Metal Casting and Solidification

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SYLLABUS

- **Liquid metals and gating & feeding of castings:**
- Fluidity of liquid metals, mould factors in metal flow, the gating of casting. The feeding characteristics of alloys, methods for feeding of castings; design modifications, padding chills & insulation, the feeding of cast irons, solidification modeling.

GATING SYSTEM

- The term gating system refers to all passageways through which the molten metal passes to enter the mould cavity.
- The gating system is composed of

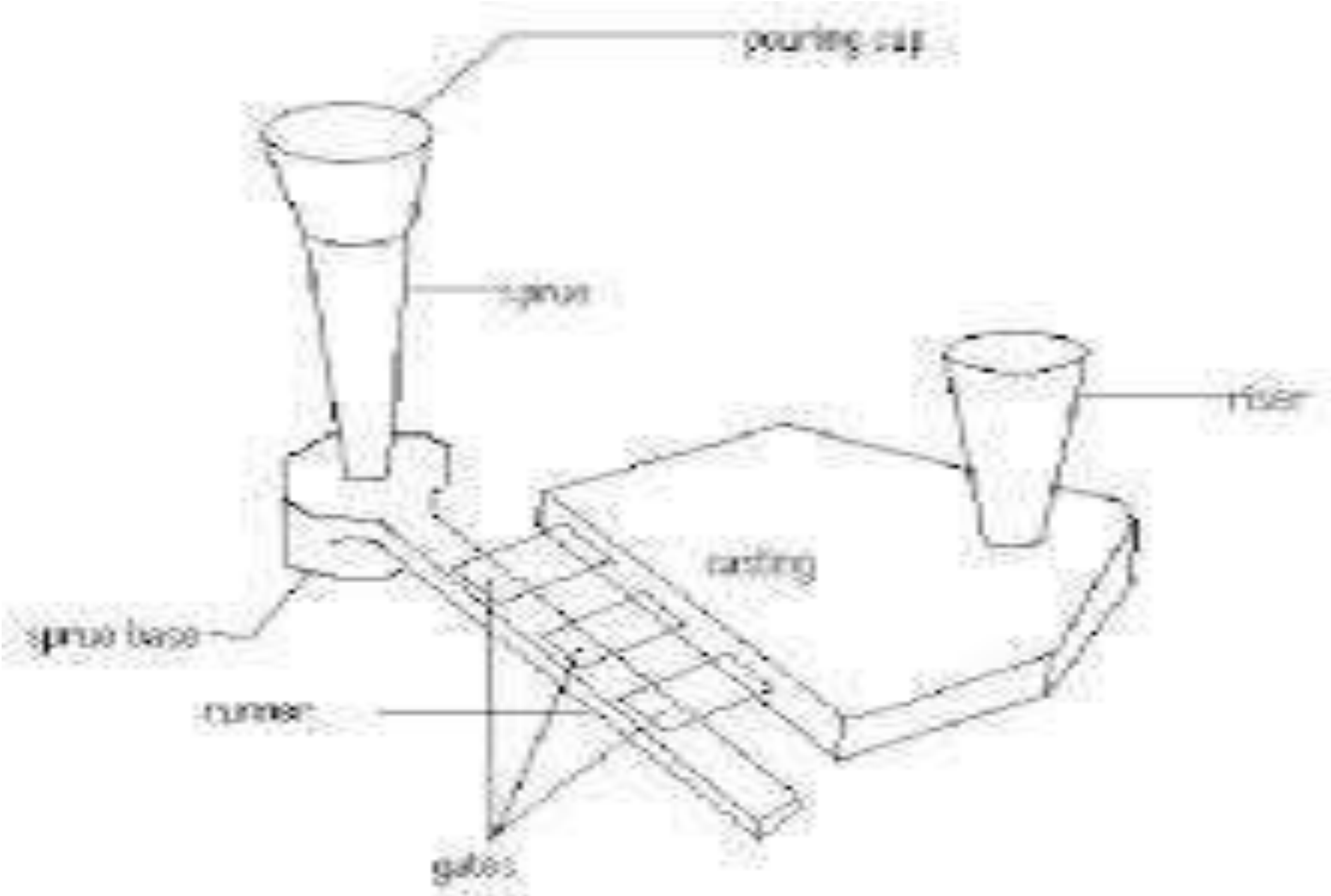
✓ Pouring basin

✓ Sprue

✓ Runner

✓ Gates

✓ Risers



Components of Gating System

- Any gating system designed should aim at providing a defect free casting. This can be achieved by considering following requirements.

- ✓ A gating system should avoid sudden or right angle changes in direction.

- ✓ A gating system should fill the mould cavity before freezing.

- ✓ The metal should flow smoothly into the mould without any turbulence. A turbulence metal flow tends to form dross in the mould.

- ✓ Unwanted materials such as slag, dross and other mould materials should not be allowed to enter the mould cavity.

- ✓ The metal entry into the mould cavity should be properly controlled in such a way that aspiration of the atmospheric air is prevented.

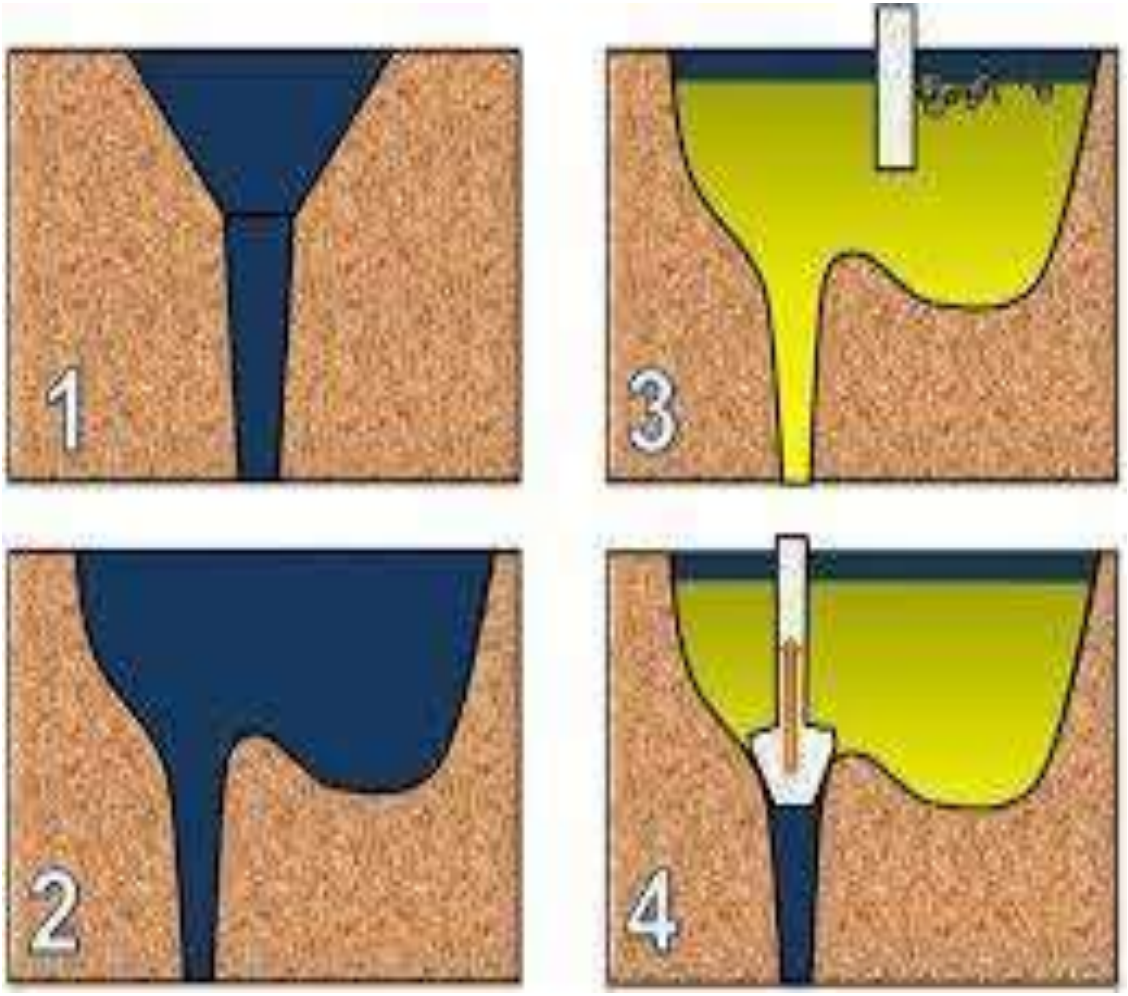
- ✓ A proper thermal gradient should be maintained so that the casting is cooled without any shrinkage cavities or distortions.
- ✓ Metal flow should be maintained in such a way that no gating or mould erosion takes place.
- ✓ The gating system should ensure that enough molten metal reaches the mould cavity.
- ✓ It should be economical and easy to implement and remove after casting solidification.

TH

- For proper functioning of the gating E following factors need to be controlled.

- ✓ Type of pouring equipment, such as ladles, pouring basin etc.
- ✓ Temperature/ Fluidity of molten metal.
- ✓ Rate of liquid metal pouring.
- ✓ Type and size of sprue.
- ✓ Type and size of runner.
- ✓ Size, number and location of gates connecting runner and casting.
- ✓ Position of mould during pouring and solidification.

POURING BASINS



- A pouring basin makes it easier for the ladle or crucible operator to direct the flow of metal from crucible to sprue.
- Helps maintaining the required rate of liquid metal flow.
- Reduces turbulence at the sprue entrance.
- Helps separating dross, slag etc., from metal before it enters the sprue.

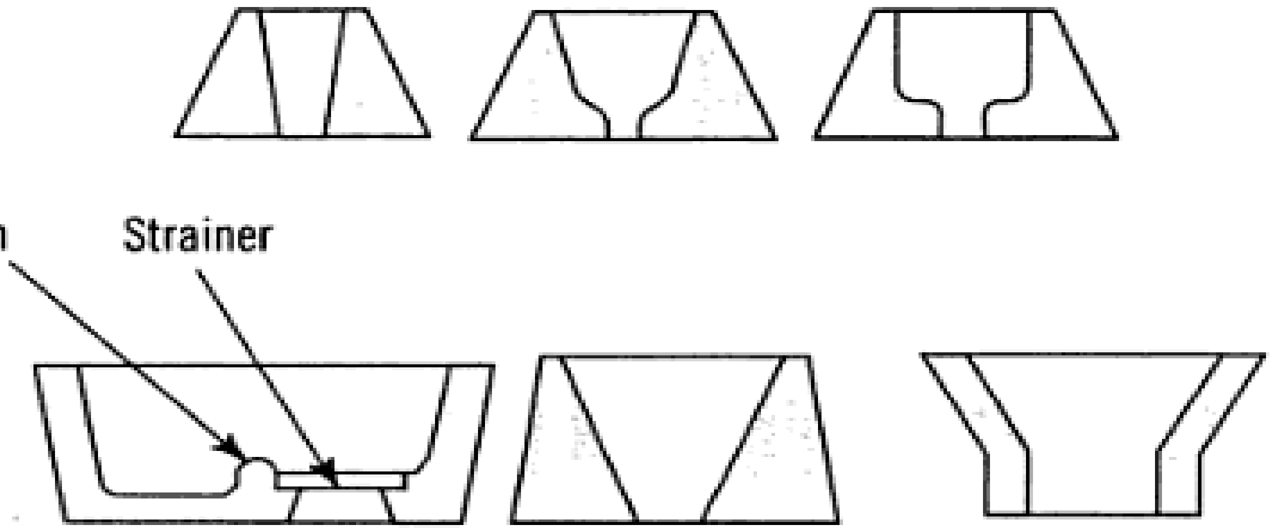


Fig. 5.2 *Typical shapes of pouring basins*

•If the pouring basins are made large,

✓Dross and slag formation will tend to float on the surface of the metal and may be stopped from entering the sprue and hence the mould.

✓They may be filled quickly without overflowing and may act as a reservoir of liquid metal to compensate metal shrinkage or contraction.

SPRUE

- A sprue feeds metal to runner which in turn reaches the casting through gates.

- A sprue is tapered with its bigger end at top to receive the liquid metal. The smaller end is connected to runner.

GATES

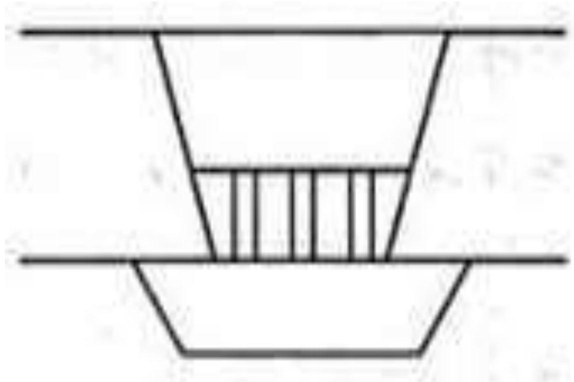
- A gate is a channel which connects runner with the mould cavity and through which molten metal flows to fill the mould cavity.
- A small gate is used for a casting which solidifies slowly and vice versa.
- A gate should not have sharp edges as they may break during pouring and sand pieces thus may be carried with the molten metal in the mould cavity.
- **Types**
- Top gate
- Bottom gate
- Parting line side gate

TOP GATE

- A top gate is sometimes also called as Drop gate because the molten metal just drops on the sand in the bottom of the mould.

- Generation of favourable temperature gradients to enable directional solidification from the casting towards the gate which serves as a riser too.

(A)



(E)

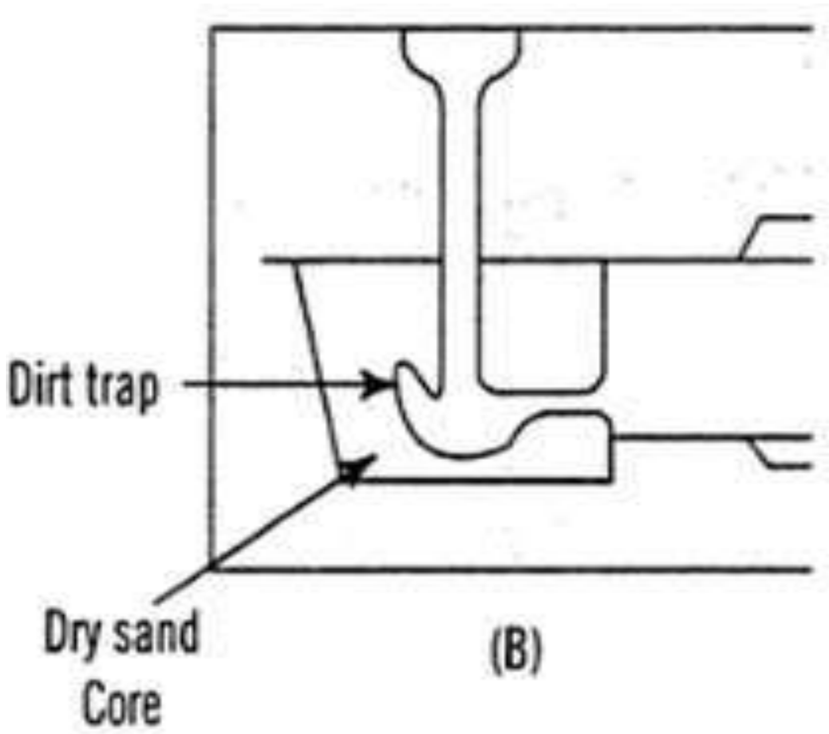
Disadvantages

- The dropping liquid metal stream erodes the mould surface.

- There is a lot of turbulence.

Bottom gates

- A bottom gate is made in the drag portion of the mould.
- In a bottom gate the liquid metal fills rapidly the bottom portion of the mould cavity and rises steadily and gently up the mould walls.
- As comparison to top gate, bottom gate involves little turbulence and sand erosion.
- Bottom gate produces good casting surfaces.



(B)

Disadvantages

- In bottom gates, liquid metal enters the mould cavity at the bottom. If freezing takes place at the bottom, it could choke off the metal flow before the mould is full.

- A bottom gate creates an unfavourable temperature gradient and makes it difficult to achieve directional solidification.

PARTING LINE SIDE GATE

- Middle or side or parting gating systems combine the characteristics of top and bottom gating systems.

- In this technique gate is provided along the parting line such that some portion of the mould cavity will be below the parting line and some portion will be above the parting line.

- The cavity below the parting line will be filled by assuming top gating and the cavity above the parting line will be filled by assuming bottom gating.

DESIGN OF GATING SYSTEM

- To fill the mould cavity without breaking the flow of liquid metal and without using very high pouring temperatures.
- To avoid erosion of mould cavity.
- To minimize turbulence and dross formation.
- To prevent aspiration of air or mould gases in the liquid metal stream.
- To obtain favourable temperature gradients to promote directional solidification.

Defects occurring due to improper design of gating system

- Oxidation of metal
- Cold shuts
- Mould erosion
- Shrinkages
- Porosity
- Misruns
- Penetration of liquid metal into mould walls.

Reynold's number (Re)

$$\text{Re} = \frac{\rho \ Vd}{\mu}$$

$$= \frac{(\text{density}) * (\text{velocity}) * (\text{diameter})}{(\text{viscosity})}$$

Critical Reynold's number

- $Re < 2{,}000$
  - – viscosity dominated, laminar flow
- $Re > 4{,}000$
  - – inertia dominated, turbulent flow
- Controlled through gate and runner design

METAL FLOW RATE AND VELOCITY CALCULATIONS

- Studies of gating system have been based upon two laws of fluid dynamics.
- Law of continuity
- $Q = A_1V_1 = A_2V_2$
- Q = volume rate of flow
- A = cross sectional area of flow passage
- V = linear velocity of flow

Bernoulli's Equation

- Used to calculate flow velocities
- Assumptions: steady state, incompressible, inviscid Flow

- $P_1/\rho g + V_1^2/ 2g + h_1 = P_2/\rho g + V_2^2/ 2g + h_2$

P = pressure h = height above the datum plane
ρ= density
v = velocity

Design criteria for pouring basin

- The pouring basin should be designed such that the proper uniform flow system is rapidly established.
- This can be achieved by-

✓ Use of strainer core

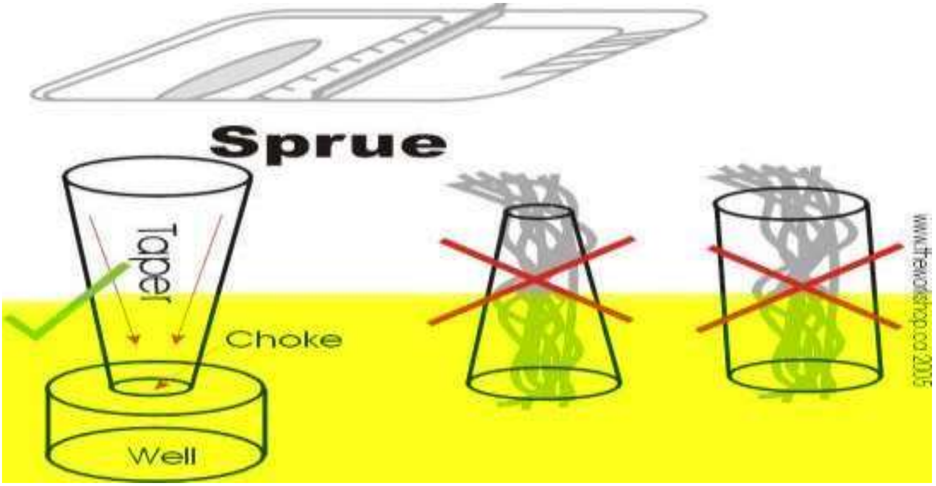
✓ Use of DAM to make steady flow

✓ Use of sprue plug

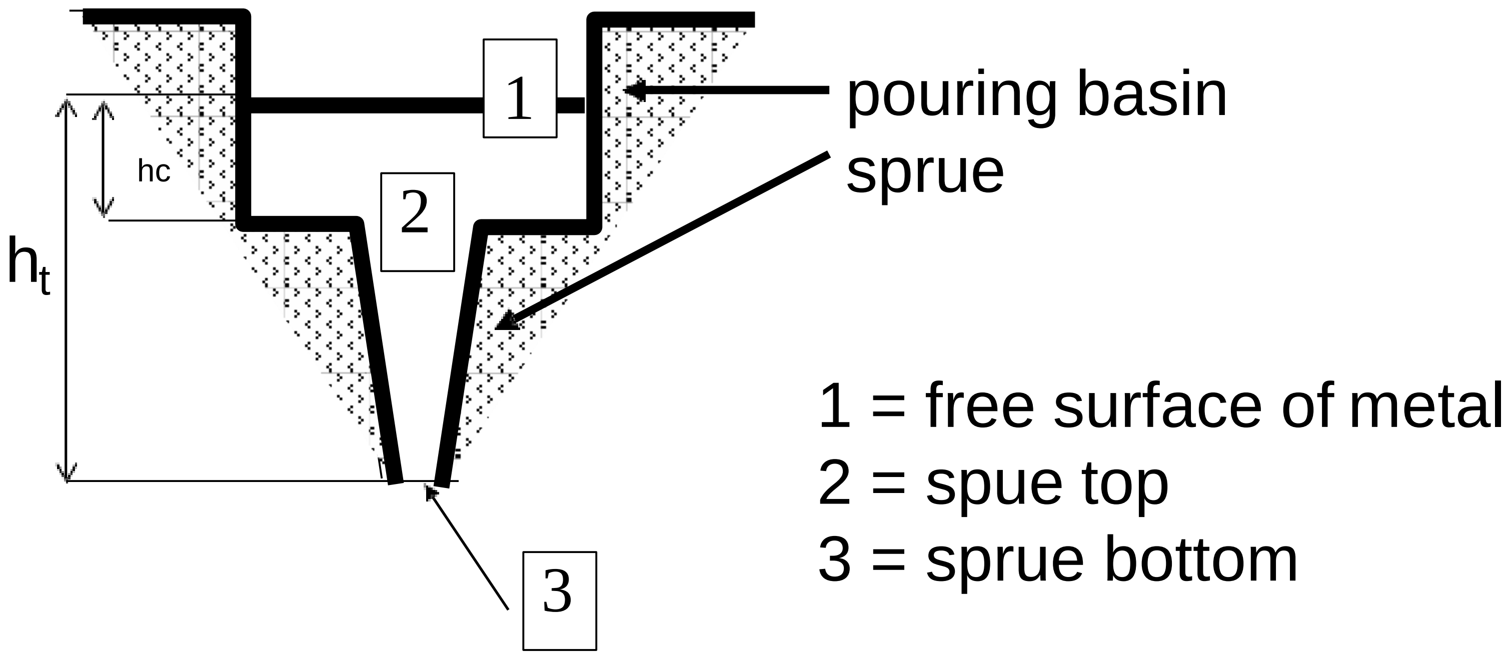
- It should be easy and convenient to fill pouring basin.

Design of sprue

- As the liquid metal passes down the sprue it loses its pressure head but gains velocity.



To reduce turbulence and promote Laminar Flow, from the Pouring Basin, the flow begins a near vertical incline that is acted upon by gravity and with an accelerative gravity force



- Assuming
  - entire mould is at atmospheric pressure (no point below atmospheric)
  - metal in the pouring basin is at zero velocity (reservoir assumption)

Mass flow rate = ρ A V = constant

APPLYING CONTINUITY EQUATION BETWEEN POINT 2 AND 3 WE GET-

$$\frac{A_2}{A_3} = \frac{V_3}{V_2} = \sqrt{\frac{2gh_t}{2gh_c}} = \sqrt{\frac{h_t}{h_c}}$$

$$\frac{h_t}{h_c} = \left(\frac{A_2}{A_3}\right)^2$$

- ✓Actual shape of sprue is Parabola
- ✓But in order to avoid manufacturing difficulty we use tapered cylinder shape.

- Tapered sprue reduces the rate of flow at which the liquid metal enters the mould cavity and hence mould erosion is reduced.
- The area at the sprue exit controls-
  - ✓ Flow rate of liquid metal into mould cavity
  - ✓ Velocity of liquid metal
  - ✓ Pouring time

➢ **Choke** is that part of the gating system which has the smallest cross section area.

➢ **In a free gating system** sprue serves as choke.

- ✓ This reduces mould erosion and turbulence because velocity of liquid metal is less.
- ✓ This system causes air aspiration effect.

- ➢ In a **choked system,** gate serves as the choke.
- ✓ This creates a pressurized system.
- ✓ Due to high metal velocity and turbulence, this system experiences oxidation and erosion in mould cavity.
- ➢ The area at the sprue exit which if is the least is known as choke area and can be calculated from the following relation-

$$C_A = \frac{W}{c.dt\sqrt{2gH}}$$

C_A is choke area

W is the weight of casting

C is nozzle coefficient

d is density of liquid metal

t is pouring time

H effective liquid metal head

POURING TIME

•High pouring rates leads to mould erosion, rough surface, excessive shrinkages etc.

•Low pouring rate may not permit the complete filling of the mould cavity in time if the molten metal freezes fast and thus defects like cold shuts may develop.

•It is very necessary to know optimum pouring rate or pouring time for metals to be cast. Optimum pouring rate a function of casting shape and size.

- Pouring time for brass or bronze
- Varies from 15 seconds to 45 seconds may be used for casting weighing less than 150 kg.
- Pouring time for steel casting
- Steel has a high freezing range as compared to other cast alloys, it is poured rapidly to avoid early freezing.
- Pouring time = $K\sqrt{W}$ seconds

W is weight of casting in lbs
K is fluidity factor

- Pouring time for gray cast iron casting

➢ casting weighing more than 1000 lbs.

✓ $$K\left[0.95+\frac{T}{0.853}\right]\sqrt[3]{w}\ \text{seconds}$$

➢ Casting weighing less than 1000 lbs

✓ $$K\left[0.95+\frac{T}{0.853}\right]\sqrt{w}\ \text{seconds}$$

W is weight of casting in lbs

T is average section thickness in inches

K is fluidity factor

•Pouring time of light metal alloys

•Unlike steel, Al and Mg alloys are poured at a slow rate, this is necessary to avoid turbulence, aspiration and drossing.

DESIGN OF RUNNER AND GATES

- In a good runner and gate design-
- ✓ Abrupt changes in section and sharp corners which create turbulence and gas entrapment should be avoided.
- ✓ A suitable relationship must exist between the cross-sectional area of sprue, runner and in gates.

GATING RATIO

- Gating ratio= a:b:c where,
- a= cross-sectional area of sprue
- b= cross-sectional area of runner
- c= total cross-sectional area of ingates.
- Gating ratio reveals-
- whether the total cross- section decreases towards the mould cavity. This provides a choke effect which pressurizes the liquid metal in the system.
- Whether the total cross-sectional area increases so that the passages remain incompletely filled. It is an unpressurized system.

S.N.	Pressurized gating systems	Unpressurized gating systems
1.	Gating ratio may be of the order of 3: 2: 1	Gating ratio may be of the order of 1: 3: 2
2.	Air aspiration effect is minimum	Air aspiration effect is more
3.	Volume flow of liquid from every ingate is almost equal.	Volume flow of liquid from every ingate is different.
4.	They are smaller in volume for a given flow rate of metal. Therefore the casting yield is higher.	They are larger in volume because they involve large runners and gates as compared to pressurized system and thus the cast yield is reduced.
5.	Velocity is high, severe turbulence may occur at corners.	Velocity is low and turbulence is reduced.

- Ideally, in a system, pressure should be just enough to avoid aspiration and keep to all feeding channels full of liquid metal.

- Gating ratio and positions of ingates should be such that the liquid metal fills the mould cavity just rapidly to-

- ✓ Avoid misruns and coldshuts in thin sectioned castings.

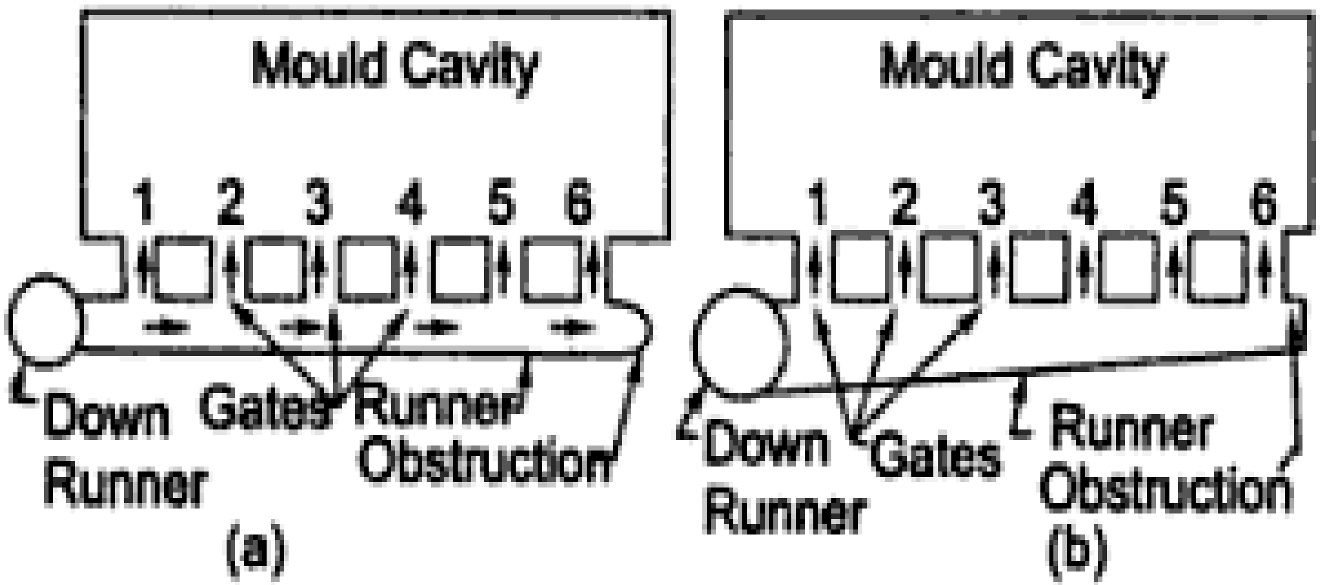
- ✓ Reduce turbulence and mould erosion in casting of thicker casting.

- The maximum liquid metal tends to flow through the farthest ingate.

- For a gating ratio 1:2:4, 66% of liquid metal enters through gate no. 2 and only 34% does so through gate no. 1.

- Total ingate area is reduced by making gates farthest from sprue of smaller cross-section so that less volume of metal flows through them and makes a uniform distribution of metal at all ingates.

- Besides with reduced total ingate area, still more satisfactory result may be obtained if runner beyond each ingate is reduced in cross section to balance the flow in all parts of the system and to equalise further velocity and pressure.



STREAMLINING THE GATING SYSTEM

- Streamlining includes-
- Removing sharp corners or junction by giving a generous radius.
- Tapering the sprue.
- Providing radius at sprue entrance and exit.

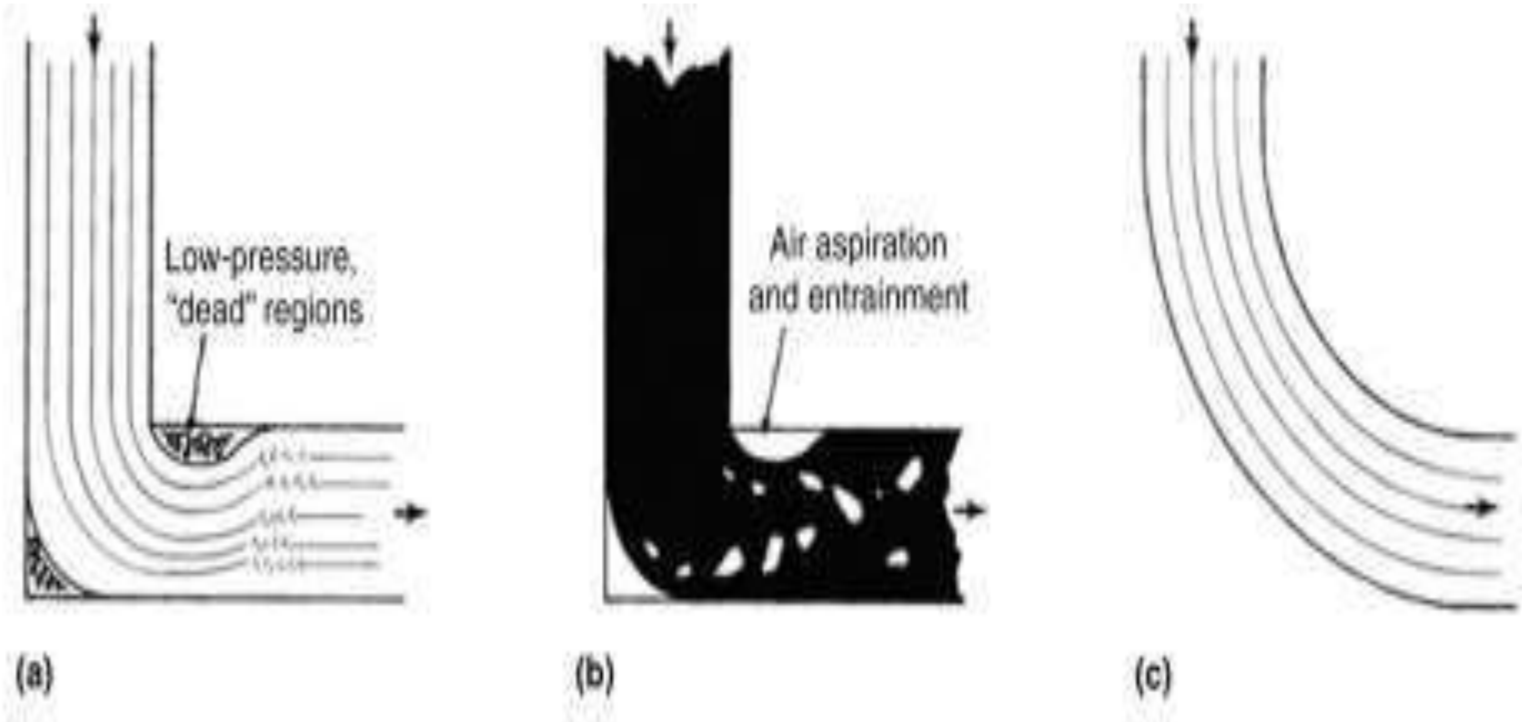


Fig. 7 Schematic illustrating fluid flow around right-angle and curved bends in a gating system. (a) Turbulence resulting from a sharp corner. (b) Metal damage resulting from a sharp corner. (c) Streamlined corner that minimizes turbulence and metal damage

ADVANTAGES OF STREAMLINING

- Metal turbulence is reduced.
- Air aspiration is avoided.
- Mould erosion and dross are minimized.
- Sound and clean casting are obtained.

POURING EQUIPMENTS

- Ladles are the commonly used equipment for pouring the molten form the furnace. After reading this article you will learn about the five main types of pouring ladles.
- The types are: 1. Hand Ladle 2. Shank or Bull Ladle 3. Tea Pot Ladle 4. Bottom-Poured Ladle 5. Monorail or Trolly Ladle.

- **Type # 1. Hand Ladle:**
- It is a bucket with removable, lever arm and handle shank. It is used when the quantity of molten metal is small. It can be carried by a single person. Its carrying capacity varies from 10 to 20 kg. Fig. 4.7 (a).
- **Type # 2. Shank or Bull Ladle:**
- A shank or bull ladle is carried by two persons and used for medium capacity of molten metal. Its carrying capacity varies from 30 to 150 kg. Fig. 4.7 (b).

- **Type # 3. Tea Pot Ladle:**
- Tea pot ladle is used for small and medium-sized mould. Tea pot ladle allows the molten metal to be taken out from the bottom opening provided. The bottom opening is advantageous as it does not disturb the slag floats on top. Fig. 4.7 (c).

- **Type # 4. Bottom-Poured Ladle:**
- Bottom poured ladle is used for top-run or direct-pour into the mould. The molten metal is poured through the bottom hole, which is operated by a graphite stopper and lever. Slag, being lighter, floats at the top of the molten metal and pure metal is poured into the mould. Therefore, it is also known as self-cleaning ladle. Fig. 4.7 (d).
- **Type # 5. Monorail or Trolly Ladle:**
- The molten metal is carried in a trolly. The trolly is mounted on the monorail for easy movement to the pouring site. The molten metal is poured through a lever provided with crucible. A hand wheel is also provided for raising and lowering the crucible. Fig. 4.7 (e).

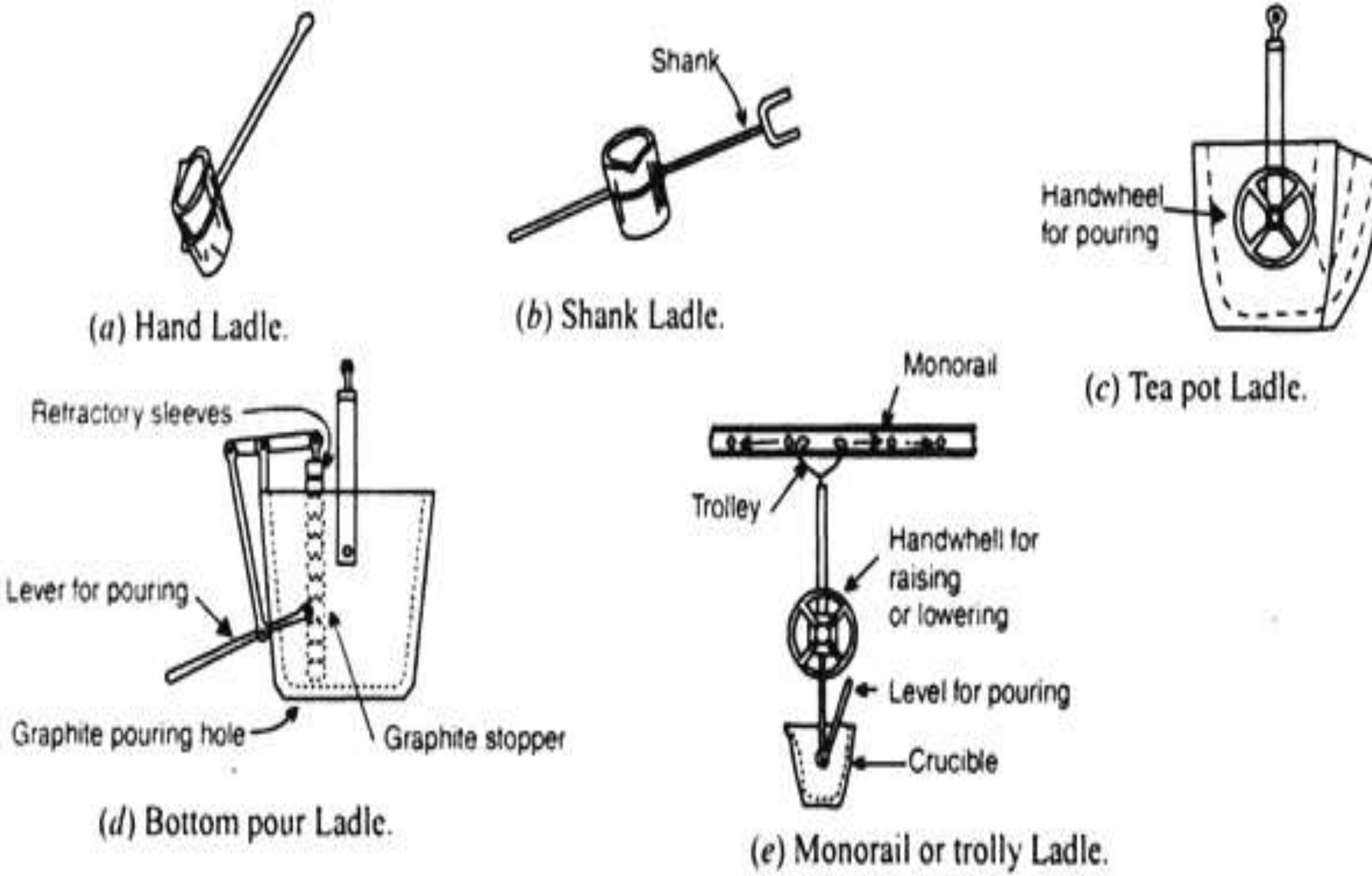
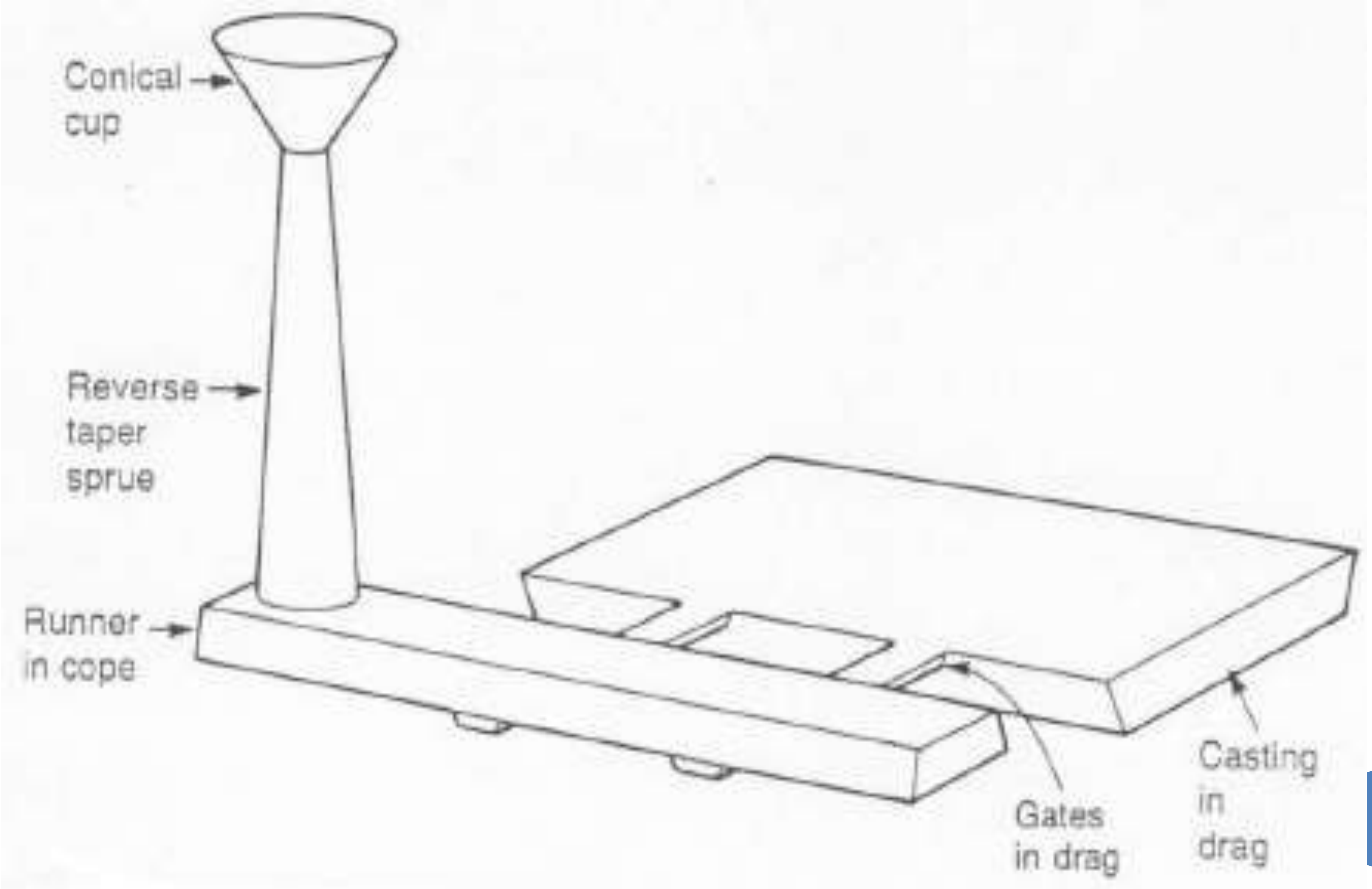
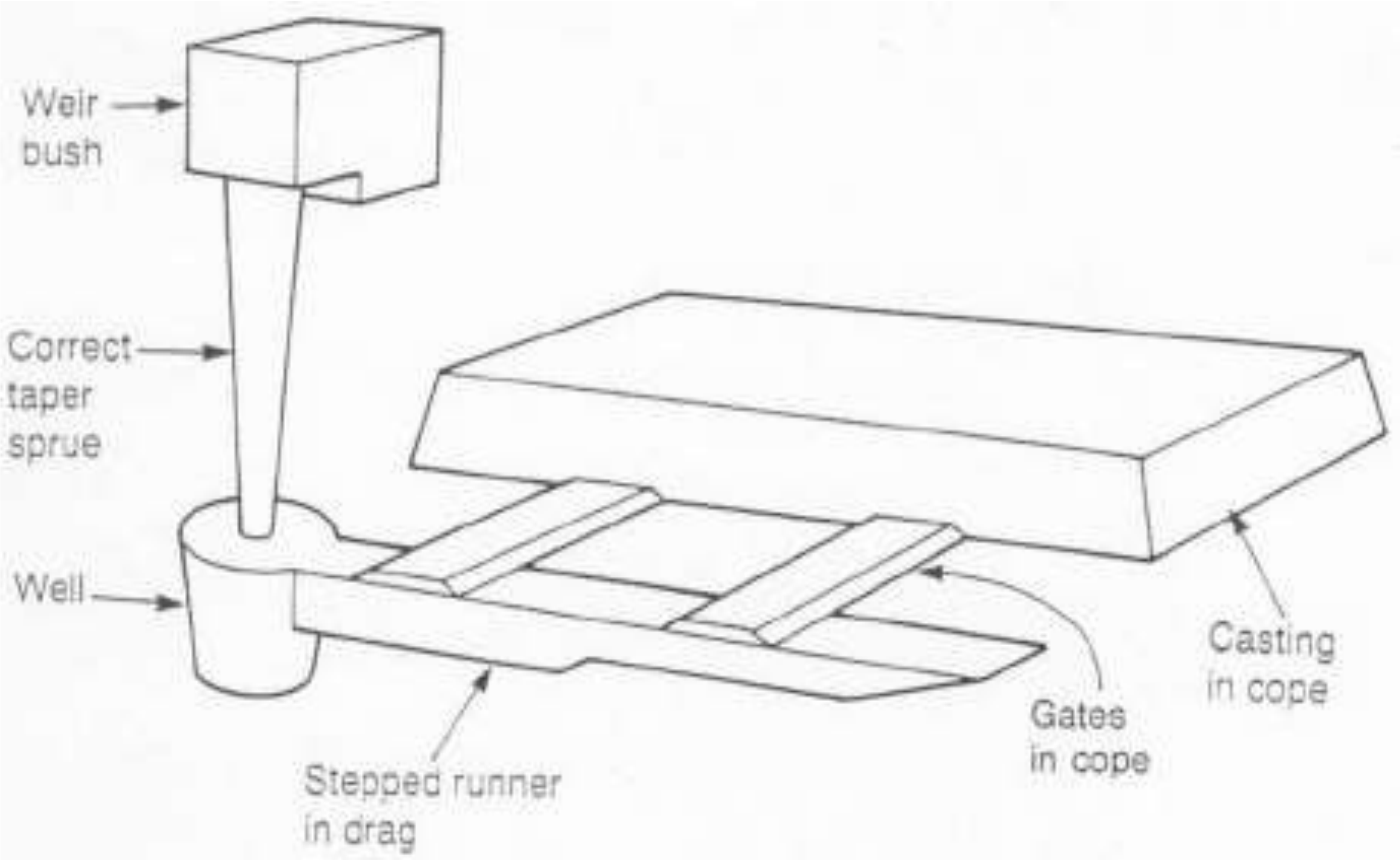


Fig. 4.7. Types of pouring ladles.

A POOR RUNNING & GATING SYSTEM:



A satisfactory running & gating system:



Design of Gating System:

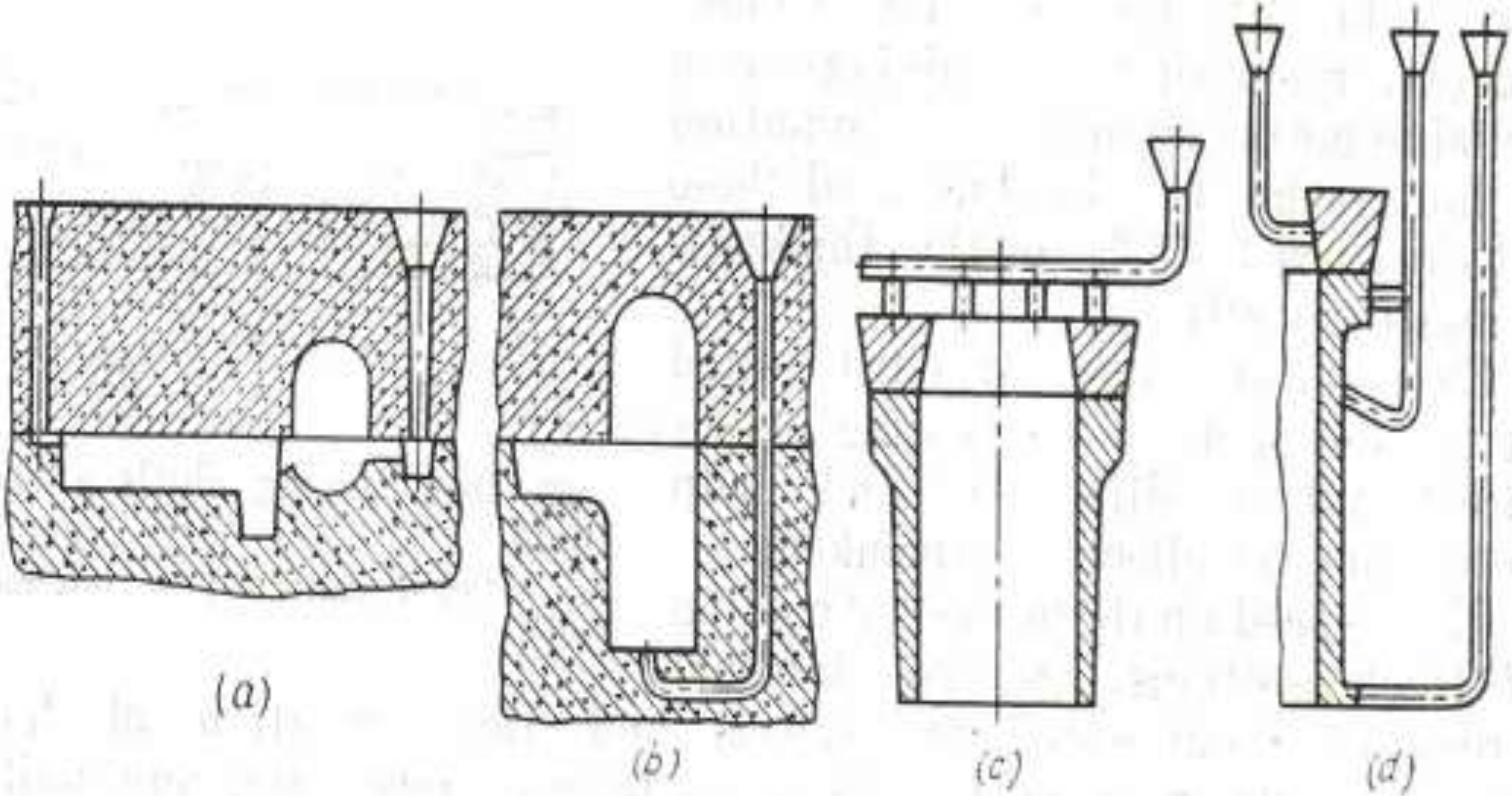


Fig. Designs of gating systems

(a) gating at parting joint; (b) bottom gating; (c) top gating; (d) composite gating

RISERING OF CASTINGS

- A riser is a hole cut or moulded in the cope to permit the molten metal to rise above the highest point in the casting. The riser serves a number of useful purposes. It enables the pourer to see the metal as it falls into the mould cavity. If the metal does not appear in the riser, it signifies that either the metal is insufficient to fill the mould cavity or there is some obstruction to the metal flow between the sprue and riser.

- The riser facilitates ejection of the steam, gas, and air from the mould cavity as the mould is filled with the molten metal. Most important, the riser serves as a feeder to feed the molten metal into the main casting to compensate for its shrinkage.

- The use of several risers may be necessary in the case of an intricate or large casting with thin sections.

- The main requisites of an effective riser are the following:

i. It must have sufficient volume as it should be the last part of the casting to freeze.
ii. It must completely cover the sectional thickness that requires feeding.
iii. The fluidity of the molten metal must be adequately maintained so that the metal can penetrate the portions of the mould cavity freezing towards the end.
iv. It should be so designed that it establishes and effects temperature gradients within the castings so that the latter solidifies directionally towards the riser.

ROLE OF RISER IN SAND CASTING

- Metals and their alloys shrink as they cool or solidify and hence may create a partial vacuum within the casting which leads to casting defect known as shrinkage or void. The primary function of riser as attached with the mould is to feed molten metal to accommodate shrinkage occurring during solidification of the casting.
- As shrinkage is very common casting defect in casting and hence it should be avoided by allowing molten metal to rise in riser after filling the mould cavity completely and supplying the molten metal to further feed the void occurred during solidification of the casting because of shrinkage.

- Riser also permits the escape of evolved air and mould gases as the mould cavity is being filled with the molten metal.
- It also indicates to the foundry man whether mould cavity has been filled completely or not. The suitable design of riser also helps to promote the directional solidification and hence helps in production of desired sound casting.

CONSIDERATIONS FOR DESIGNING RISER

- While designing risers the following considerations must always be taken into account.

(A) Freezing time

1. For producing sound casting, the molten metal must be fed to the mould till it solidifies completely. This can be achieved when molten metal in riser should freeze at slower rate than the casting.
2. Freezing time of molten metal should be more for risers than casting. The quantative risering analysis developed by Caine and others can be followed while designing risers.

FEEDING RANGE

1. When large castings are produced in complicated size, then more than one riser are employed to feed molten metal depending upon the effective freezing range of each riser.
2. Casting should be divided into divided into different zones so that each zone can be feed by a separate riser.
3. Risers should be attached to that heavy section which generally solidifies last in the casting.
4. Riser should maintain proper temperature gradients for continuous feeding throughout freezing or solidifying.

Feed Volume Capacity

1. Riser should have sufficient volume to feed the mould cavity till the solidification of the entire casting so as to compensate the volume shrinkage or contraction of the solidifying metal.
2. The metal is always kept in molten state at all the times in risers during freezing of casting. This can be achieved by using exothermic compounds and electric arc feeding arrangement. Thus it results for small riser size and high casting yield.
3. It is very important to note that volume feed capacity riser should be based upon freezing time and freezing demand. Riser system is designed using full considerations on the shape, size and the position or location of the riser in the mould.

EFFECT OF RISER

- Riser size affects on heat loss from top at open risers. Top risers are expressed as a percentage of total heat lost from the rises during solidification. Risers are generally kept cylindrical. Larger the riser, greater is the percentage of heat that flows out of top.

- Shape of riser may be cylindrical or cubical or of cuboids kind. If shape is cylindrical i.e. 4″ high and 4″ dia, insulated so that heat can pass only into the circumferential sand walls, with a constant K value of min./sq.ft. Chvorinov's rule may be used to calculate the freezing time for cylinder as 13.7 min. The freezing time of a 4″ steel cube of same sand is 6.1 minutes and the freezing time of a 2″, 8″ and 8″ rectangular block is also 6.1 min.

- Since the solidification time as calculated of the cylinder is nearly twice as long as that of either the block of the cube. Hence cylindrical shape is always better. Insulation and shielding of molten metal in riser also plays a good role for getting sound casting

TYPES OF RISERS

- Risers may be classified as *open risers and blind risers*. In the open riser, the upper surface is open to the atmosphere and the riser is usually placed on the top of the casting or at the parting plane. The open riser seldom extends downwards into the drag, i.e., below the parting plane. This riser, therefore, derives feeding pressure from the atmosphere and from the force of gravity on the metal contained in the riser. In case a certain thickness of metal solidifies in the upper part of the riser, atmospheric pressure no longer remains effective, rendering metal flow from the riser to the casting difficult.

- The blind riser, on the other hand, is surrounded by moulding sand on all sides and is in the form of a rounded cavity in the mould placed at the side or top of the casting. It may be located either in the cope or in the drag. Since this riser is closed from all sides, atmospheric pressure is completely shut out. The pressure due to the force of gravity is also reduced due to the formation of vacuum within its body.
- In some of the improved designs, a permeable dry sand core, fitted at the top of the blind riser, extends up through the cope to the atmosphere. Due to its permeable nature, air is able to enter the riser and exert some pressure. There is also less chilling effect, due to the use of dry sand core, and the solidification of the riser is slowed down, thus making it more effective.

- Sometimes, artificial pressure is created in blind risers by putting some explosive substance in the riser cavity. When the substance comes in contact with the molten metal, it explodes, creating high pressure within the riser.

Types of Risers:

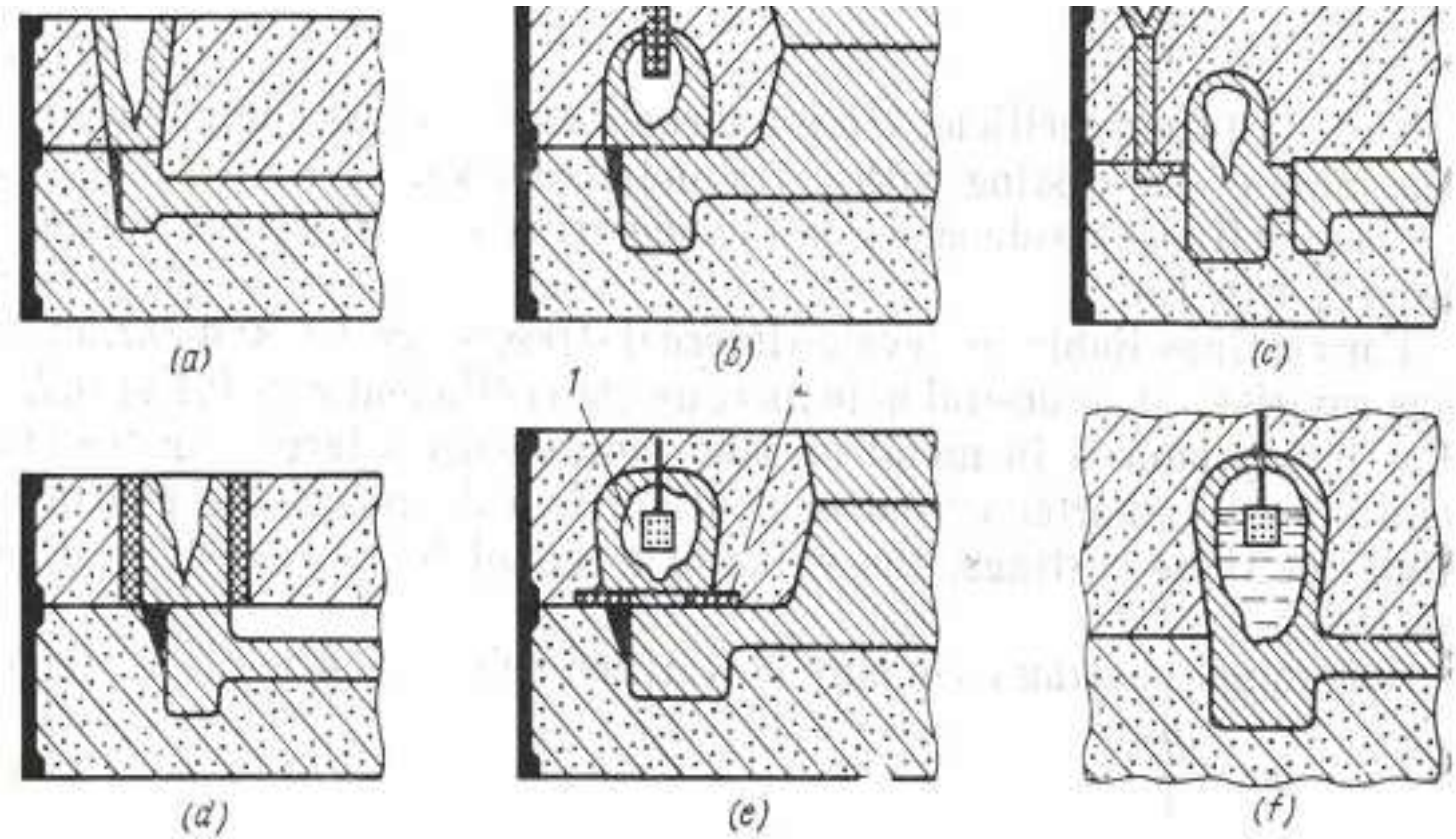


Fig. Ways of placing risers on steel castings

(a) Open Riser (b) Blind riser (c) Side Riser (d) Exothermic Sleeve
(e) Special Cartridge (f) Special Cartridge get decomposed to give heat & melt

DIRECTIONAL SOLIDIFICATION

- *Directional solidification* is the solidification of molten metal from the sprue to the mould cavity and then to the riser to produce a casting which is free from voids and internal cavities.

- As the molten metal cools in the mould and solidifies, it contracts in volume. The contraction of the metal takes place in three stages:
  - (i) Liquid contraction;
  - (ii) Solidification contraction; and
  - (iii) Solid contraction.

- Liquid contraction occurs when the molten metal cools from the temperature at which it is poured to the temperature at which solidification commences. Solidification contraction takes place during the time the metal changes from the liquid state to the solid, e.g., when the metal loses its latent heat. Solid contraction spans the period when the solidified metal cools from freezing temperature to room temperature.

- Only the first two of these shrinkages are considered for risering purposes, since the third is accounted for by the patternmaker's contraction allowance. Of the first two types, liquid shrinkage is generally negligible but solidification contraction is substantial and should therefore be considered.

- Since all the parts of the casting do not cool at the same rate, owing to varying sections and differing rates of heat loss to adjoining mould walls, some parts tend to solidify more quickly than others. This contraction phenomenon causes voids and cavities in certain regions of the casting.
- These voids must be filled up with liquid metal from the portion of the casting that is still liquid and the solidification should continue progressively from the thinnest part, which solidifies, first, towards the risers, which should be the last to solidify.
- If the solidification takes place in this manner, the casting will be sound with neither voids nor internal shrinkage. This process is known as directional solidification, and ensuring its progress should be a constant endeavor for the production of sound castings.

- In actual practice, however, it may not always be easy to fully achieve directional solidification owing to the shape and design of the casting, the type of casting process used, and such other factors. In general, directional solidification can be controlled by
  - Proper design and positioning of the gating

    system and risers Inserting insulating sleeves for

    risers
  - The use of padding to increase the thickness of certain sections of the casting
  - Adding exothermic material in the risers or in the facing sand around

    certain portions of the castings
  - Employing chills in the Moulds
  - Providing blind risers

DESIGN AND POSITIONING OF RISERS

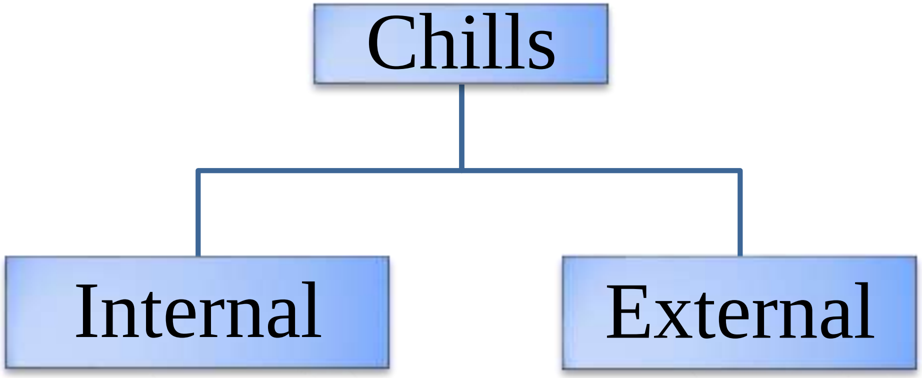
- *Riser Shape and Size*
- *Riser Location*
- *Types of Risers*
- *Riserless Design*
- *Use of Padding*
- *Use of Exothermic Materials*
- *Use of Chills*

Chills

Introduction

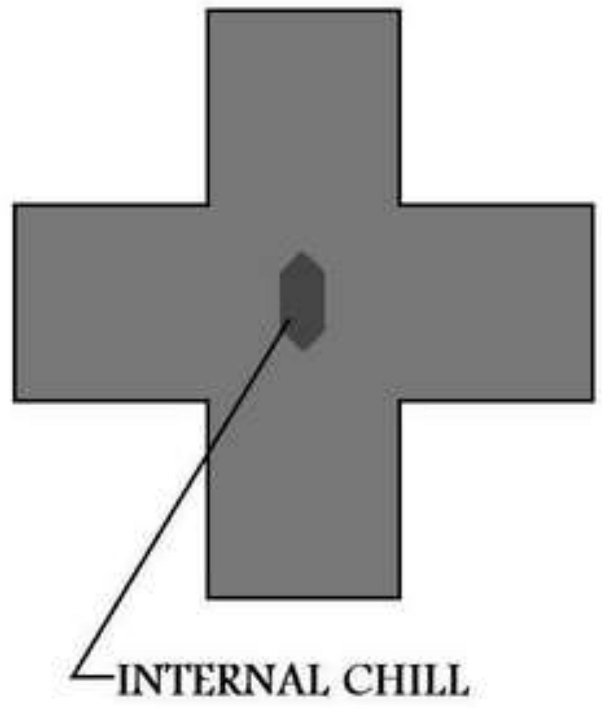
- A chill is an object used to promote solidification in a specific portion of a metal casting mold.
- Chill blocks are inserted into the mold to enhance the feeding distance by creating a steeper temperature gradient. The chill surface in contact with the casting must be clean and dry.
- Chills can be used with a thin refractory coating or carbon black. Cast iron or steel chills, for all practical purposes, are equally effective. Water-cooled copper chills are more effective than uncooled cast iron or graphite. Graphite chills may deteriorate with use.

Classification of Chills



Internal chills

- Internal chills are pieces of metal that are placed inside the molding cavity. When the cavity is filled, part of the chill will melt and ultimately become part of the casting, thus the chill must be the same material as the casting. Internal chills will absorb both heat capacity and heat of fusion energy.
- Internal chills are placed internally at locations in the mold cavity that can't be reached with external chills.
- Internal chill use is more problematic than external chills. In external chills, the makeup isn't as critical because they are outside the cavity; in internal chills the metal used must be compatible with the metal being poured.
- In addition, the chill must have a melting temperature nearly equal to that of the metal being poured. Sometimes, internal chills do not fuse completely with the casting, thus establishing points of weakness, such as lack of pressure tightness and radiographic unsoundness.
- Because internal chills will be completely surrounded by metal, it is critical that they be clean. Gas created from unclean internal chills can't readily escape.



External chills

- External chills are masses of material that have a high heat capacity and thermal conductivity. They are placed on the edge of the molding cavity, and effectively become part of the wall of the molding cavity. This type of chill can be used to increase the feeding distance of a riser or reduce the number of risers required.
- External chills are shapes usually made of steel, iron, graphite, chromite or copper. They are placed where hot spots or slow freezing rates may occur, these chills are normally rammed up with the pattern and become part of the mold wall. They not only promote directional solidification but also affect temperature gradients that reduce the possibility of micro-porosity.
- External chills are used effectively at junctions or other portions of the casting that are difficult to feed with risers.
- Chill size is determined by the cooling requirement. Generally, a chill's thickness shouldn't be less than that of the metal section it is chilling. They are frequently covered with a protective wash, silica flour or other refractory material.