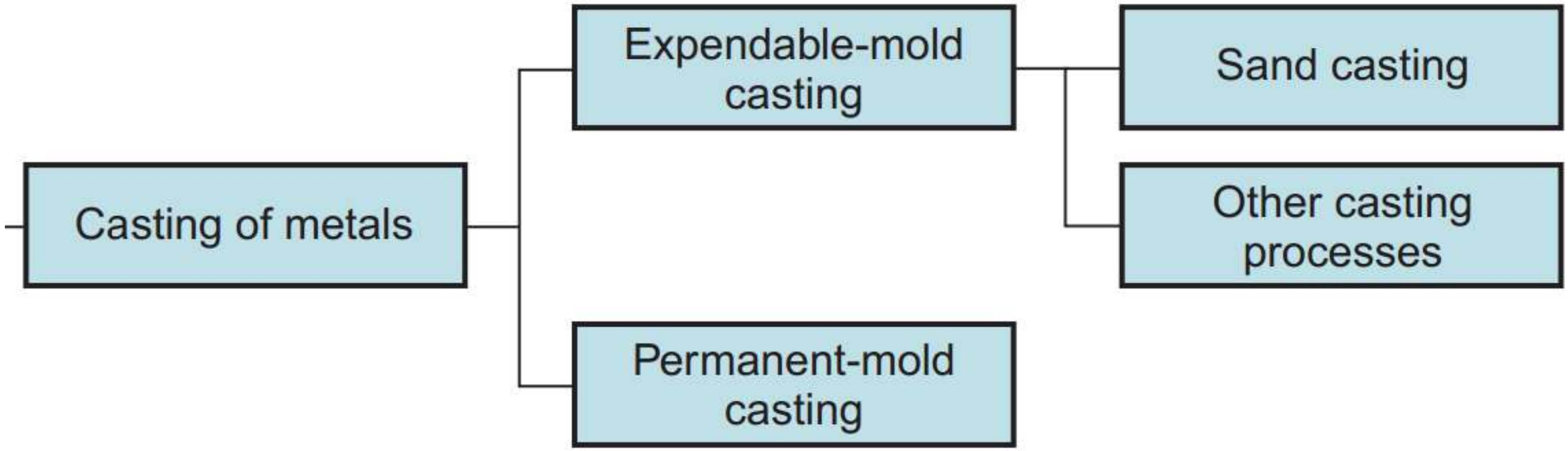
Disadvantages of Casting

- Different disadvantages for different casting processes:
  - ***Limitations*** on ***mechanical properties***
  - ***Poor dimensional accuracy*** and ***surface finish*** for some processes; e.g., ***sand casting***
  - ***Safety hazards*** to workers due to hot molten metals
  - ***Environmental problems***

Parts Made by Casting

- ***Big parts***
  - Engine blocks and heads for automotive vehicles, wood burning stoves, machine frames, railway wheels, pipes, church bells, big statues, pump housings
- ***Small parts***
  - Dental crowns, jewelry, small statues, frying pans
- ***All varieties of metals can be cast, ferrous and nonferrous***

Two Categories of Casting Processes



Two Categories of Casting Processes

1. ***Expendable mold processes*** - mold is sacrificed to remove part
   - ***Advantage***: more complex shapes possible
   - ***Disadvantage:*** production rates often limited by time to make mold rather than casting itself
2. ***Permanent mold processes*** - mold is made of metal and can be used to make many castings
   - ***Advantage***: higher production rates
   - ***Disadvantage***: geometries limited by need to open mold

Expendable mold processes

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, and cleaning the finished casting
- Workers who perform casting are called ***foundrymen***

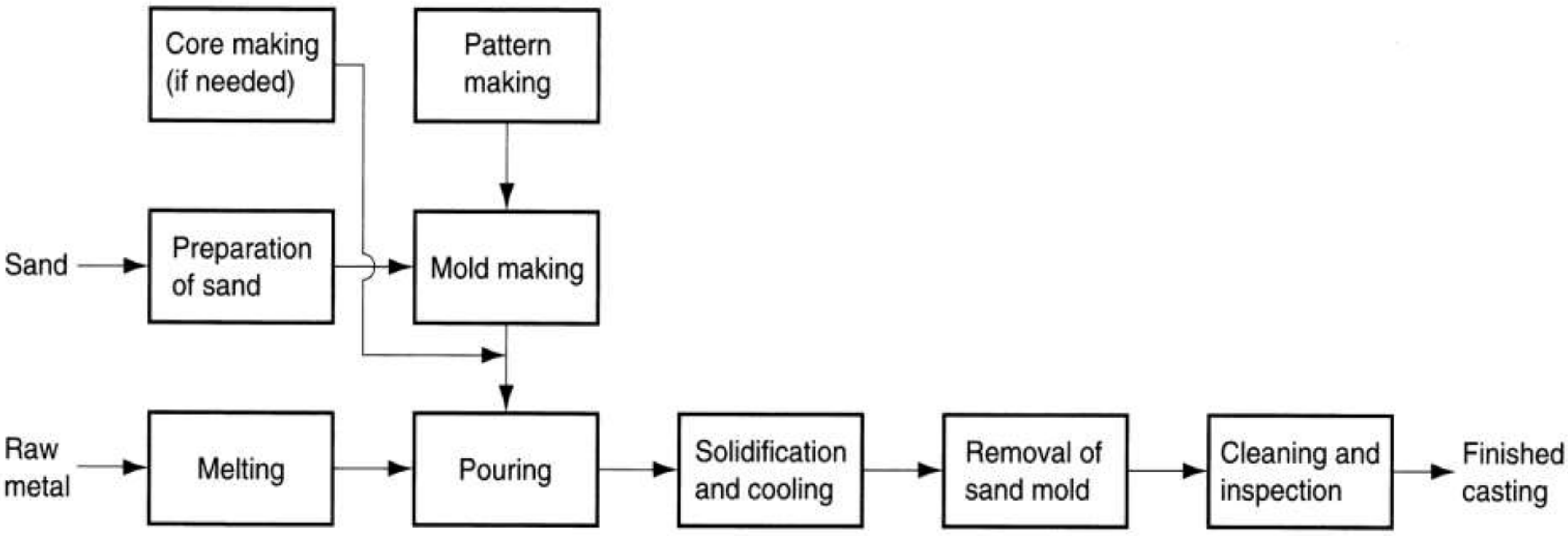
Casting Steps

- Steps in casting seem simple:
  - ***Melt*** the metal
  - ***Pour*** it into a mold
  - Let it ***freeze***

Casting Steps

1. ***Pour the molten metal into sand mold***
2. ***Allow time for metal to solidify***
3. ***Break up the mold to remove casting***
4. ***Clean and inspect casting***
   - ***Separate gating and riser system***
5. ***Heat treatment of casting is sometimes required to improve metallurgical properties***

Sand Casting Production Sequence



PATTERN

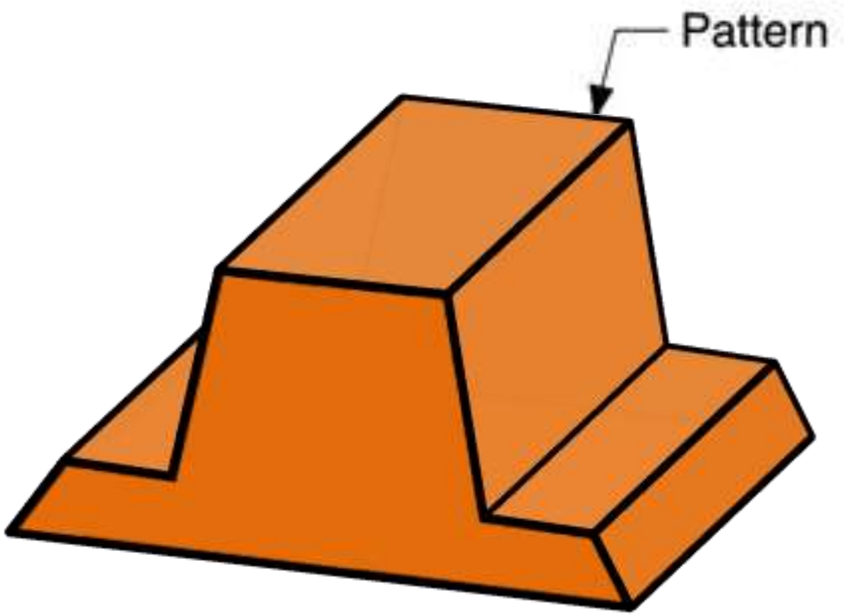
The Pattern

- A ***pattern*** is a full-sized ***model*** of the part which is made ***slightly large*** to account for shrinkage and machining ***allowances*** in the casting.
- Pattern materials:
  - ***Wood*** - common material because it is easy to work, but it warps
  - ***Metal*** - more expensive to make, but lasts much longer
  - ***Plastic*** - compromise between wood and metal

1. Solid (one-piece) pattern

- The simplest is made of one piece, called a ***solid pattern*** —same geometry as the casting, adjusted in size for shrinkage and machining.
- ***One-piece patterns*** are relatively cheap to construct, but the subsequent molding process is usually slow.
- As a result, they are generally used when the shape is relatively simple and the number of duplicate castings is rather small.

1. Solid (one-piece) pattern



Pattern Allowances

- The patterns are not made the exact size as the desired casting because such a pattern would produce undersize casting.
- When a pattern is prepared, certain allowances are given on the sizes specified in the drawing so that the finished and machined casting produced from the pattern will conform to the specified sizes.
- Pattern allowance is a vital feature as it affects the dimensional characteristics of the casting.

Pattern Allowances

- The selection of correct allowances greatly helps to reduce machining costs and avoid rejections. The allowances usually considered on patterns are as follows:

1. Shrinkage or contraction allowance
2. Machining or finish allowance
3. Draft or taper allowance
4. Distortion or camber allowance
5. Rapping allowance

1. Shrinkage or Contraction Allowance

- In practice it is found that all common cast metals shrink a significant amount when they are cooled from the molten state.
- The total contraction in volume is divided into the following parts:

a) Liquid contraction, i.e. the contraction during the period in which the temperature of the liquid metal or alloy falls from the pouring temperature to the liquidus temperature.

1. Shrinkage or Contraction Allowance

b) Contraction on cooling from the liquidus to the solidus temperature, i.e. solidifying contraction.

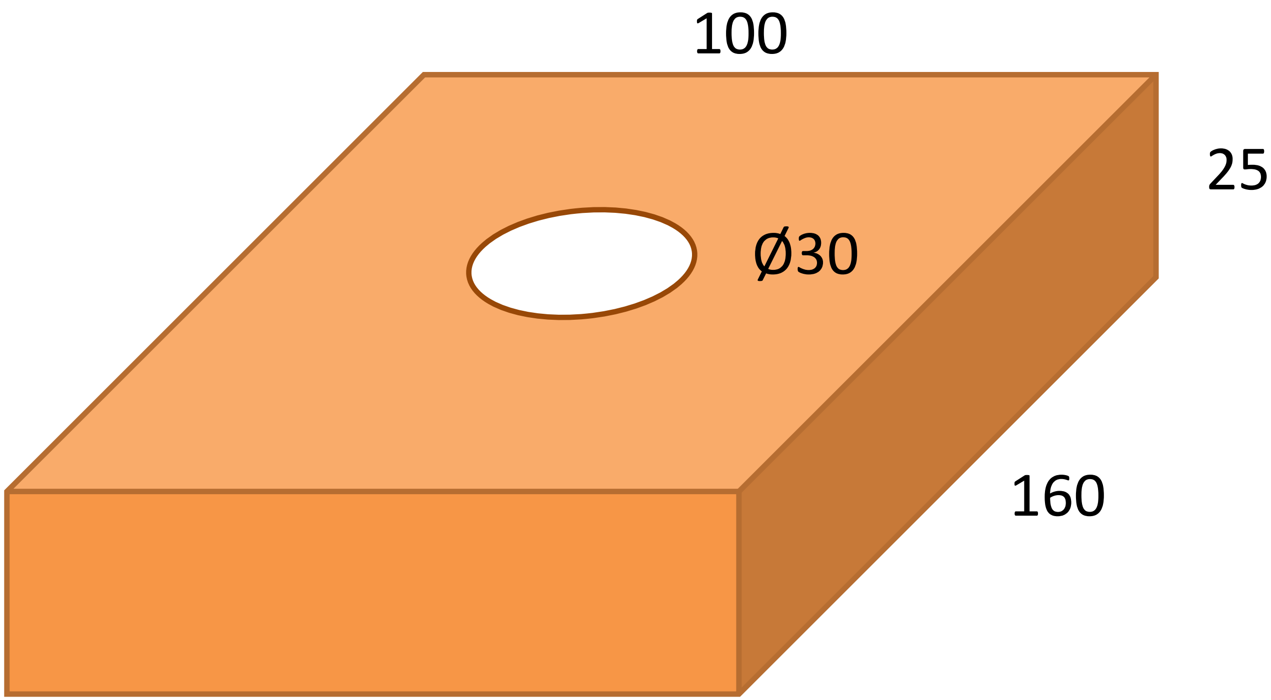
c) Contraction that results there after until the temperature reaches the room temperature. This is known as solid contraction.

- The first two of the above are taken care of by proper gating and riser design. Only the last one, i.e. the solid contraction is taken care by the pattern makers by giving a positive shrinkage allowance.

1. Shrinkage or Contraction Allowance

- This contraction allowance is different for different metals.
- The contraction allowances for different metals and alloys such as
  - Cast Iron : 10 mm/mt.
  - Brass : 16 mm/mt.
  - Aluminium Alloys : 15 mm/mt.
  - Steel : 21 mm/mt.
  - Lead : 24 mm/mt

1. Shrinkage or Contraction Allowance

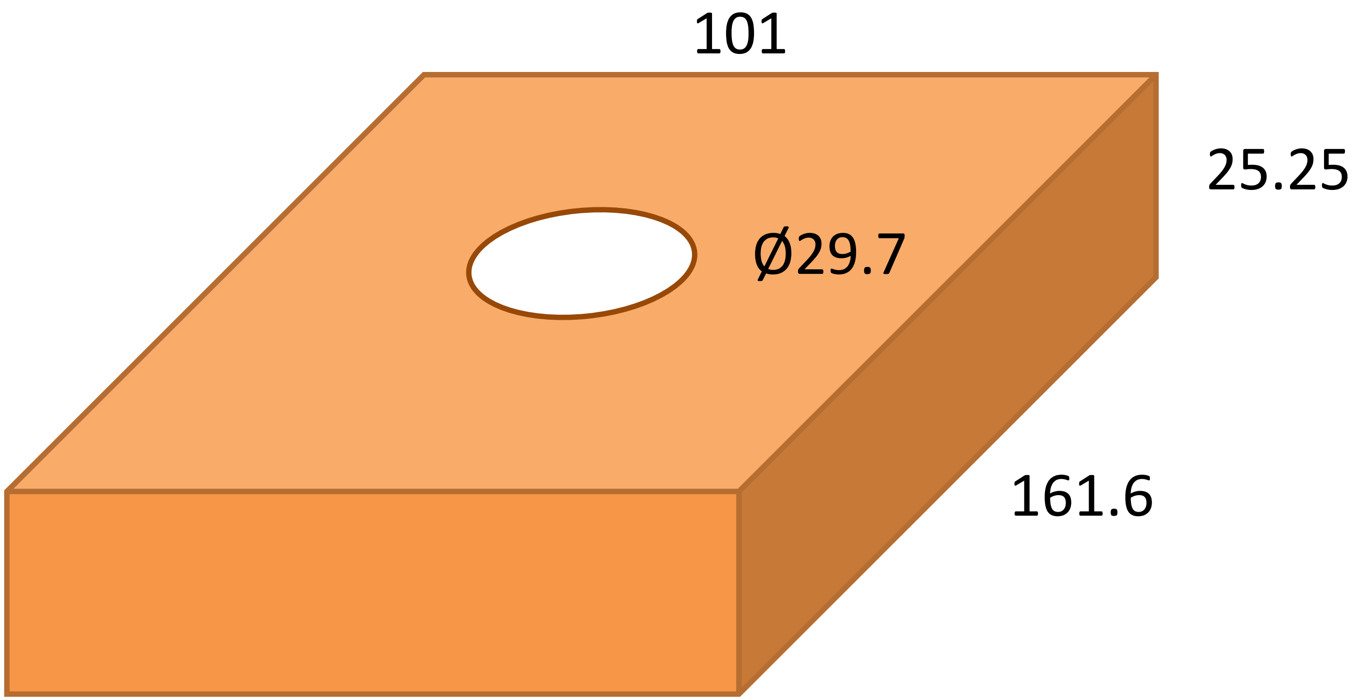


The casting shown is to be made in ***cast iron*** using a wooden pattern. Assuming only shrinkage allowance, calculate the dimension of the pattern

1. Shrinkage or Contraction Allowance

- For dimension **100mm**,
  - allowance = 100 *X* 10 /1000 = **1mm**
- For dimension **160mm**,
  - allowance = 160 *X* 10 /1000 = **1.6mm**
- For dimension **25mm**,
  - allowance = 25 *X* 10 /1000 = **0.25mm**
- For dimension **30mm**,
  - allowance = 30 *X* 10 /1000 = **0.3mm**

1. Shrinkage or Contraction Allowance



The pattern drawing with required dimension

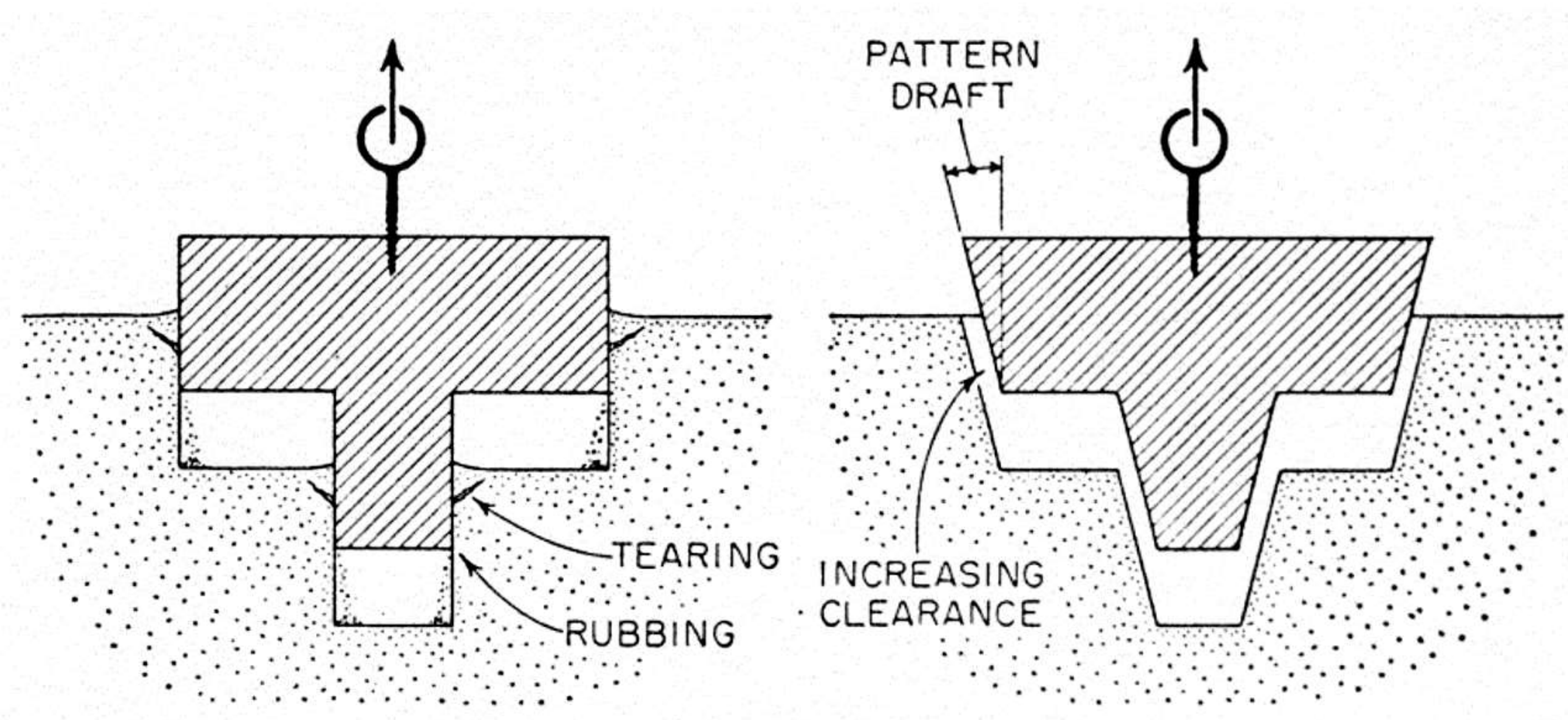
2. Machining or Finish Allowance

- The finish and accuracy achieved in sand casting are generally poor and therefore when the casting is functionally required to be of good surface finish or dimensionally accurate, it is generally achieved by subsequent machining.
- Machining allowance is a positive allowance given to compensate for the amount of material that is lost in machining or finishing the casting.
- If this allowance is not given, the casting will become undersize after machining.

2. Machining or Finish Allowance

- The amount of this allowance depends on the size of casting, methods of machining and the degree of finish. In general, however, the value varies from 3 mm. to 18 mm.

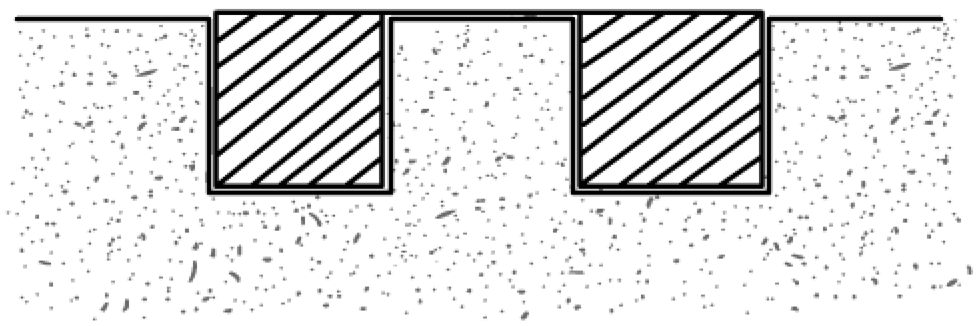
3. Draft or taper allowance



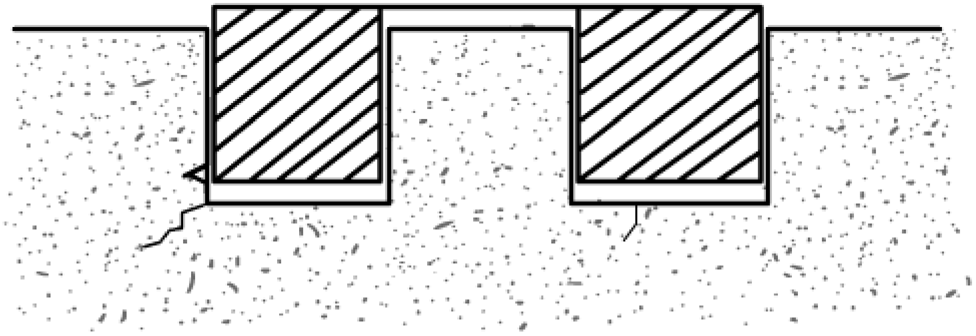
3. Draft or taper allowance

- Draft is the taper provided by the pattern maker on all vertical surfaces of the pattern so that it can be removed from the sand without tearing away the sides of the sand mold and without excessive rapping by the molder.
- Figure shows a pattern having no draft allowance being removed from the pattern.
- Till the pattern is completely lifted out, its sides will remain in contact with the walls of the mold, thus tending to break it.

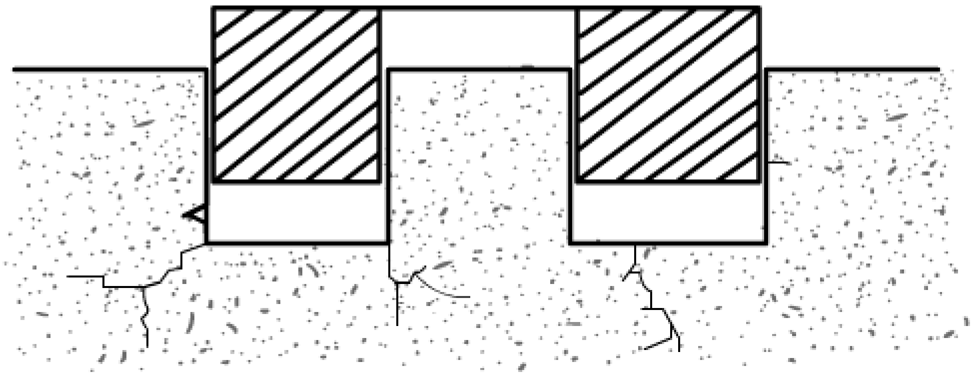
Removal of Pattern without Draft



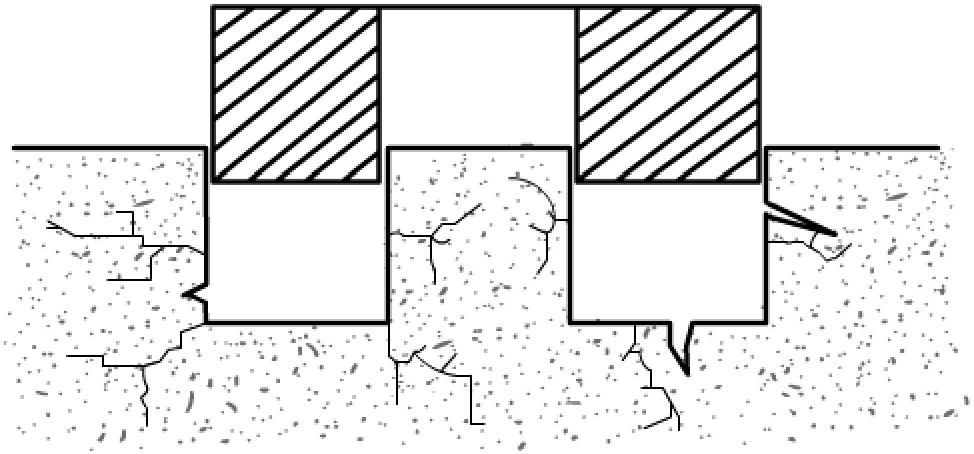
Removal of Pattern without Draft



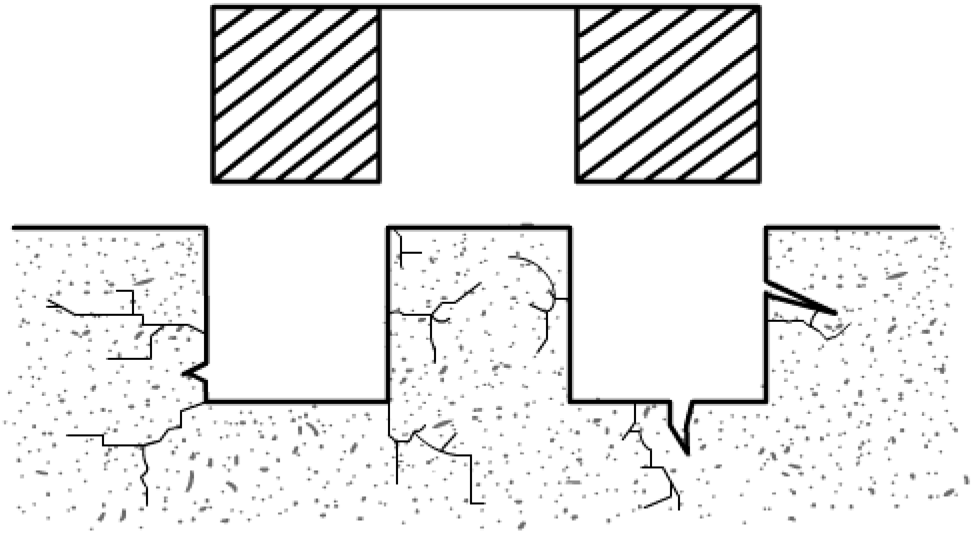
Removal of Pattern without Draft



Removal of Pattern without Draft



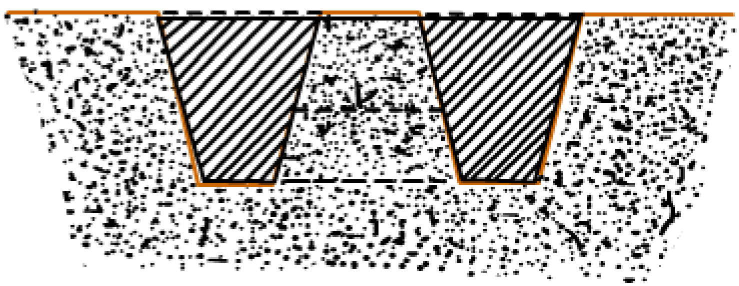
Removal of Pattern without Draft



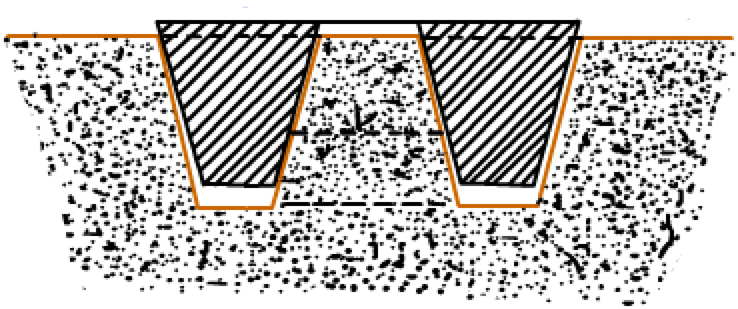
3. Draft or taper allowance

- Next figure shows an illustration of a pattern having proper draft allowance.
- Here, the moment the pattern lifting commences, all of its surfaces are well away from the sand surface.
- Thus the pattern can be removed without damaging the mold cavity

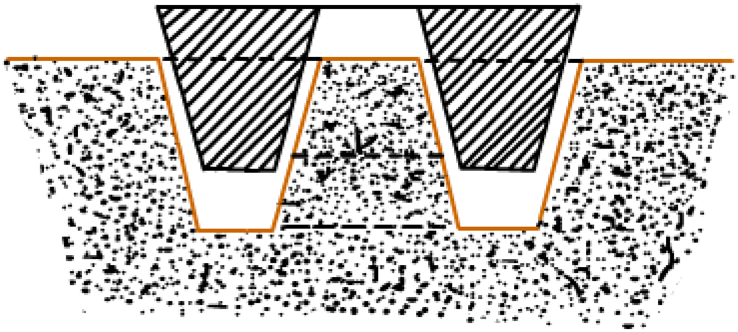
Removal of Pattern with Draft



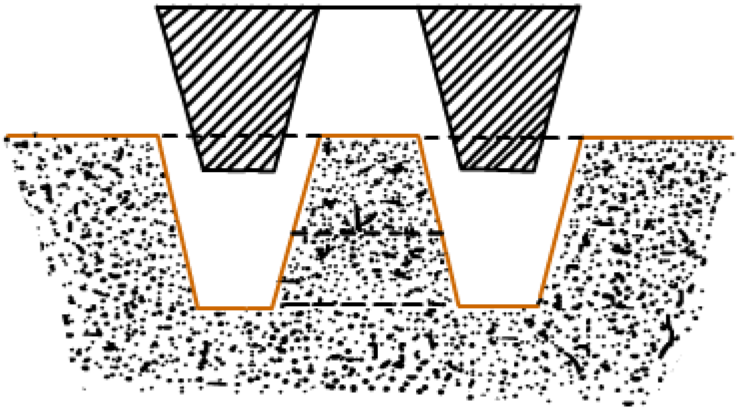
Removal of Pattern with Draft



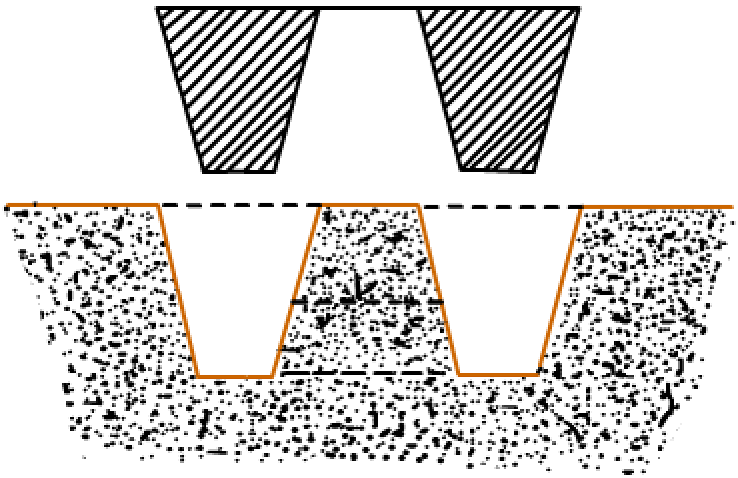
Removal of Pattern with Draft



Removal of Pattern with Draft



Removal of Pattern with Draft



3. Draft or taper allowance

- The normal amount of taper on the external surfaces varies from 10 mm to 20 mm/mt.

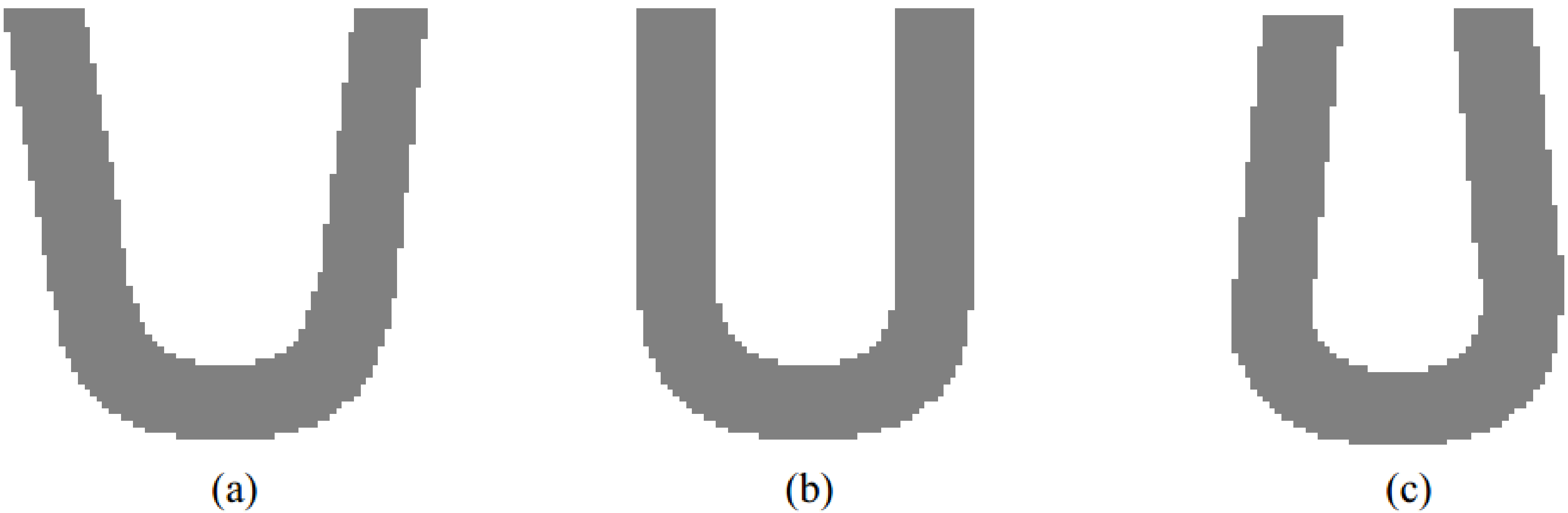
4. Distortion or Camber Allowance

- Sometimes castings, because of their size, shape and type of metal, tend to warp or distort during the cooling period depending on the cooling speed.
- This is due to the uneven shrinkage of different parts of the casting.
- Expecting the amount of warpage, a pattern may be made with allowance of warpage.
- It is called camber.

4. Distortion or Camber Allowance

- For example, a U-shaped casting will be distorted during cooling with the legs diverging, instead of parallel .
- For compensating this warpage, the pattern is made with the legs converged but, as the casting cools, the legs straighten and remain parallel.
- Warpage depends on the thickness and method of casting and it is actually determined by experience. Generally 2 to 3 mm is considered appropriate for 1 metre length.

4. Distortion or Camber Allowance



Example of camber: (a) Casting without camber,
(b) Actual casting, (c) Pattern with camber allowance

5. Rapping or Shaking Allowance

- Before withdrawing the pattern it is rapped and thereby the size of the mould cavity increases.
- Actually by rapping, the external sections move outwards increasing the size and internal sections move inwards decreasing the size.
- This movement may be insignificant in the case of small and medium size castings, but it is significant in the case of large castings.

5. Rapping or Shaking Allowance

- This allowance is kept negative and hence the pattern is made slightly smaller in dimensions 0.5-1.0 mm.

6. Mould wall Movement Allowance

- Movement of mould wall in sand moulds takes place because of heat and the static pressure exerted on the walls of the mould which comes in contact with the molten metal.

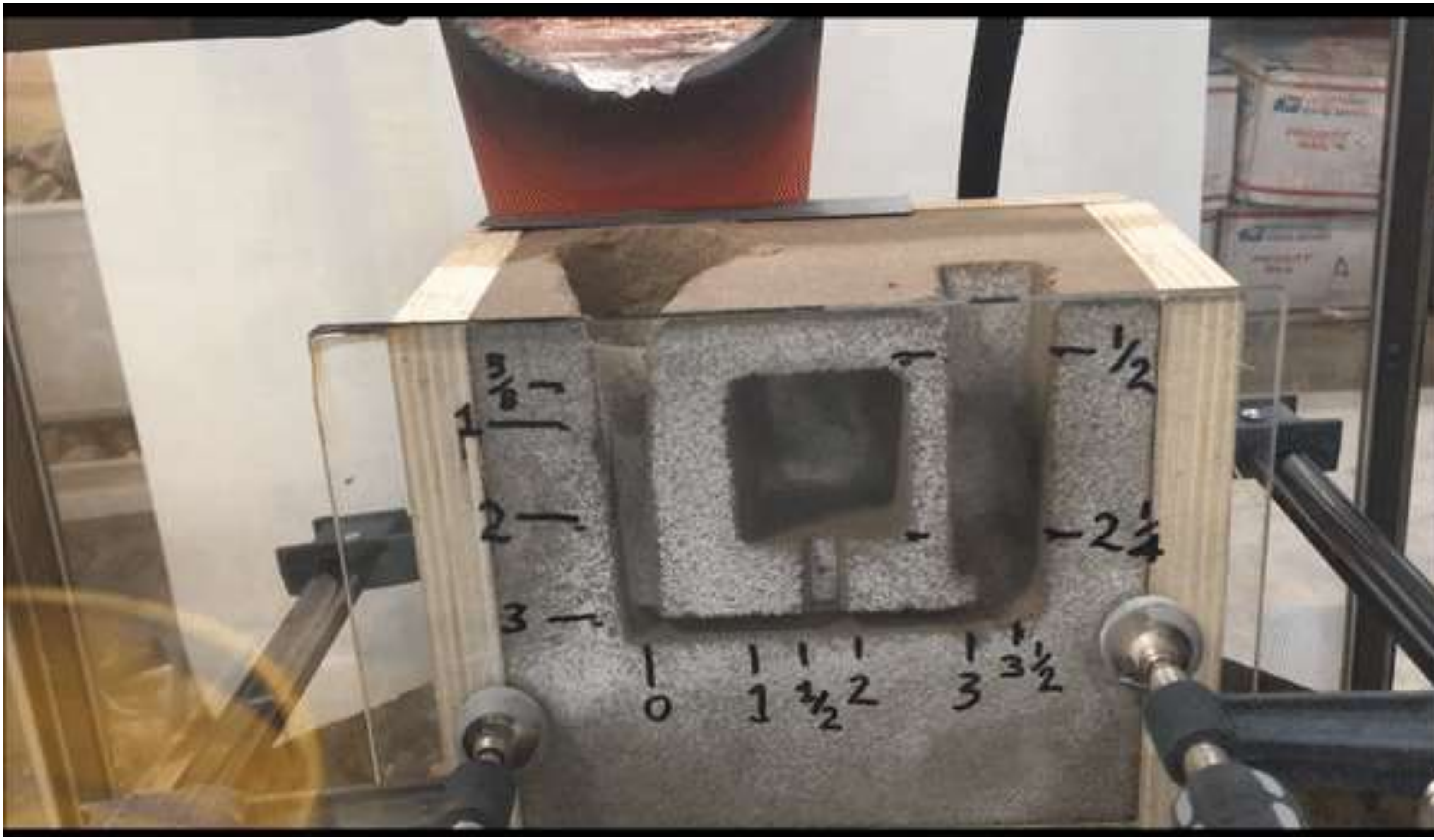
Manufacturing Processes
UTA026

MOLD & GATING SYSTEM
Lecture - 20

The Mold in Casting

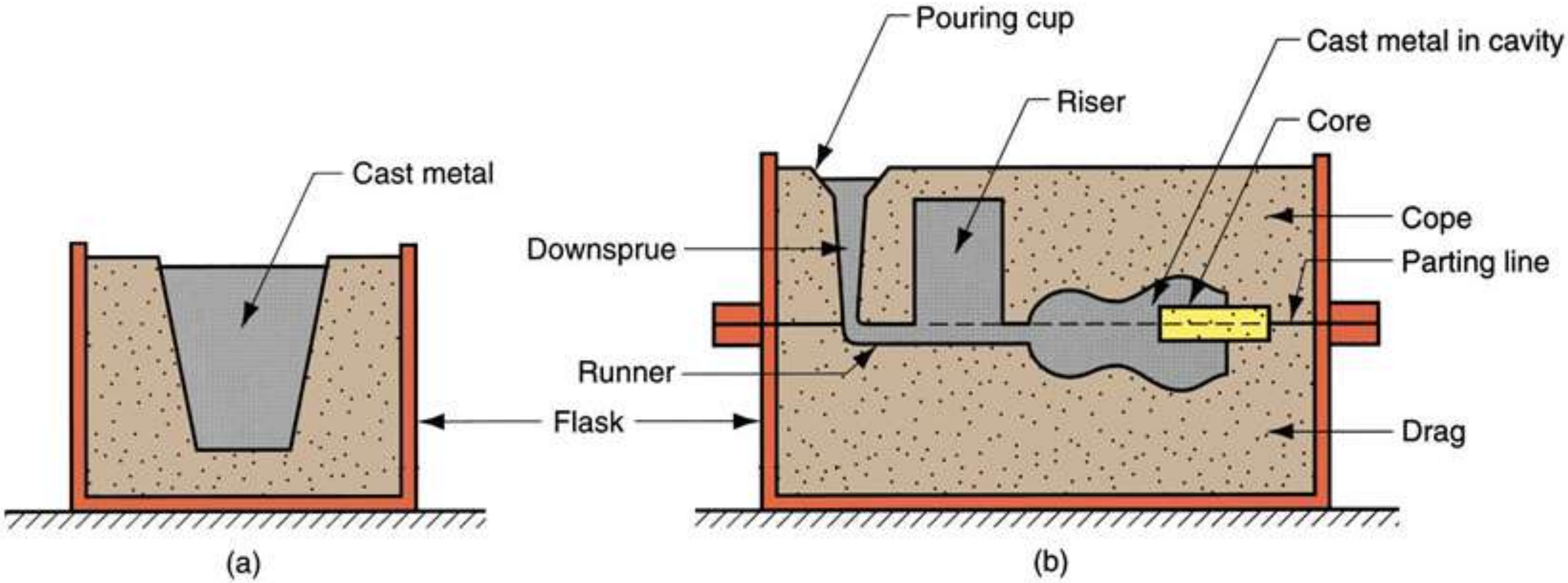
- The ***Mold*** contains a ***cavity*** whose geometry determines the shape of the cast part.

- Mold is a hollow container (***cavity***) used to give shape to ***molten*** or ***hot liquid*** material (such as wax or metal) when it cools and hardens.



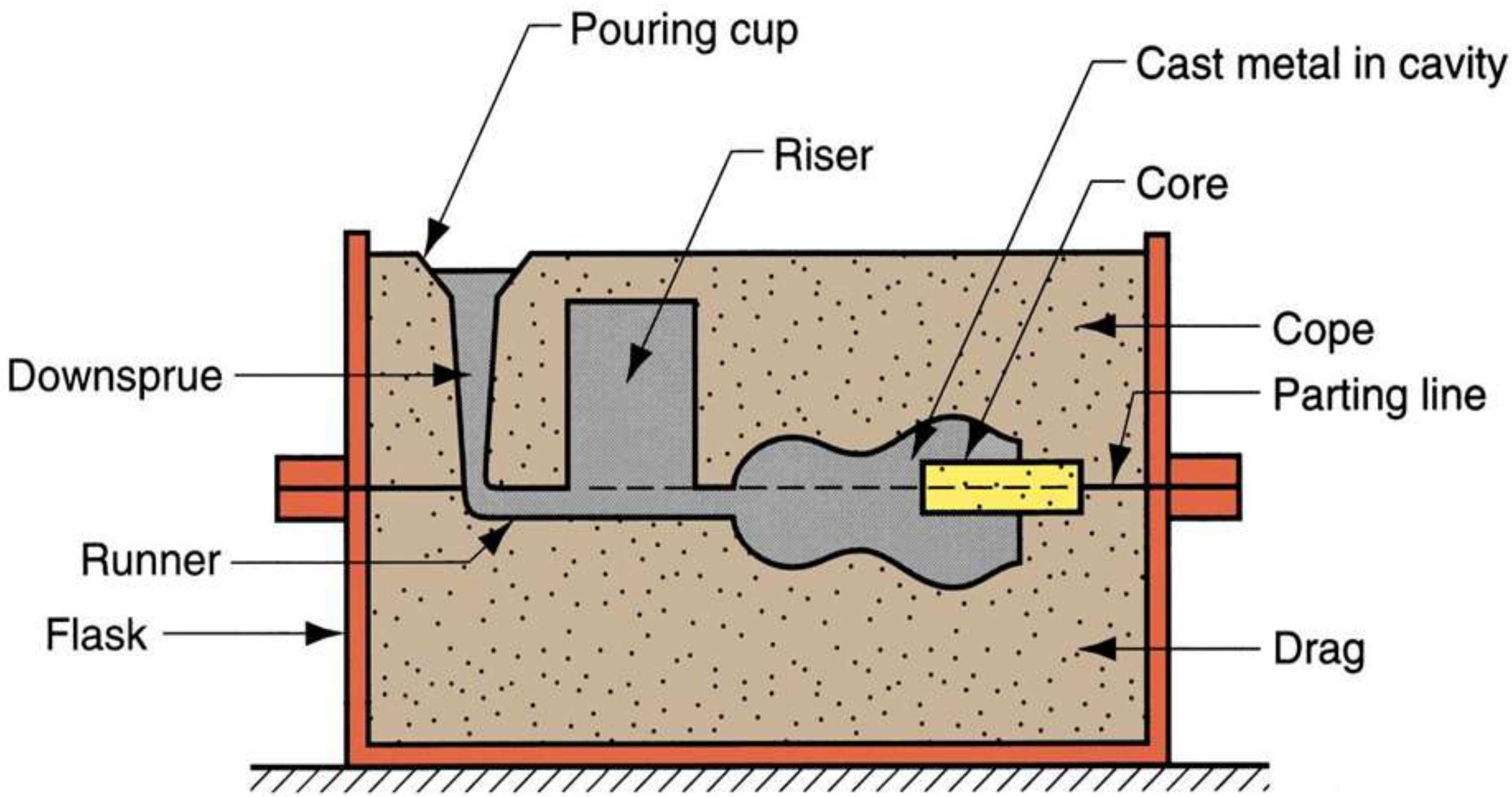
*https://www.youtube.com/watch?v=vovhaSxjIzU

Open Molds and Closed Molds



Two forms of mold: (a) open mold, simply a container in the shape of the desired part; and (b) closed mold, in which the mold geometry is more complex and requires a gating system (passageway) leading into the cavity.

Sand Casting Mold (Closed)



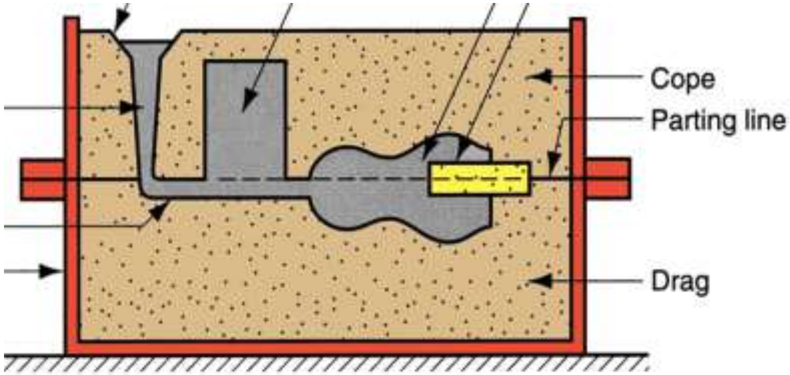
Sand Casting Mold (Closed)

- ✓ Actual size and shape of cavity must be slightly ***oversized*** to allow ***shrinkage*** of metal during ***solidification*** and ***cooling.***

- ✓ Molds are made of a variety of materials, including-
  - ***Sand,***
  - ***Plaster,***
  - ***Ceramic,***
  - ***Metals***

Mold Terms

- Mold consists of two halves:
  - *Cope* = upper half of mold
  - *Drag* = bottom half



  - ***Cheek*** = intermediate molding flask ***(optional for bigger molds)***

- The rigid metal or wood frame that holds the moulding sand together is called as ***flask***.

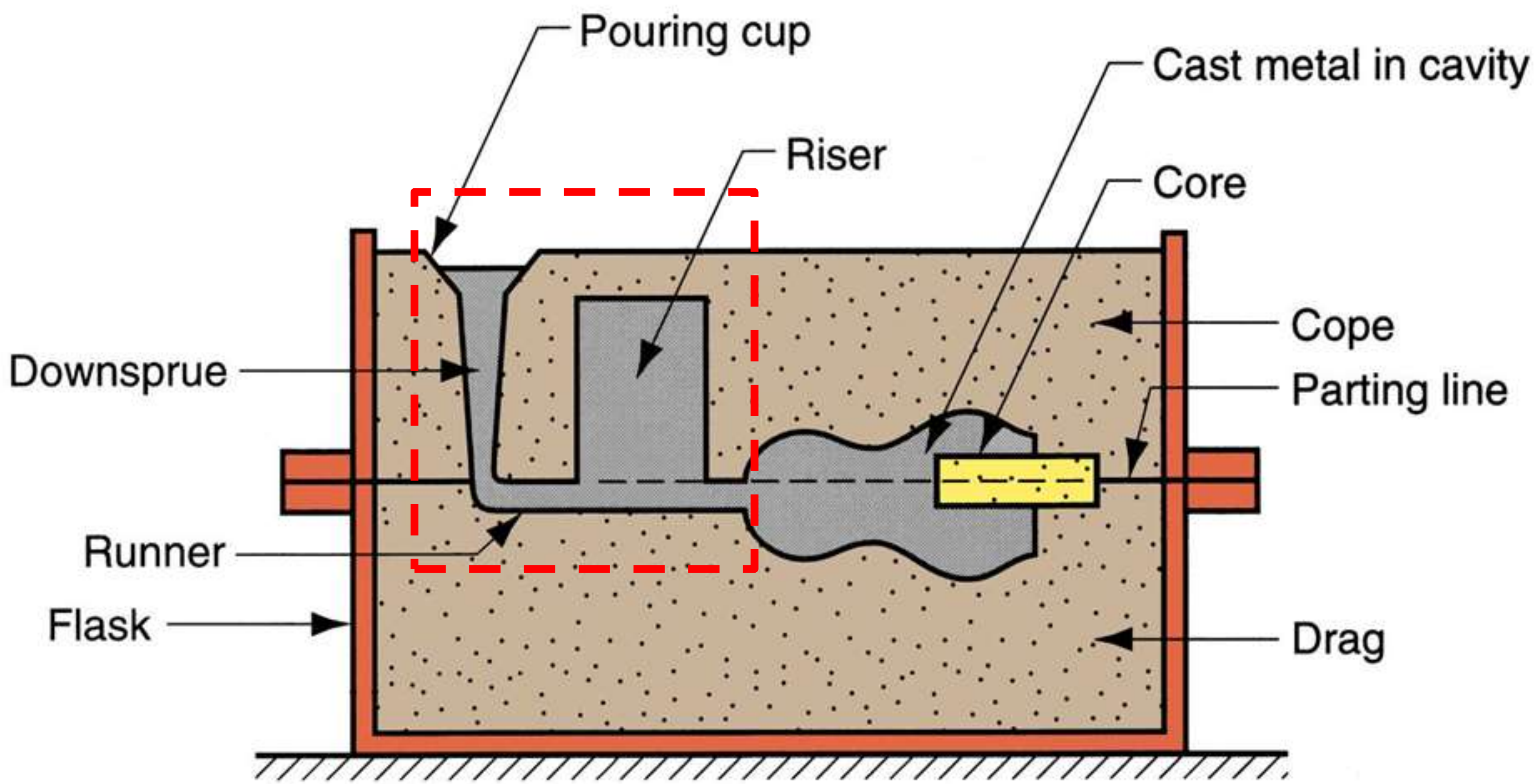
- The two halves separate at the ***parting line.***

Desirable Mold Properties

- ***Strength*** - to maintain shape and resist erosion
- ***Permeability*** - to allow hot air and gases to pass through voids in sand
- ***Thermal stability*** - non reactive with hot molten metal
- ***Collapsibility*** - allow casting to shrink without cracking the casting or mold
- ***Reusability*** - sand of broken mold can be reused to make other molds

Gating System

The ***gating system*** in a casting mold is the ***channel***, or network of channels, through which ***molten metal flows*** into cavity from outside of mold.



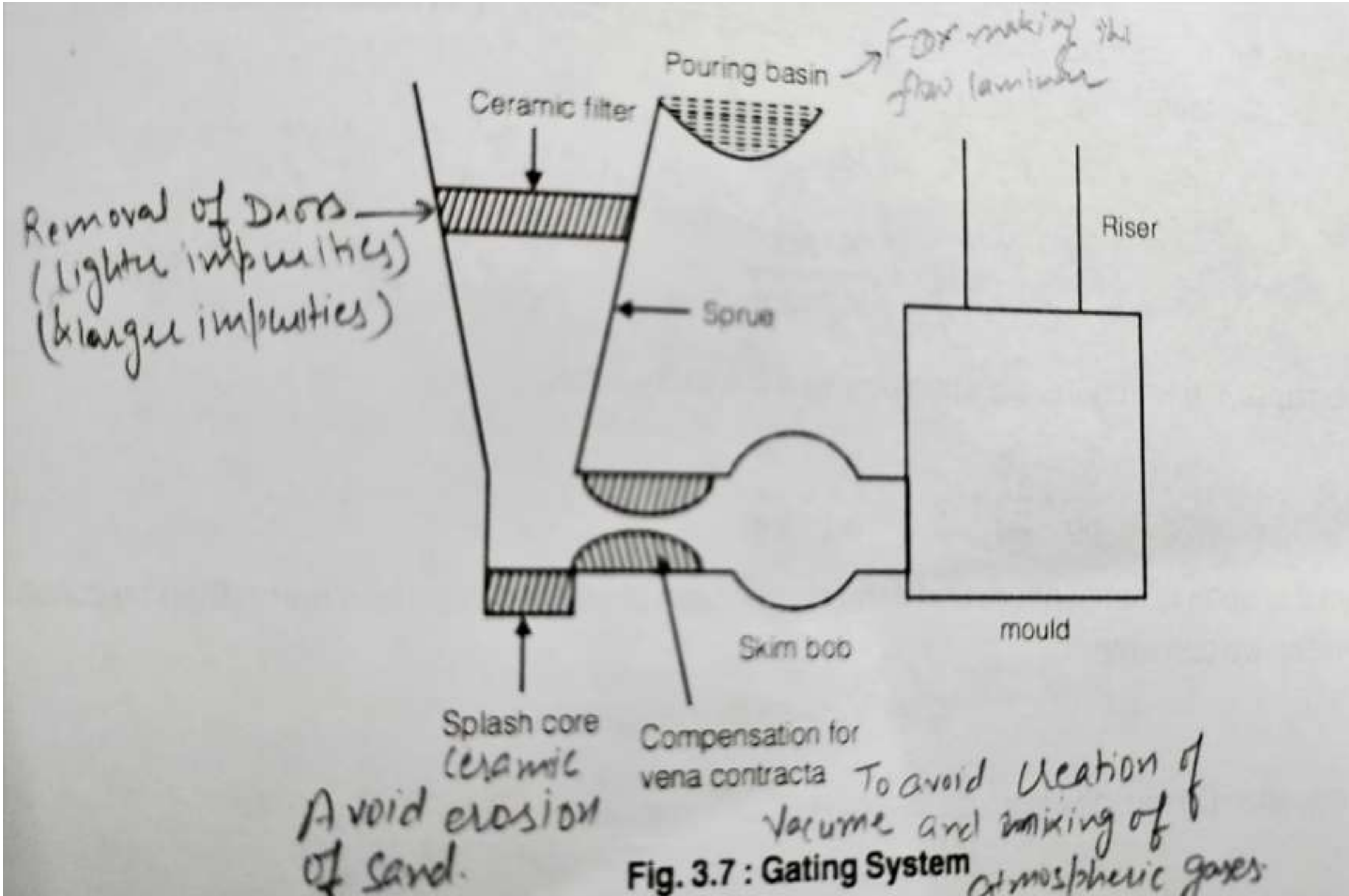
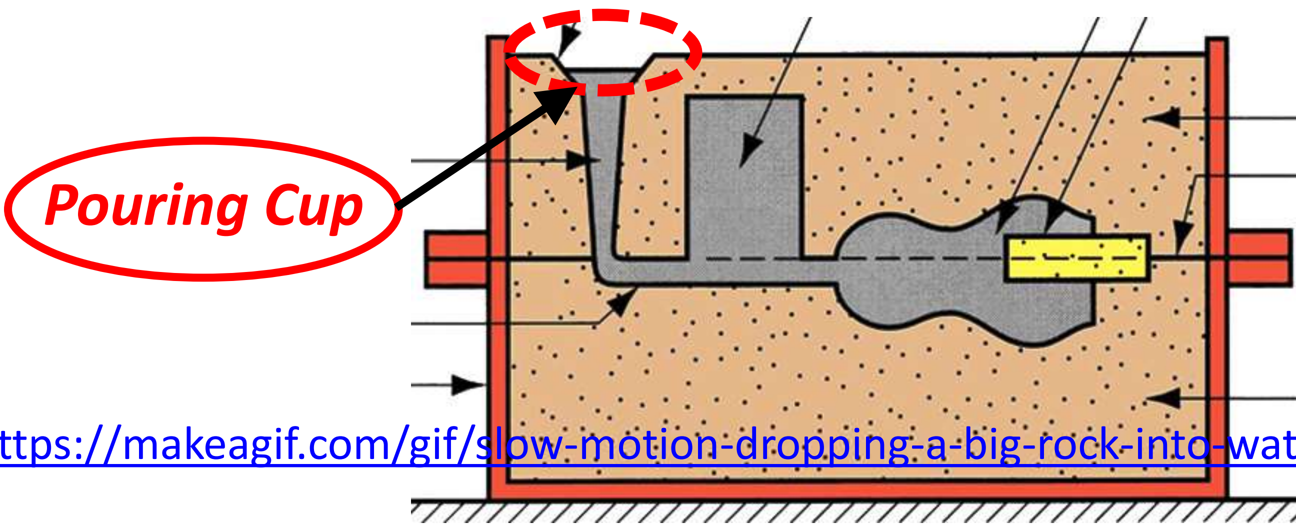


Fig. 3.7 : Gating System

Gating System

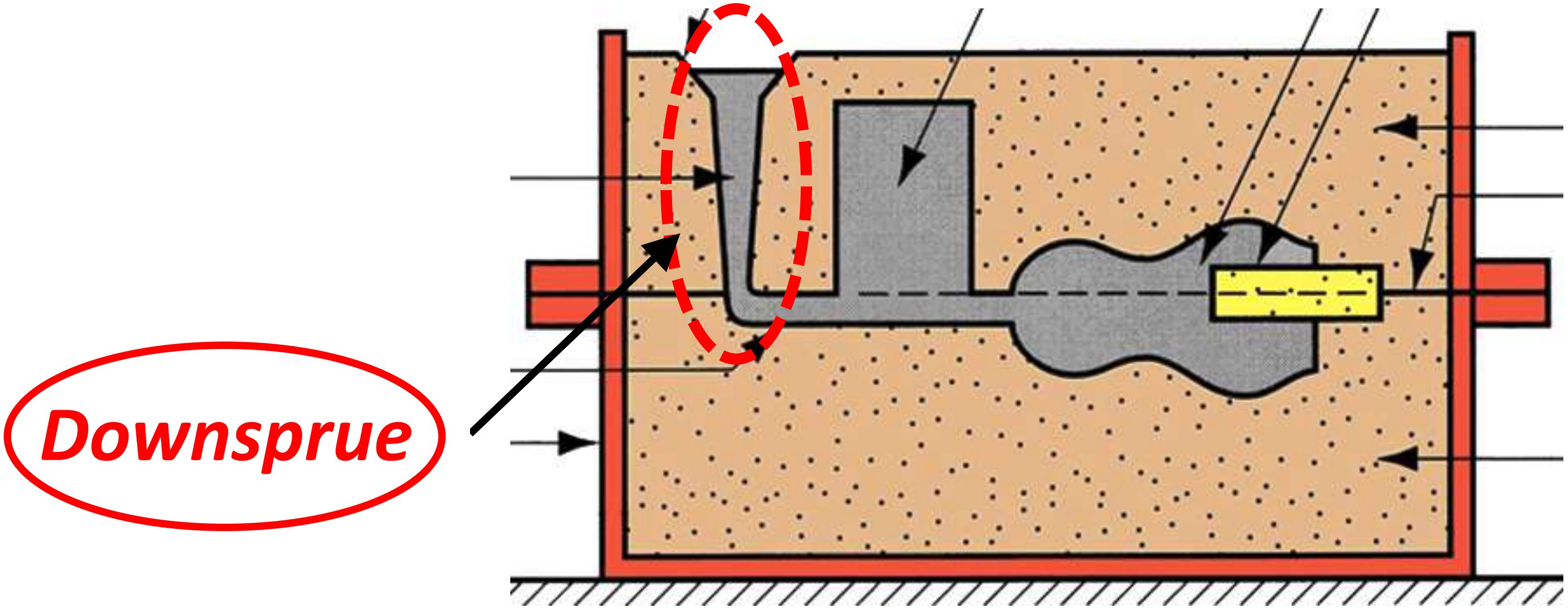
- ***The pouring cup*** (or pouring ***basin***) is the portion of the gating system that receives the molten metal from the **pouring vessel** and delivers it to the rest of the mold.
- ***Pouring cup*** is often used to minimize **splash** and **turbulence** as the metal flows into downsprue



https://makeagif.com/gif/slow-motion-dropping-a-big-rock-into-water-_c8rnH

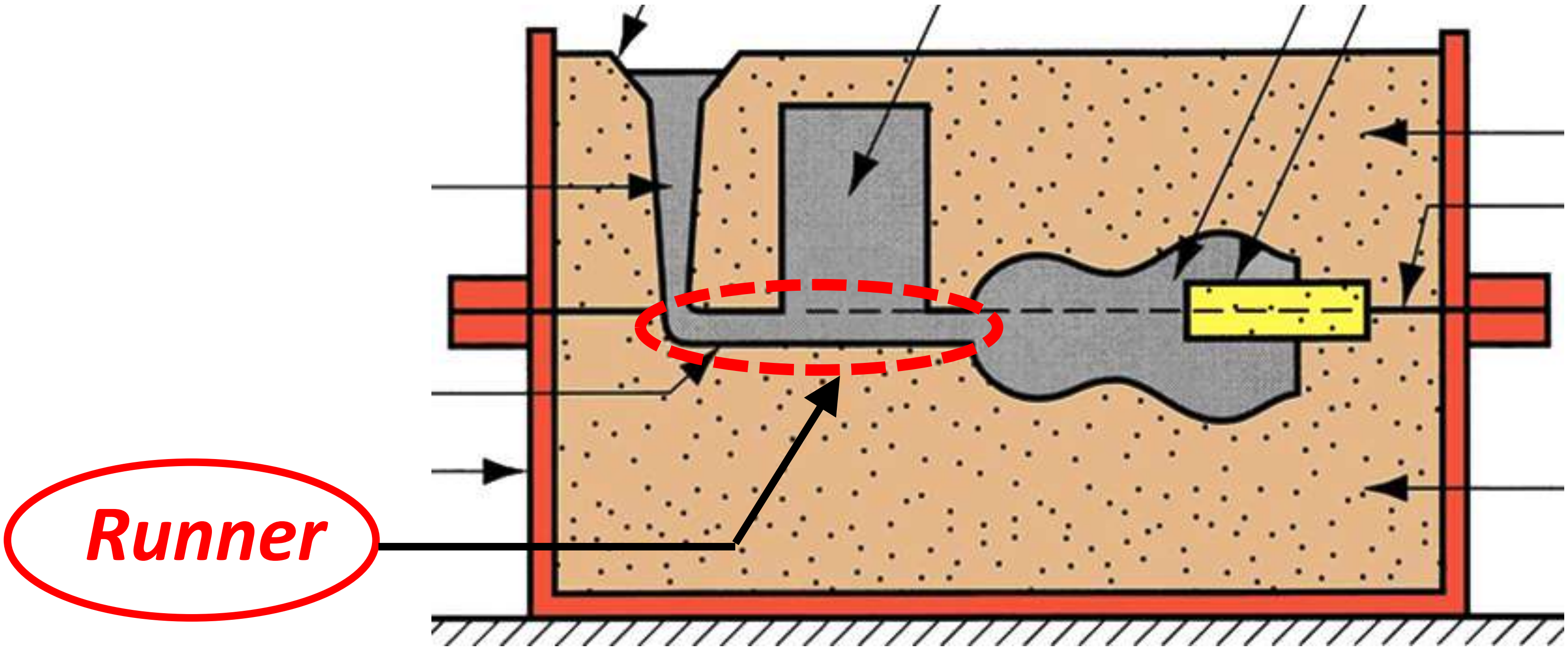
Gating System

- From the pouring cup, the metal travels down a ***downsprue*** *also called simply the* ***sprue*** (the vertical portion of the gating system).



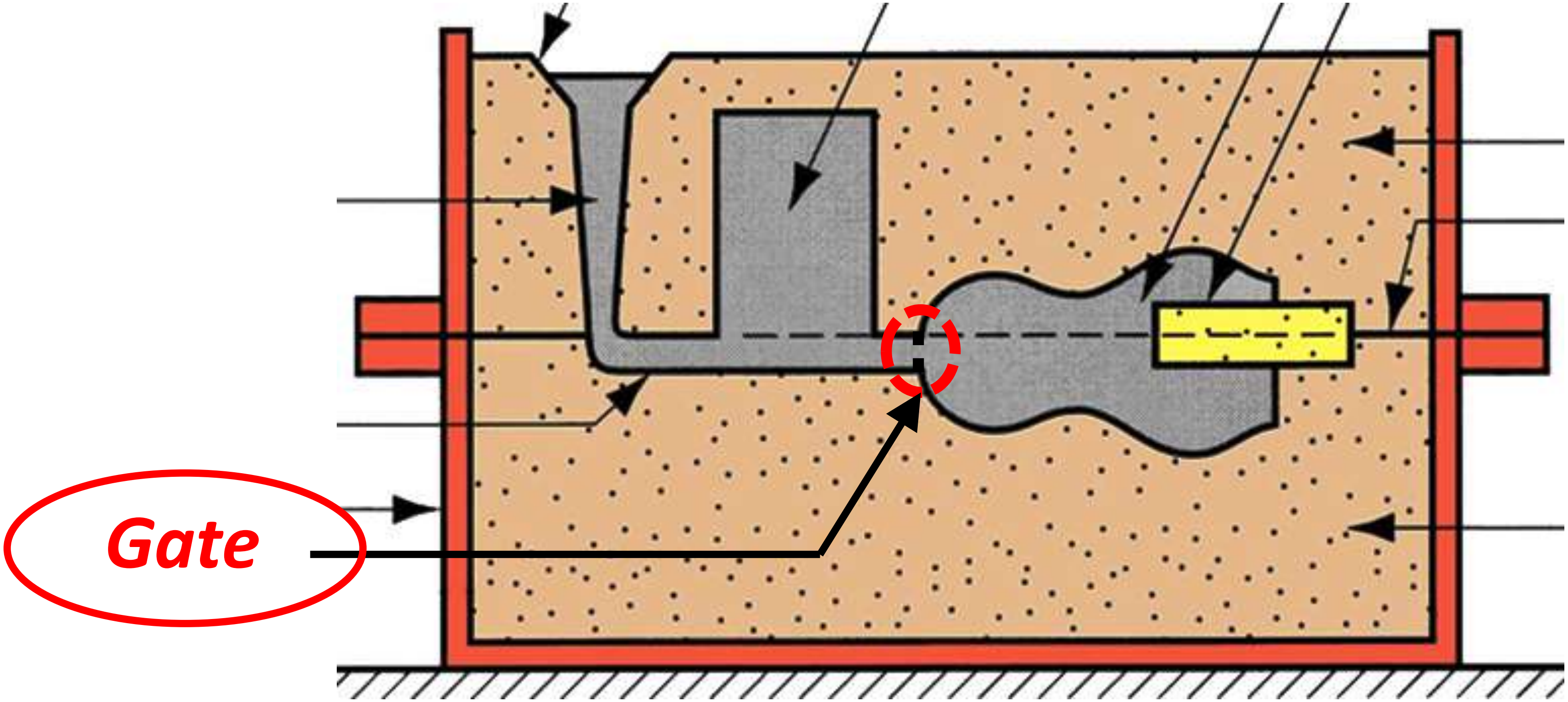
Gating System

- Then liquid metal flow along horizontal channels, called ***runners***.



Gating System

- Finally liquid metal through controlled entrances (i.e. ***gates)*** reaches into the mold cavity.



Gating System

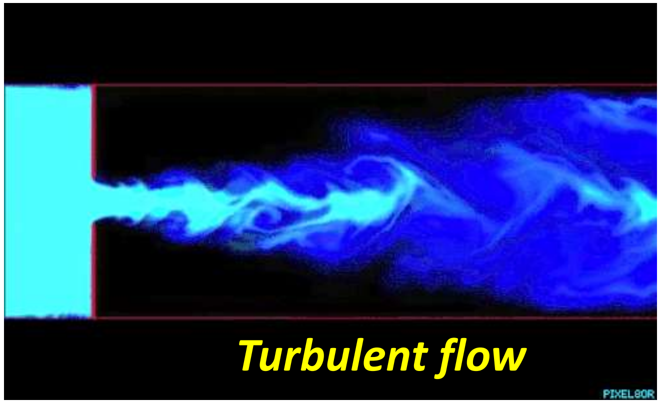
- The ***gates*** are usually ***attached*** to the

  1. ***thickest or heaviest sections*** of a casting **to control** **SHRINKAGE**
  2. ***to the bottom of the casting*** to **minimize** **TURBULENCE AND SPLASHING**.

- For large castings, ***multiple gates*** and runners is used to introduce metal at more than one point in the mold cavity.

Gating System

- ***Turbulent flow*** is generated while pouring the molten metal into the mold which causes the following problems:
  - *absorption of gases,*
  - *oxidation of the metal, and*
  - *erosion of the mold.*

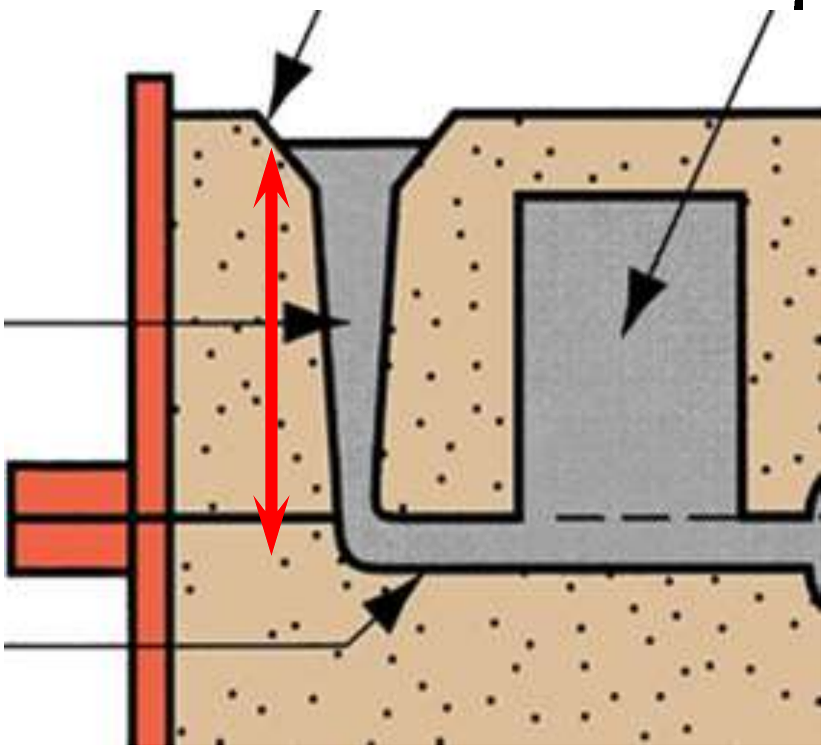


- Therefore gating systems should be designed to ***minimize turbulent flow.***

https://www.tumblr.com/tagged/dynamics

Gating System

- ***Short sprues*** are desirable, since they minimize the distance that metal falls when entering to the mold and kinetic energy acquires during that fall.



https://www.youtube.com/watch?v=vovhaSxjIzU

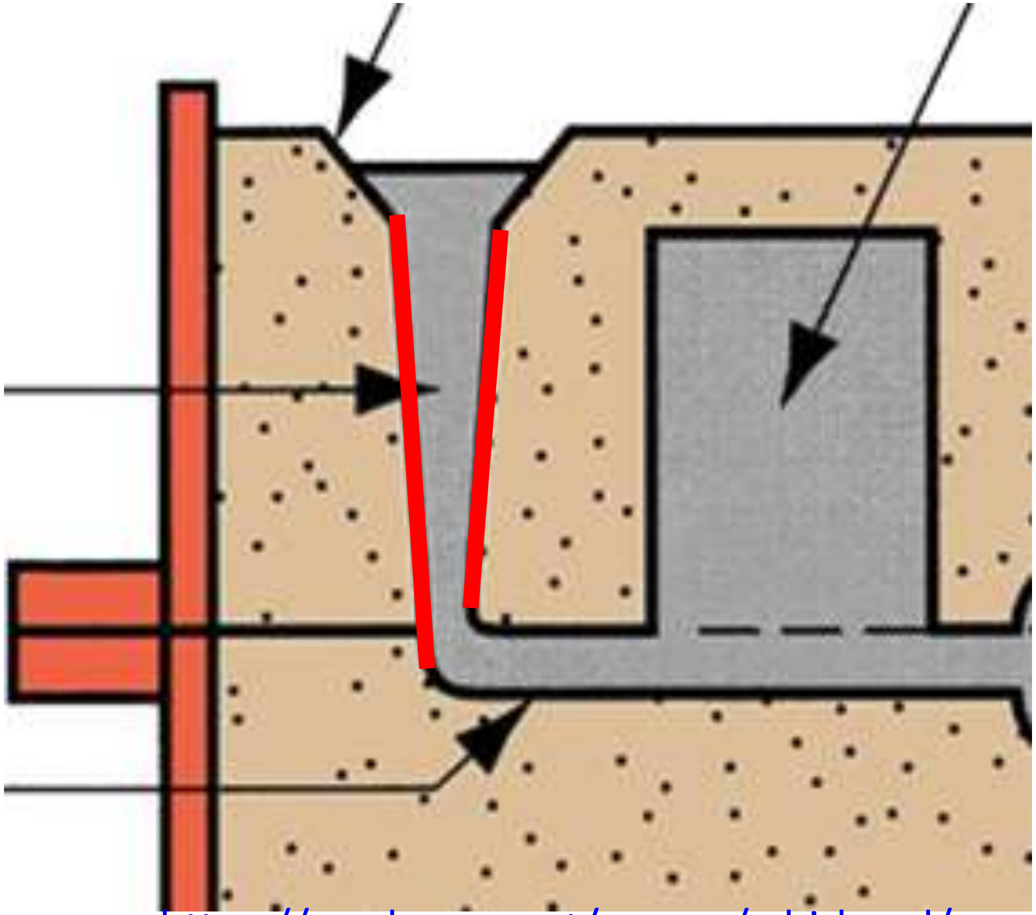
Gating System

- ***Rectangular pouring cups*** prevent the formation of a ***vortex or spiralling funnel***, which tends to suck gas and oxides into the sprue.

https://forum.freecadweb.org/viewtopic.php?t=8468

Gating System

- ***Tapered sprues*** also prevent ***vortex formation***.



https://mscharrer.net/povray/whirlpool/

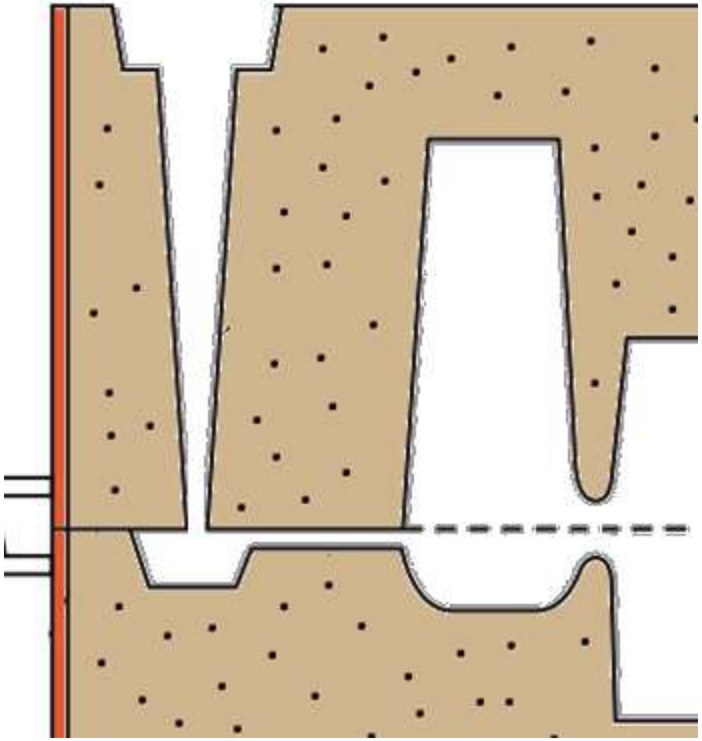
Gating System

- ***A large sprue well*** can be used to dissipate the kinetic energy of the falling stream and prevent splashing and turbulence as the metal makes the turn into the runner.

- The ***choke*** , or ***smallest cross-sectional*** area in the gating system, serves to control the rate of metal flow.

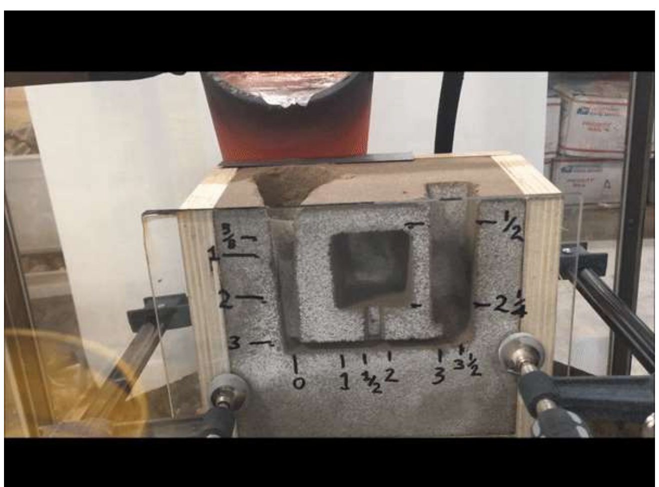
Gating System

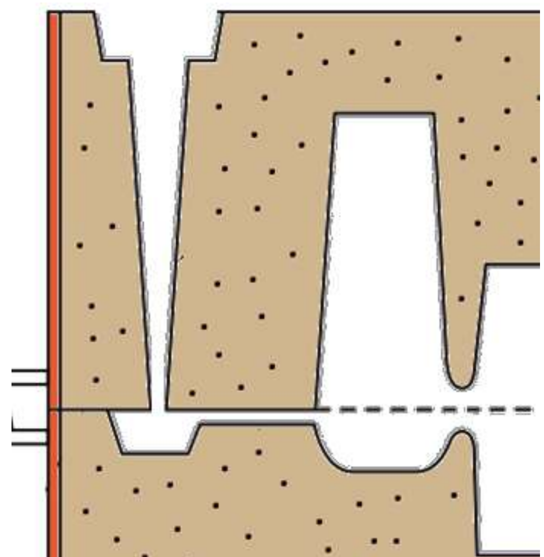
- Gating systems can also be designed to trap ***dross (slag)*** and ***sand particles*** and keep them from entering the mold cavity.



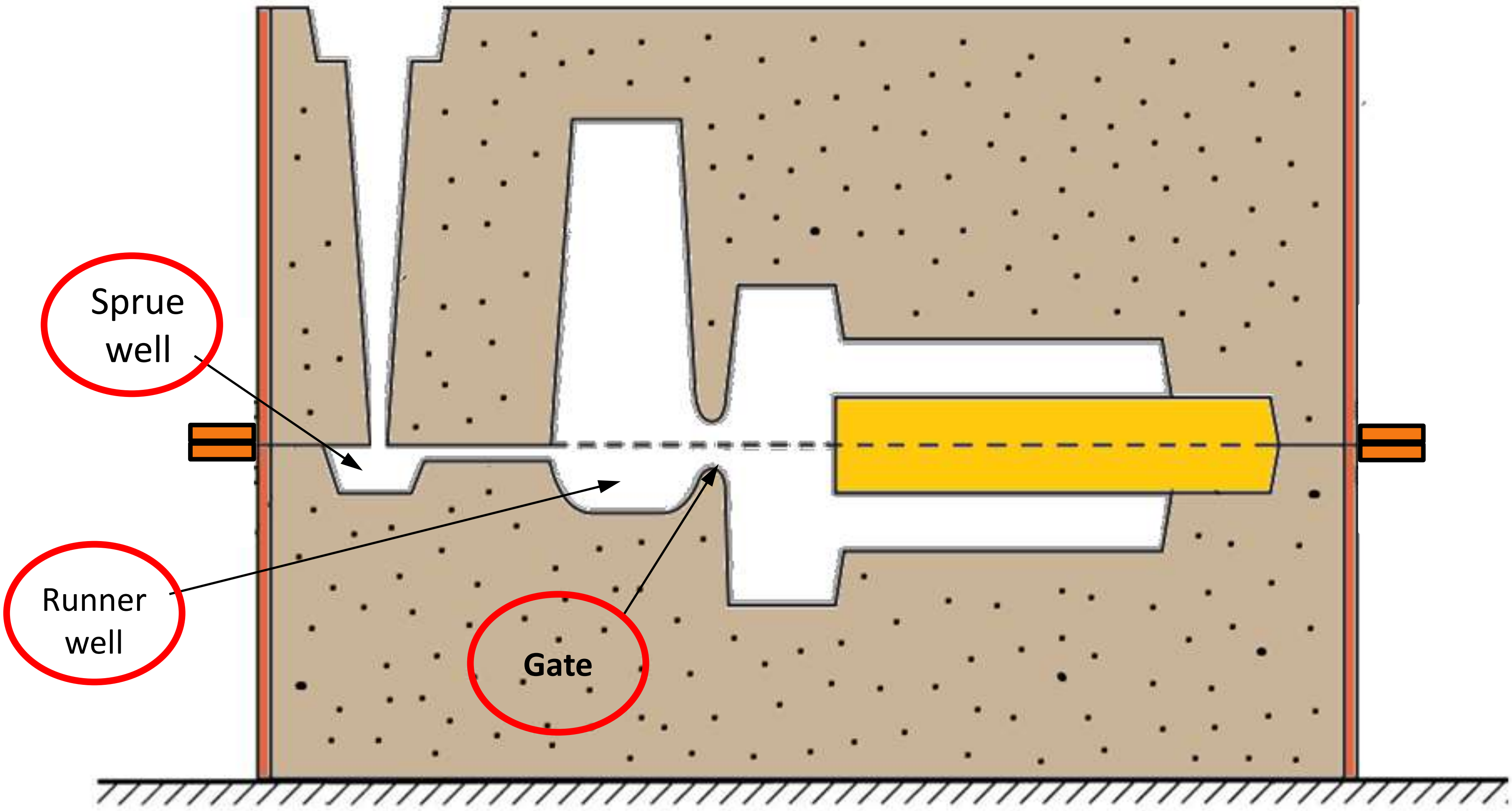
Gating System

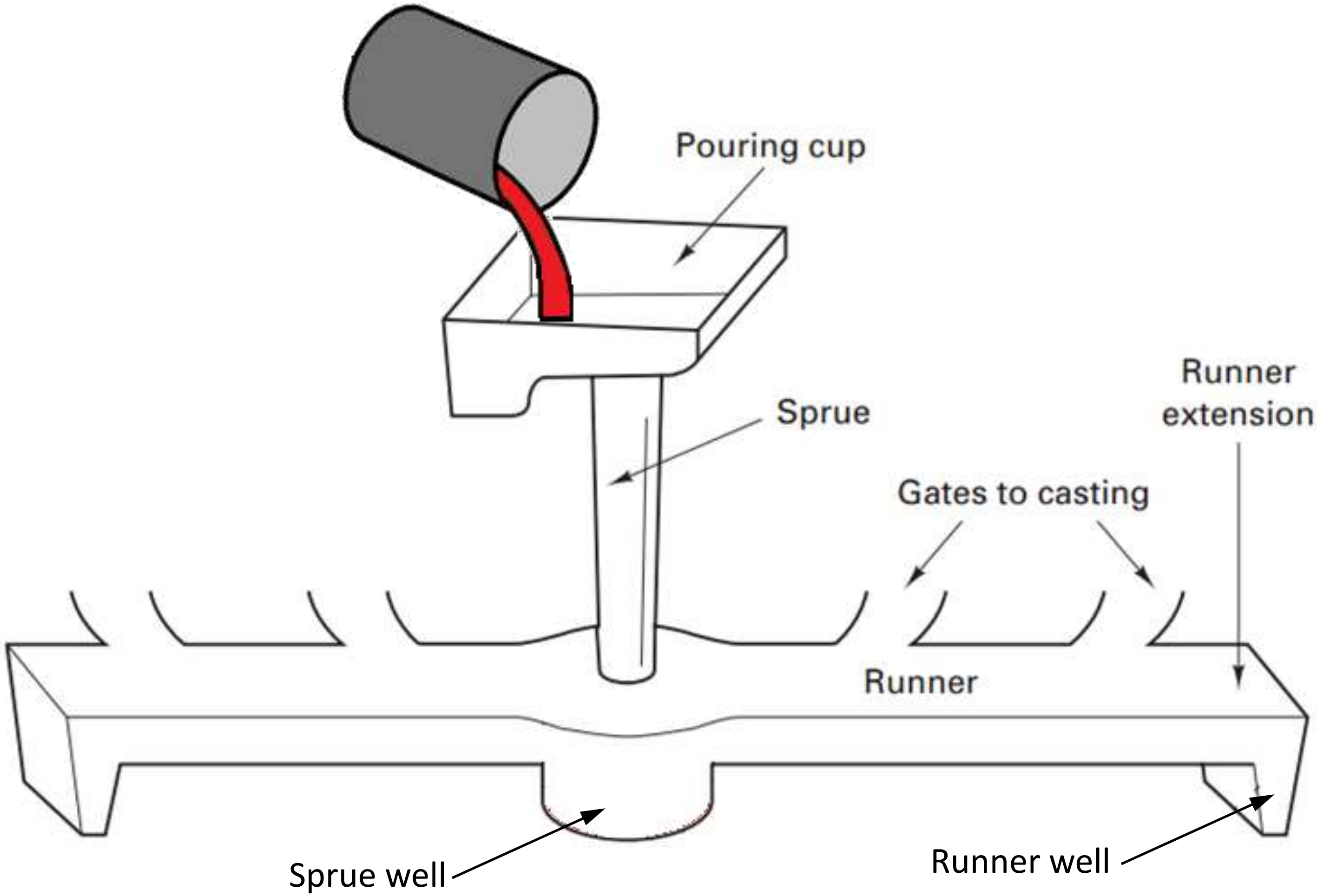
- Since the first metal to enter the mold is most likely to contain the foreign matter (dross from the top of the pouring ladle and loose particles washed from the walls of the gating system), ***RUNNER EXTENSIONS*** and ***RUNNER WELLS*** can be used to catch and trap this first metal and keep it from entering the mold cavity.

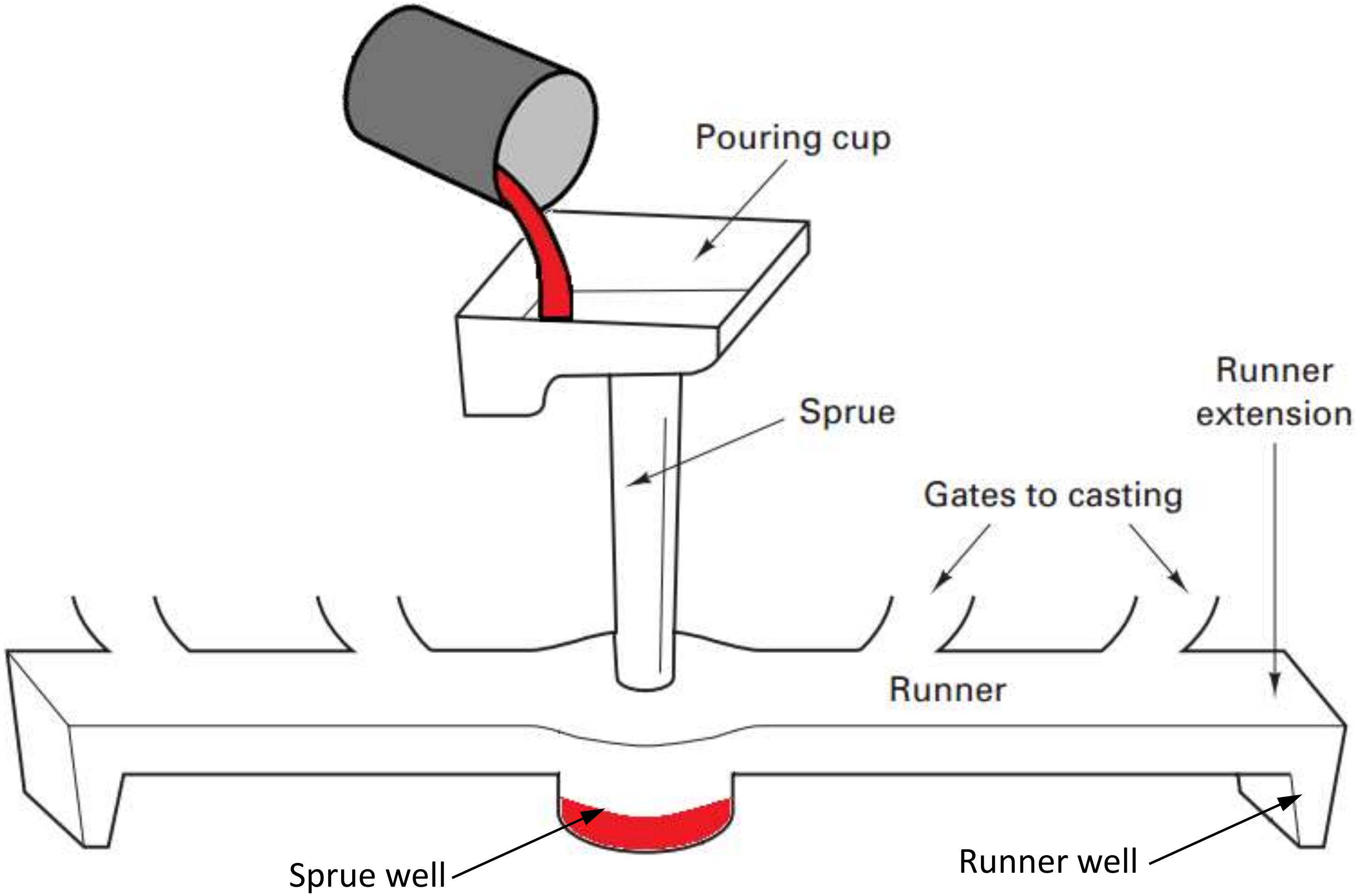




Gating System




Pouring cup
Sprue
Runner extension
Gates to casting
Runner
Sprue well
Runner well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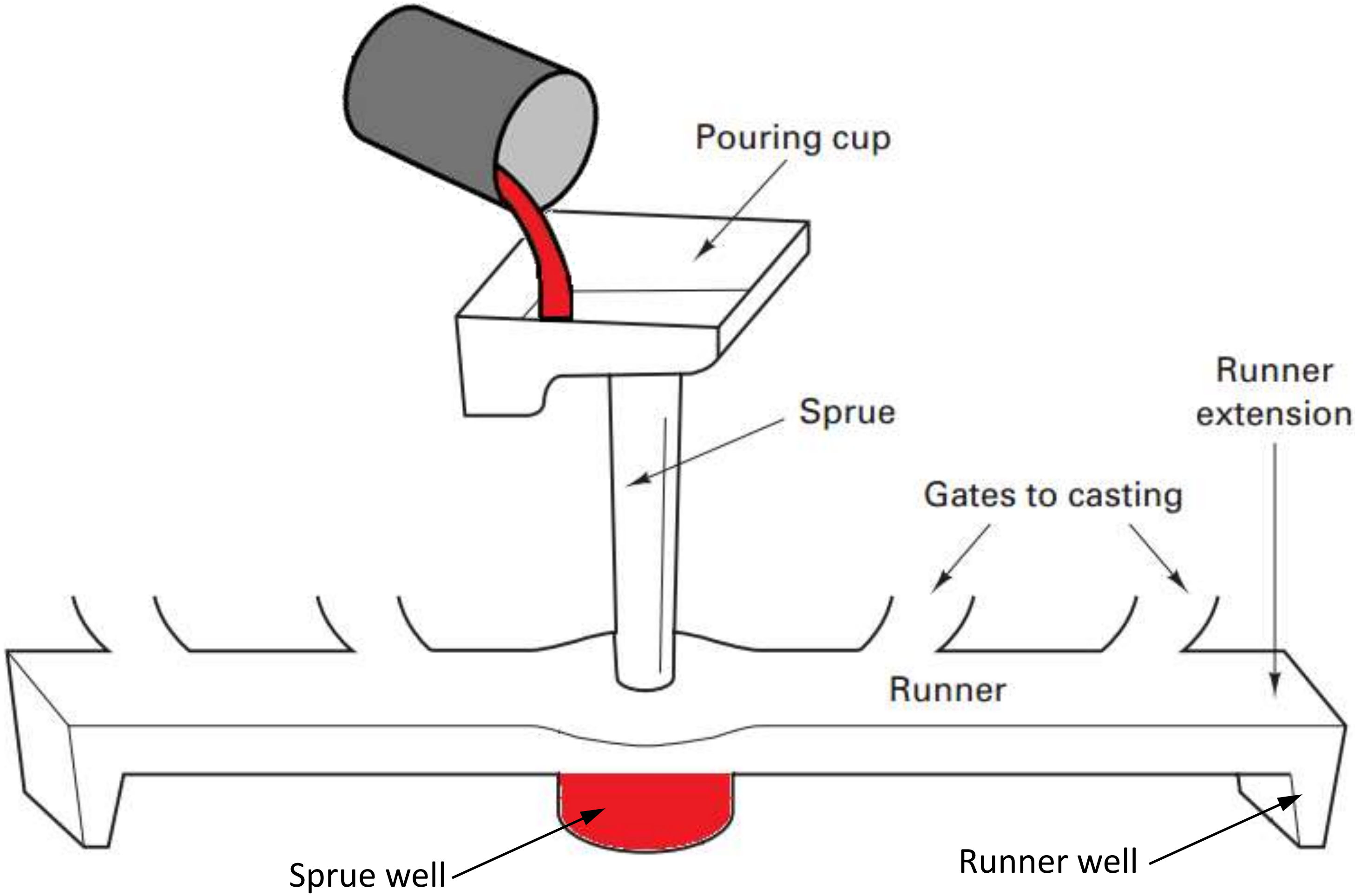
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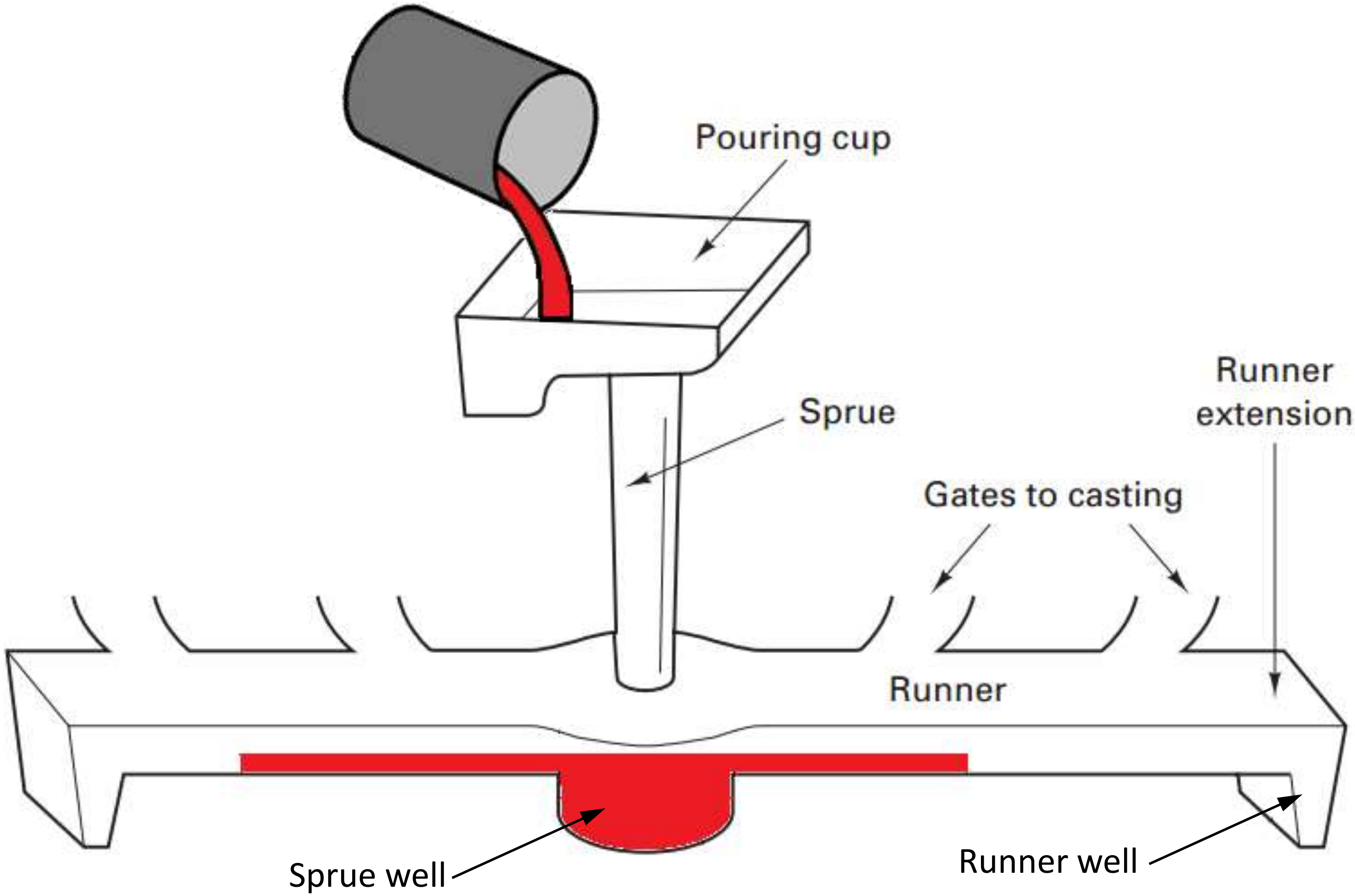
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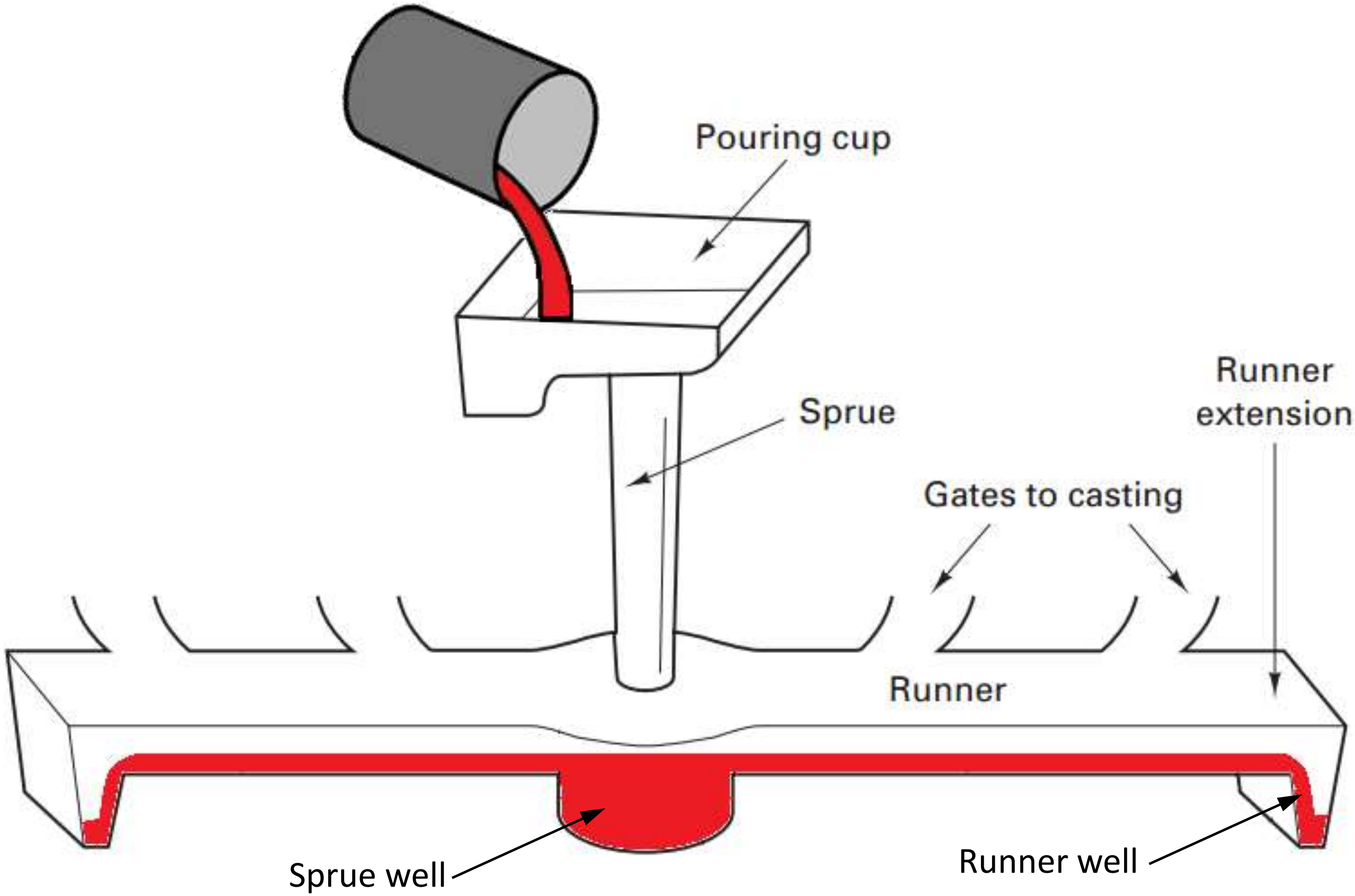
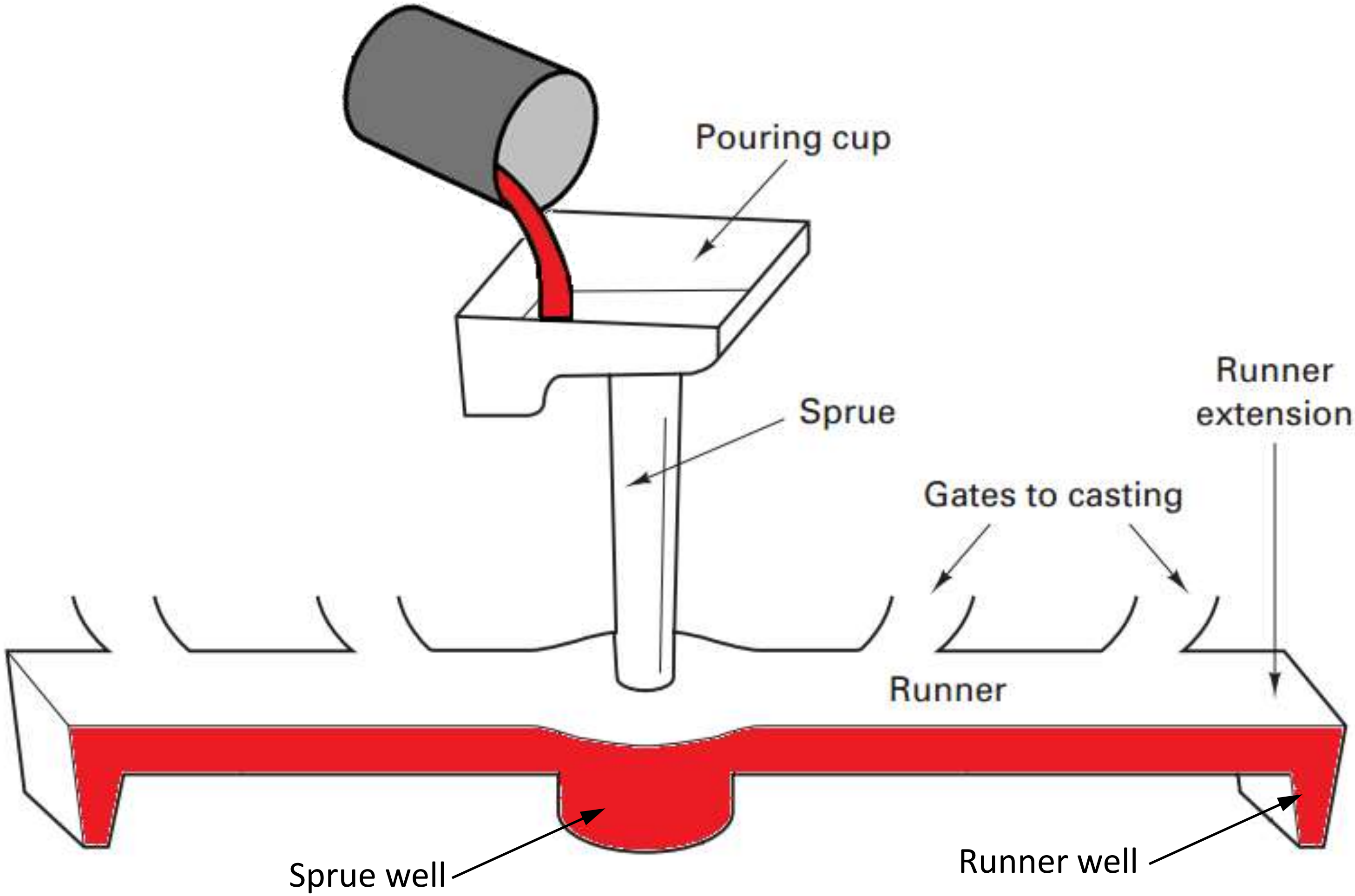
Runner well


Pouring cup
Sprue
Runner
extension
Gates to casting
Runner
Sprue well
Runner well



Pouring cup
Sprue
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Gates to casting
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Sprue well
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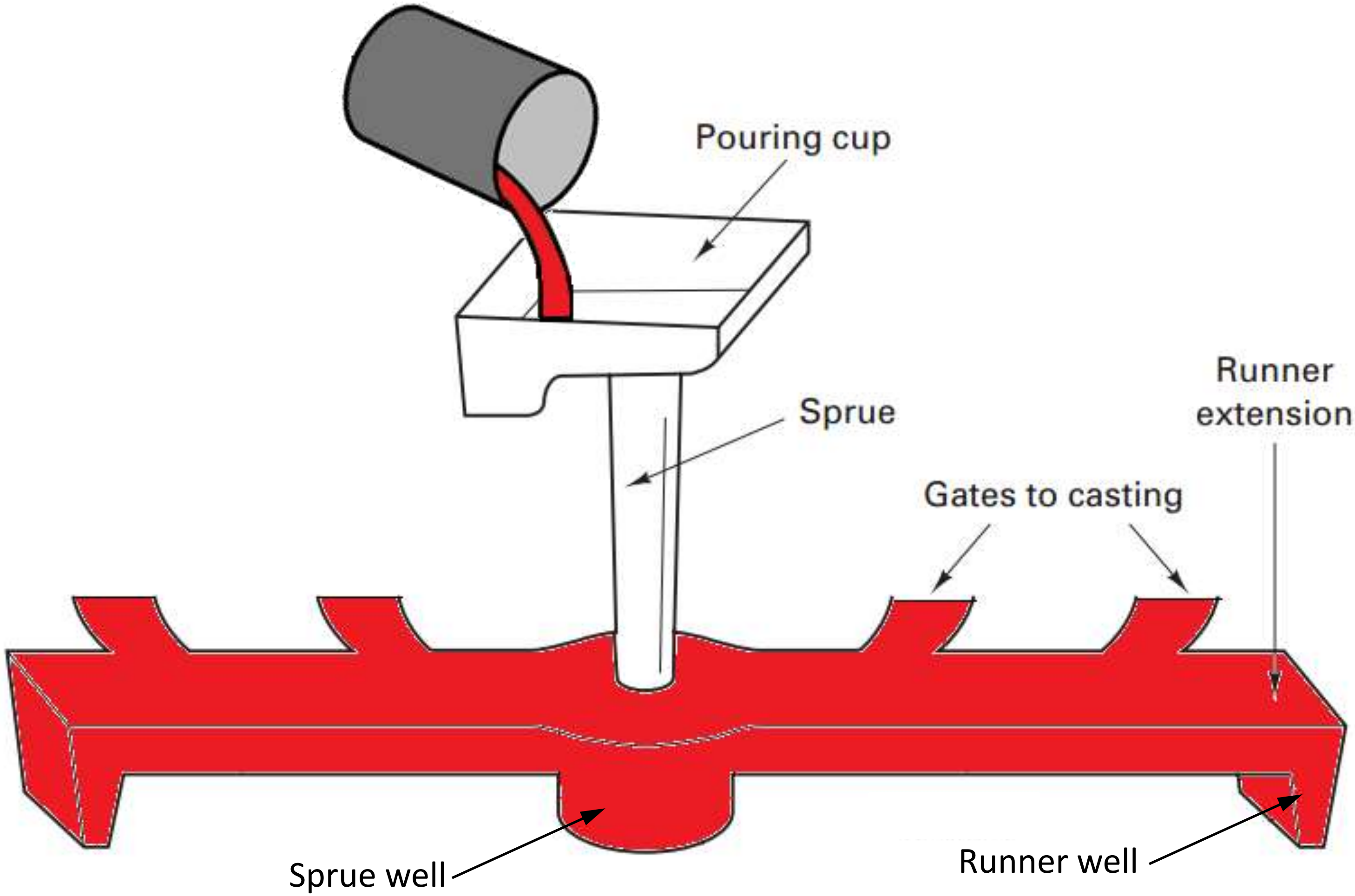
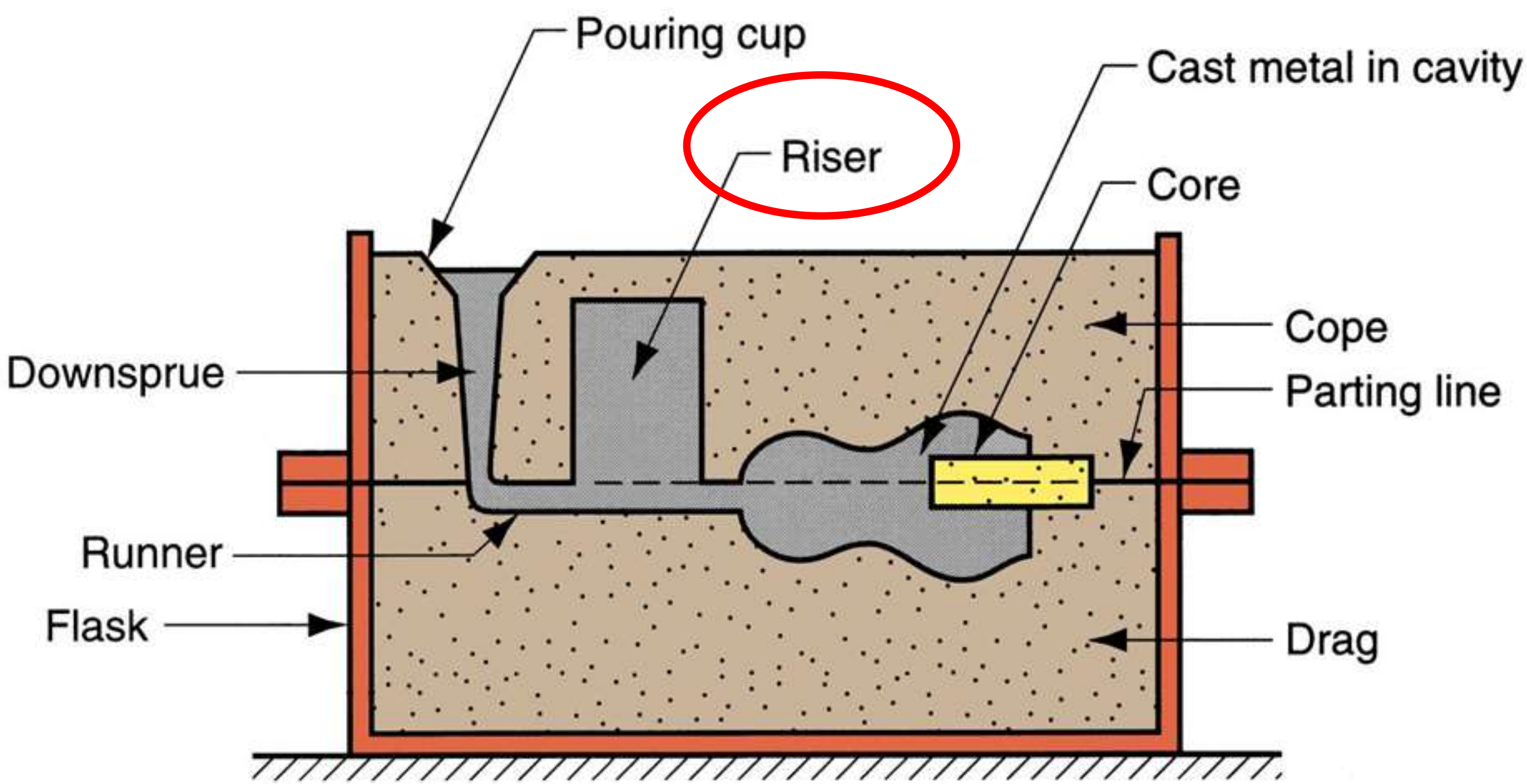

Pouring cup
Sprue
Runner
extension
Gates to casting
Sprue well
Runner well

Riser

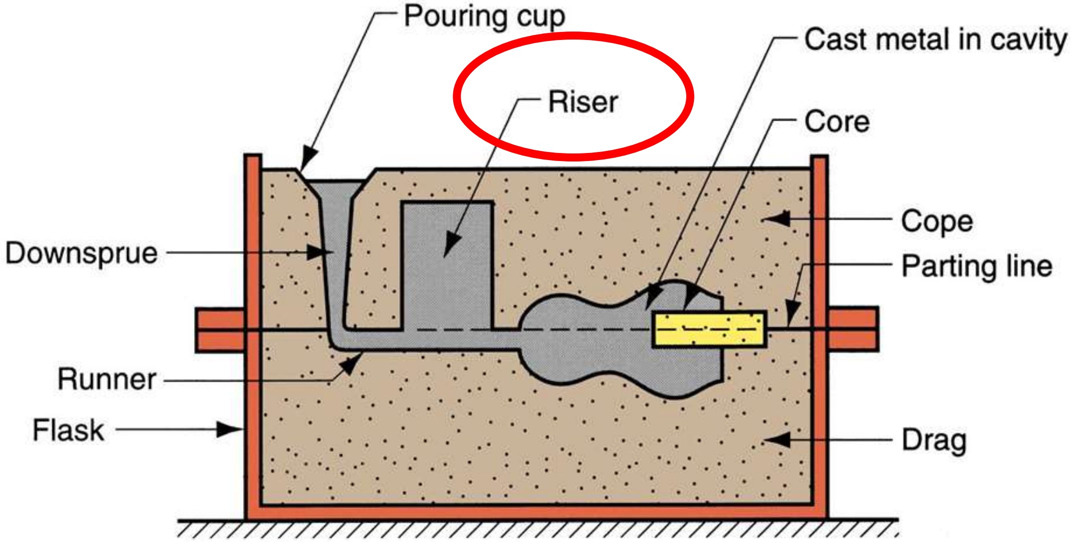
- A ***Riser*** is an additional void in the mold that also fills with molten metal.



Riser

- ***Riser*** is a ***reservoir*** of additional molten metal that can flow into the mold to ***compensate*** for ***shrinkage*** of the part ***during solidification .***

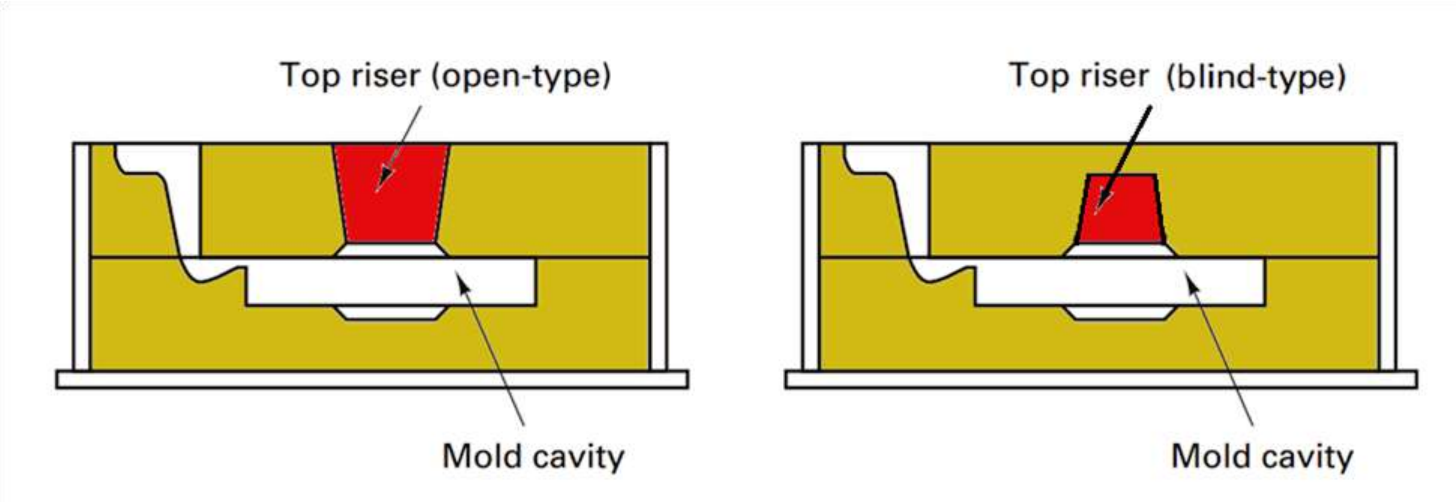
- The ***riser must*** be designed to ***freeze after*** the main ***casting*** in order to satisfy its function i.e. it should have a **larger volume-to-area ratio** so that the main casting solidifies first.



Riser

- ***Dead (or cold)*** ***risers*** fill with metal which already flowed through the mold cavity.
- As shown in Figure, ***top risers*** are almost always dead risers.

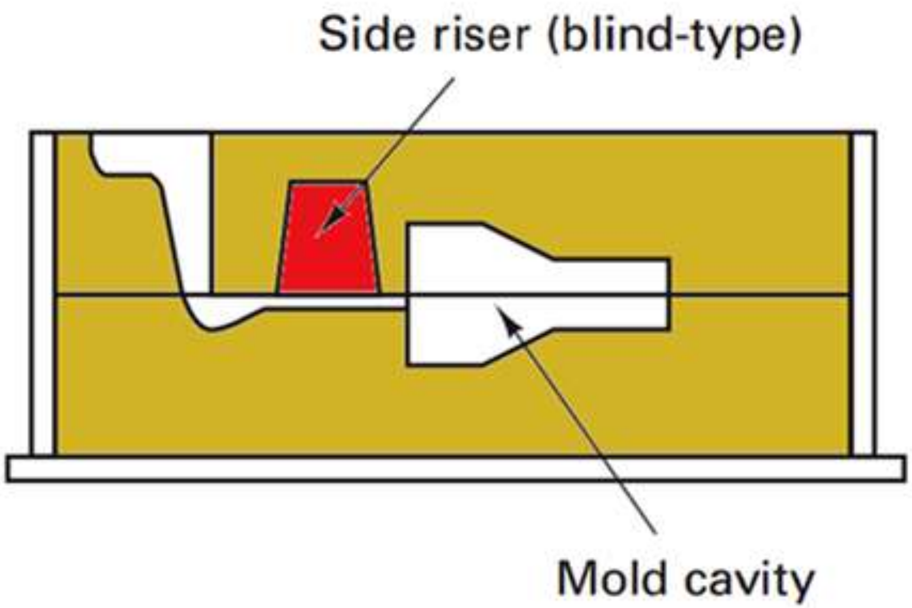
Dead Riser



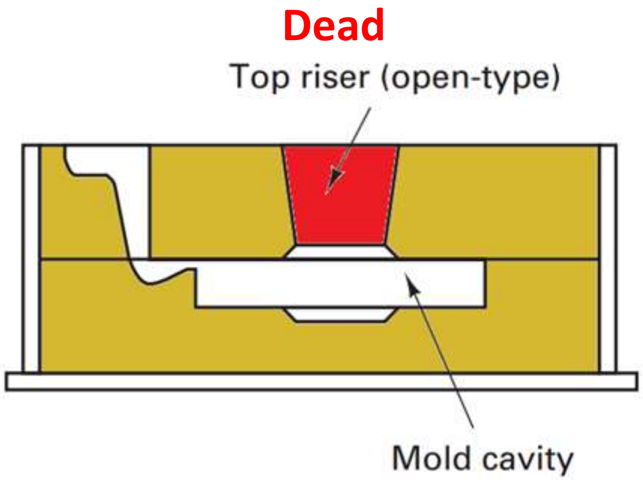
Riser

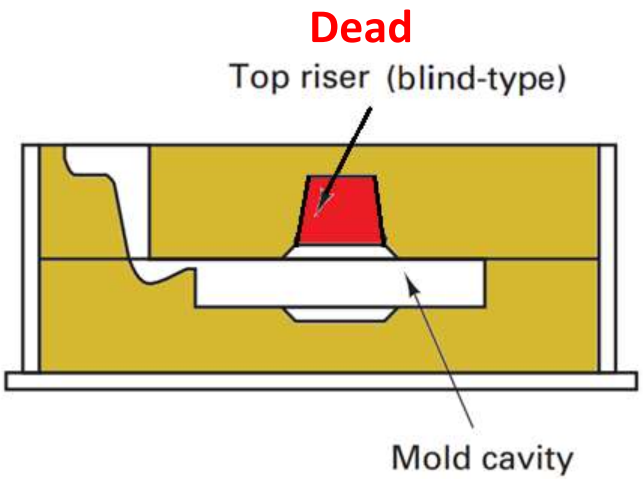
- ***Live risers*** (also known as ***hot risers***) receive the last hot metal that enters the mold.
- Risers that are part of the gating system generally ***live risers***.

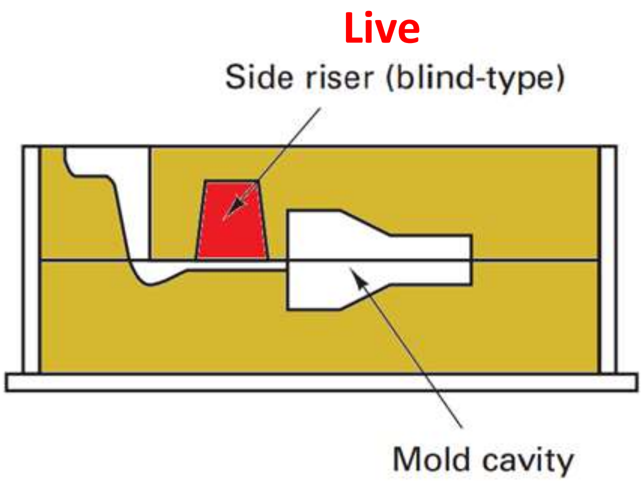
Live Riser



Riser


Dead
Top riser (open-type)
Mold cavity


Dead
Top riser (blind-type)
Mold cavity


Live
Side riser (blind-type)
Mold cavity

Riser Location

- A riser should be located in such a way that directional solidification is obtained.

- Since the heaviest section of the casting solidifies last, the riser should be located to feed this section.

- The heaviest section will now act as a riser for other sections which are not so heavy or thick.

- For small castings, a single riser can feed the entire casting, but more than one riser is required for large castings.

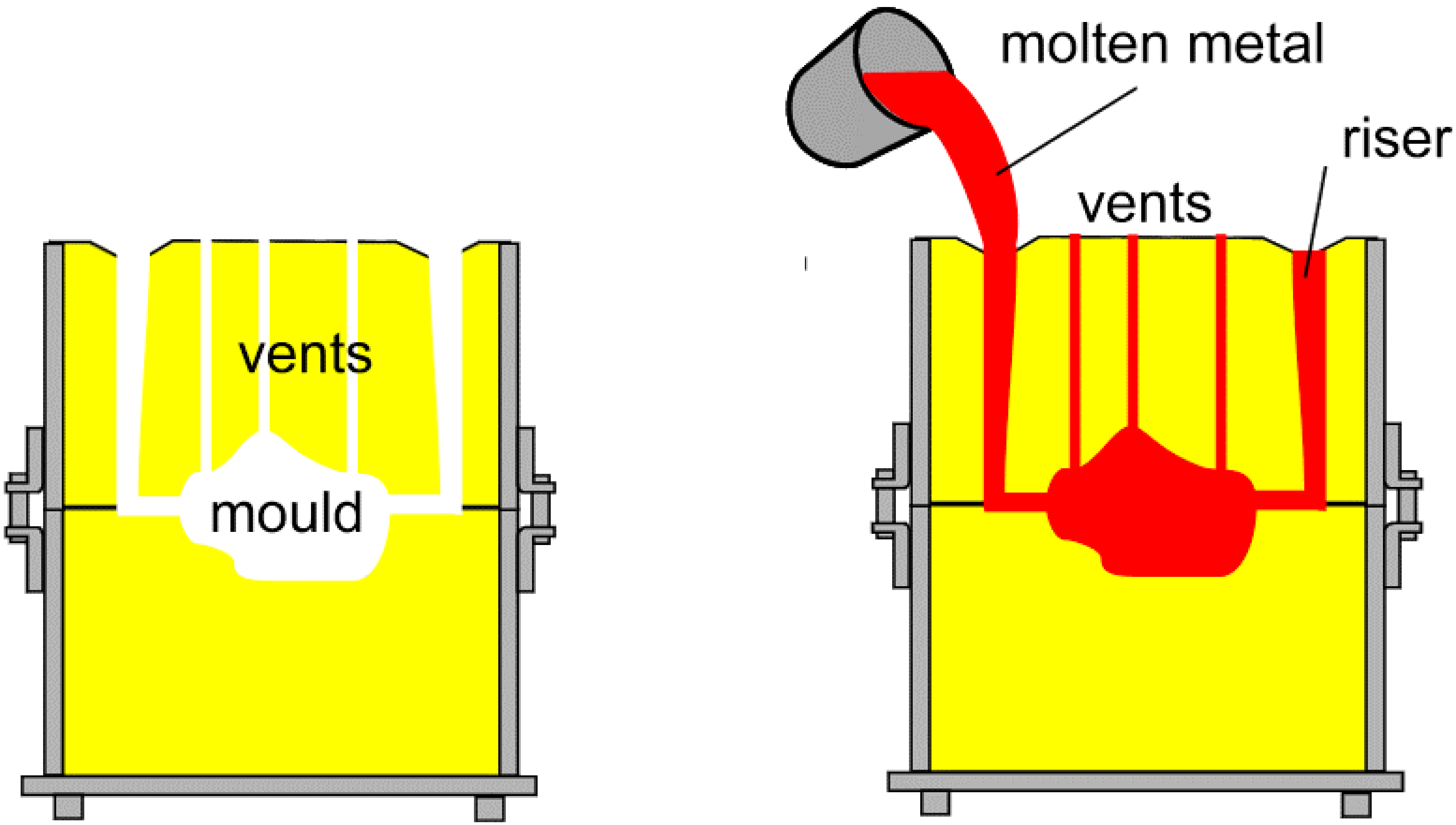
Riser Location

- The number of risers and their locations depend on the casting configuration.
- The risers are generally located at a short distance from the casting since they are ultimate separated from the final casting.
- The connecting channel between the casting and the riser should be large enough (Diameter) to ensure that this link does not freeze before the casting.

Vent holes

- As the metal flows into the mould, the air that previously occupied the cavity, as well as hot gases formed by reactions of the molten metal, must be evacuated so that the metal will completely fill the empty space.
- In sand casting, for example, the natural porosity of the sand mould permits the air and gases to escape through the walls of the cavity.
- In permanent-metal mould, small vent holes are drilled into the mould or machined into the parting line to permit removal of air and gases.

Vent holes



*https://www.the-warren.org/GCSERevision/engineering/casting.htm

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Manufacturing Processes
UTA026

CORE & CHAPLETS
Lecture - 20

Core

- ***A core*** is a full scale model (sand or metal) that is inserted into a mold to produce the internal features of a casting, such as holes or passages for water cooling.
- ***Cores*** are produced in wood, metal, or plastic tooling, known as ***core boxes.***
- A ***core print*** is a feature that is added to a pattern, core, or mold and is used to locate and support a core within the mold.

Core

- The ***mold*** cavity provides the ***external surfaces*** of the cast part
- In addition, a casting may have ***internal surfaces***, determined by a ***core***, ***placed inside*** the ***mold*** cavity to define the ***interior geometry*** of part
- Cores are Generally Made of the Sand and are Even Used in Permanent molds.

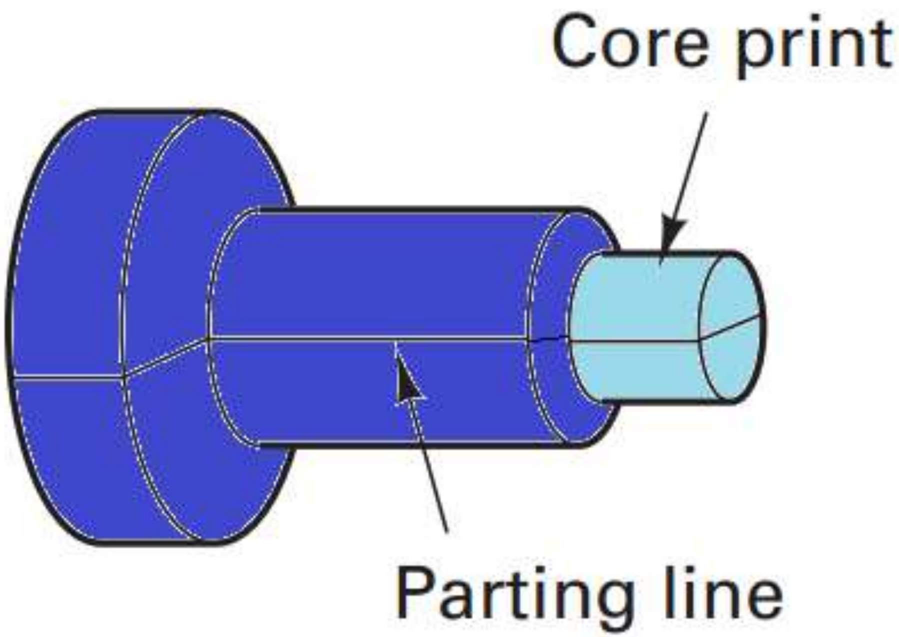
Core Print

- The part of a foundry pattern which makes an opening in a mold to receive a core and to support it while the metal is being poured is called ***core print***.

- Core prints are provided so that the cores are ***securely*** and ***correctly positioned*** in the mold cavity.

- Design of core prints takes care of the ***weight*** of the core before pouring and the upward ***metallostatic*** pressure of the melt after pouring.

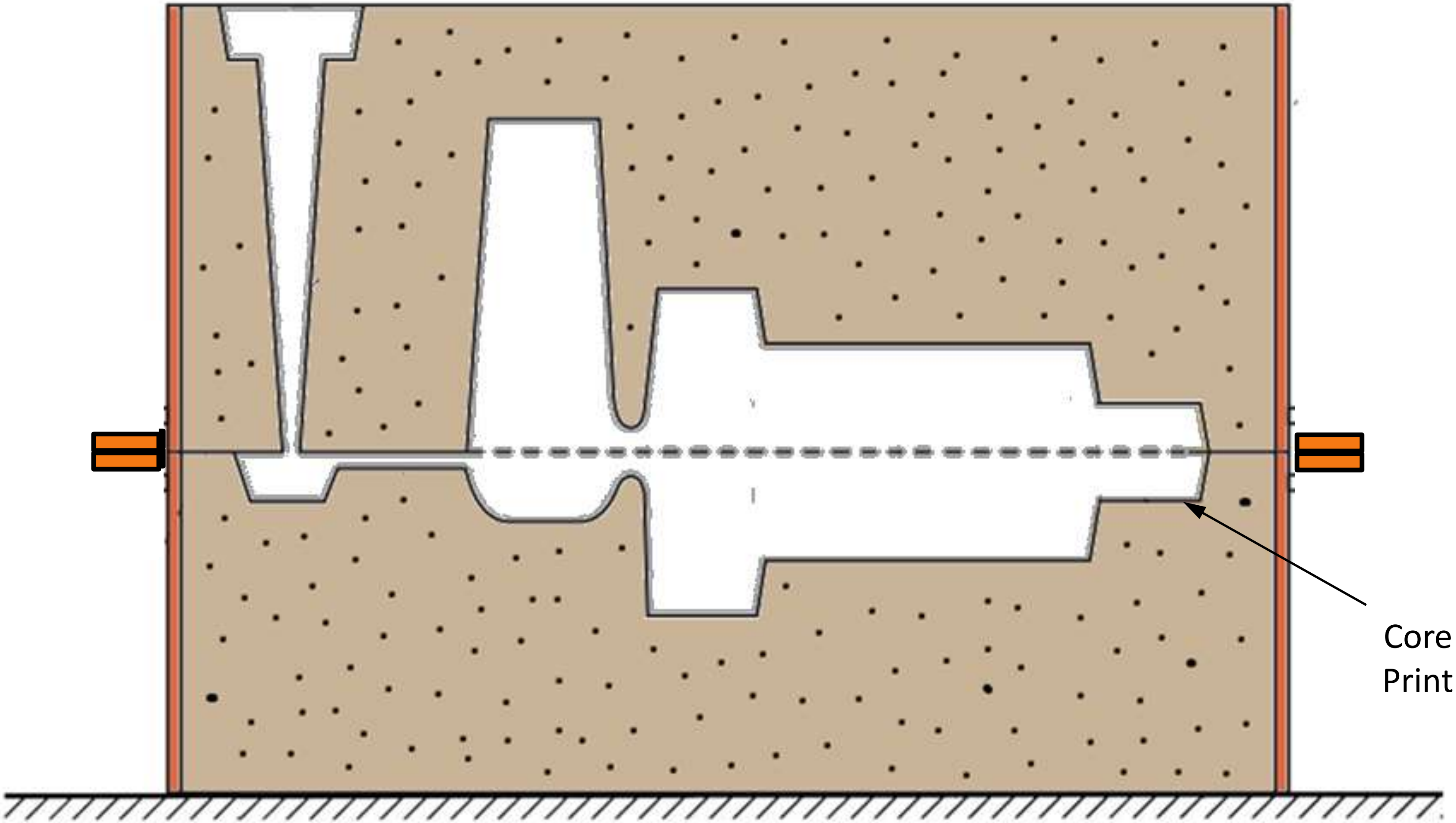
Use of a Core in the Mold Cavity



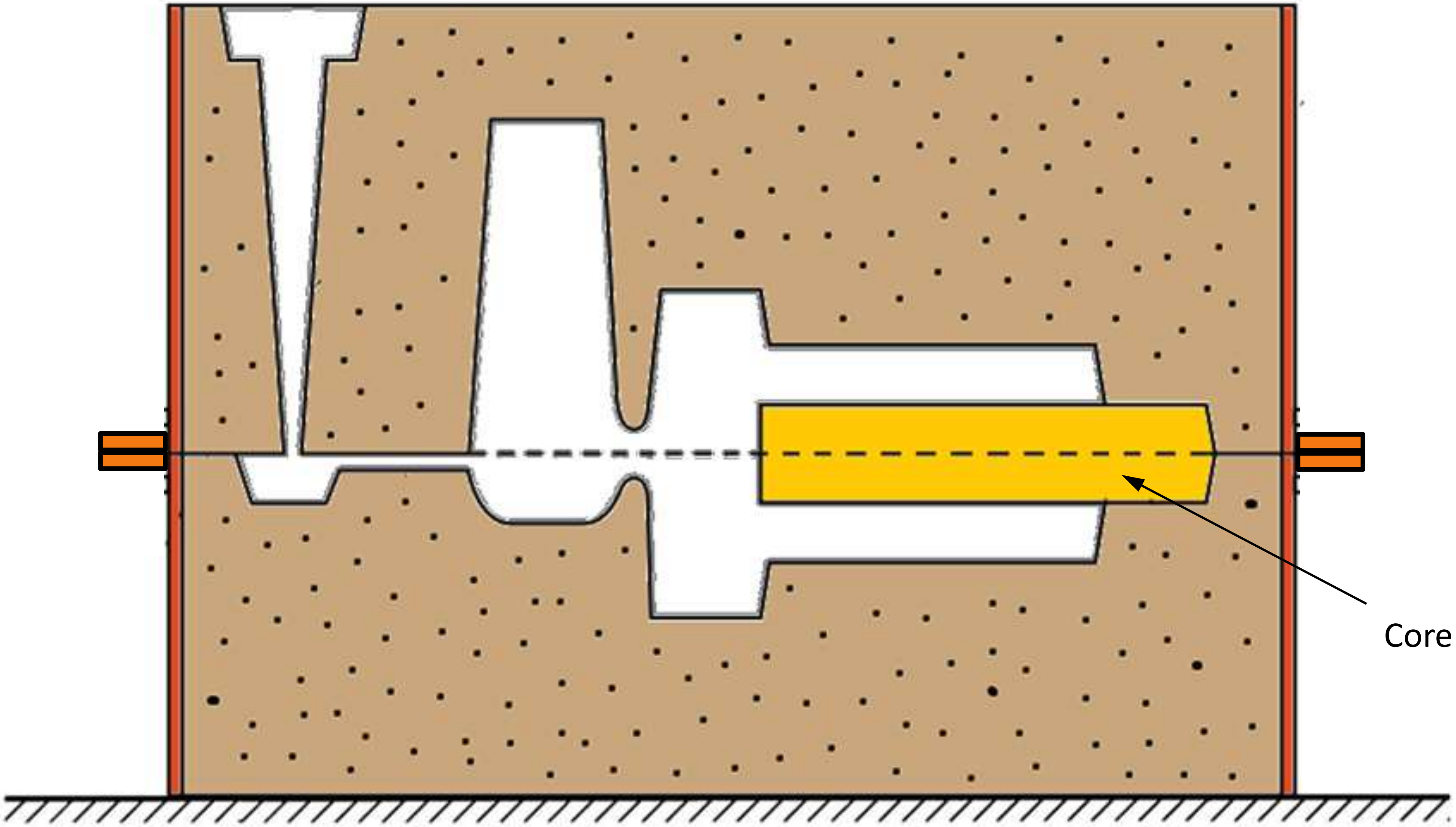
Split Pattern with a Core Print

Core

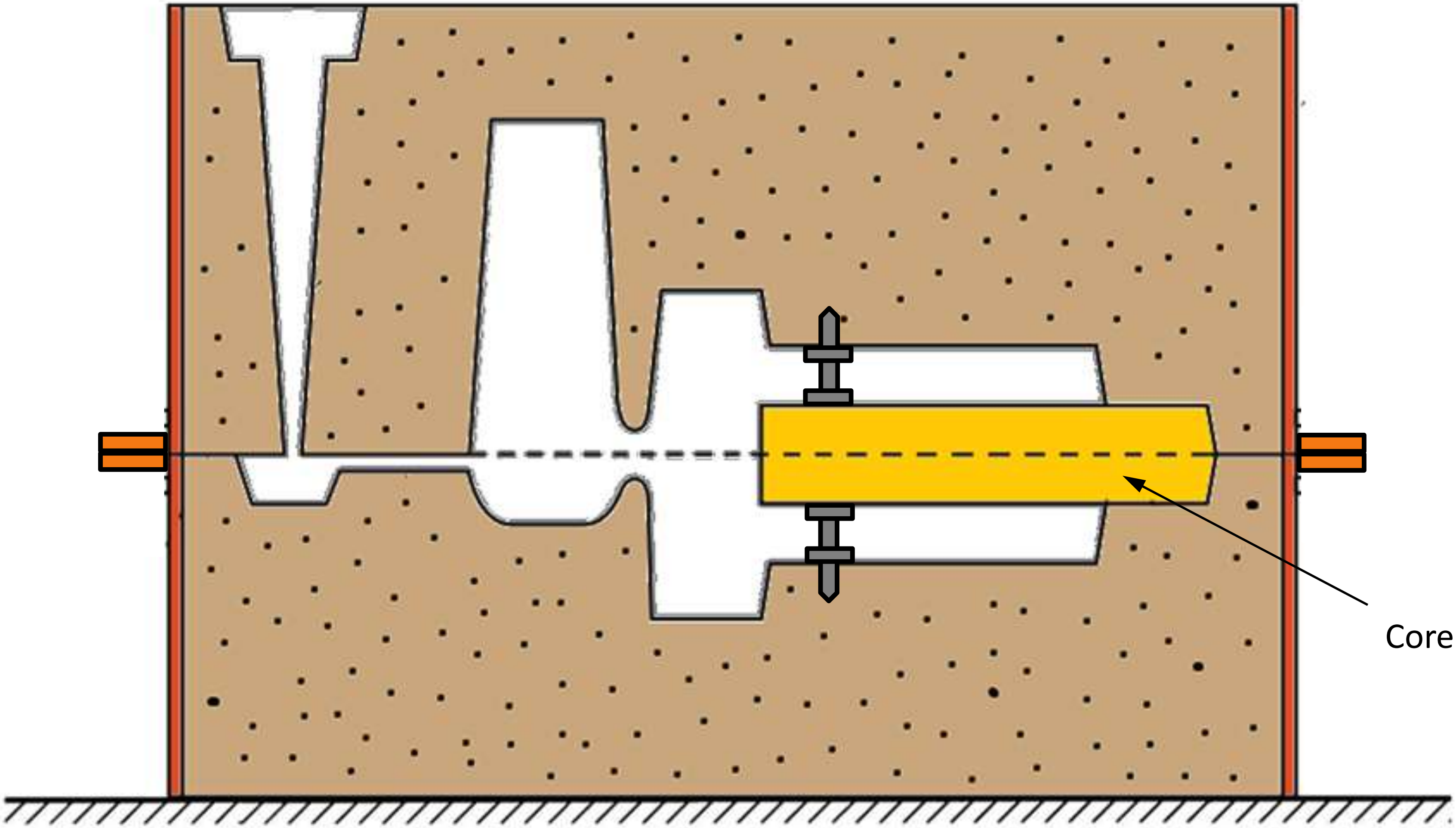
Core Print in Mold Cavity



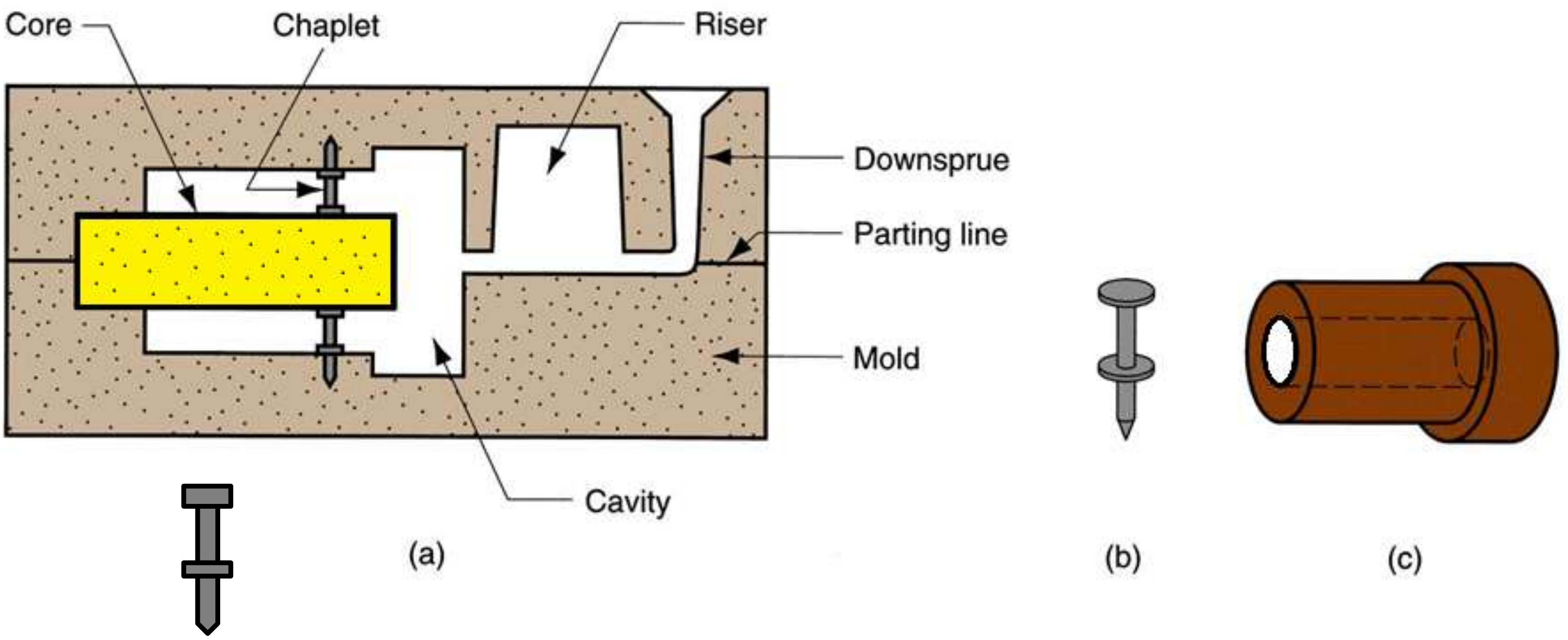
Core in Mold Cavity



Chaplets



Chaplets



(a) Core held in place in the mold cavity by chaplets, (b) possible chaplet design, (c) casting with internal cavity.

Chaplets

- ***Chaplets*** are the supports provided to hold the core in its position in the mold cavity during pouring.
- Because the chaplets are positioned within the mold cavity, they ***become an integral part of the finished casting.***
- Chaplets should therefore be of the ***same***, or at least comparable, ***composition*** as the material being poured.

Chaplets

- They should be ***large enough*** that they do not completely melt and permit the core to move, ***but small enough*** that their ***surface melts*** and ***fuses*** with the ***metal being cast***.
- Since chaplets are one more source of possible defects and may become a location of weakness in the finished casting, efforts are generally made to minimize their use.

Desirable properties of cores

- ***Sufficient strength and hardness***. Strength could be of two types:
  - Green strength : A core made of green sand should be strong enough to retain the shape till it goes for baking.
  - Dry strength: core should have adequate dry strength so that when the core is placed in the mold, it is able to resist the cast material pressure acting on it.
- ***A smooth surface***. Surface of the core should be smooth so as to provide a good finish to the casting surfaces in contact with the cores.

Desirable properties of cores

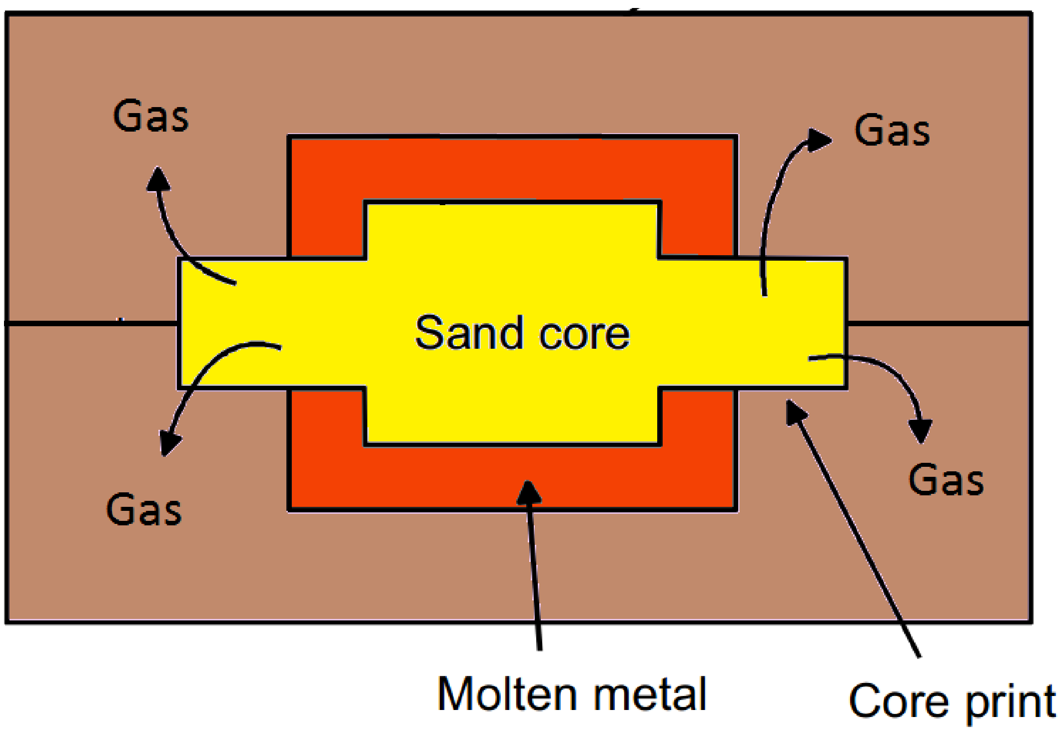
- ***Adequate refractoriness***. Being surrounded by hot metal, cores can become quite a bit hotter than the adjacent mold material. They should not melt or adhere to the casting.
- ***Collapsibility***. As the casting cools, it shrinks, and so the core should have good collapsibility (ability to decrease in size).Lack of collapsibility may provide resistance against shrinkage and can cause the casting defect of hot tears.

Desirable properties of cores

- ***Low gas emission***: because the cores are subjected to very high temperature, the evolution of gases from the inside are very high at that temperature. These gases are otherwise likely to produce gas inclusion defects. So the cores should be made such that the evolution of gases is minimum.

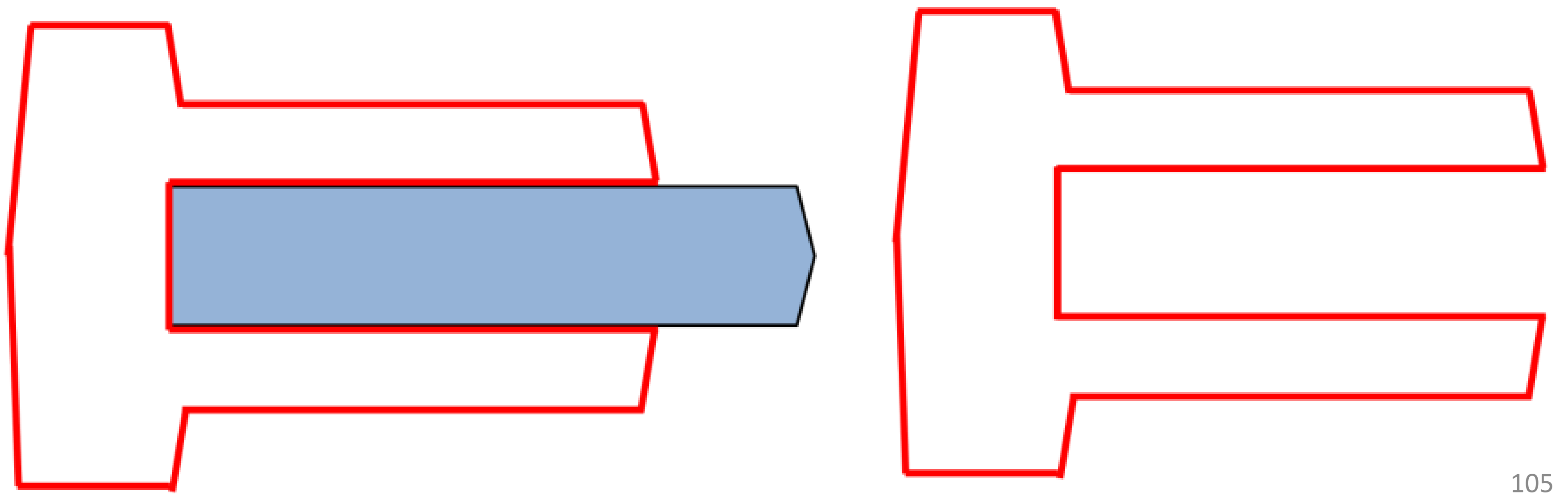
Desirable properties of cores

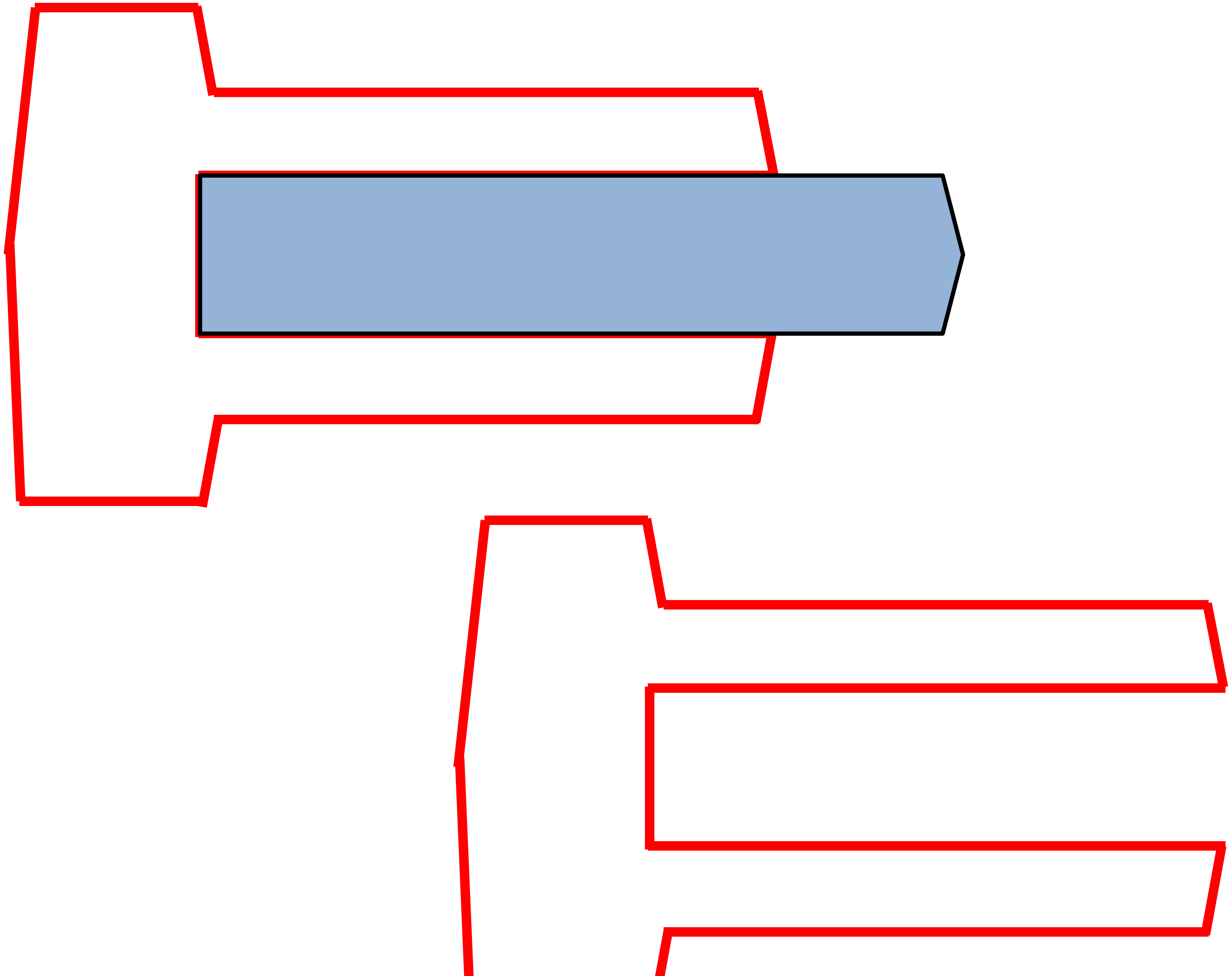
- ***Adequate permeability*** to permit the escape of gas. Since cores are largely surrounded by molten metal, the gases must escape through the core.



Desirable properties of cores

- ***Friability*** (ability to crumble): after the casting is completely cooled, the core should be removed from the casting before it is processed further. Hence the friability is also an important consideration.





Pouring and Solidifications

Pouring the Metal

- After heating, the metal is ready for pouring.
- For this step to be successful, metal must flow into all regions of the mold, most importantly the main cavity, before solidifying.
- Factors affecting the pouring operation include

  a) Pouring temperature

  b) Pouring rate

  c) Turbulence

Pouring temperature

- The ***pouring temperature*** is the temperature of the molten metal as it is introduced into the mold.
- What is ***important*** here is the ***difference*** between the temperature at pouring and the temperature at which freezing begins (Melting point).
- This temperature difference is sometimes referred to as the ***superheat***.
- This term is also used for the ***amount of heat*** that ***must be removed*** from the molten metal between pouring and when solidification commences

Pouring Rate

- Pouring rate refers to the ***volumetric rate*** at which the molten metal is poured into the mold.
- If the rate is ***too slow***, the metal will chill and freeze before filling the cavity.
- If the pouring rate is ***excessive***, turbulence can become a serious problem.

Turbulence

- ***Turbulence*** in fluid flow is characterized by erratic variations in the magnitude and direction of the velocity throughout the fluid.
- The flow is agitated and irregular rather than smooth and streamlined, as in laminar flow.
- Turbulent flow ***should be avoided*** during pouring for several reasons.

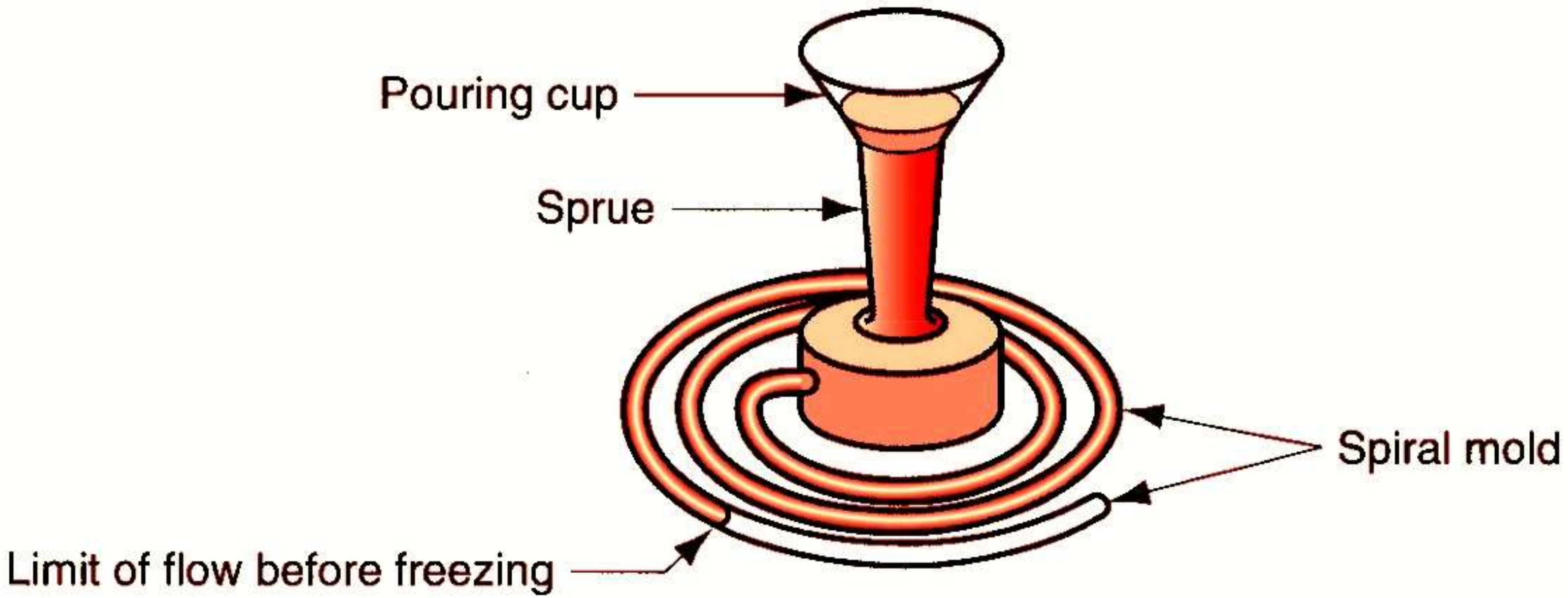
Turbulence

- It tends to accelerate the ***formation of metal oxides*** that can become entrapped during solidification, thus degrading the quality of the casting.
- Turbulent flow tends to promote ***absorption of gases***.
- Turbulence also aggravates ***mold erosion***, the gradual wearing away of the mold surfaces due to impact of the flowing molten metal.

Fluidity

- The molten metal flow characteristics are often described by the term fluidity, a measure of the capability of a metal to flow into and fill the mold before freezing.
- Fluidity is the inverse of viscosity; as viscosity increases, fluidity decreases.
- Standard testing methods are available to assess fluidity, including the spiral mold test shown in Figure .

Fluidity



- Fluidity is indicated by the length of the solidified metal in the spiral channel

- A longer cast spiral means greater fluidity of the molten metal

Solidification of Metals

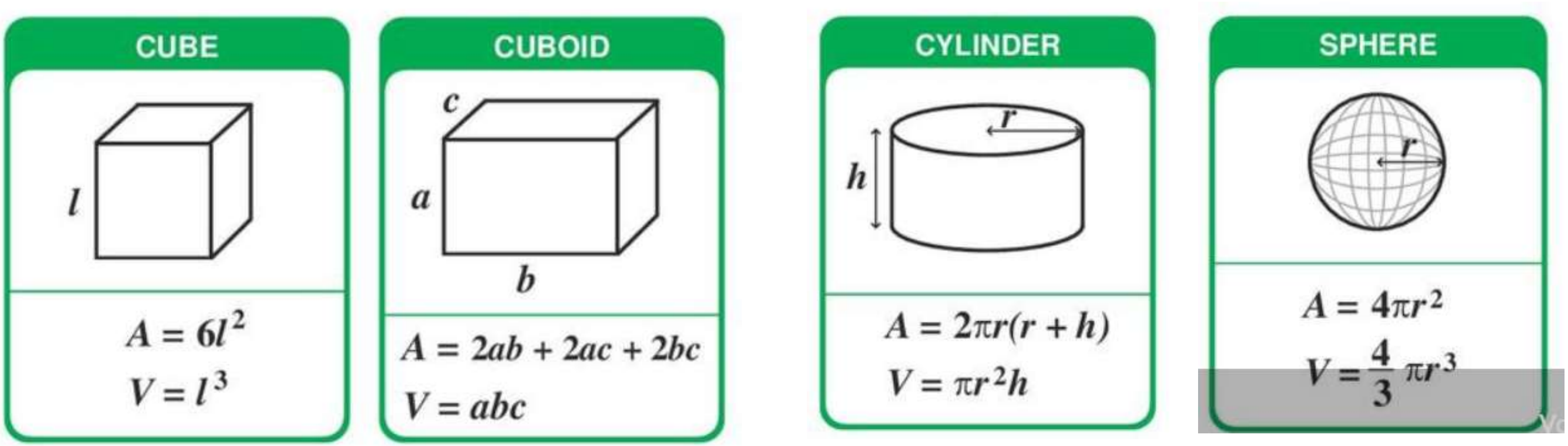
- Transformation of molten metal into solid state
- Solidification differs depending on whether the metal is
  - A pure element or
  - An alloy
- The total solidification time is the time required for the casting to solidify after pouring.
- This time is dependent on the size and shape of the casting by an empirical relationship known as Chvorinov's rule, which states: the formulae…next page

Solidification of Metals

$$T_{TS} = C_m \left(\frac{V}{A}\right)^n$$

- T_{TS} = total solidification time, minutes
- V = volume of the casting, cm^3
- A = surface area of the casting, cm^2
- n = an exponent usually taken to n=2
- C_m = the ***mold constant***

Solidification of Metals



shape	a	b	c	L	Surface area	volume	V/A
cube	2	2	2	2	24	8	0.33
Cuboid	1	2	3		22	6	0.27
Cylinder	R=1	h=2			18.84	6.28	0.33
Sphere	R=1				12.56	4.18	0.33

Keeping volume of shapes constant : Surface area would be different
Or vice-versa.........Calculate on your own for variations.......

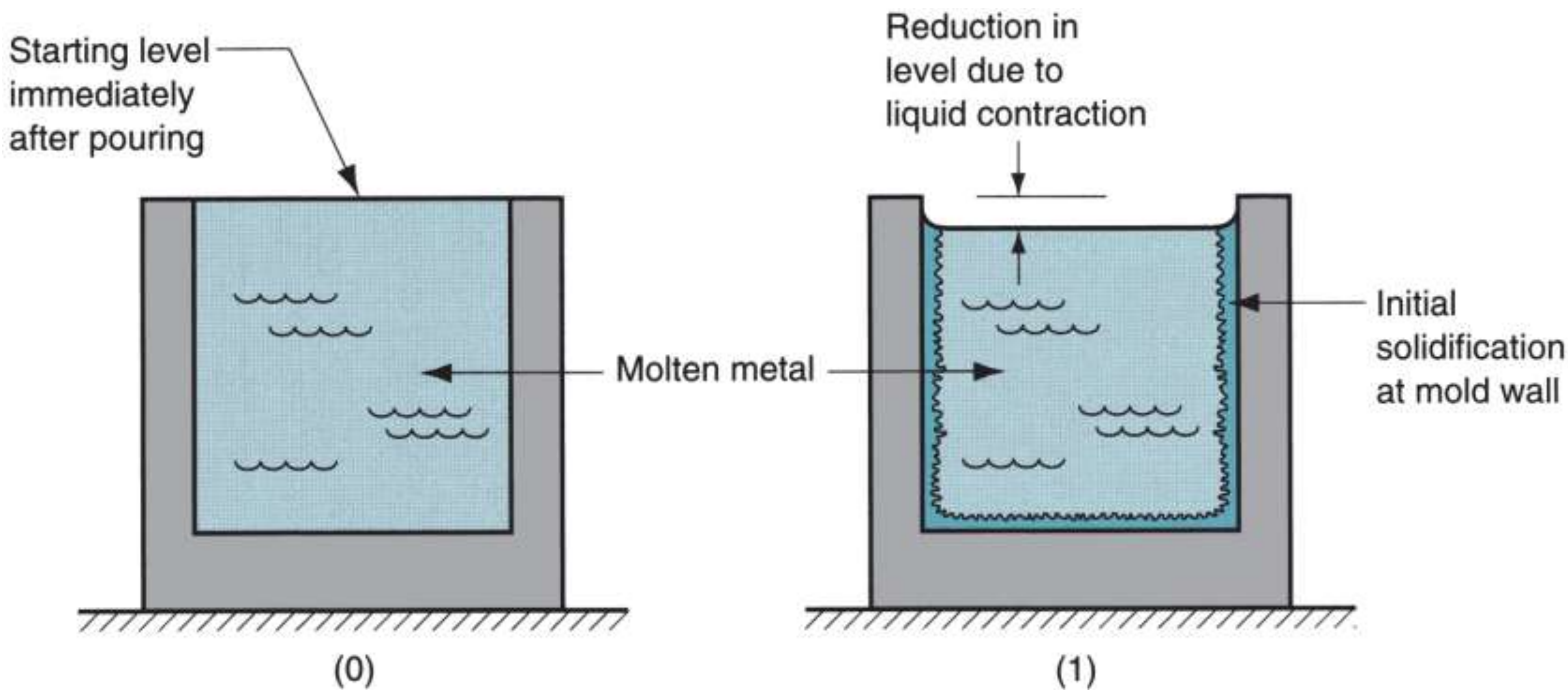
Solidification of Metals

- A casting with a higher ***volume-to-surface area*** ratio cools and solidifies more slowly than one with a lower ratio
- To feed molten metal to main cavity, **Total Solidification Time (TST)** for riser must greater than **TST** for main casting
- **Riser** must be designed to have a **larger volume-to-area ratio** so that the main casting solidifies first
- This **minimizes** the effects of shrinkage

Shrinkage in solidification and Cooling

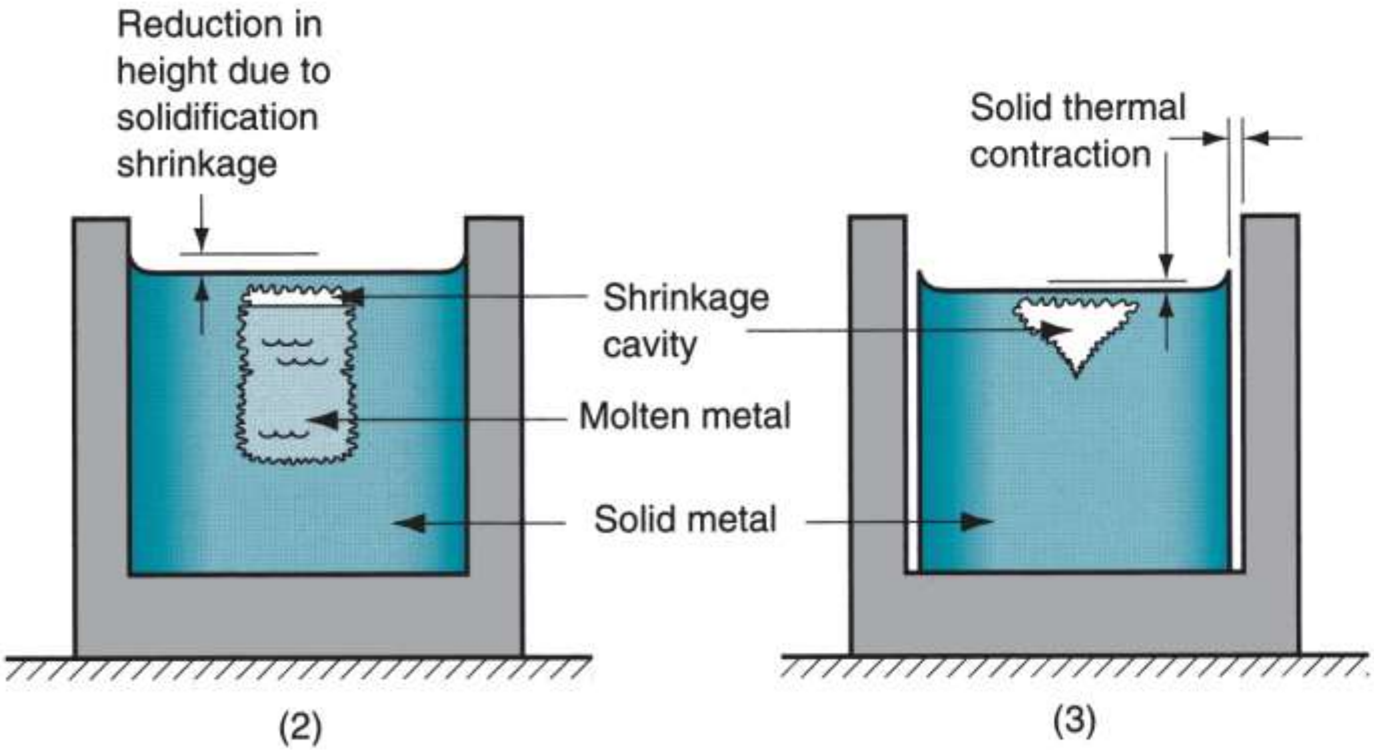
- Shrinkage usually occurs during cooling and freezing.
- Shrinkage occurs in three steps:
  1) liquid contraction during cooling prior to solidification;
  2) contraction during the phase change from liquid to solid, called solidification shrinkage; and
  3) thermal contraction of the solidified casting during cooling to room temperature.

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).

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

- Solidification shrinkage occurs in nearly all metals because the solid phase has a higher density than the liquid phase.
- The ***exception is cast iron containing high carbon content***, whose solidification during the final stages of freezing is complicated by a period of graphitization, which results in ***expansion*** that tends to counteract the volumetric decrease associated with the phase change.

A metallurgical change in the microstructure of joints in carbon and certain low-alloy steels subjected to long term service in the temperature range of 450 to 600°C . . Graphitization is a breakdown of carbides in the steel to small patches of graphite and Iron caused by heat.

Compensation for Solidification Shrinkage

- Compensation for solidification shrinkage is achieved in several ways depending on the casting operation.
- In ***sand casting***, liquid metal is supplied to the cavity by means of ***risers*** .
- In ***die casting***, the molten metal is applied under ***pressure***.

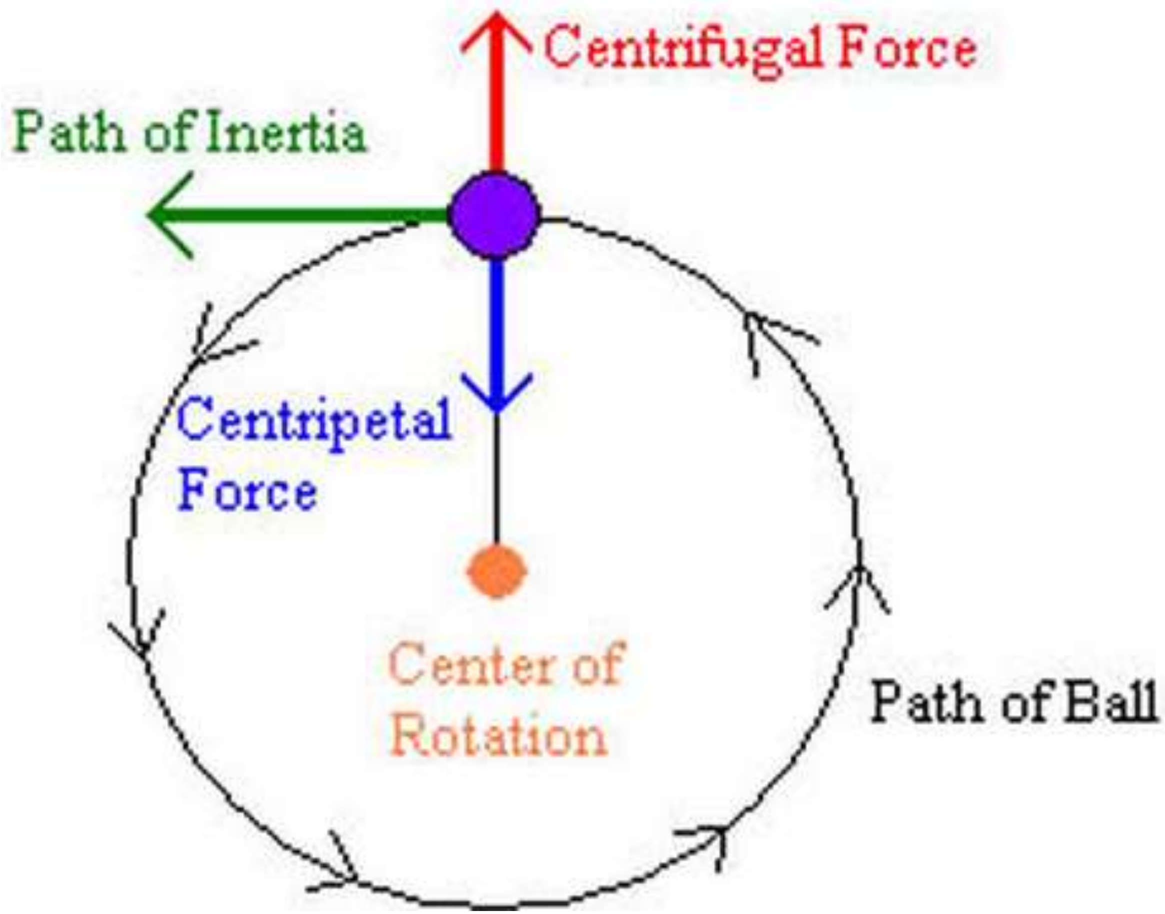
Shrinkage Allowance

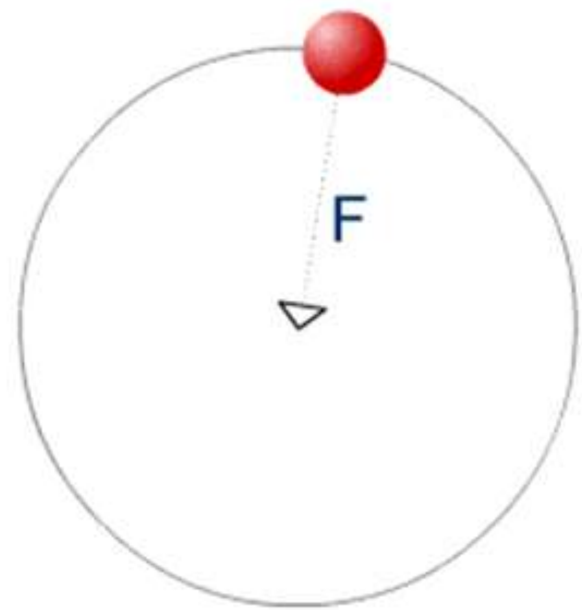
- Patternmakers account for solidification shrinkage and thermal contraction by making ***mold cavity oversized***
- ***Amount*** by which mold is ***made larger relative to final casting*** size is called ***pattern shrinkage allowance***
- Casting dimensions are expressed linearly, so allowances are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

MANUFACTURING PROCESSES

Centrifugal & Die Casting

Concept of centrifugal force





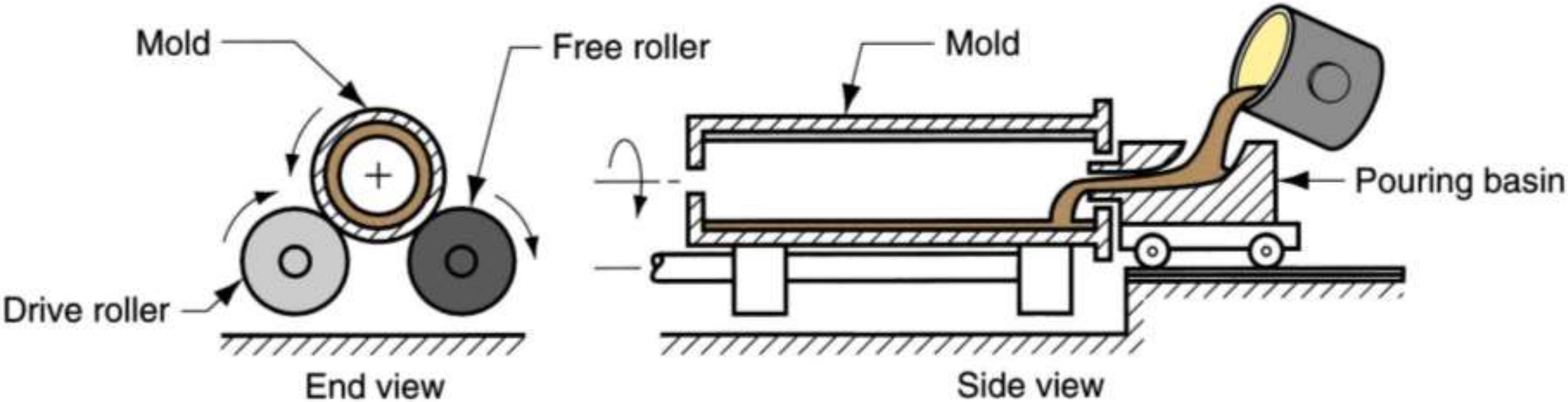
Centrifugal Casting

- As its name implies, the ***centrifugal-casting*** process utilizes inertial forces to distribute the molten metal into the mould cavities.
- In this process, the mould is ***rotated*** rapidly about its central axis as the metal is poured into it.
- Because of the ***centrifugal force***, a ***continuous pressure*** will be acting on the metal as it solidifies.

Centrifugal Casting

- The ***slag, oxides*** and other ***impurities*** being lighter, get separated from the metal and segregate ***towards the center***.
- Spinning equipment can be expensive.
- There are ***three types*** of centrifugal casting:
  1. ***<u>True centrifugal casting,</u>***
  2. ***<u>Semi-centrifugal casting,</u>***
  3. ***<u>Centrifuging.</u>***

1. True Centrifugal Casting



Source: Centrifugal Casting of Ductile Iron Pipe (https://www.youtube.com/watch?v=3G2sBqXkRT8)

1. True Centrifugal Casting

- In true centrifugal casting, ***hollow cylindrical parts***(such as pipes, gun barrels, bushings, engine-cylinder liners, bearing rings with or without flanges, and street lampposts) are produced by the technique shown in Fig.
- In this process, molten metal is poured into a rotating mould (300 to 3000 rpm).
- The axis of rotation is usually horizontal, but can be vertical for short workpieces.

1. True Centrifugal Casting

- ***Moulds*** are made of steel, iron, or graphite and may be ***coated with a refractory lining*** to increase mould life.
- ***The exterior profile*** is usually round (as with gun barrels, pipes, and tubes), but hexagons and other symmetrical shapes are also possible.
- ***The inner surface*** of the casting remains cylindrical, because the molten metal is distributed uniformly by the centrifugal forces, ***therefore no core is required.***

1. True Centrifugal Casting

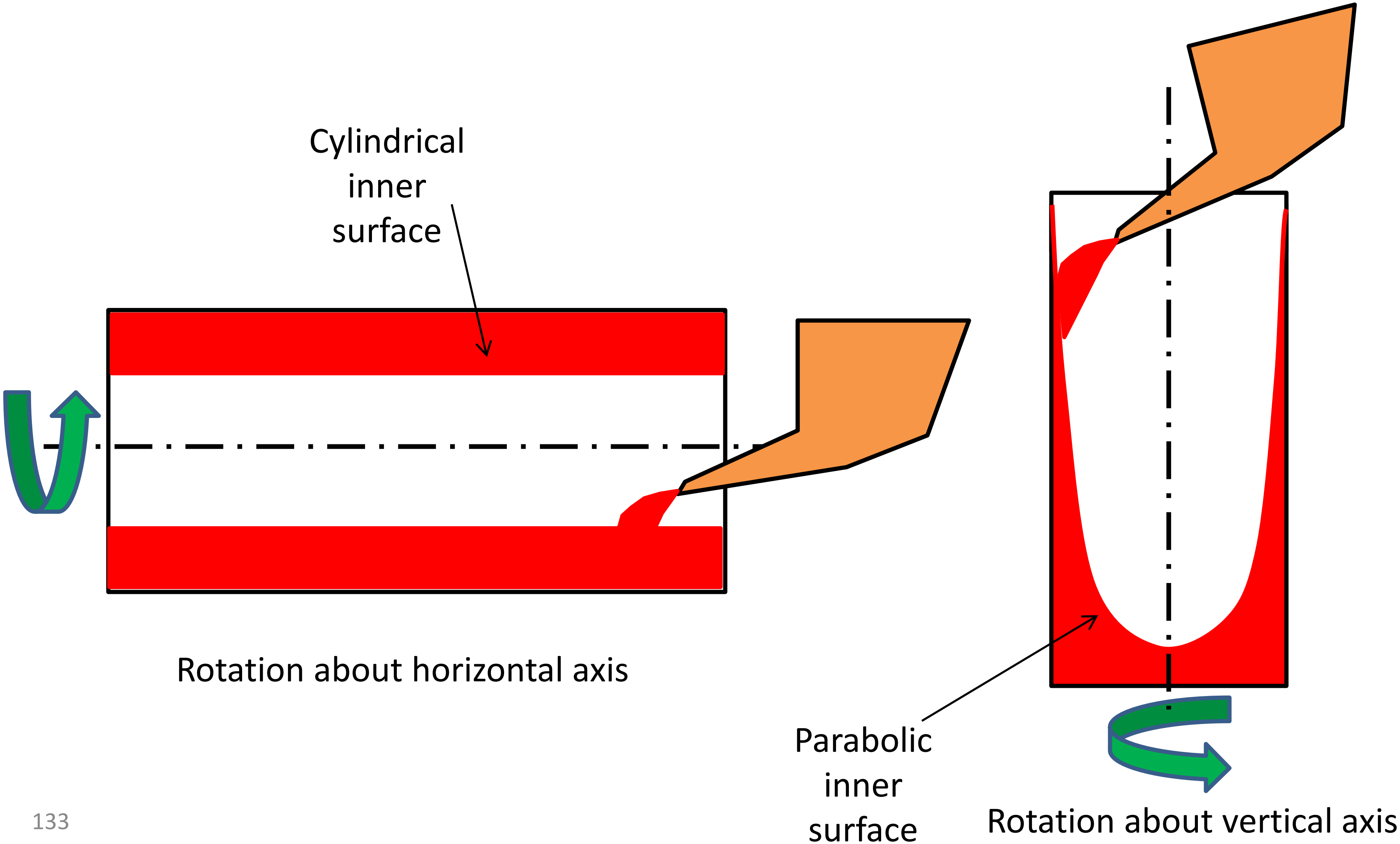
- However, because of density differences, ***lighter elements*** (such as dross, ***impurities***) tend to collect on the ***inner surface of the casting***.

Source: Vertical and Horizontal centrifugal casting processes at UNI Abex, Dharwad plant,India.(https://www.youtube.com/watch?v=7goyNtA5UCo)

1. True Centrifugal Casting

- When rotation is about the ***horizontal*** axis, the inner surface is always cylindrical.
- If the mould is oriented ***vertically,*** gravitational forces cause the inner surface to become ***parabolic***.
- ***Wall thickness*** can be controlled by varying the amount of metal that is introduced into the mould.

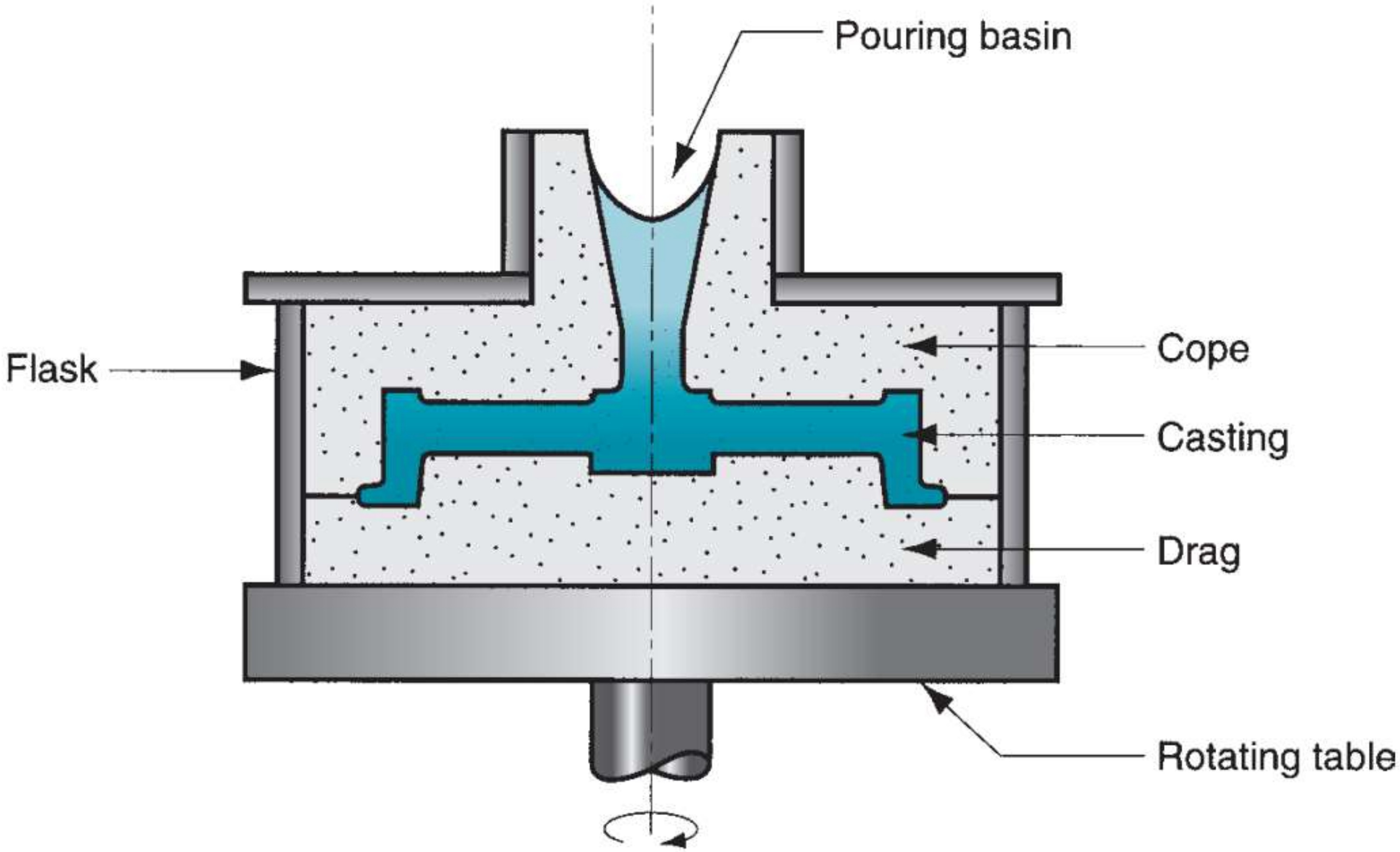
1. True Centrifugal Casting



1. True Centrifugal Casting

- During the rotation, the metal is forced against the outer walls of the mould with considerable force, and ***solidification begins at the outer surface.***
- Centrifugal force continues to feed molten metal as solidification progresses inward.
- Since the process compensates for shrinkage, ***no risers are required.***
- ***Bi-metal castings are possible***, example: create a hard outer layer and ductile inner layer

2. Semi-Centrifugal Casting



2. Semi-Centrifugal Casting

2. Semi-Centrifugal Casting

- This method is used to cast parts with ***rotational symmetry, such as a wheel with spokes.***
- In this method, centrifugal force is used to produce ***solid castings***, rather than tubular parts.
- The moulds are designed with ***risers at the center*** to supply feed metal.

2. Semi-Centrifugal Casting

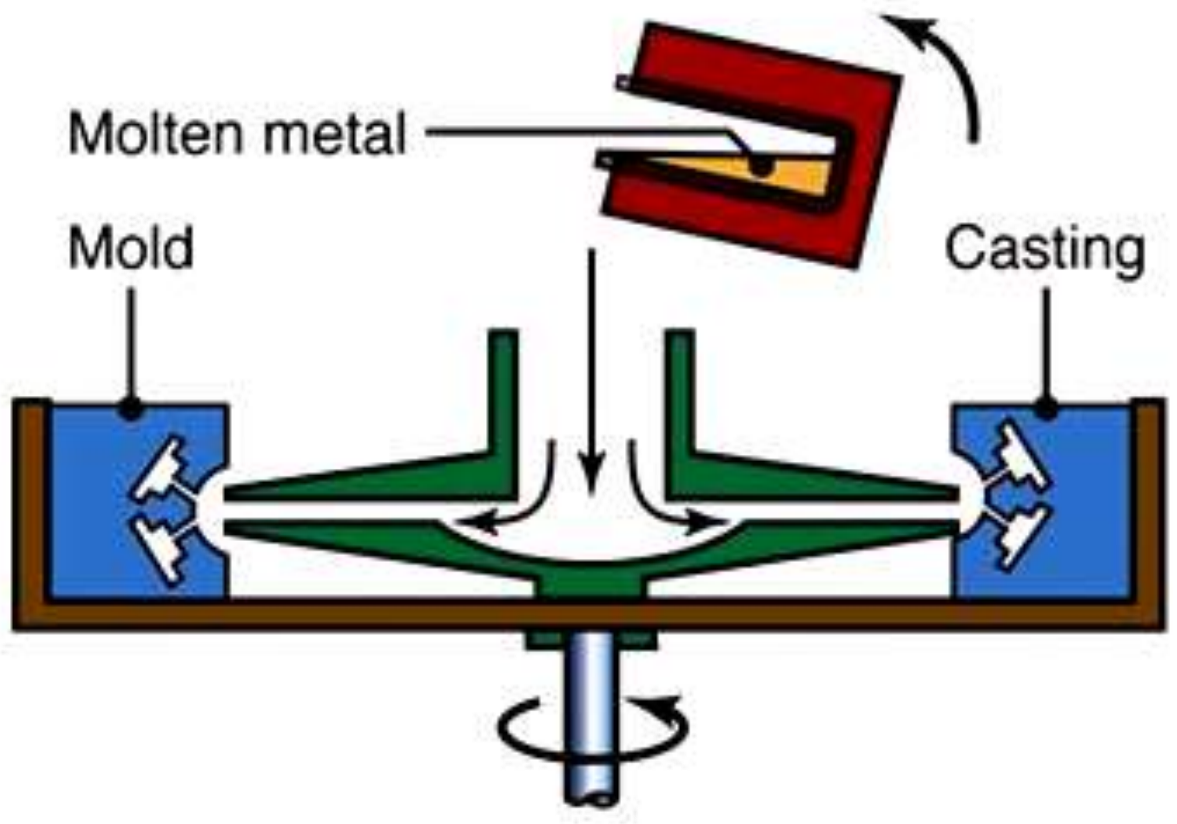
- The rotational ***speeds*** are usually ***lower*** than for true centrifugal casting.
- In general, the ***mould shape is more complex*** than for true centrifugal casting, and cores can be placed in the mould to further increase the complexity of the product.
- ***Density*** of metal in the final casting is ***greater in the outer sections*** than at the center of rotation.

2. Semi-Centrifugal Casting

- ***Common products*** include gear blanks, pulley sheaves, wheels, impellers, and electric motor rotors.

https://divineindia.co.in/images/pump/pump-impeller.jpg

3. Centrifuging Casting



3. Centrifuging Casting

- In centrifuging (also called centrifuge casting), mould cavities of ***any shape*** are placed at a ***certain distance*** from the ***axis*** of rotation.
- Moulds are located radially about a central sprue or riser, which acts as the axis of rotation.
- The molten metal is poured from the center.
- ***Centrifugal force*** provides the ***pressure*** that ensures complete ***filling*** of the mould cavities.

3. Centrifuging Casting

- Relatively low rotational speeds are required to produce sound castings with ***thin walls and intricate shapes.***
- Centrifuging is often used to assist in the pouring of ***multiple-product investment casting trees***.

MANUFACTURING PROCESSES

Die Casting

Permanent-Mould/ Gravity Die Casting

- ***Permanent-mould*** casting uses a metal mould constructed of two sections that are designed for easy, precise opening and closing.
- ***Mould*** are made from materials with high resistance to erosion and thermal fatigue, such as cast iron, steel, bronze, graphite, or refractory metal alloys.
- ***Typical parts*** made are auto-mobile pistons, cylinder heads, connecting rods, gear blanks for appliances, and kitchenware.

Parts made by Permanent-Mould Casting






Permanent-Mould Casting

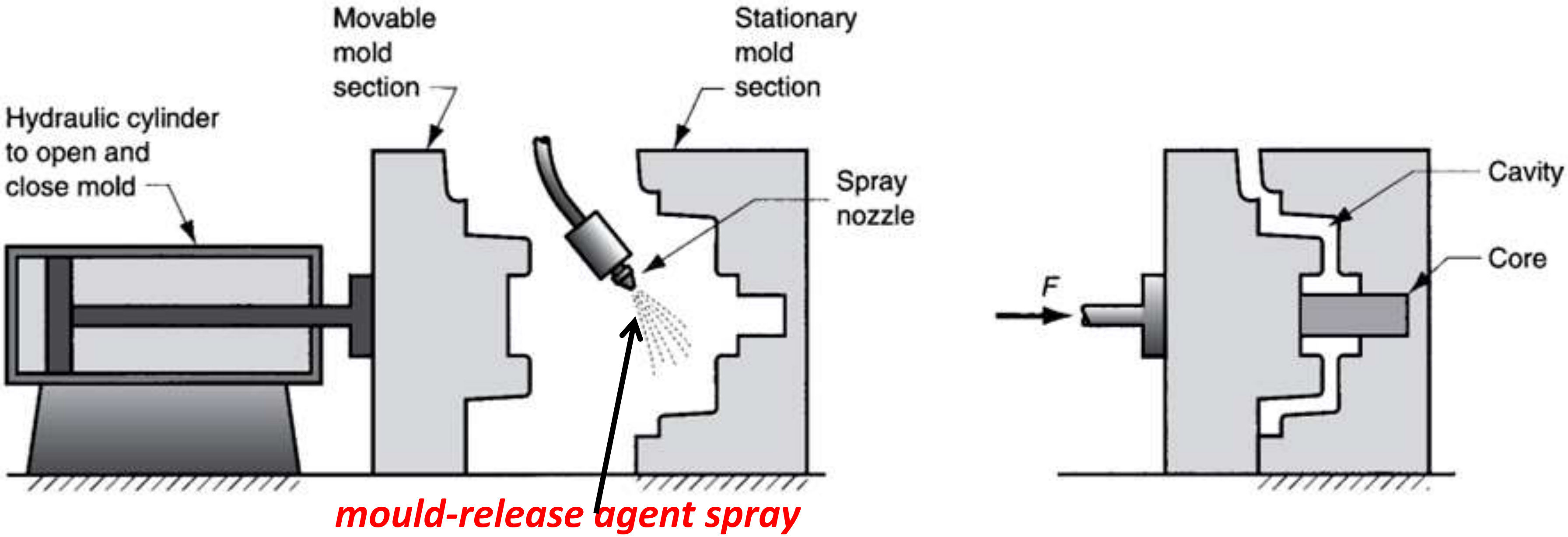
- Parts that can be made economically generally weigh less than 25kg, although special castings weighing a few hundred kilograms have been made using this process.

- ***Metals*** commonly cast in permanent moulds include aluminium, magnesium, copper-base alloys, and cast iron.

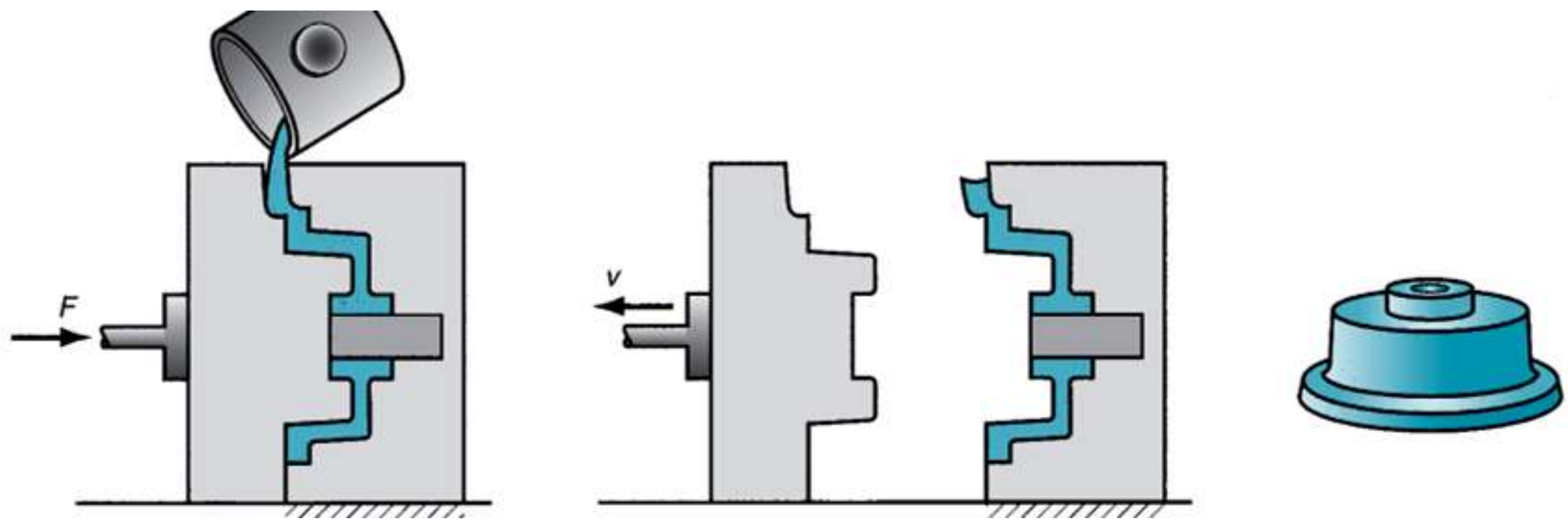
Permanent-Mould Casting

- ***However,*** cast iron requires a high pouring temperature, 1250°C to 1500°C, which takes a heavy toll on mould life.

- The ***very high pouring temperatures*** of ***steel*** make permanent moulds ***unsuitable*** for this metal, unless the mould is made of refractory material.



(1) mould is preheated and coated; (2) cores (if used) are inserted and mould is closed



(3) molten metal is poured into the mould; and (4) mould is opened. Finished part is shown in (5).

Preheating of Mould

- The moulds are ***clamped together*** by mechanical means and ***heated*** to about 150°to 200°C to facilitate metal flow and reduce thermal damage to the dies due to high-temperature gradients.
- Preheating the moulds in permanent-mold casting is advisable in order to ***reduce the chilling*** effect of the metal mold, which could lead to low metal fluidity.
- After preheating, a refractory or ***mould coating*** is applied to the preheated mould, and the mould is clamped shut.

Mould Coating & Vent

- The ***purpose*** of these coatings is to control or direct the cooling, prevent the casting from sticking, and prolong the mould life by minimizing thermal shock and fatigue.
- Since the moulds are not permeable, ***special provision*** must be made for venting.
- This is usually accomplished through the ***slight cracks*** between mould halves or by very small vent holes that permit the escape of trapped air but not the passage of molten metal.

Mould Cooling and Use of Core

- The ***mould*** often incorporates ***special cooling features***, such as a means of pumping cooling water through the channels located in the mould and the use of cooling fins.

- ***Cores***, both expendable sand or plaster or retractable metal, can be used to increase the complexity of the casting, and multiple cavities can often be included in a single mould.

Features of Permanent mould

- The permanent moulds contain the
  - ***mould cavity,***
  - ***pouring basin,***
  - ***sprue,***
  - ***runners,***
  - ***risers,***
  - ***gates,***
  - ***possible core supports,***
  - ***alignment pins, and***
  - ***some form of ejection system.***

Advantages

- ***Near-net shapes*** can be produced that require little finish machining.
- The mould is ***reusable***.
- ***Good surface finish*** is obtained if the mould is in good condition.
- Dimensions are consistent from part to part, and ***dimensional accuracy*** can often be held to within 0.25 mm.
- ***Directional solidification*** can be achieved.

Advantages

- The result is usually a sound, ***defect-free casting*** with ***good mechanical properties***.
- The faster cooling rates of the metal mould produce a ***finer grain structure, reduced porosity, and higher-strength products*** than would result from a sand casting process.
- ***Labour costs*** are kept ***low*** through automation.

Disadvantages

- On the negative side, the process is generally limited to the ***lower-melting-point alloys***, and high mould costs can make low production runs prohibitively expensive.
- The useful life of a mould is generally set by molten metal erosion or ***thermal fatigue***.
- When making products of steel or cast iron, mould life can be ***extremely short***

Disadvantages

- ***Only simple part geometries*** can be made as compared to sand casting (because of the need to open the mould).
- ***Equipment costs*** can be high because of high mould costs.

Die Casting/Pressure Die Casting

- Die casting is a ***permanent-mould*** casting process in which the molten metal is injected into the mould cavity under ***high pressure***.
- Typical pressures are ***7 to 350 MPa.***
- The pressure is maintained ***during solidification***, after which the mould is opened and the part is removed.
- ***Moulds*** in this casting operation are ***called dies***; hence the name die casting.

Die Casting-Mould material

- The use of ***high pressure*** to force the metal into the die cavity is the most notable feature that distinguishes this process from others in the permanent-mould category.
- Moulds used in die casting operations are usually made of ***tool steel, mould steel, or maraging steel.***
- ***Tungsten and molybdenum*** with good refractory qualities are also being used, especially in attempts to die cast ***steel and cast iron***.

Die Casting

- ***Dies*** can be single-cavity or multiple-cavity.
- ***Ejector pins*** are required to remove the part from the die when it opens, as in our diagrams.
- ***Lubricants*** must also be sprayed into the cavities to prevent sticking.

Die Casting

- Because the die materials have no natural porosity and the molten metal rapidly flows into the die during injection, venting holes and passageways must be built into the dies at the parting line to evacuate the air and gases in the cavity.
- ***The vents are quite small; yet they fill with metal during injection because of high pressure.***
- This metal must later be trimmed from the part.

Die Casting

- Also, formation of ***flash*** is common in die casting, in which the liquid metal under high pressure squeezes into the small space between the die halves at the ***parting line*** or ***into the clearances around the cores and ejector pins.***
- This flash ***must be trimmed*** from the casting, along with the sprue and gating system.

Advantages

- ***High*** production rates possible;
- There is almost a complete ***elimination of subsequent machining;***
- ***Economical*** for large production quantities;
- ***Close tolerances*** possible, on the order of ± 0.076 mm for small parts
- ***Good*** surface finish ;
- Rapid cooling provides small grain size and ***good strength to the casting.***

Advantages

- ***Thin sections are possible***, down to about 0.5 mm.
- ***Note*** that because of the high pressures involved in die casting, wall thicknesses less than those attainable by other casting methods are possible.

  Also, because of the high pressures, the velocity of metal in the runners is higher than other processes; small parts can be cast before the runner solidifies.

Advantages

- But there is a limit to the minimum thickness which can be cast by die casting because of the high thermal conductivity the metal dies exhibit, there is a limiting thickness below which the molten metal will solidify prematurely before completely filling the mold cavity.
- It should be noted that small parts can also be produced in processes such as investment casting, but the smallest parts are in die casting because of the application of high pressures.

NOTE

- ***Risers are not used*** in the die-casting process since the high injection pressures ensure the continuous feed of molten metal from the gating system into the casting.
- ***The porosity*** that is often found in die castings is not shrinkage porosity; it is more likely to be the result of either entrapped air or the turbulent mode of die filling.
- This porosity tends to be confined to the interior of castings, and its formation ***can be minimized*** by smooth metal flow, good venting, and proper application of pressure.

NOTE

- ***Sand cores cannot be used*** in die casting because the high pressures and flow rates cause the cores to either disintegrate or have excessive metal penetration.
- As a result, ***metal cores are required***, and provisions must be made for their retraction, usually before the die is opened for removal of the casting.

NOTE

- Die temperatures are usually maintained at about 150° to 250°C below the solidus temperature of the metal being cast in order to promote rapid freezing.

Die Life

- ***Die life*** is usually limited by wear (or erosion), which is strongly dependent on the temperature of the molten metal.
- ***Surface cracking*** can also occur in response to the large number of heating and cooling cycles that are experienced by the die surfaces.
- If the rate of temperature change is the dominant feature, the problem is called ***heat cracking*** .
- If the number of cycles is the primary cause, the problem is called ***thermal fatigue*** .

Types of Die Casting

1. Hot Chamber DIE casting

2. Cold Chamber DIE casting

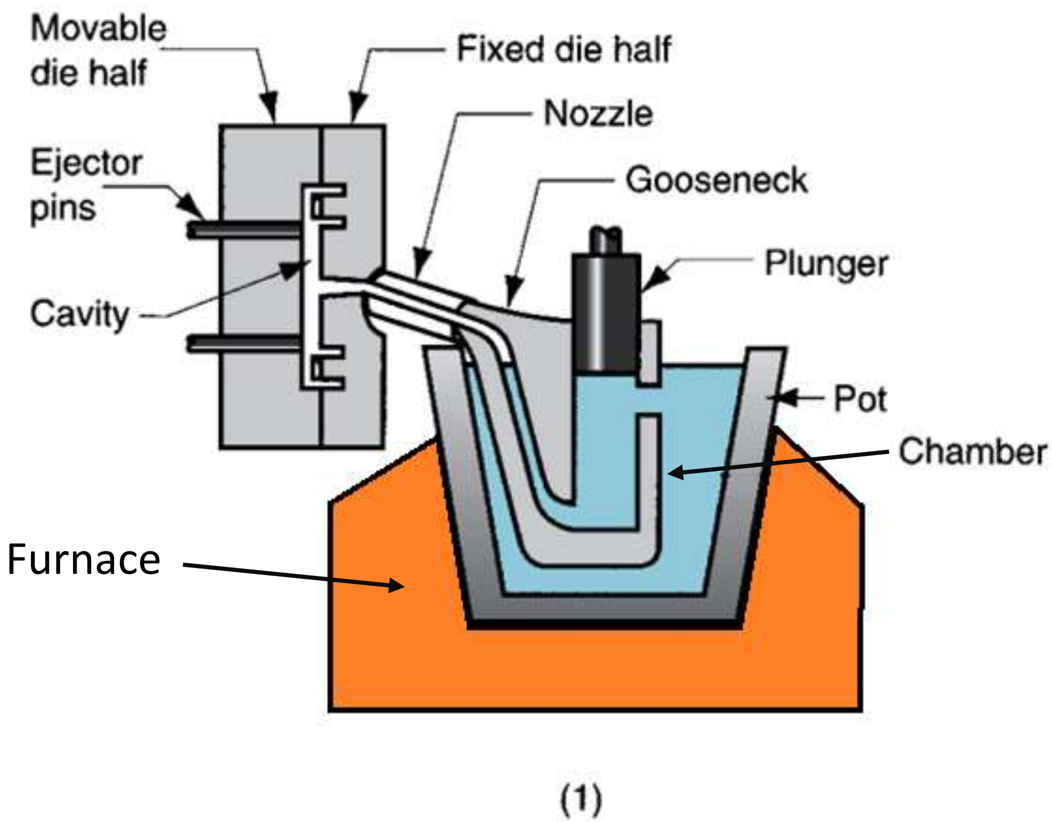
1. Hot Chamber DIE casting

- In hot-chamber machines, the metal is melted in a container attached to the machine, and a piston is used to inject the liquid metal under high pressure into the die.
- Typical injection pressures are ***7 to 35 Mpa***.
- Production rates up to ***100 shots per minute*** can be achieved.
- It has ***faster cycling*** time than cold chamber die casting because there is no handling or transfer of molten metal.

1. Hot Chamber DIE casting

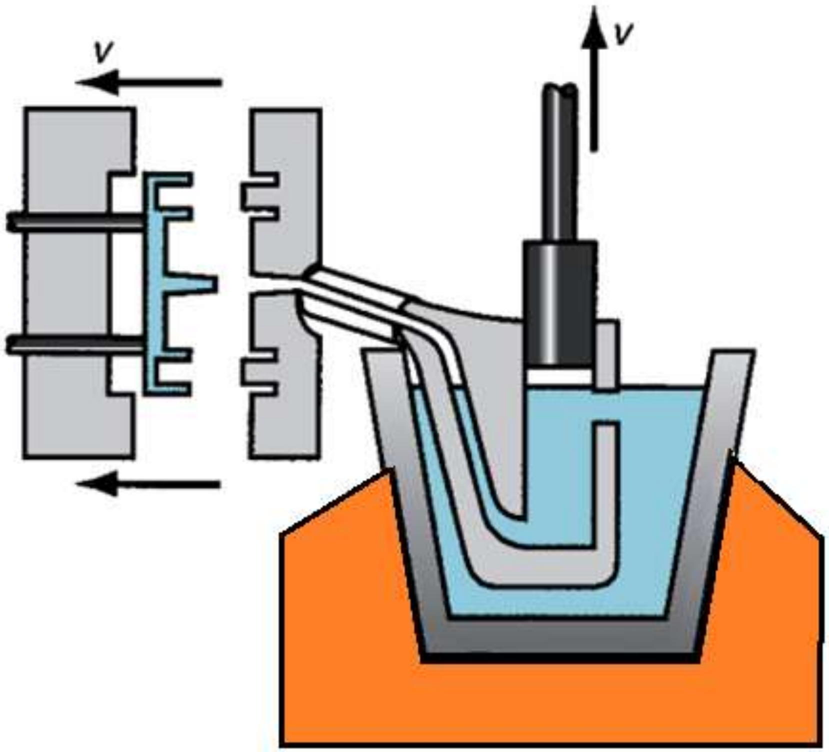
- Hot-chamber die casting imposes a ***special hardship/damage*** on the injection system because much of it is submerged in the molten metal.
- The process is therefore limited in its applications to ***low-melting-point*** metals that do not chemically attack the plunger and other mechanical components.
- The metals include ***zinc(419.5 °C), tin(231.9 °C), lead(327.5 °C).***

1. Hot Chamber DIE casting



(1) with die closed and plunger withdrawn, molten metal flows into the chamber (2) plunger forces metal in chamber to flow into die, maintaining pressure during cooling and solidification.

1. Hot Chamber DIE casting



(3)

(4)

(3) plunger is withdrawn, die is opened, and solidified part is ejected. Finished part is shown in (4).

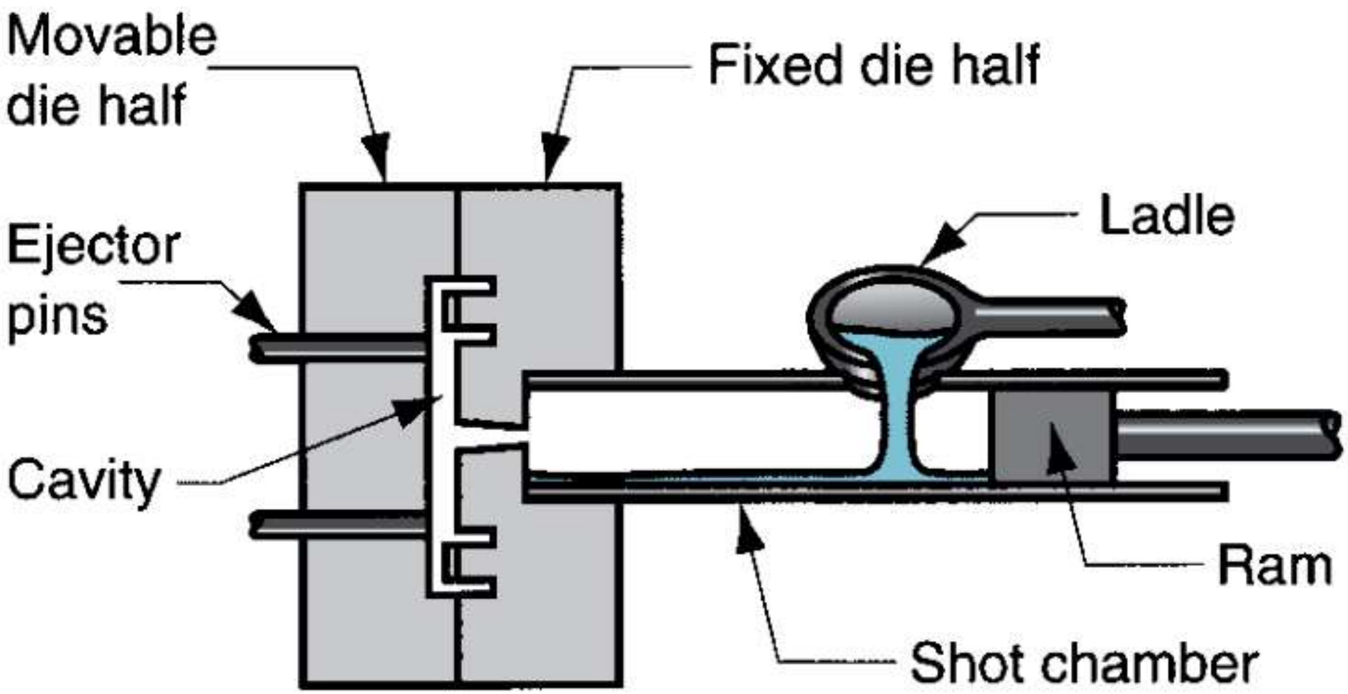
2. Cold Chamber DIE casting

- In cold-chamber die casting machines, molten metal is poured into an unheated chamber from an ***external melting container***, and a piston is used to inject the metal under high pressure into the die cavity.
- Injection pressures used in these machines are typically ***14 to 140 Mpa***.
- Compared to hot-chamber machines, ***cycle rates are not usually as fast*** because of the need to ladle the liquid metal into the chamber from an external source.

2. Cold Chamber DIE casting

- Nevertheless, this casting process is a high production operation.
- Cold-chamber machines are typically used for casting ***aluminium(660.3°C), brass (900 to 940 °C), and magnesium alloys (650 °C +).***

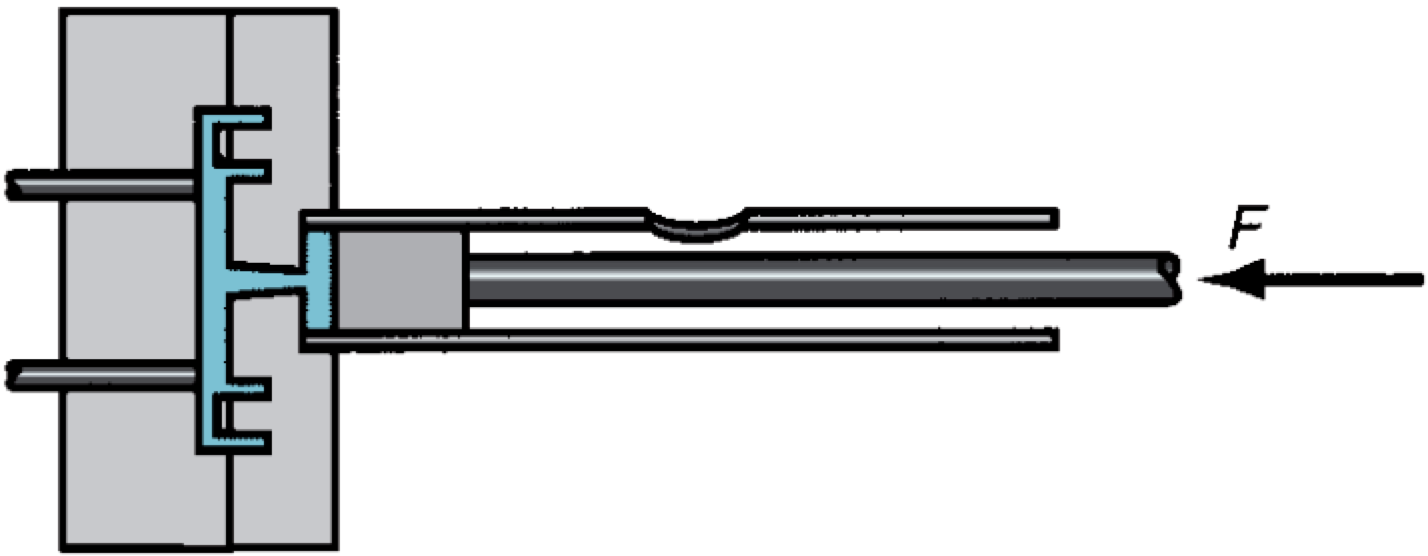
2. Cold Chamber DIE casting



(1)

(1) with die closed and ram withdrawn, molten metal is poured into the chamber

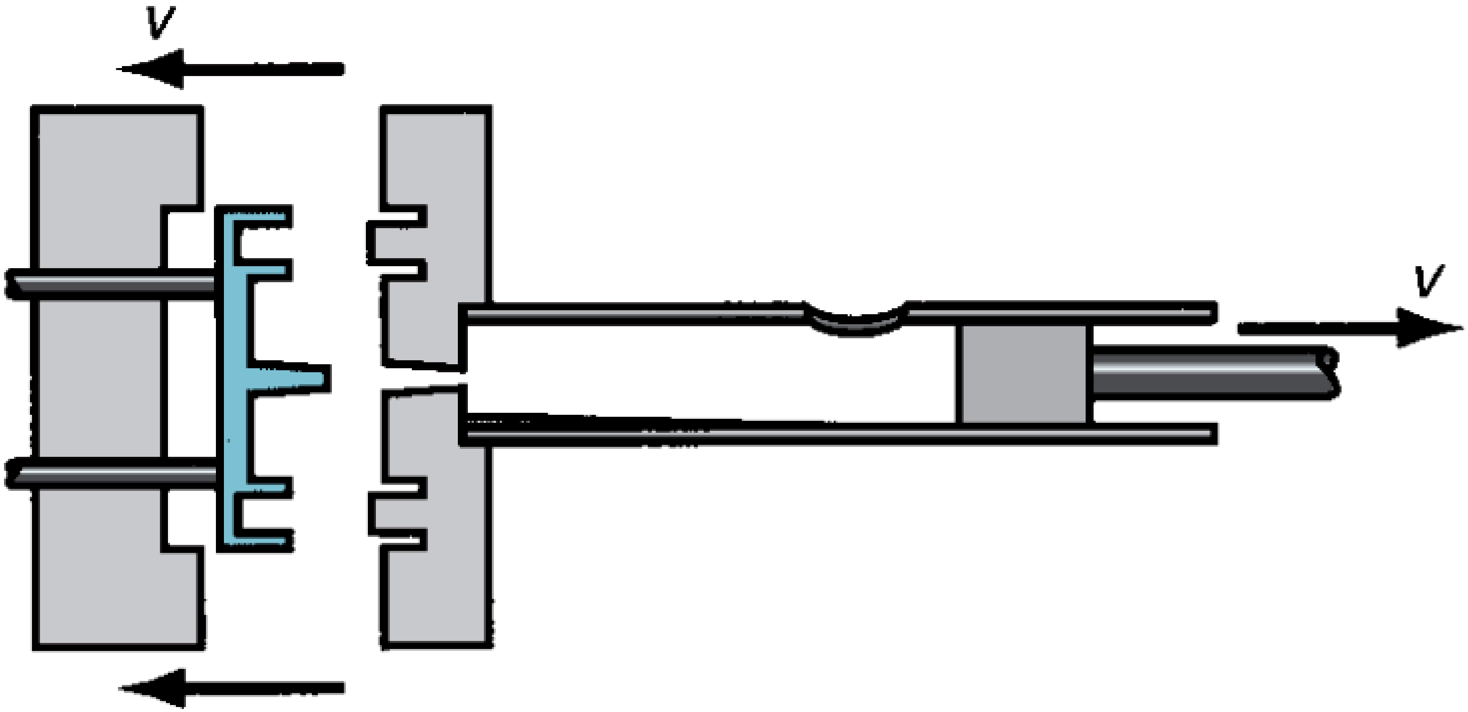
2. Cold Chamber DIE casting



(2)

(2) ram forces metal to flow into die, maintaining pressure during cooling and solidification

2. Cold Chamber DIE casting



(3)

((3) ram is withdrawn, die is opened, and part is ejected

Manufacturing Processes
UTA026

CASTING DEFECTS

Introduction

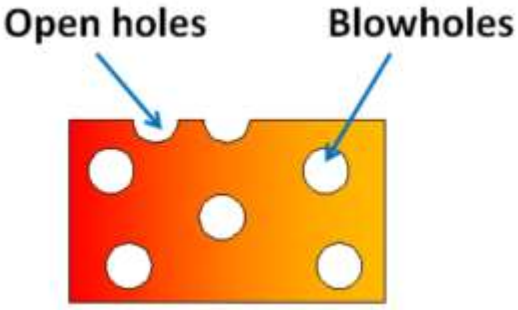
- **Casting Defects:** It is an unwanted irregularities that appear in the casting during metal casting process
- It may sometimes be tolerated, sometimes eliminated with proper moulding practice or repaired using methods such as welding, metallization etc.
- The following are the major defects, which are likely to occur in sand castings
  1. Gas defects: blow holes, open holes, pinholes.
  2. Shrinkage defects: Shrinkage cavity
  3. Molding material defects: Cut and washes, fusion
  4. Pouring metal defects: Cold shut, Mis-run, slag inclusion
  5. Metallurgical defects: Hot tears, Hot spot.

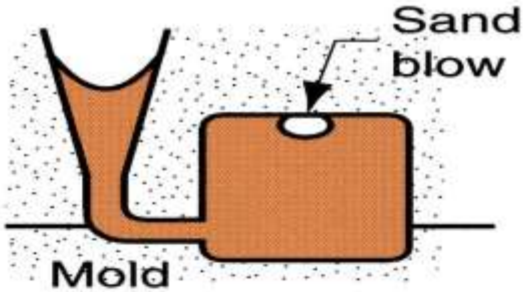
1. Gas Defects

- A condition existing in a casting caused by the *trapping of gas* in the molten metal or by mold gases *evolved during the pouring of the casting*
- All *gas defects* are caused to the greater extent:
  - Lower *gas passing tendency of mold*, which may be due to *lower venting*
  - *Lower permeability* of the mold
  - *Improper design* of casting
- The defects in this category can be classified into *blowholes and pinhole porosity*

1. a. Blow holes and Open blows

- *It occurs at or below the casting surface near the top of the casting*.
- Part of which when *entrapped into the casting end up* as blow holes or end up as *open blow when it reaches the surface.*





(a)

CAUSES:

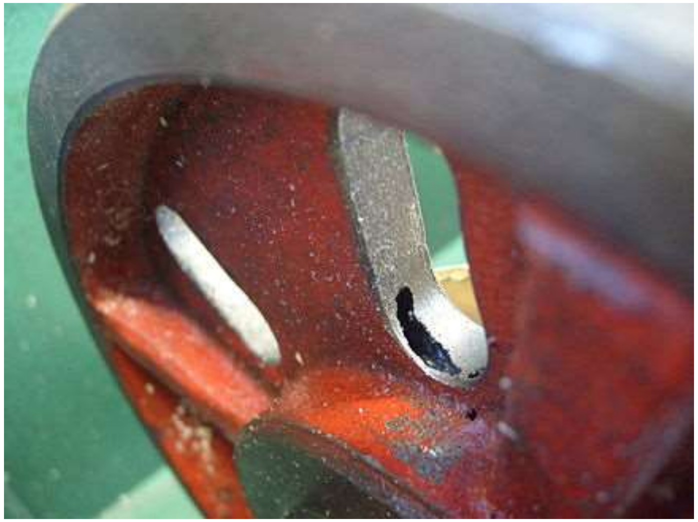
- *Low sand permeability,*
- *poor venting, and*
- *high moisture content* of the sand mold

are the usual causes.

1. a. Blow holes and Open blows

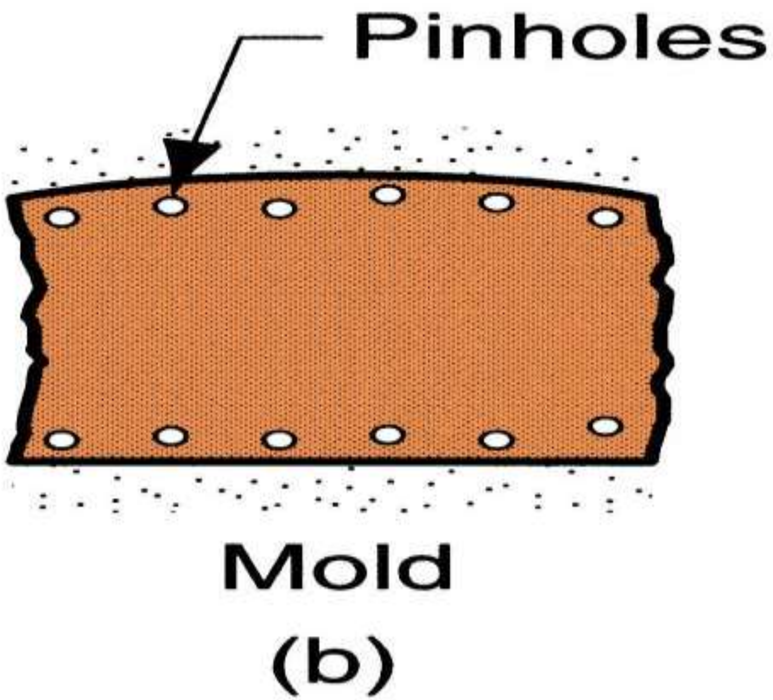
Remedies :

- Control of moisture content in moulding sand.
- Use of rust free chills, chaplets & inserts.
- Provide adequate venting in mould and cores.



1. b. Pin holes

- Pin holes are *tiny blow holes* appearing just below the casting surface.



1. b. Pin holes

- ***Causes:***

  -sand with high moisture content.

  -absorption of hydrogen gas in the metal.

  -alloy not being properly degassed.

  -sand containing gas producing ingredients.

- ***Remedies:***

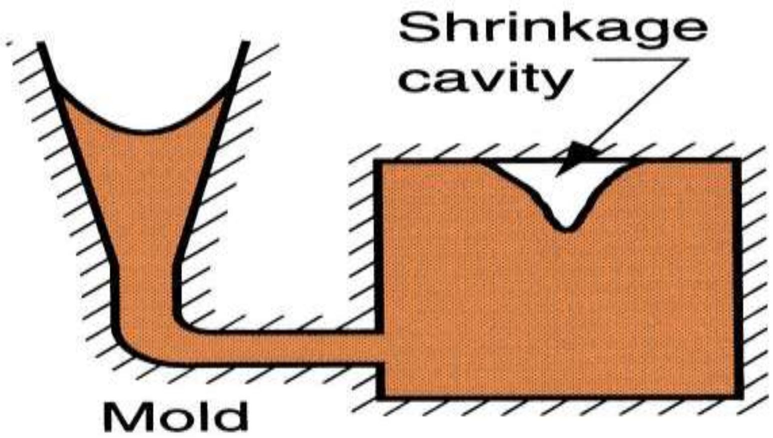
  -reducing the moisture content of molding sand.

  -increasing its permeability.

  -employing good melting and fluxing practices.

2. Shrinkage Cavities

- Shrinkage cavity is a *depression in the surface* or an internal void in the casting.
- Shrinkage cavity occur when *feed metal is not available* to compensate for shrinkage as the metal solidifies.
- It often occurs *near the top of the casting*.
- The problem can often be solved by *proper riser design and using chills.*



(d)

Cavities

Causes :

- Inadequate and improper gating & risering system.
- Too much high pouring temperature.
- Improper chilling.

Remedies :

- Ensure proper directional solidification by modifying gating, risering & chilling system.

3. Molding Material Defects

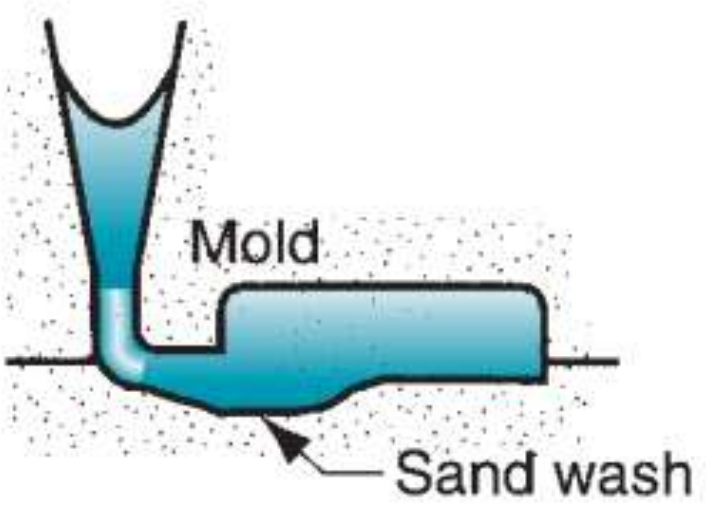
- Under these category are those defects which are caused by ***the characteristic of molding material***. The defects can be put into this category are:

a. Cut and washes

b. Fusion

3. a. Cut and Washes

- Sand wash, which is an *irregularity in the surface* of the casting *that results from erosion of the sand mold during pouring*, and the *contour of the erosion* is formed in the *surface* of the final cast part.



3. a. Cut and Washes

- ***Causes:***
  - Weak strength of the molding sand
  - Molten metal flowing at a high velocity

- ***Remedies:***
  - Selecting proper molding sand
  - Using appropriate molding method
  - Increasing size of gates or using multiples ingates to reduce the turbulence in the metal.

3. b. Fusion

- Fusion of sand grains with molten metal, giving a brittle, glassy appearance on the cast surface.
- ***Causes:***
  – Clay in the molding material has low *refractoriness* or pouring temp is very high.
- ***Remedies:***
  – Choice of appropriate types and bentonite clay would cure this effect

4. Pouring Metal Defects

- The likely defects in this category are

  a. Slag inclusion

  b. Mis-runs

  c. Cold shuts

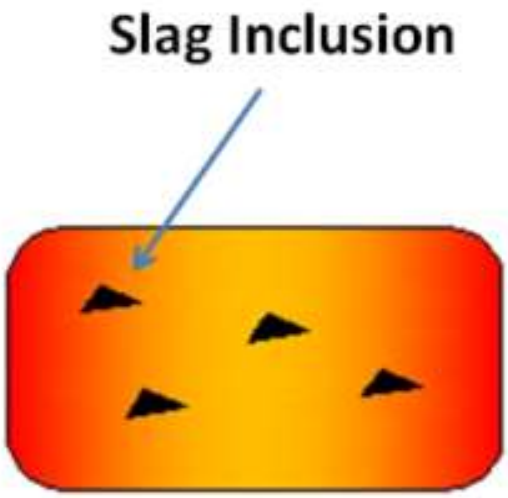
4. a. Slag Inclusion

- There are a number of chemical reactions that can occur between molten metal and its surroundings.
- These reactions and their products can often lead to defects in the final casting.
- For example, oxygen and molten metal can react to produce metal oxides which can then be carried with the molten metal during the pouring and filling of the mold.
- Known as dross or slag , this material

can become trapped in the casting

and poor surface finish, machinability,

and mechanical properties.



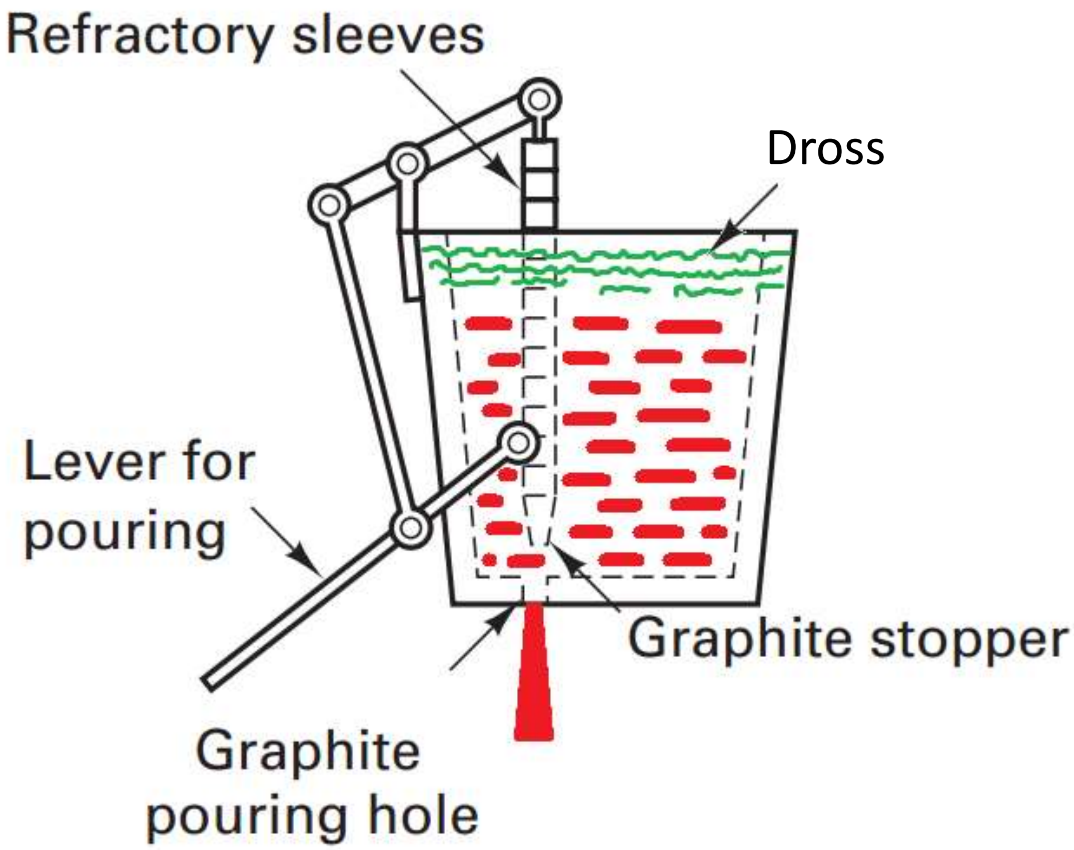
4. a. Slag Inclusion- Prevention

- *Lower pouring temperatures* slows the rate of dross-forming reactions.
- *Fluxes can be used to cover and protect* molten metal during melting.
- The melting and pouring can be performed *under a vacuum or protective* atmosphere.

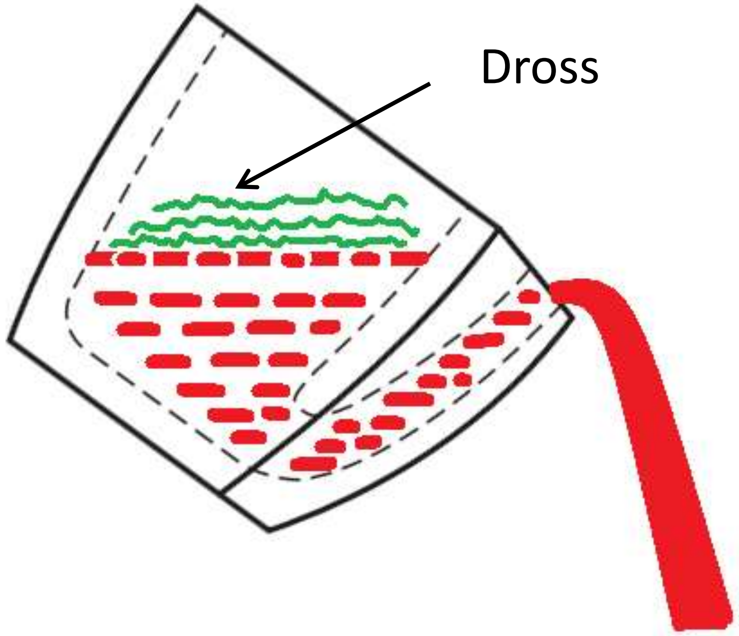
4. a. Slag Inclusion - Prevention

- Measures can be taken to cause the dross to float to the surface of the metal, where it can be skimmed off prior to pouring.
- Special ladles can be used that extract metal from beneath the surface thereby avoiding the dross to enter the mould.
- In Addition ceramic filter can be inserted to feeder channel of the mold.

4. a. Bottom – pour ladle

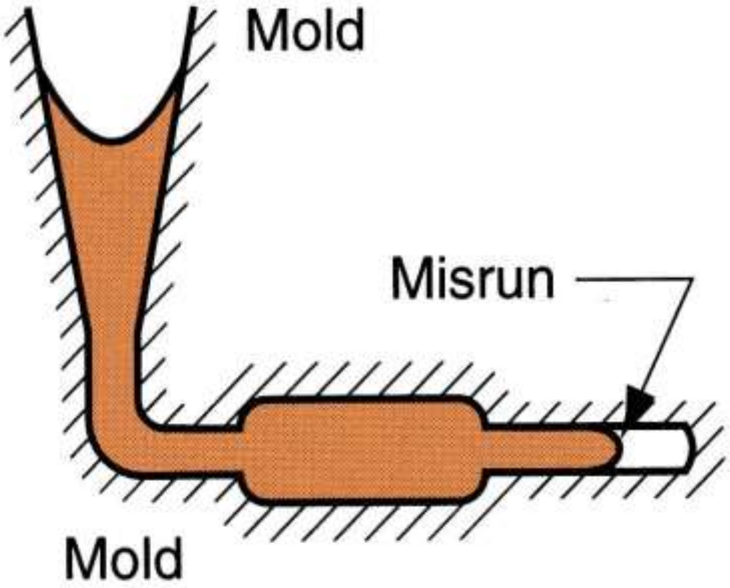


Tea pot ladle



4. b. Misrun

- When the *molten metal fails to fill the entire mould cavity before the metal starts solidifying*, resulting in an incomplete casting, the defect is known as Misrun. *The edge of defect is round and smooth.*



4. b. Mis-runs

***Causes*:**

–Low pouring temperature of molten metal, reduce fluidity

–Too thin casting sections

–Slow and intermitted pouring

–Improper alloy composition

–Improper gating system

–Casting with large surface area to volume ratio

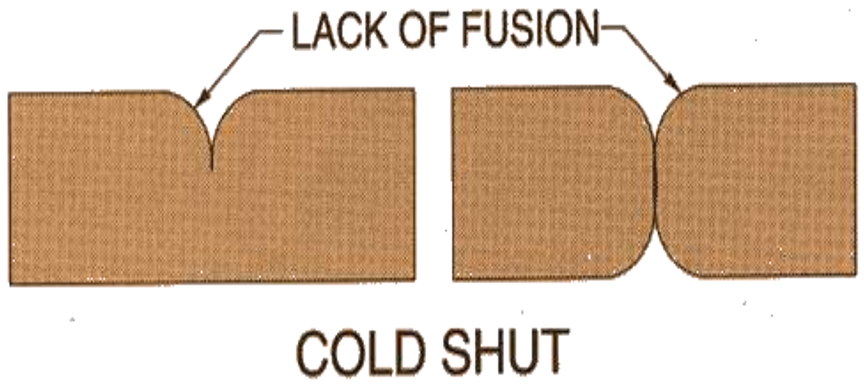
–Back pressure due to gases in the mold which is not properly vented

4. b. Mis-runs

- ***Remedies:***
  - Increase the fluidity of metal by increasing the pouring temperature or changing chemical composition.
  - Smooth pouring
  - Improve mold design

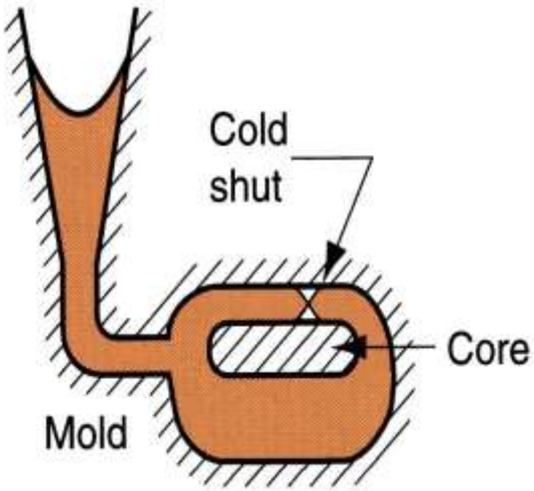
4. c. Cold Shuts

- When two streams of molten metal approach each other in the mould cavity from opposite directions but fail to fuse properly, with the result of discontinuity between them, it is called a cold shut.



Cold Shuts

- ***Causes:***
  - Low temperature of molten metal
  - Slow and intermitted pouring
  - Improper alloy composition
  - Use of damaged pattern



- ***Remedies:***

-Smooth pouring

-Properly transport mould during pouring.

-Providing appropriate pouring temperature

5. Metallurgical Defects

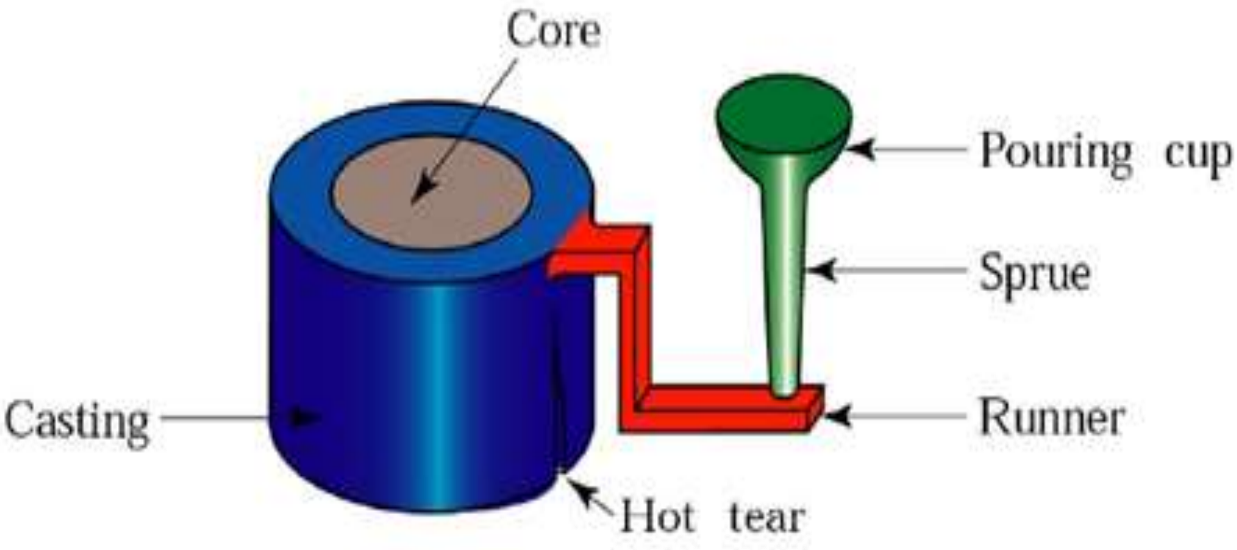
- These are defects are caused by the properties of the casting products.

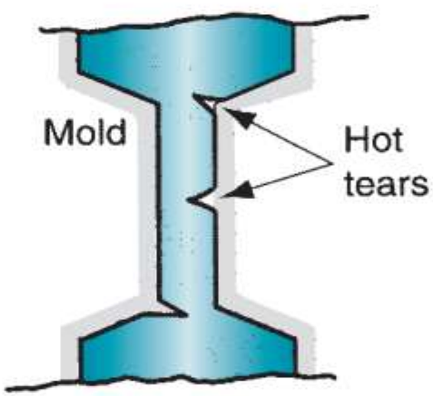
a. Hot tears/cracking

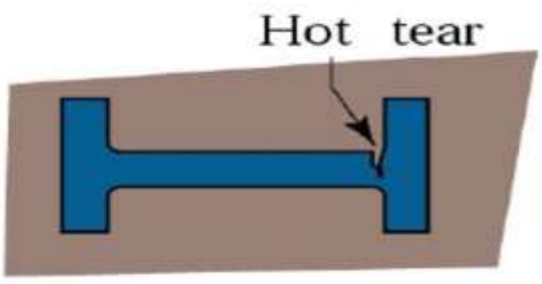
b. Hot Spot

5. a. Hot Tears/Cracking

- When the *metal is hot, it is weak and the residual stress (tensile) in the material cause the casting fails* as the molten metal cools down.
- The failure of casting in this case is looks like cracks and called as hot tears or hot cracking.







5. a. Hot Tears/Cracking

Causes

- Improper mold design.

Remedies

- Proper mold design can easily eliminate these types of casting defects.
- Elimination of *residual stress* from the material of the casting.

5. b. Hot Spots

- Hot spot defects occur when *an area on the casting cools more rapidly* than the surrounding materials
- Hot spot are *areas on the casting which is harder* than the surrounding area

Causes & Remedies

Causes:

- The rapid cooling an area of the casting than the surrounding materials causes this defect.

Remedies:

- This defect can be avoided by using proper cooling practice
- By changing the chemical composition of the metal.