ME220 MANUFACTURING TECHNOLOGY

SYLLABUS

Casting –patterns - Cores – Gating – Risering – Defects in Castings - Rolling –Defects in Rolled parts- forging – Coining – Heading – Piercing –Die Design– Extrusion Process– Extrusion Defects – Drawing Process -Principles of Location –Principles of Clamping – Types of Clamp -Sheet metal characteristics –Deep drawing –Spinning –Definition of Welding – Weldability – Solidification of Weld Metal – Heat Affected Zone – Welding Defects - Gas Welding -Arc Welding - Ultrasonic Welding – Friction Welding – Resistance Welding — Brazing- Soldering.

Course Objectives:-

1. To give an exposure to different techniques of casting and molds required.
2. To provide an exposure to different rolling processes and different rolled products
3. To familiarize with different forging methods, cautions to be adopted in die design.
4. To give an introduction to various work and tool holding devices used in manufacturing.
5. To introduce to the bending, shearing and drawing processes of sheet metal working and allied machines,
6. To give an understanding of welding metallurgy and weldability and to introduce various metal joining techniques.

Expected outcomes: .

1. Acquire knowledge in various casting processes and technology related to them.
2. Understand the rolling passes required for getting required shapes of rolled products.
3. Discuss important aspects of forging techniques
4. Discuss sheet metal working processes and their applications to produce various shapes and products.
5. Acquire knowledge in various types of welding processes.

MODULE 1

I	Sand Casting – Sand Molds-Types of Molding Sands and Testing	1	15%
	Type of patterns - Pattern Materials	1	
	Cores –Types and applications –Sand Molding Machines	1	
	Gating System – Risering	1	
	Shell Mold Casting – Ceramic Mold Casting	1	
	Investment Casting – Vacuum Casting – Slush Casting	1	
	Pressure Casting – Die Casting – Centrifugal Casting	1	
	Design Considerations based on Various Shapes - Defects in Castings – simple problems in casting	1	

MODULE 1

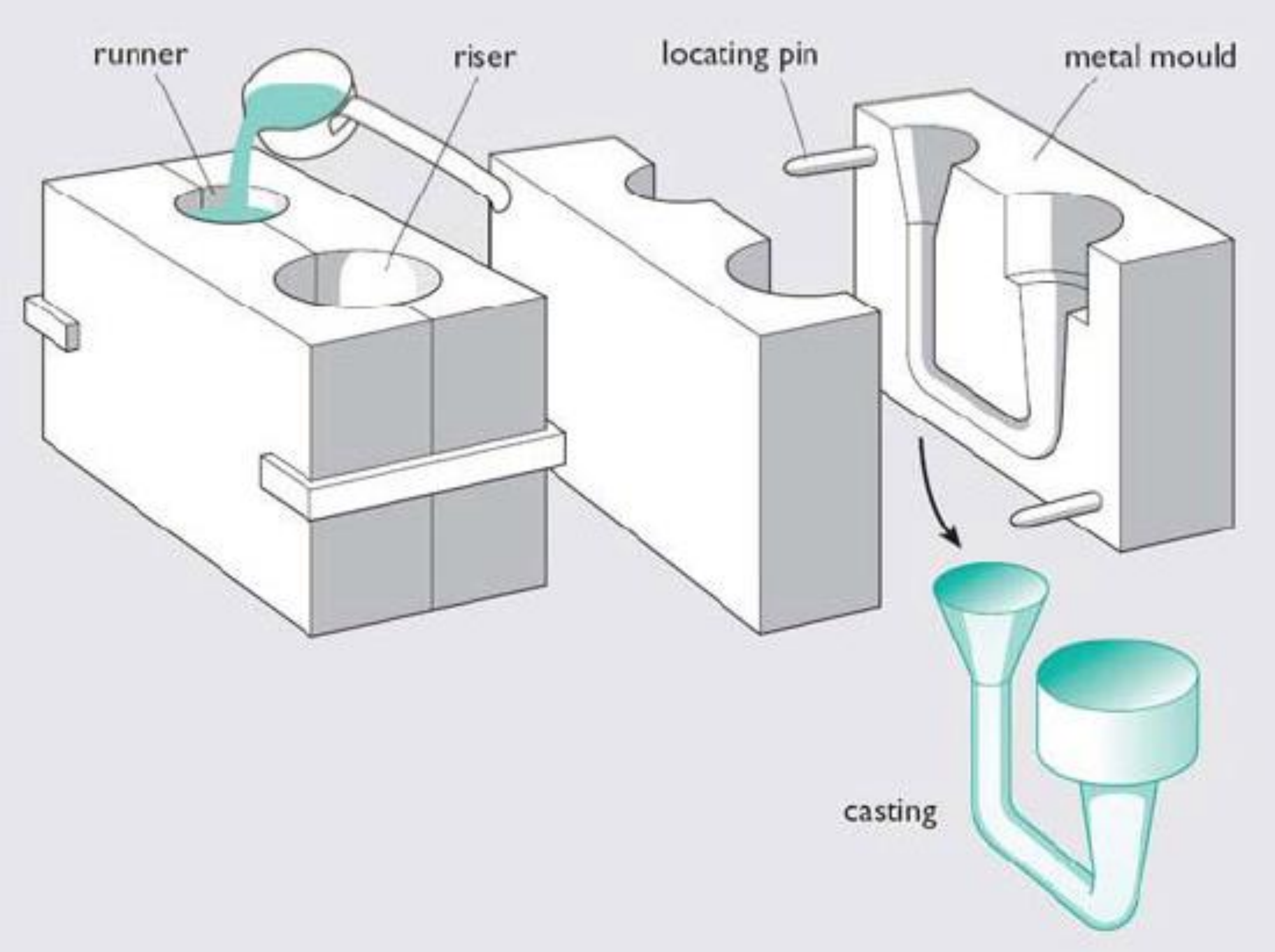
CASTING PROCESS

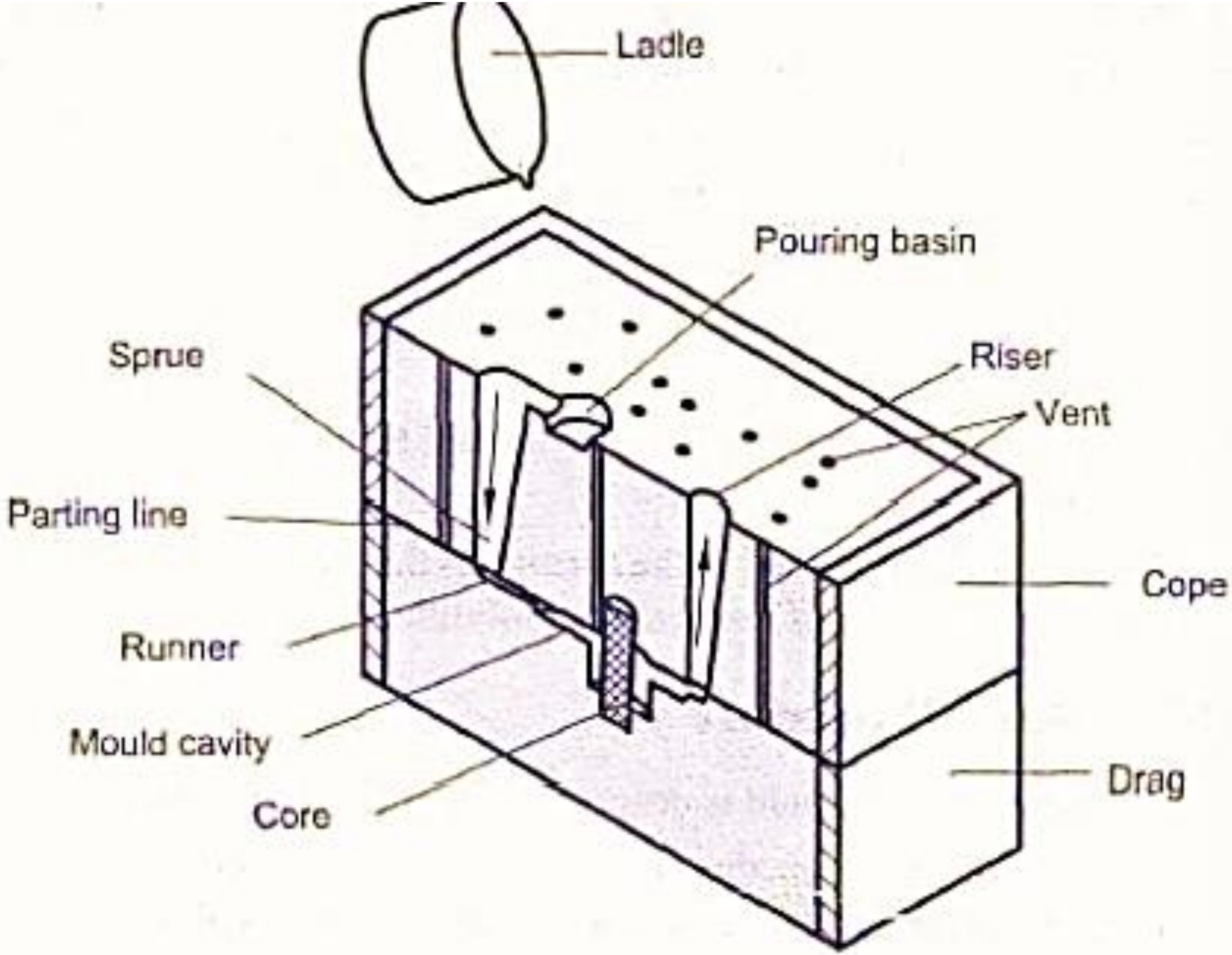
Steps:

- Making mould cavity
- Material is first liquefied by properly heating it in a suitable furnace.
- Liquid is poured into a prepared mould cavity - allowed to solidify
- product is taken out of the mould cavity, trimmed and made to shape

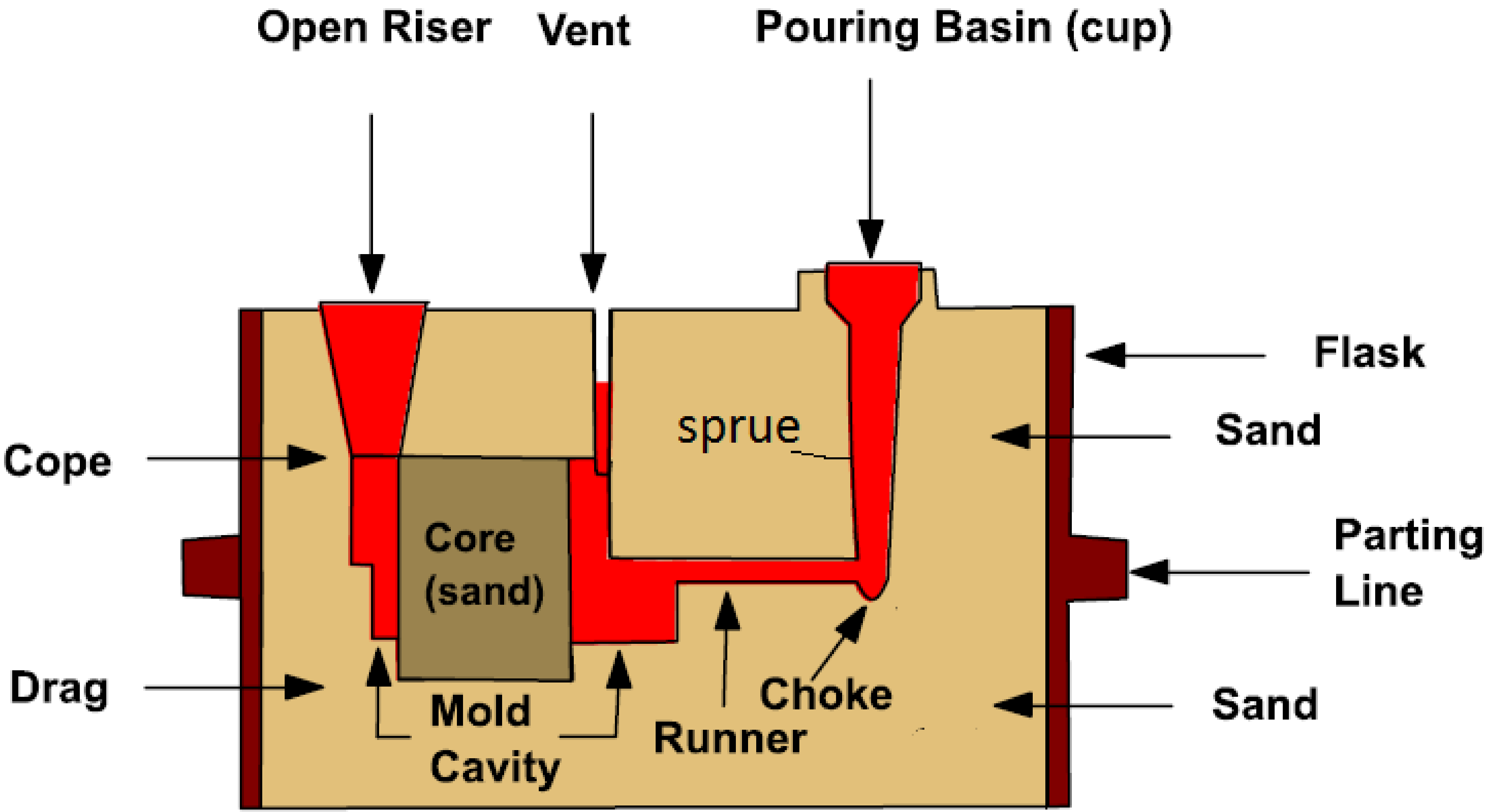
Important casting terms

1. FLASK – Cope, drag and Cheek
2. PATTERN
3. PARTING LINE
4. MOULDING SAND
5. FACING SAND
6. CORE
7. POURING BASIN
8. SPRUE
9. RUNNER
10. GATE
11. CHAPLETS
12. RISER
13. VENT

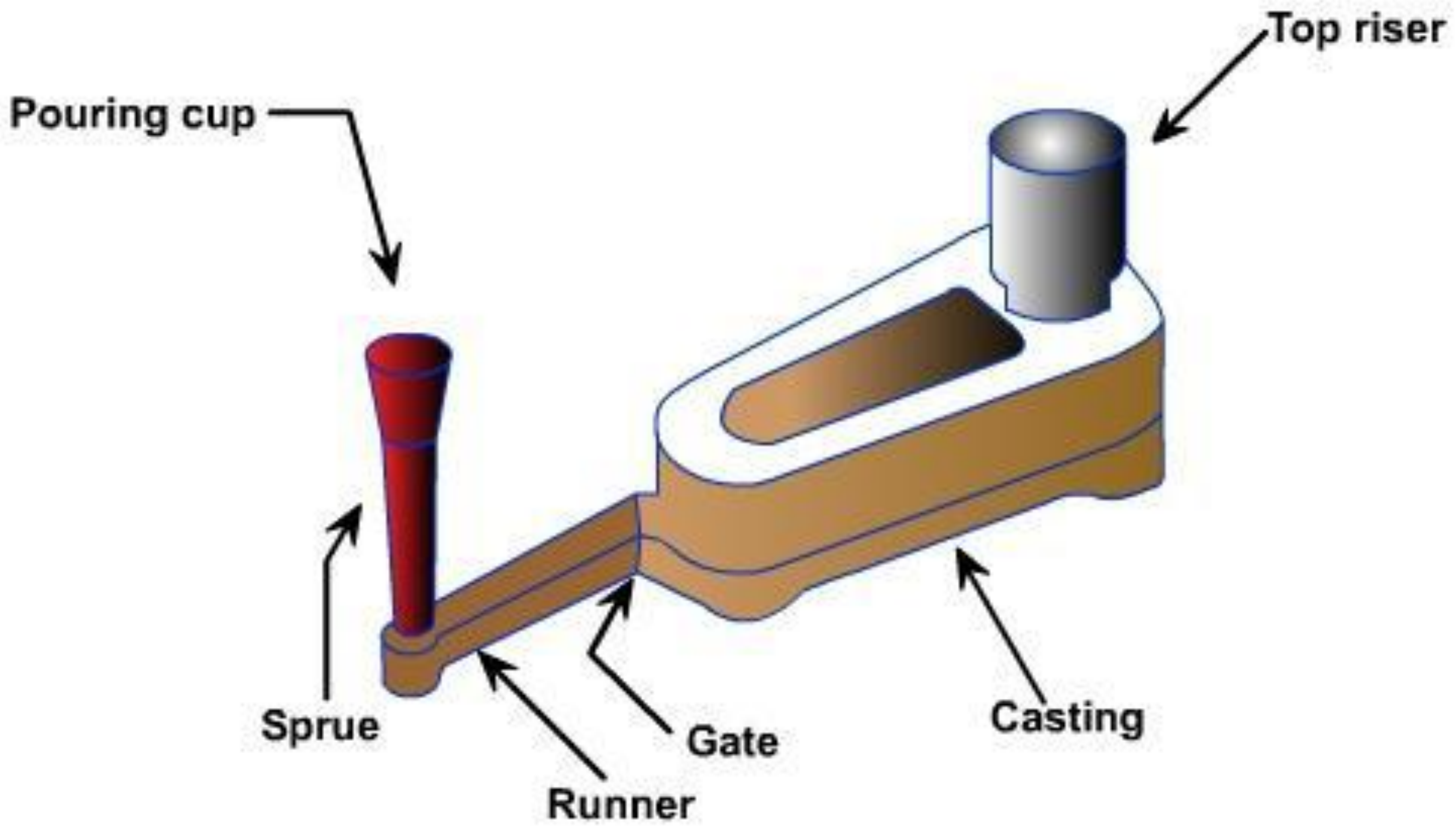

runner
riser
locating pin
metal mould
casting


Ladle
Pouring basin
Sprue
Riser
Vent
Parting line
Cope
Runner
Mould cavity
Drag
Core

Typical sand mould



Mould Section and casting nomenclature



Pattern attached with gating and risering system

Steps in making sand castings

Six basic steps in making sand castings are,

(i) Pattern making,

(ii) Core making,

(iii) Moulding,

(iv) Melting and pouring,

(v) Cleaning

MAKING A SIMPLE SAND MOULD

1) The drag flask is placed on the board

2) Dry facing sand is sprinkled over the board

3) Drag half of the pattern is located on the mould board. Dry facing sand will provide a non-sticky layer.

4) Molding sand is then poured in to cover the pattern with the fingers and then the drag is filled completely

5) Sand is then tightly packed in the drag by means of hand rammers. Peen hammers (used first close to drag pattern) and butt hammers (used for surface ramming) are used.

6) The ramming must be proper i.e. it must neither be too hard or soft. Too soft ramming will generate weak mould and imprint of the pattern will not be good. Too hard ramming will not allow gases/air to escape and hence bubbles are created in casting resulting in defects called ‘blows’. Moreover, the making of runners and gates will be difficult.

7) After the ramming is finished, the excess sand is leveled/removed with a straight bar known as strike rod.

8) Vent holes are made in the drag to the full depth of the flask as well as to the pattern to facilitate the removal of gases during pouring and solidification. Done by vent rod.

9) The finished drag flask is now made upside down exposing the pattern.

10) Cope half of the pattern is then placed on the drag pattern using locating pins. The cope flask is also located with the help of pins. The dry parting sand is sprinkled all over the drag surface and on the pattern.

11) A sprue pin for making the sprue passage is located at some distance from the pattern edge. Riser pin is placed at an appropriate place.

12) Filling, ramming and venting of the cope is done in the same manner.

13) The sprue and riser are removed and a pouring basin is made at the top to pour the liquid metal.

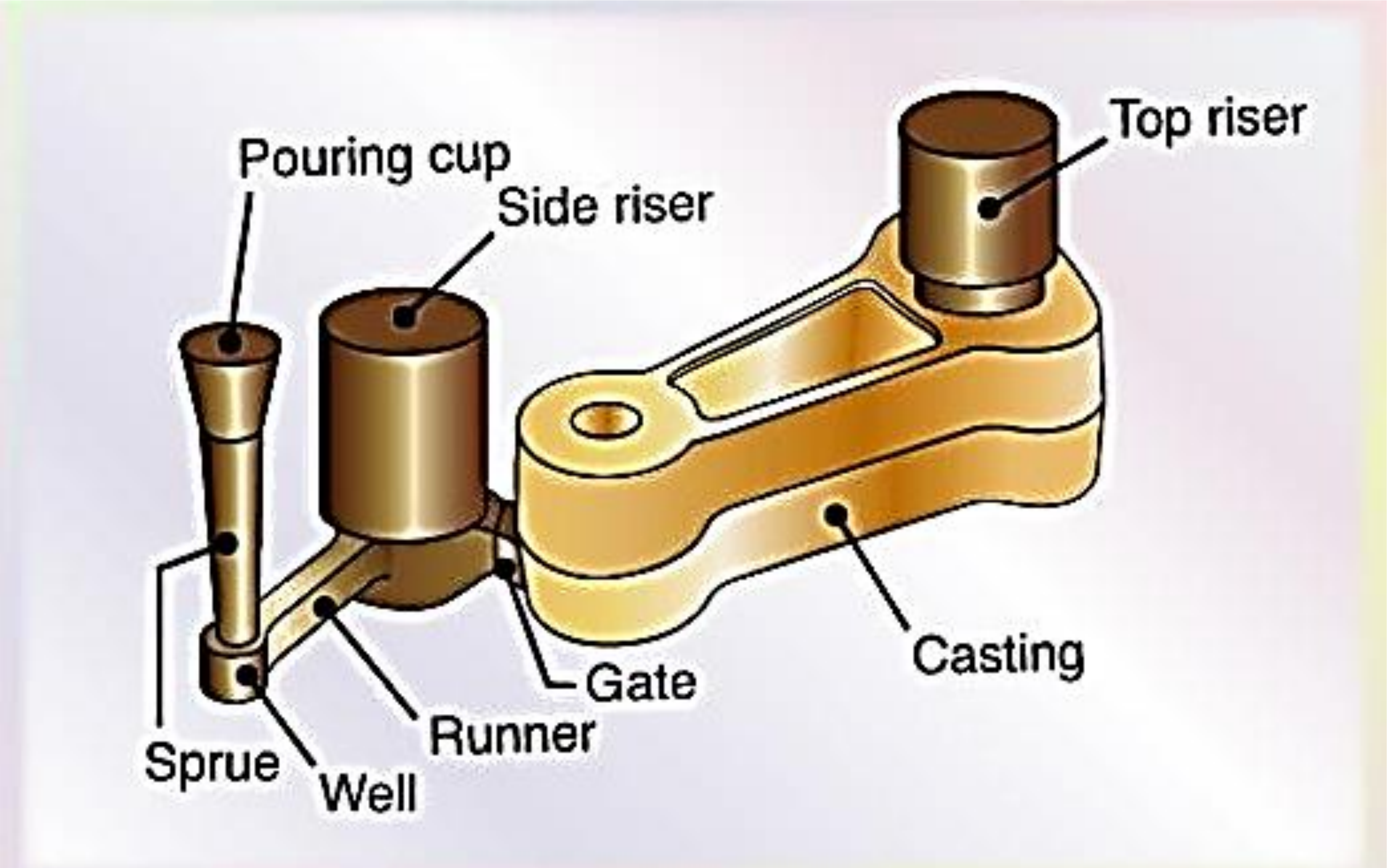
14) Pattern from the cope and drag is removed.

15) Runners and gates are made by cutting the parting surface with a gate cutter. A gate cutter is a piece of sheet metal bent to the desired radius.

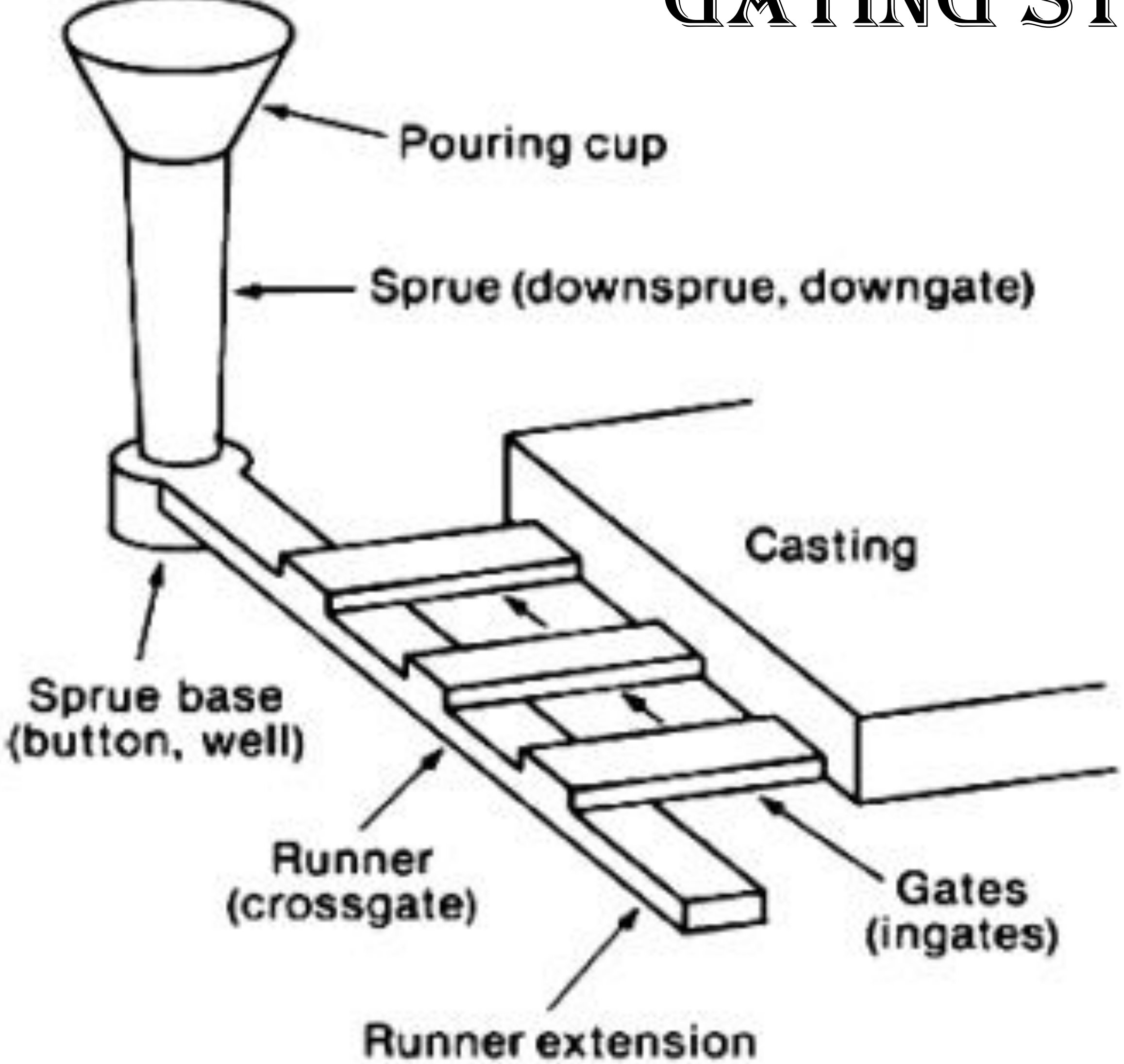
16) The core for making a central hole is now placed into the mould cavity in the drag. Rests in core prints.

17) Mould is now assembled and ready for pouring.

GATING SYSTEM & RISERING SYSTEM


Pouring cup
Side riser
Top riser
Sprue
Well
Runner
Gate
Casting

GATING SYSTEM



Basic elements of gating system

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

- A good gating design should ensure proper distribution of molten metal without excessive temperature loss, turbulence, gas entrapping and slags.

- Very slow pouring, require longer filling time and solidification will start even before filling of mould.

This can be restricted by using **super heated metal**, but in this case **gas solubility will be a problem.**

- Faster pouring can erode the mould cavity.

- So gating design is important and it depends on the metal and molten metal composition. For example, aluminium can get oxidized easily.

Gating systems refer to **all those elements** which are connected with the **flow of molten metal** from the ladle to the mould cavity.

- Pouring Basin
- Sprue
- Sprue Base Well
- Runner
- Runner Extension
- Gate or Ingate
- Riser

The purpose of gating system is to deliver the molten metal to mold.

A gating system should be able to do the following:

1. Permit complete filling of the mold cavity
2. Requires minimum time to fill the mold cavity
3. Minimum turbulence so as to minimize gas pickup
4. Regulate rate at which molten metal enters the mold cavity
5. Prevent unwanted material from entering mould cavity
6. Establish suitable temperature gradients

7. No mould erosion

8. Simple and economical design

9. Easy to implement and remove after solidification

10. Maximum casting yield

Casting yield

$$C_y = \frac{W_c}{W_c + W_g} \times 100\%$$

1. **Pouring basin** : This is otherwise called as bush or cup. It is circular or rectangular in shape. It collects the molten metal, which is poured, from the ladle.

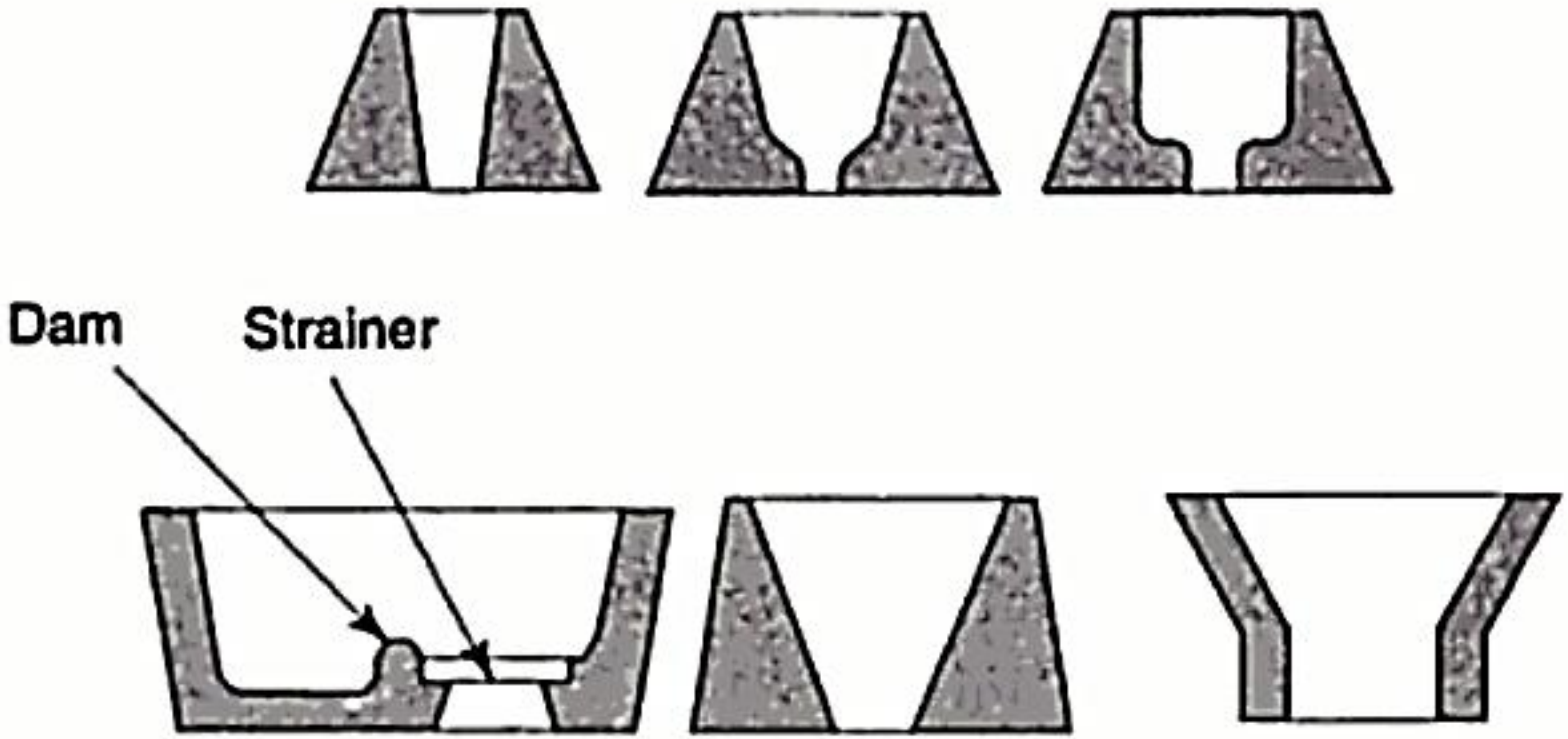
2. **Sprue** : It is circular in cross section. It leads the molten metal from the pouring basin to the sprue well.

3. **Sprue Well** : It changes the direction of flow of the molten metal to right angle and passes it to the runner.

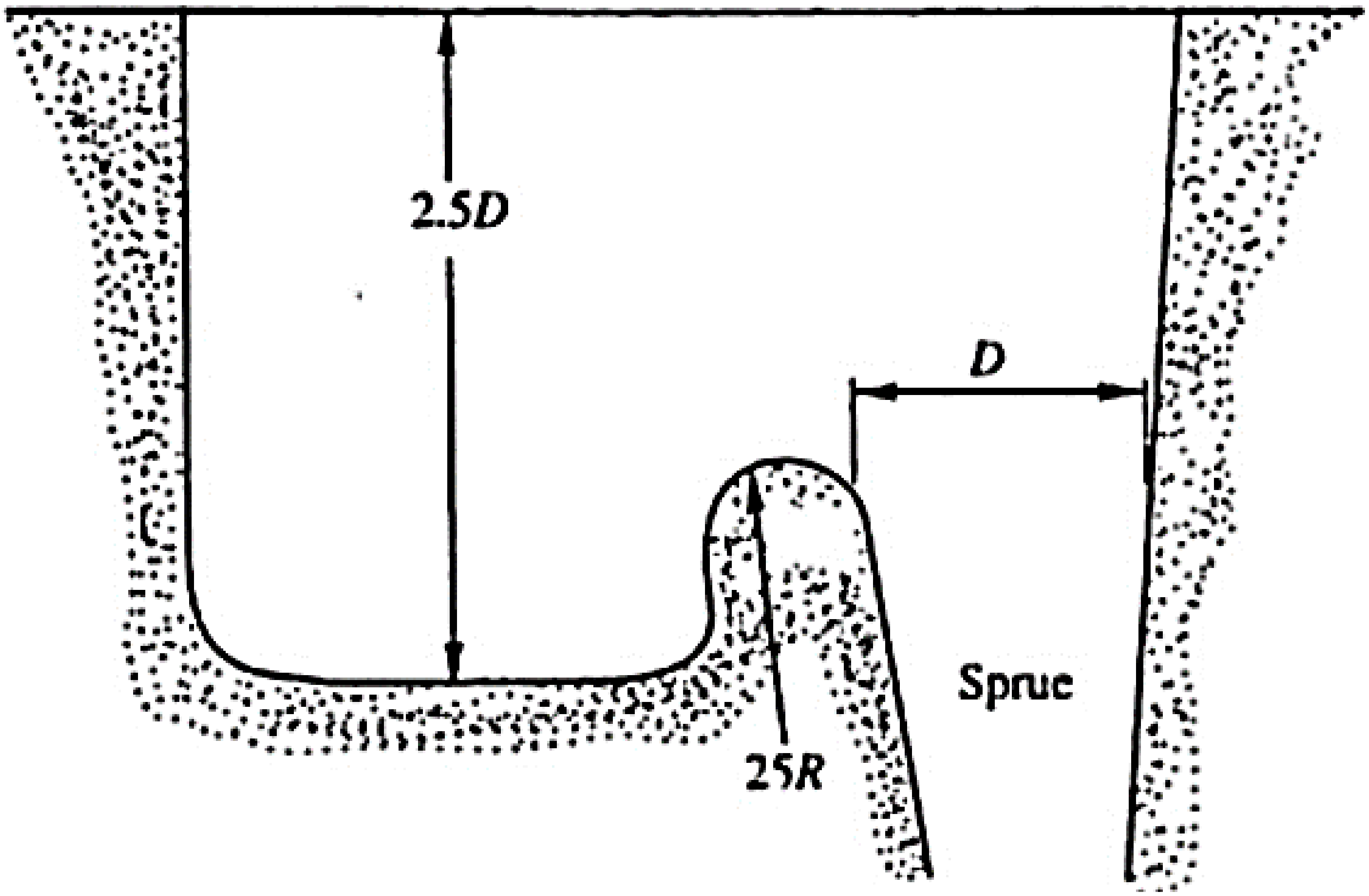
4. **Runner** : The runner takes the molten metal from sprue to the casting. Ingate: This is the final stage where the molten metal moves from the runner to the mold cavity.

5. **Slag trap** : It filters the slag when the molten metal moves from the runner and ingate. It is also placed in the runner

TYPES OF POURING BASINS

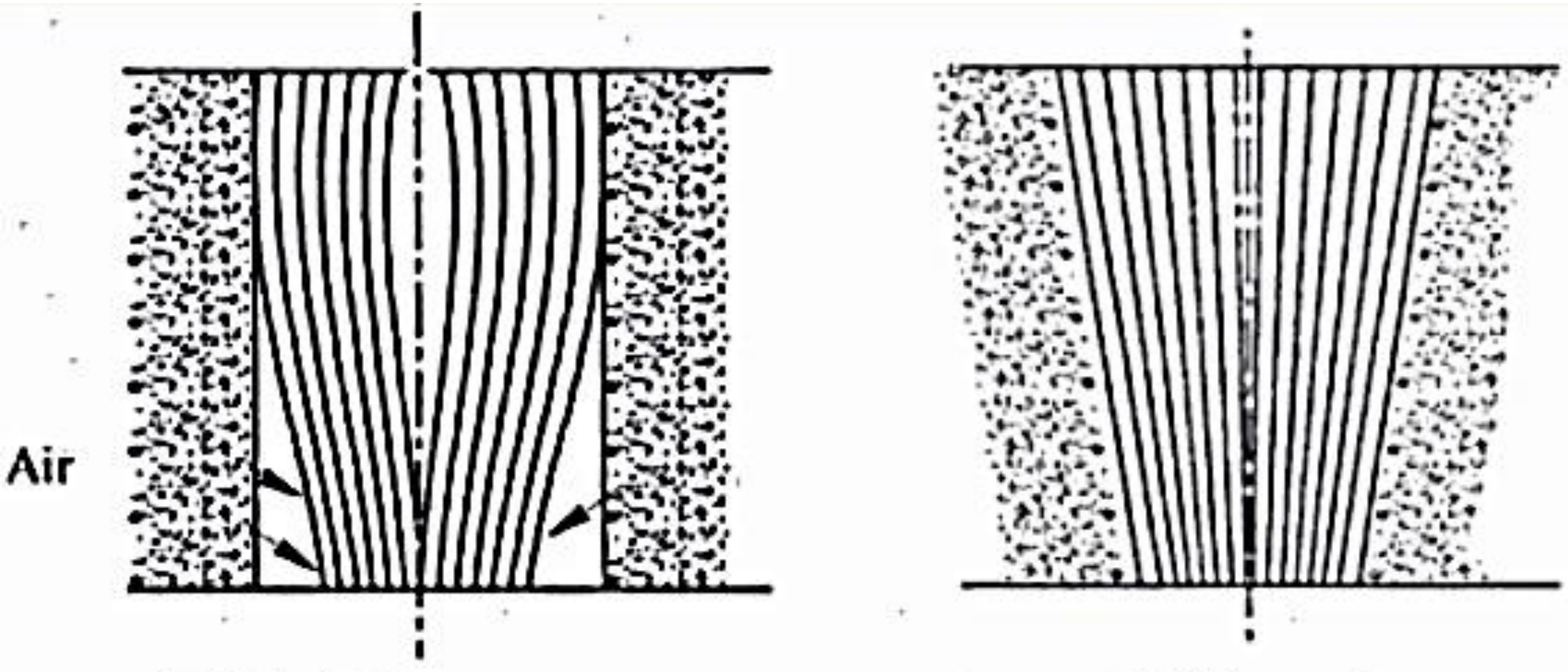


POURING BASIN DESIGN



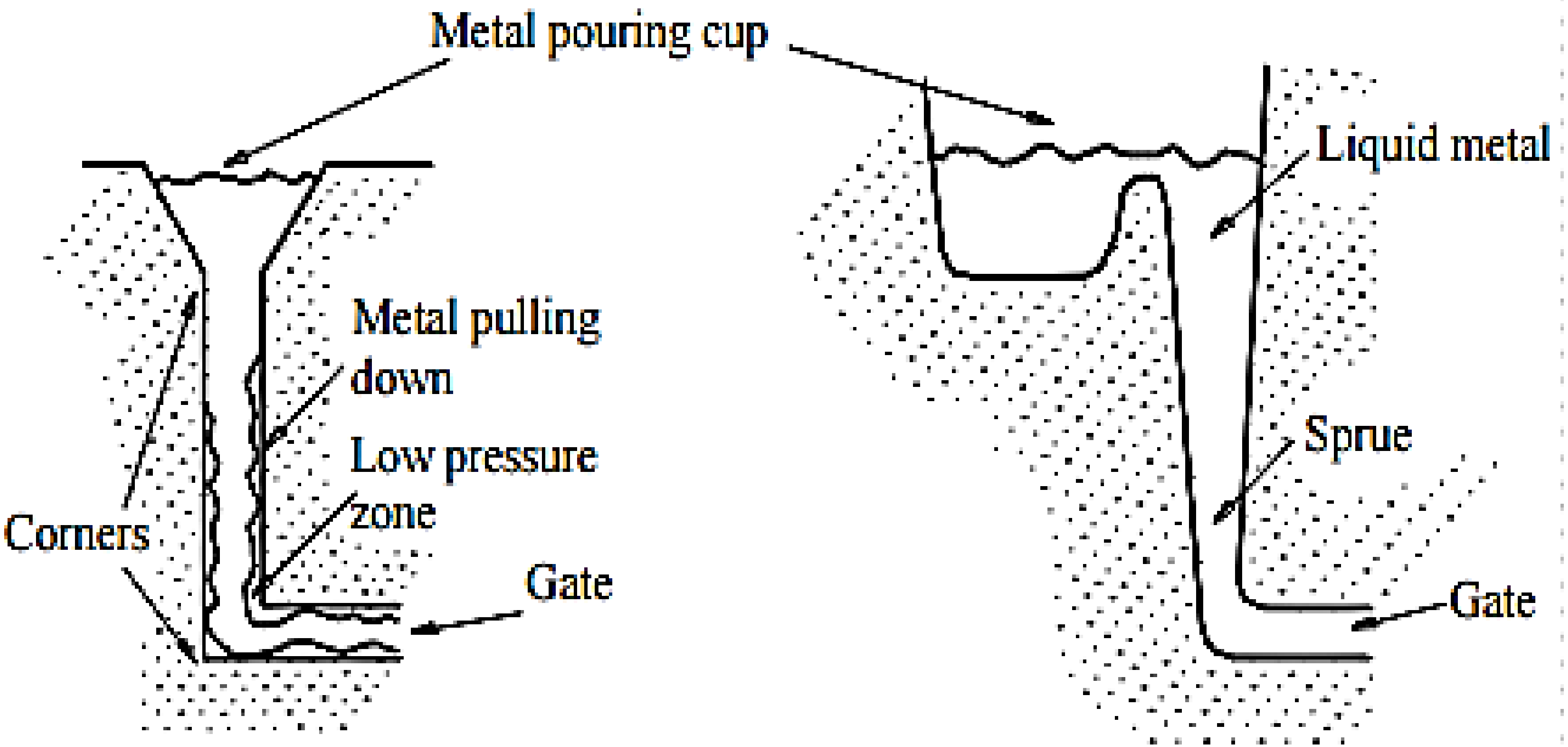
- **Sprue** : It is circular in cross section. It leads the molten metal from the pouring basin to the sprue well.

- **Sprue Well** : It changes the direction of flow of the molten metal to right angle and passes it to the runner.



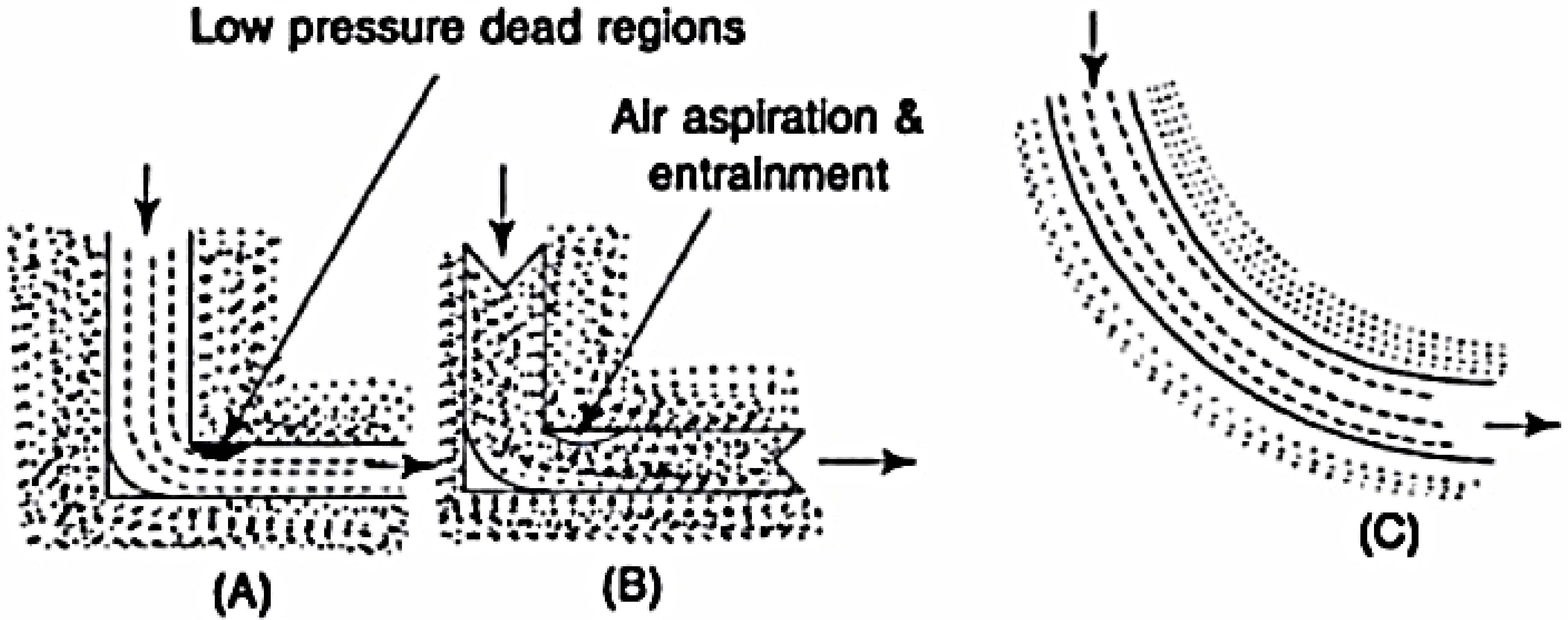
(a) Straight sprue (b) Tapered

SPRUE

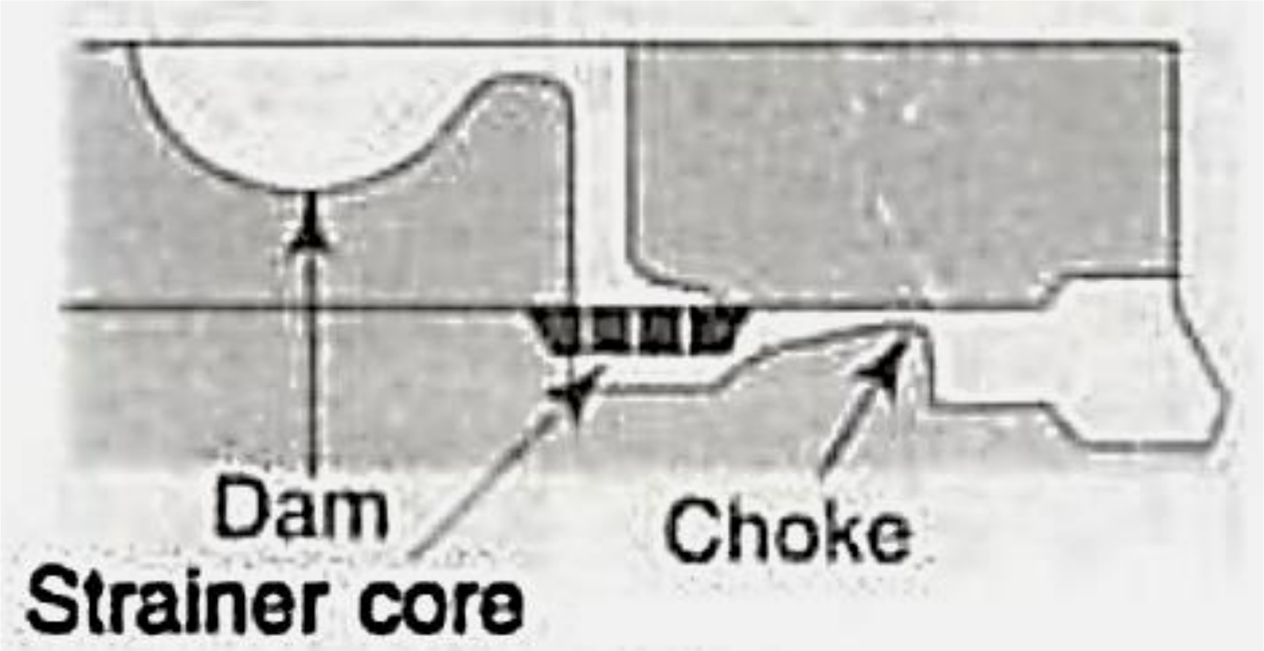


(a) Straight sprue

(b) Tapered sprue


Low pressure dead regions
Air aspiration & entrainment
(A)
(B)
(C)

- **Slag trap** : It filters the slag when the molten metal moves from the runner and ingate.



- **Runner** : The runner takes the molten metal from sprue to the Ingates of casting.

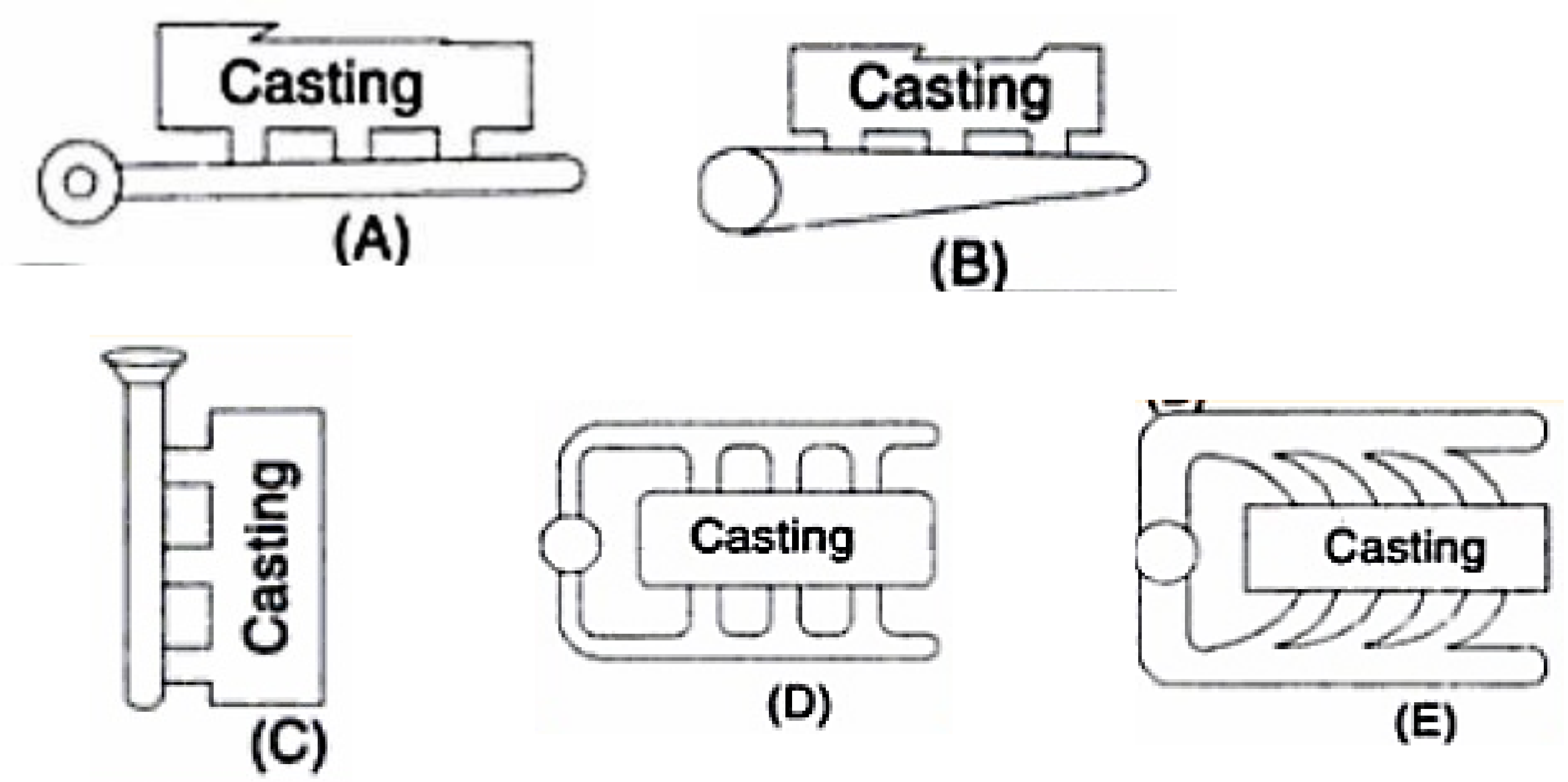
  a) Straight runner

  b) Tapered runner

  c) Step gate (may also act as feeder)

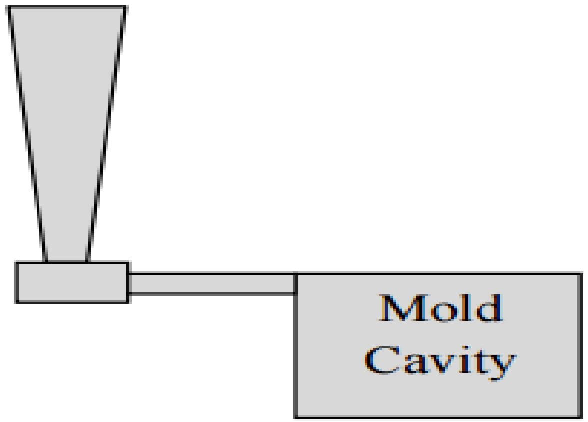
  d) Uniform size runner

  e) Runner for even distribution of metal

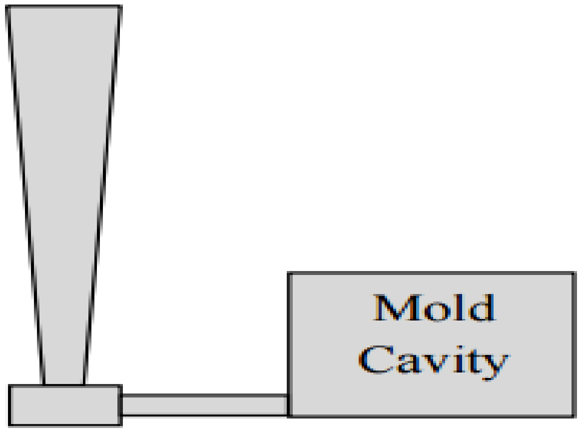

Casting
(A)
Casting
(B)
Casting
(C)
Casting
(D)
Casting
(E)

TYPES OF GATES

- **Down gates or sprue**
- **Cross gates or runners**
- **Ingates or gates**

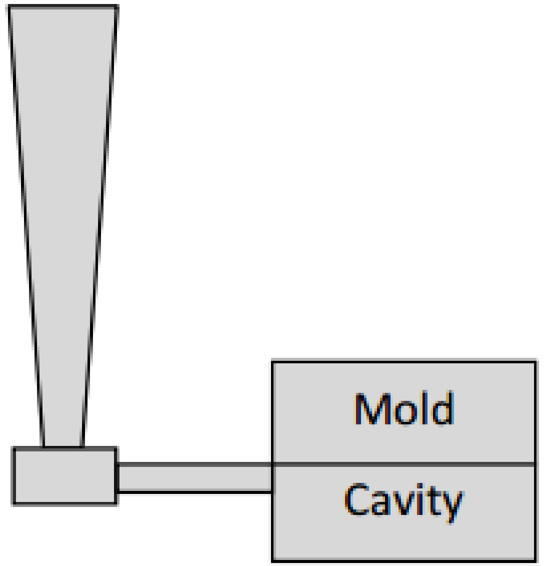


(a) Top gating



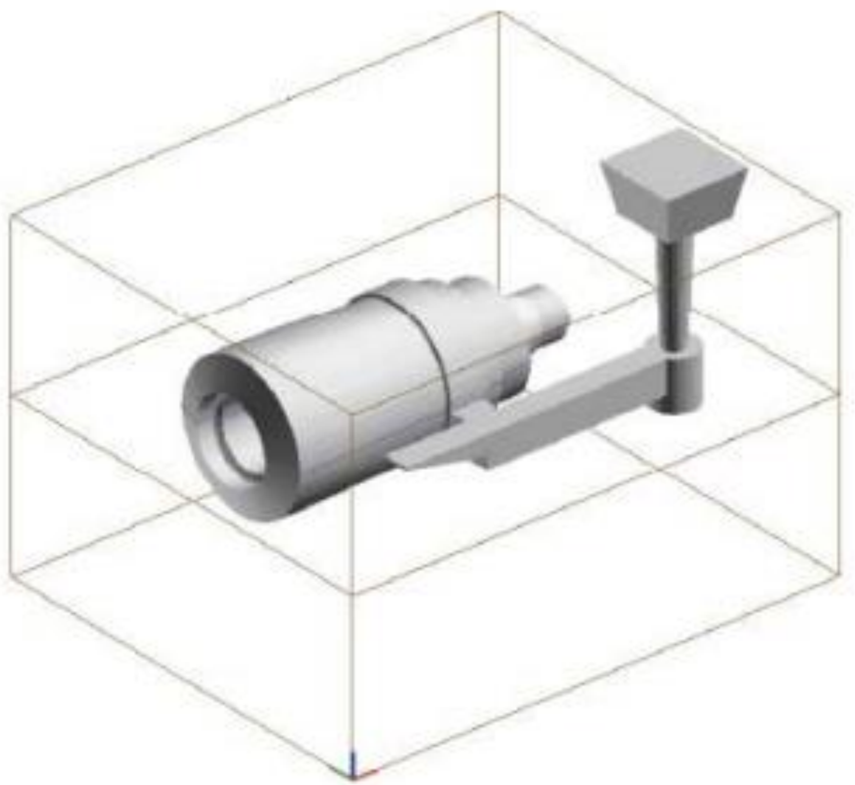
(b) Bottom gating

Depending upon the position of ingate(s)

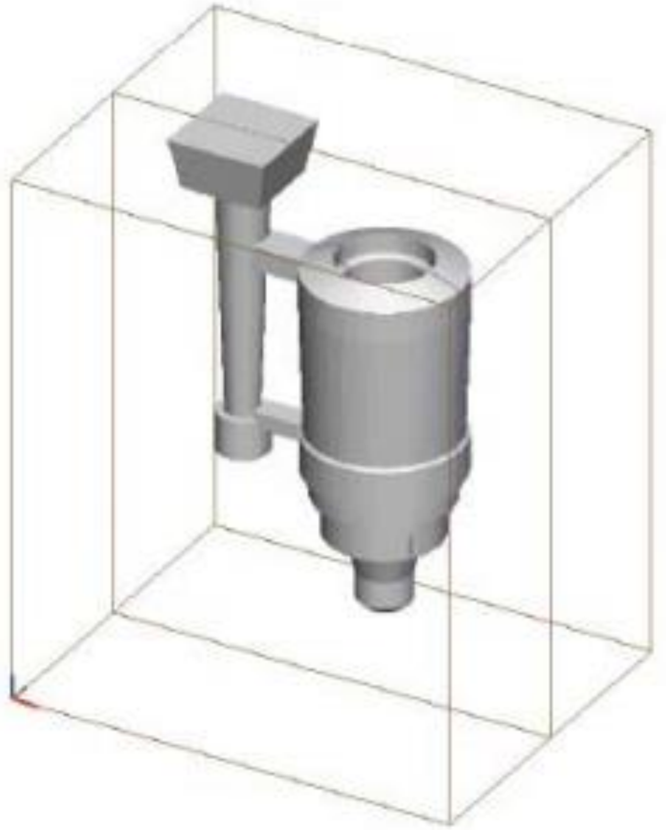


(c) Parting line gating

Depending upon the orientation of the parting plane



(a) Horizontal gating system



(b) Vertical gating system

Depending on the ratio of total cross sectional area of sprue exit, runner and ingate

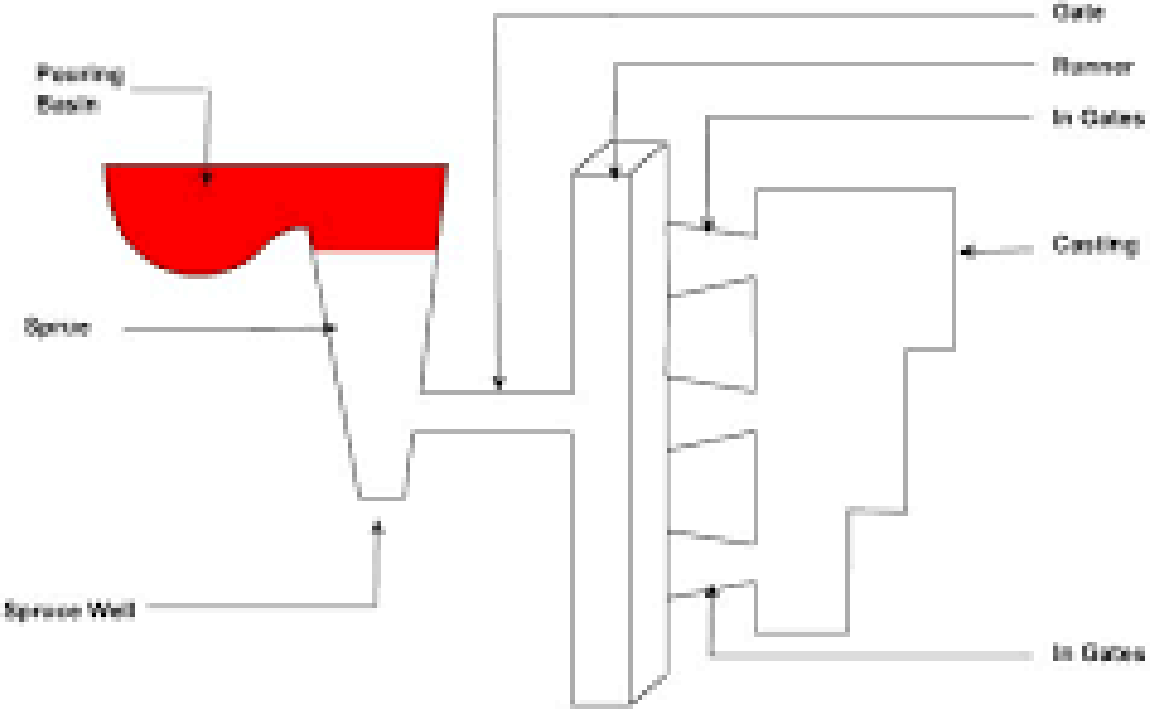
1. Pressurized gating system

2. Un-pressurized gating system

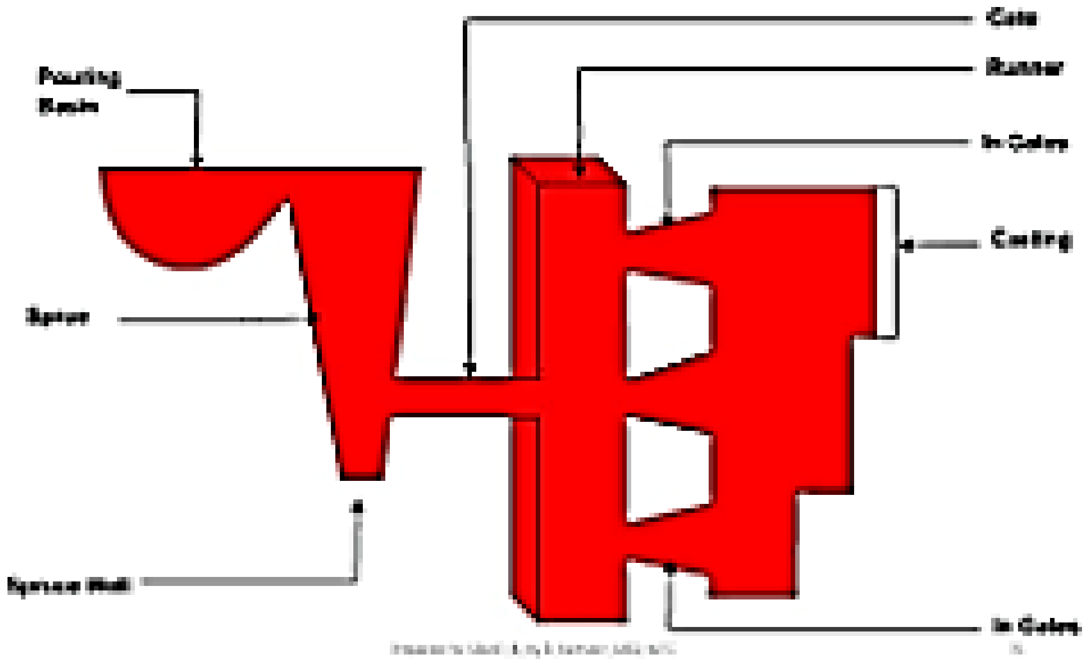
Pressurized Gating System

1. The total cross sectional area decreases towards the mold cavity
2. Back pressure is maintained by the restrictions in the metal flow
3. Flow of liquid (volume) is almost equal from all gates
4. Back pressure helps in reducing the aspiration as the sprue always runs full
5. Because of the restrictions the metal flows at high velocity leading to more turbulence and chances of mold erosion

Pressurized



Un-pressurized gating system



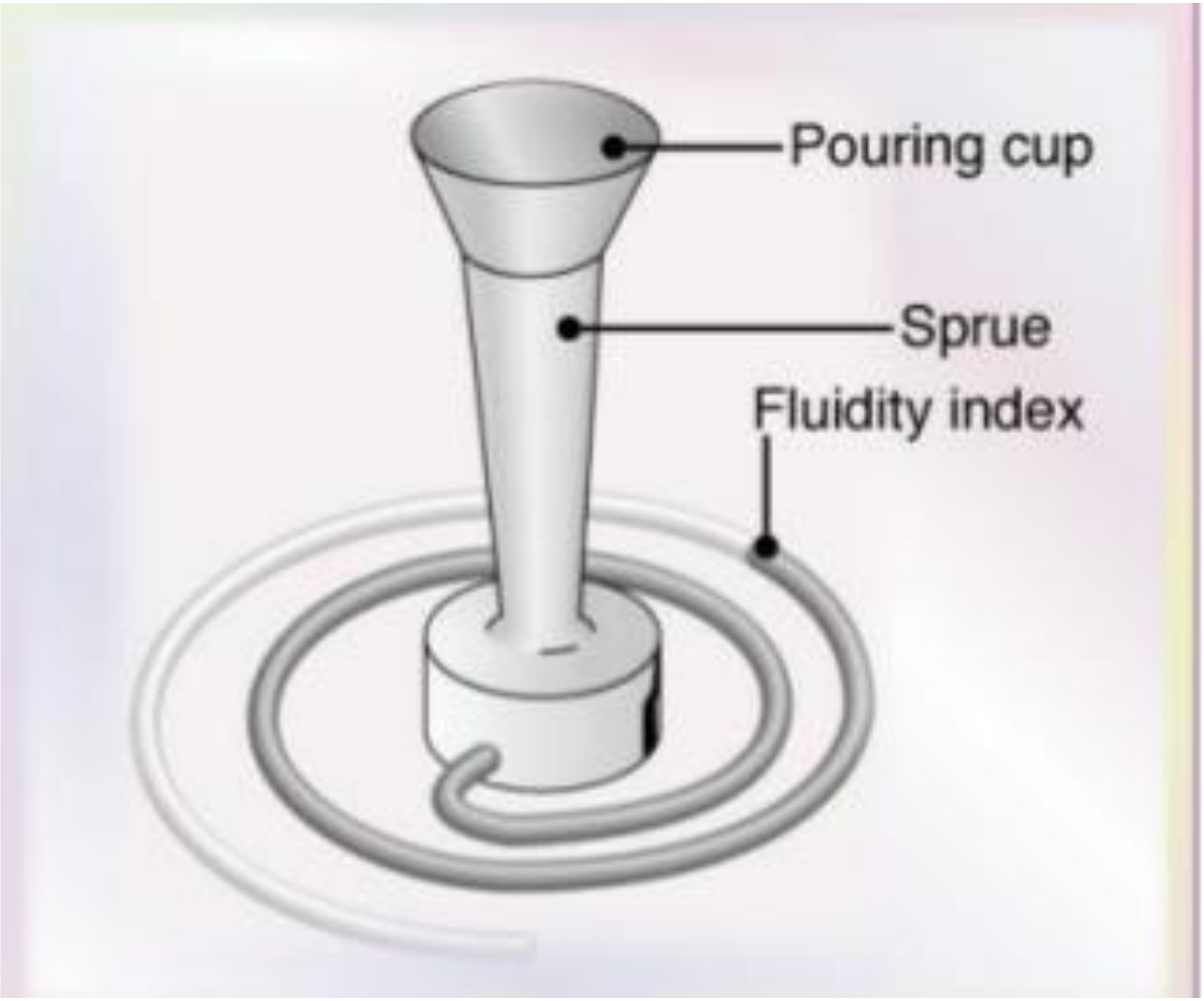
Un-Pressurized Gating System

1. The total cross sectional area increases towards the mold cavity
2. Restriction only at the bottom of sprue
3. Flow of liquid (volume) is different from all gates
4. aspiration in the gating system as the system never runs full
5. Less turbulence

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.

The goals for the gating system are

1. To minimize turbulence to avoid trapping gasses into the mold
2. To get enough metal into the mold cavity before the metal starts to solidify
3. To avoid shrinkage
4. Establish the best possible temperature gradient in the solidifying casting so that the shrinkage if occurs must be in the gating system not in the required cast part.
5. Incorporates a system for trapping the non-metallic inclusions



TEST METHOD FOR TESTING FLUIDITY

FLUIDITY INDEX – Length of solidified metal in the spiral passage. Greater the length of the solidified metal, greater is its fluidity

Hydraulic Principles used in the Gating System

Reynold’s No.,

$$R_N = \frac{VD\rho}{\mu}$$

Reynold's Number

Nature of flow in the gating system can be established by calculating Reynold's number

V	=	Mean Velocity of flow		
D	=	diameter of tubular flow		
μ	=	Kinematics Viscosity	=	Dynamic viscosity / Density
ρ	=	Fluid density		

1. Inclusion of dross or slag
2. Air aspiration into the mold
3. Erosion of the mold walls

$$h + \frac{P}{\rho g} + \frac{v^2}{2g} = const.$$

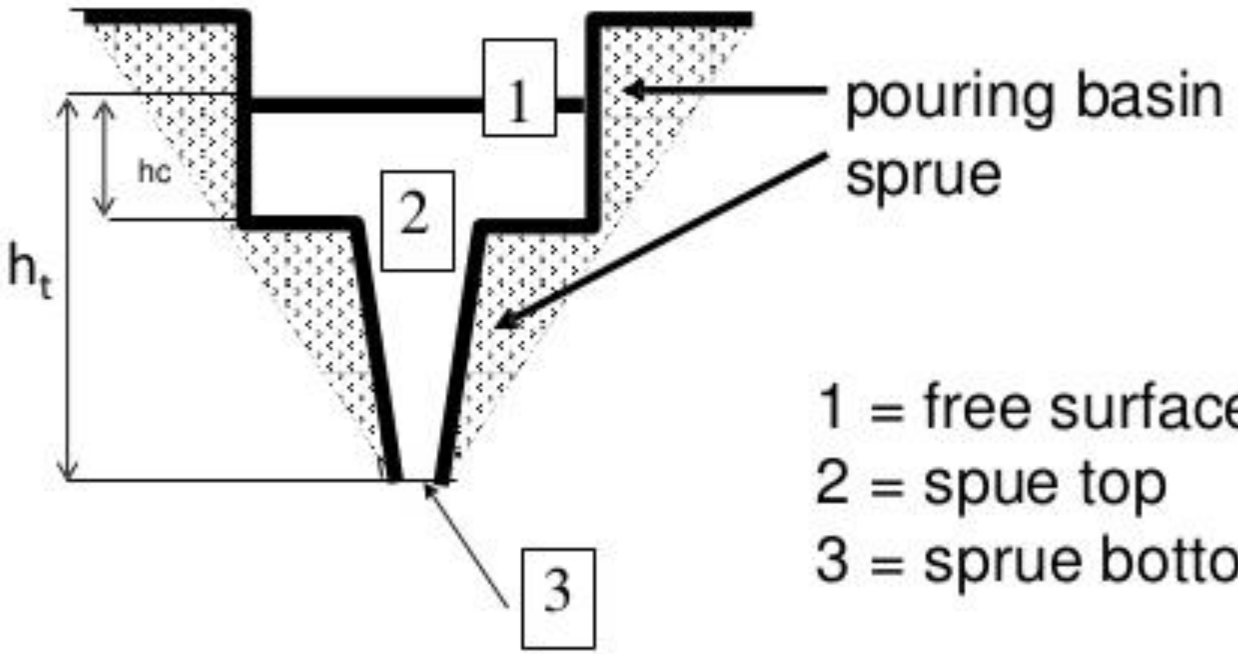
Bernoulli's Equation

h = height of liquid
P = Static Pressure
n = metal velocity
g = Acceleration due to gravity
r = Fluid density

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

DESIGN OF SPRUE



1 = free surface of metal
2 = spue top
3 = sprue bottom

- 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.

- 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

- 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
K is fluidity factor

Functions of Risers

1. Provide extra metal to compensate for the volumetric shrinkage
2. Allow mold gases to escape
3. Provide extra metal pressure on the solidifying mold to reproduce mold details more exact

Design Requirements of Risers

1. Riser size: For a sound casting riser must be last to freeze. The ratio of $(\text{volume / surface area})^2$ of the riser must be greater than that of the casting.

   When this condition does not meet the metal in the riser can be kept in liquid state by heating it externally or using exothermic materials in the risers.

2. Riser placement: the spacing of risers in the casting must be considered by effectively calculating the feeding distance of the risers.

3. Riser shape: cylindrical risers are recommended for most of the castings as spherical risers.

   To increase volume/surface area ratio the bottom of the riser can be shaped as hemisphere.

DESIGN FOR RUNNER AND 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.

PATTERN AND PATTERN ALLOWANCES

PATTERN – ***REPLICA OF THE PRODUCT***

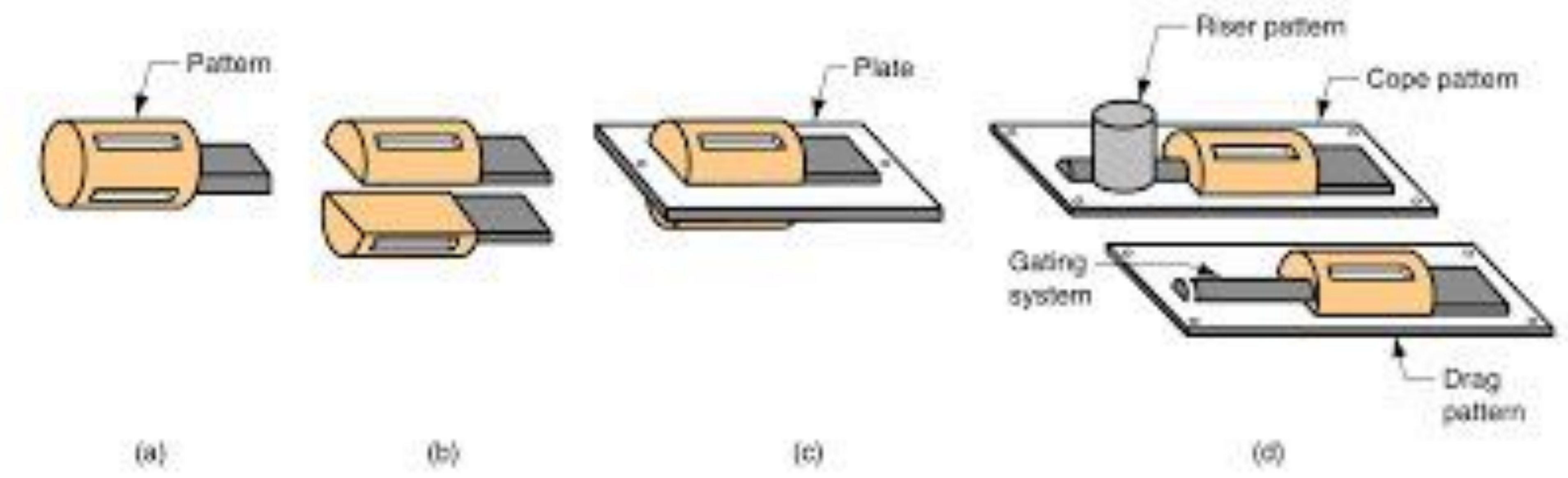
Functions of the Pattern

- Prepares a mold cavity for the purpose of making a casting.
- May contain projections known as core prints if the casting requires a core and need to be made hollow.
- Runner, gates, and risers used for feeding molten metal in the mold cavity may form a part of the pattern.
- Patterns properly made and having finished and smooth surfaces reduce casting defects.
- Properly constructed pattern minimizes the overall cost of the castings.

Pattern material should be:

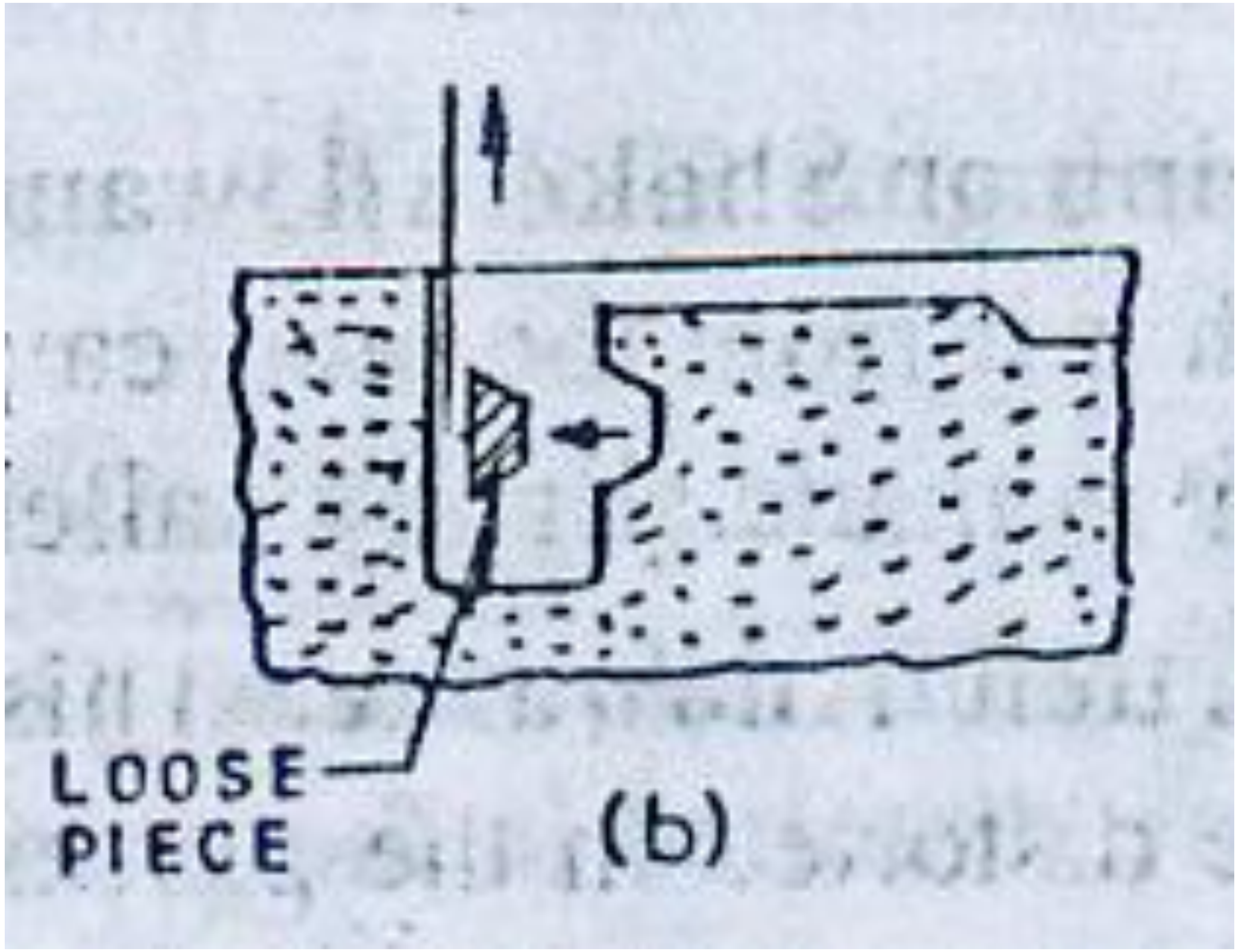
- Easily worked, shaped and joined
- Light in weight
- Strong, hard and durable
- Resistant to wear and abrasion
- Resistant to corrosion, and to chemical reactions
- Dimensionally stable and unaffected by variations in temperature and humidity
- Available at low cost

TYPES OF PATTERNS

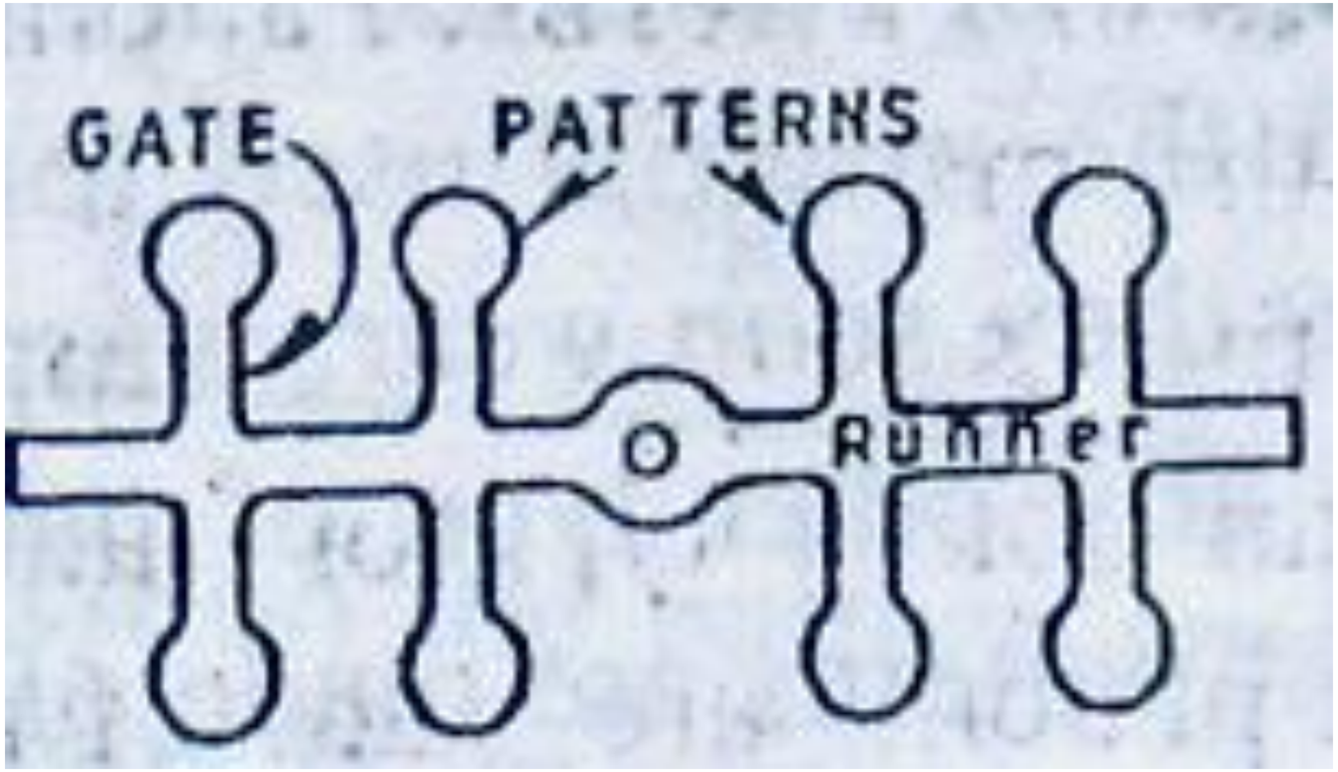


a. Single piece pattern
b. multipiece pattern
c. Matchplate pattern
d. Cope and drag pattern

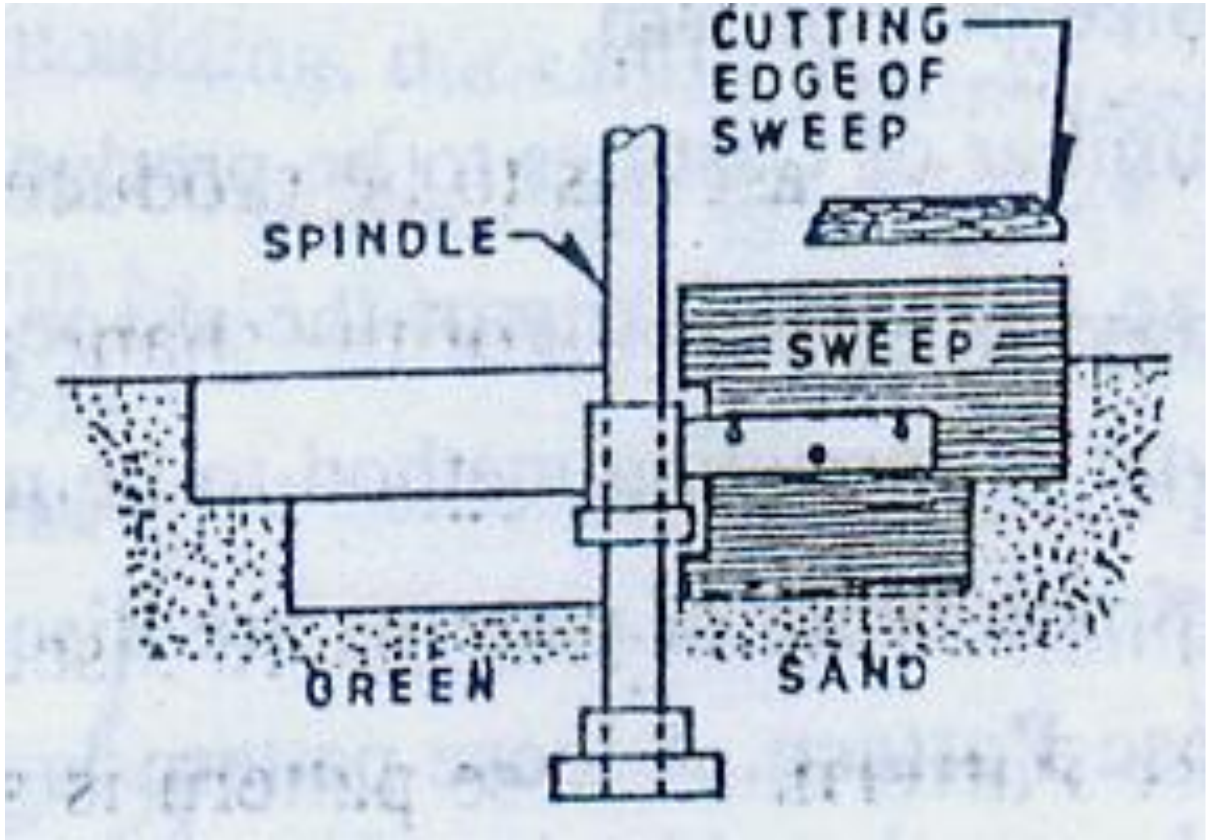
Loose piece pattern



Gated pattern



Sweep Pattern



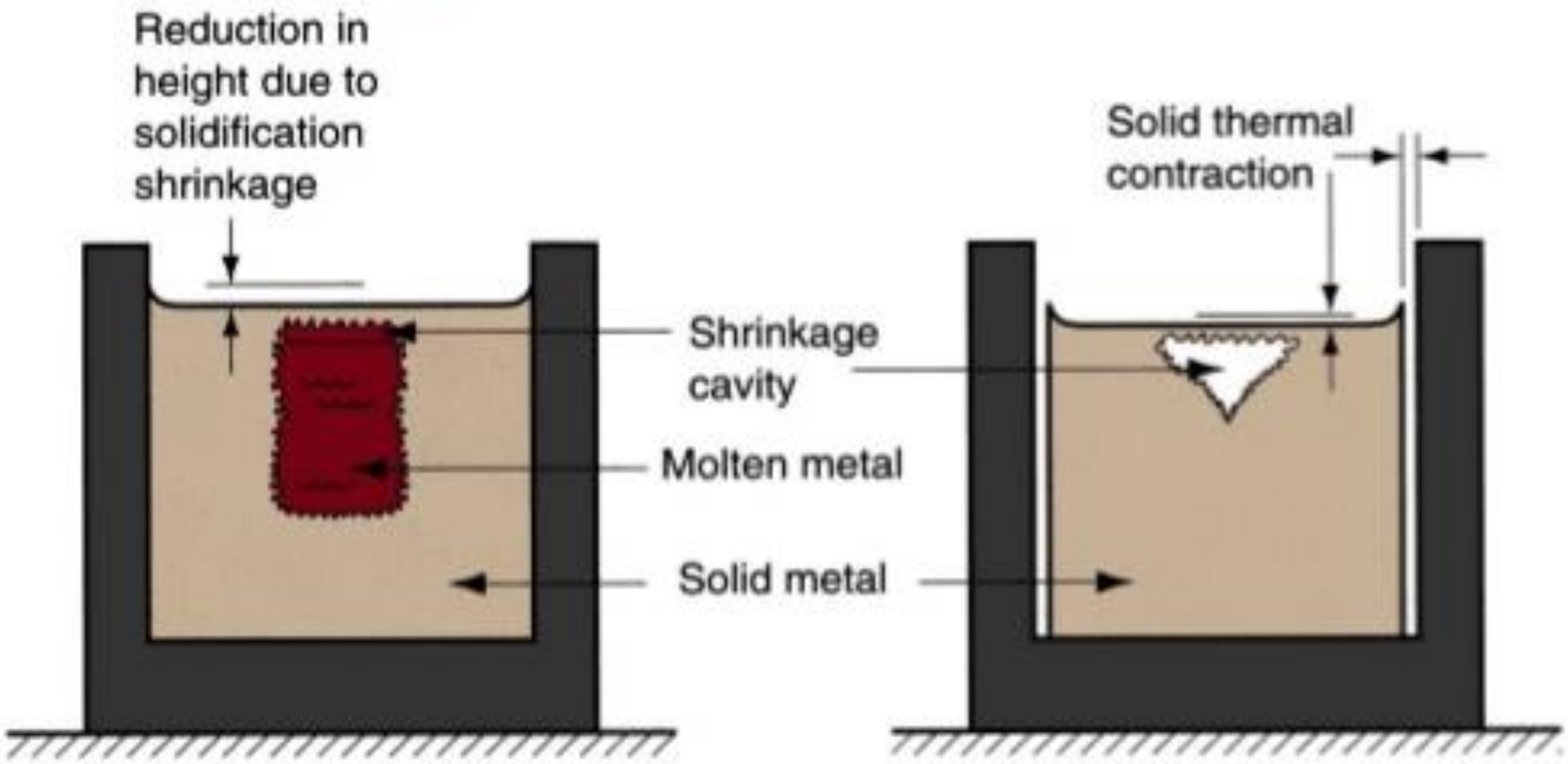
Allowances

- Shrinkage allowance
- Machining allowance
- Draft allowance
- Shake allowance
- Distortion allowance

- **Liquid Shrinkage**

- **Solid shrinkage**

- **Solid Shrinkage**:

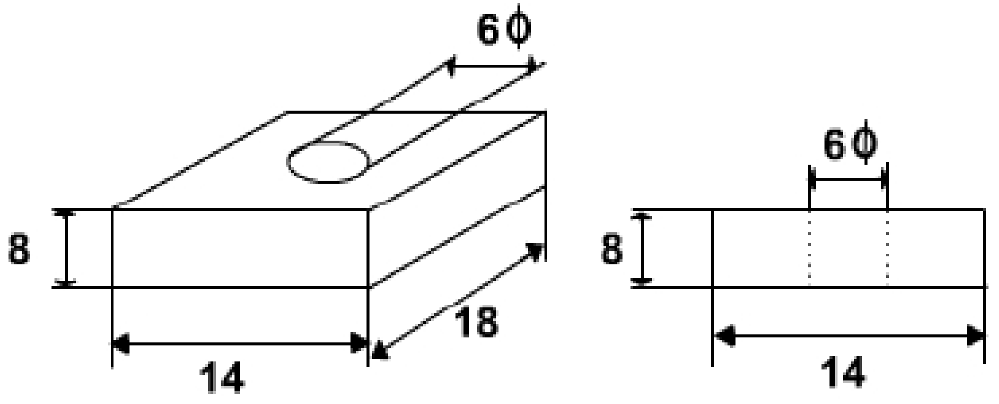


shrinkage allowance depends on the coefficient of thermal expansion of the material (**α**).

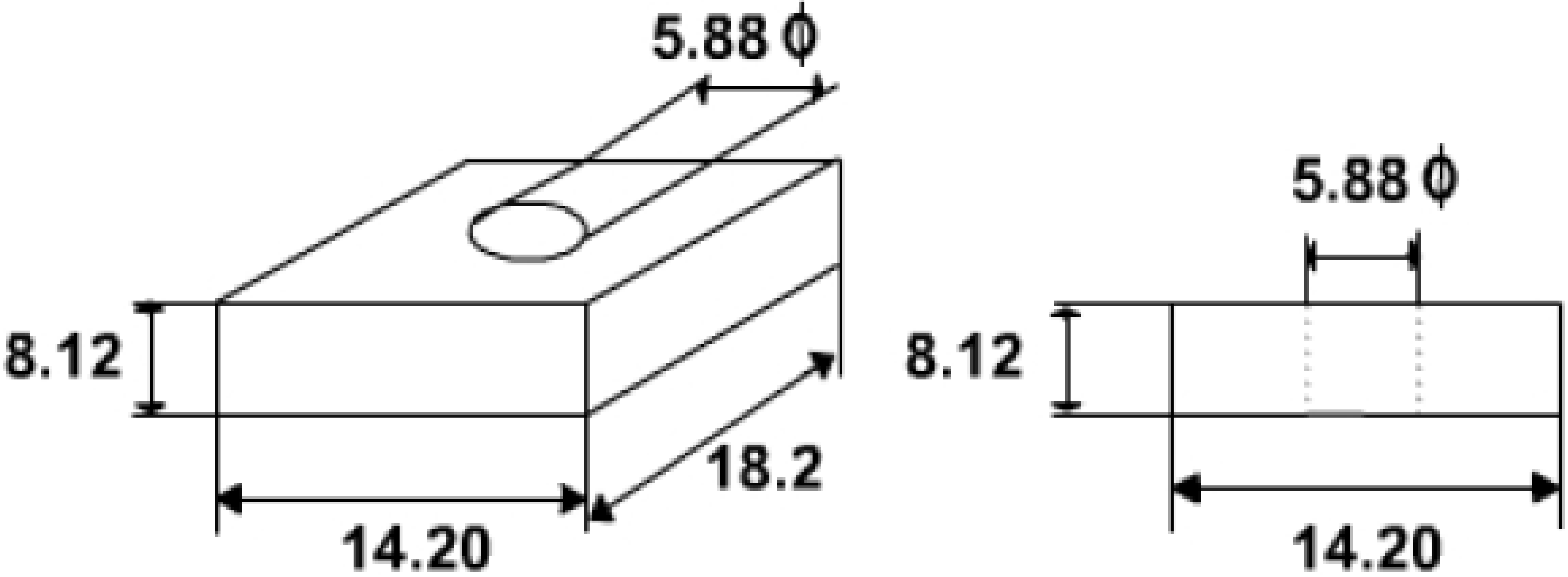
$$\alpha l\,(\theta_f - \theta_0)$$

θ_f is the freezing temperature and θ_0 is the room temperature.

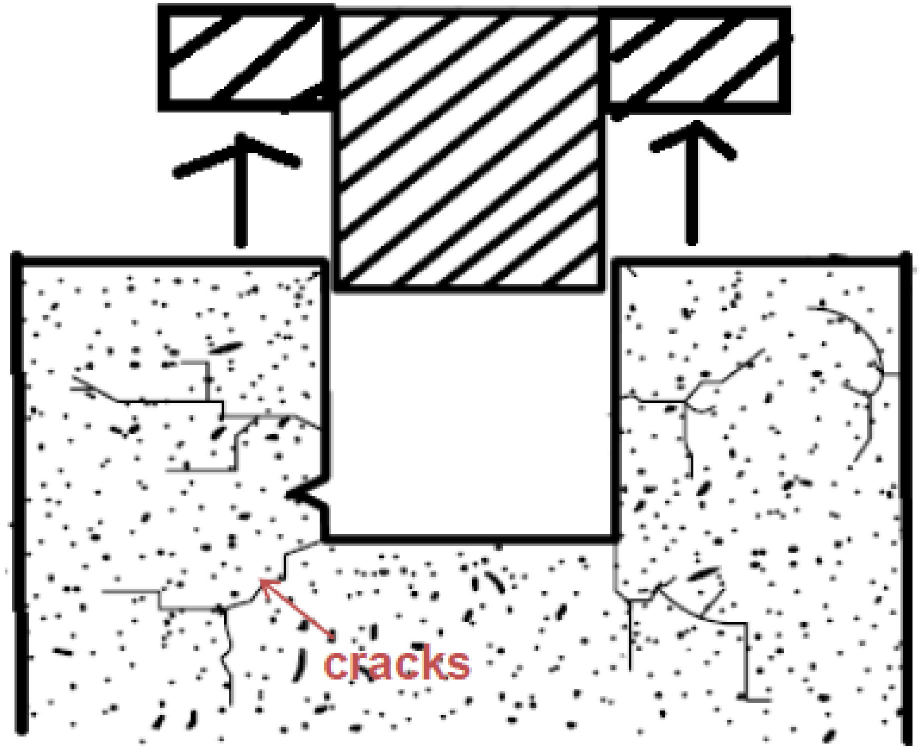
The casting shown is to be made in CI using a wooden pattern. Assuming only machining allowance, calculate the dimension of the pattern. All dimensions are in Inches



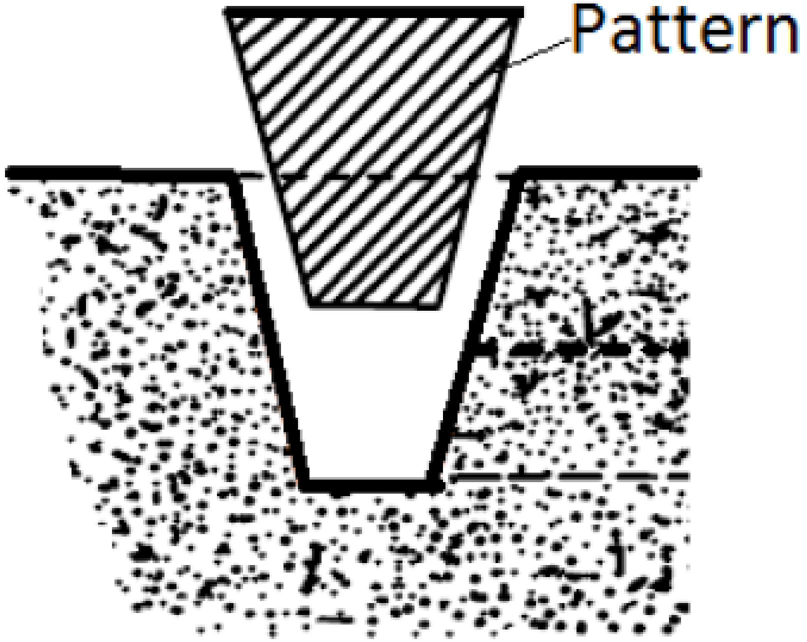
Metal	Dimension (inch)	Allowance (inch)
Cast iron	Up to 12	0.12
	12 to 20	0.20
	20 to 40	0.25
Cast steel	Up to 6	0.12
	6 to 20	0.25
	20 to 40	0.30
Non ferrous	Up to 8	0.09
	8 to 12	0.12
	12 to 40	0.16


5.88 ϕ
8.12
18.2
14.20
5.88 ϕ
8.12
14.20

TAPER ALLOWANCE

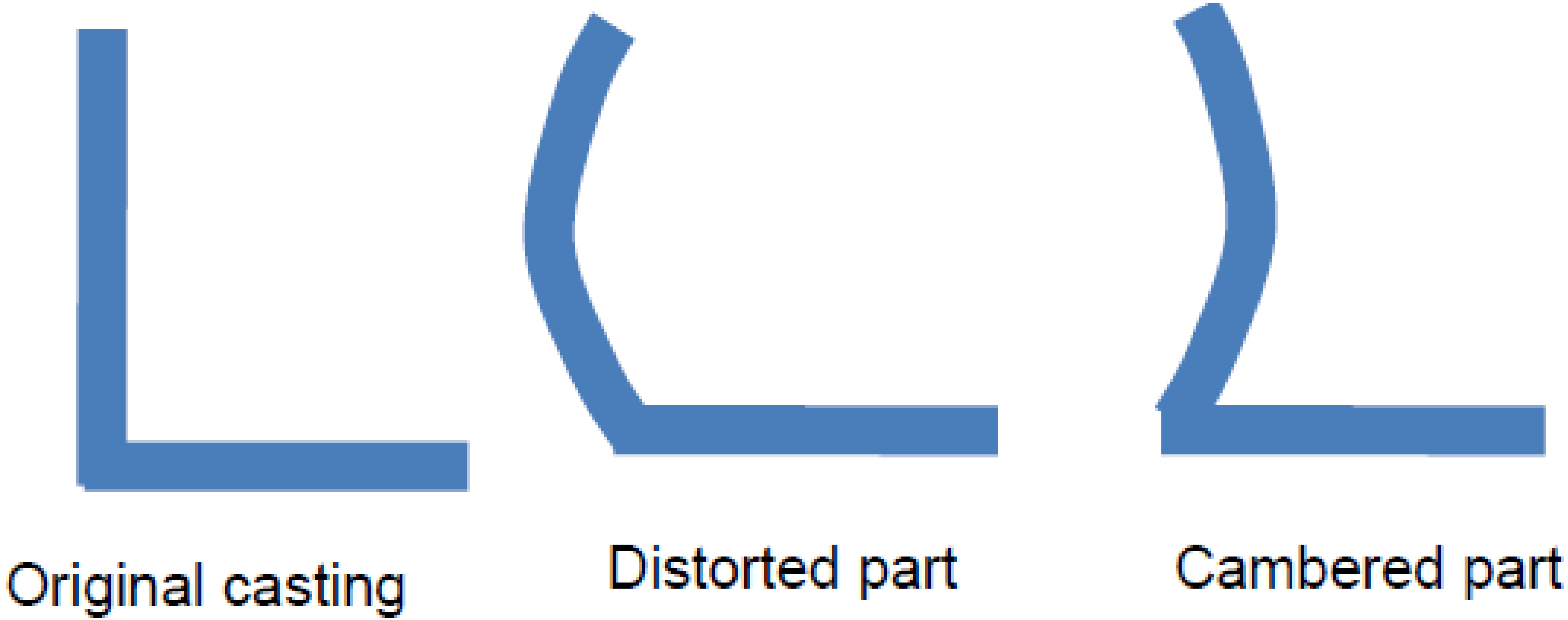


Pattern having no draft on vertical surfaces

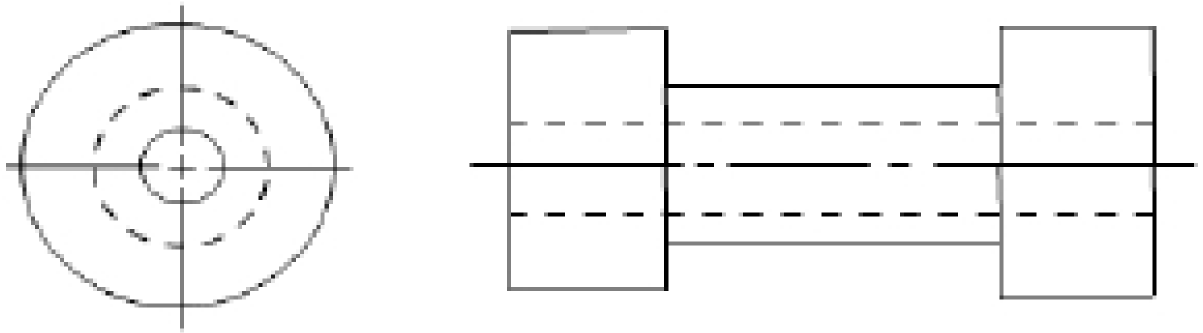


Pattern having draft allowance on vertical surfaces

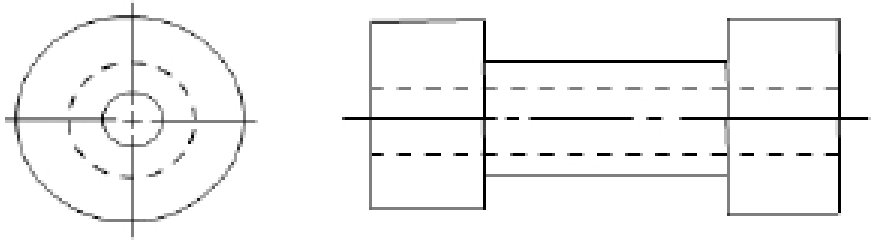
Distortion allowance (camber)



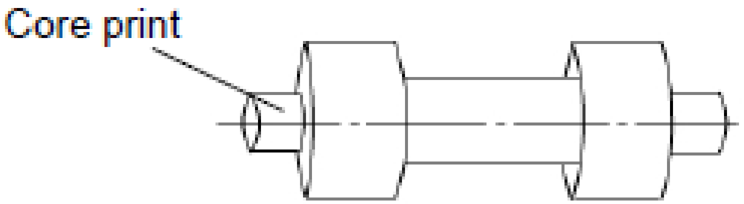
Core and core print



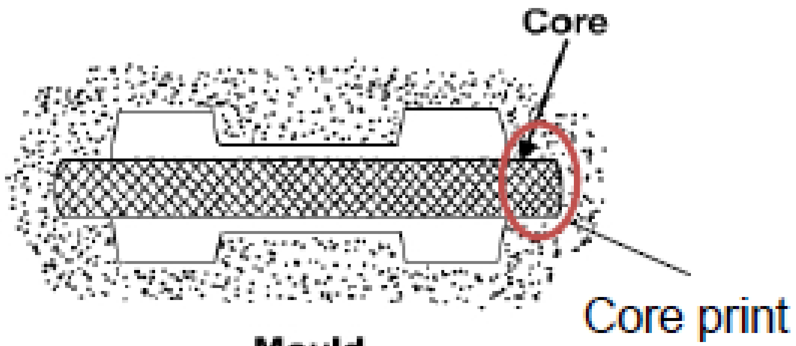
JOB



JOB

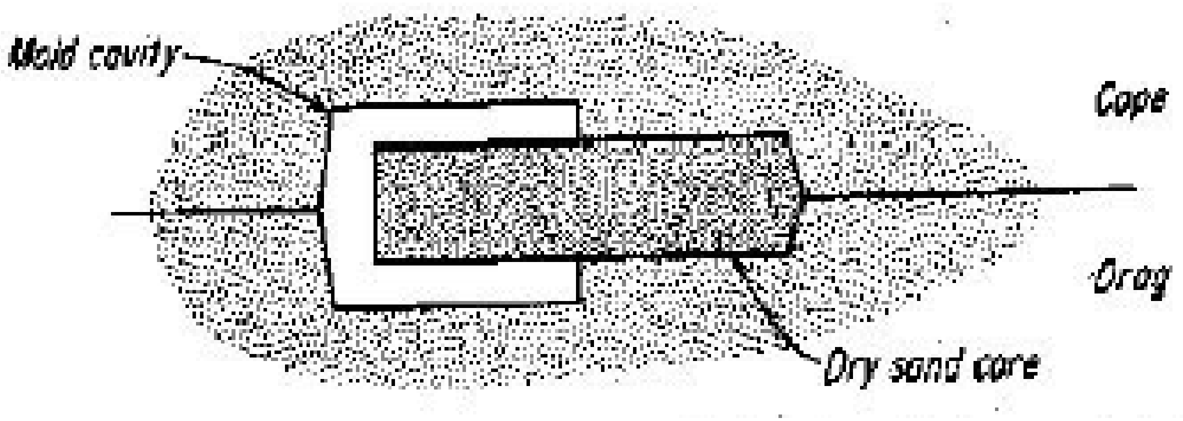


Pattern

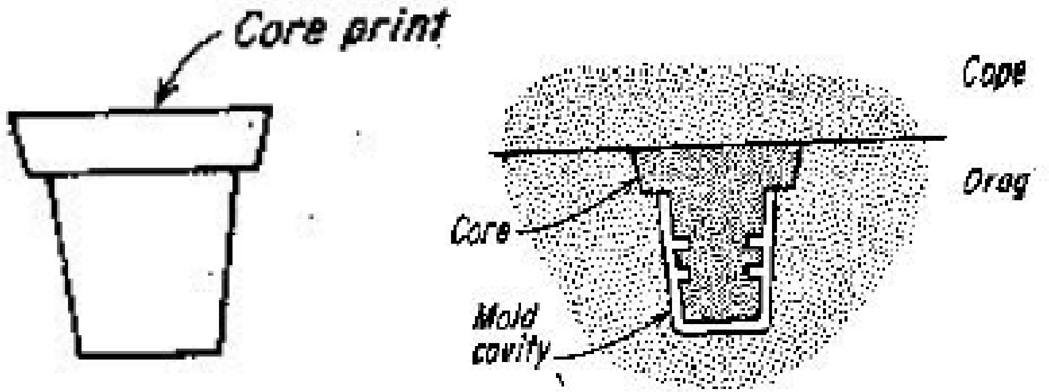


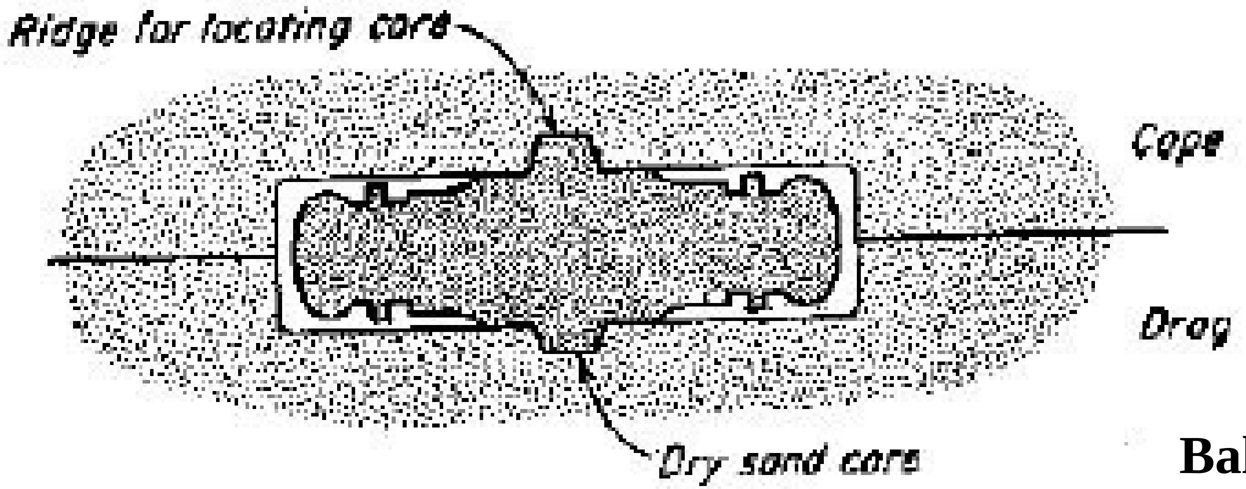
Mould

TYPES OF CORES



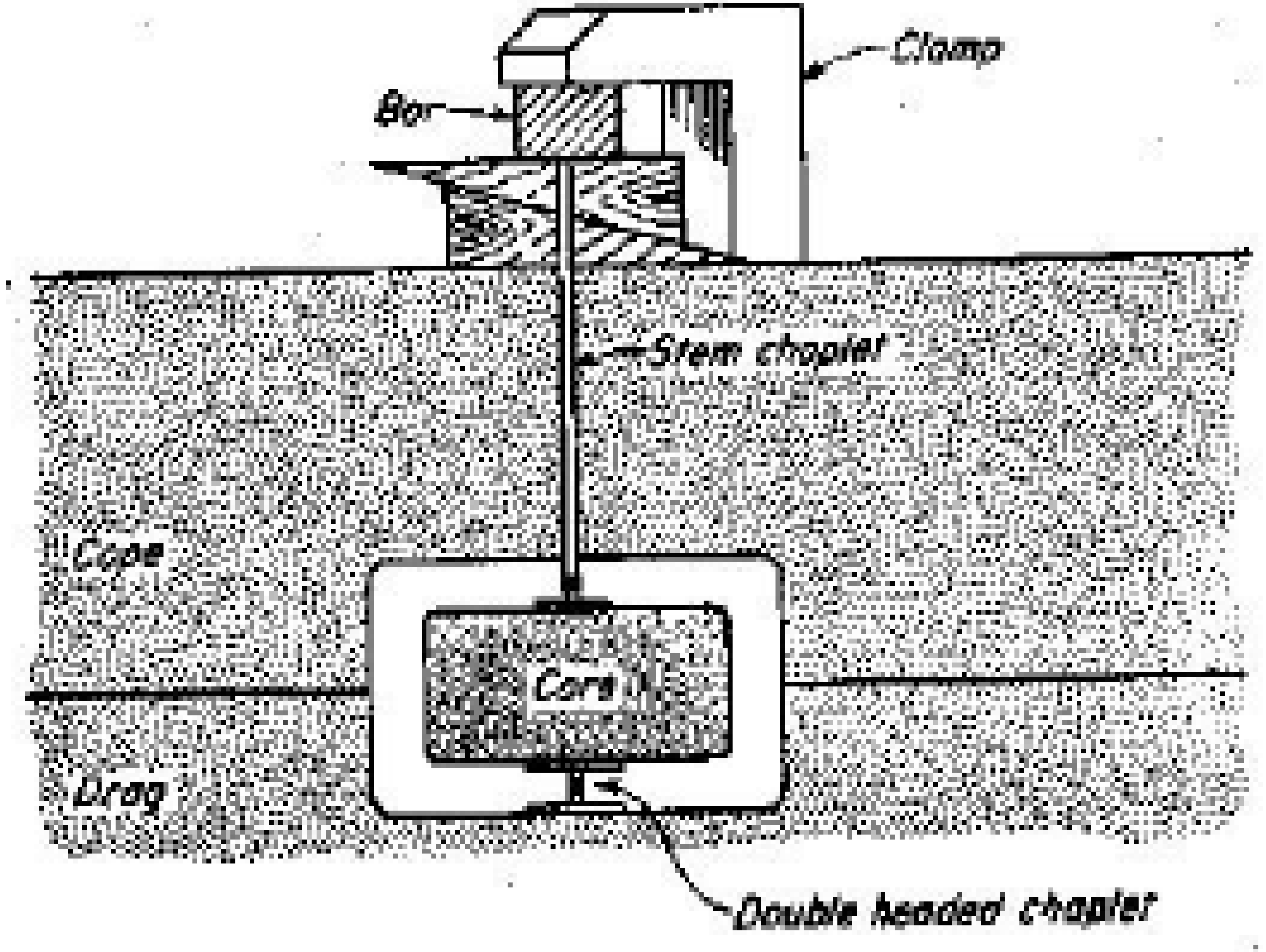
Overhanging core





Balancing core

USE OF CHAPLET FOR CORE SUPPORT



Core characteristics

Good dry sand cores should have the following characteristics:

1. Good dry strength and hardness after baking
2. Sufficient green strength to retain the shape before baking
3. Refractoriness
4. Surface smoothness
5. Permeability
6. Lowest possible amount of gas created during the pouring of casting

Natural and Synthetic molding sand

Natural molding sand

65.5% silica grains, 21.7% clay content, 12.8% undesirable impurities

Synthetic molding sand

Synthetic molding sand is made by mixing together specially selected high quality clay free silica, with about 5% of clay

Binders Used in Sand Casting for Molds, Cores

Clays:

Fire clay (kaolinite)

Southern bentonite (calcium montmorillonite)

Western bentonite (sodium montmorillonite)

Secondary mica clays (illite)

Oils:*

Vegetables (e.g. linseed oil)

Marine animal (e.g., whale oil)

Mineral (used for diluting oils given above)

Synthetic resins, thermosetting:*‡

Urea formaldehyde

Phenol Formaldehyde

Cereal binders made from corn:*

Gelatinized starch (made by wet milling, contains starch and gluten)

Gelatinized corn flour (made by dry-milling hominy)

Dextrin (made from starch, a water-soluble sugar)

Wood –product binders:*‡

Natural resin (e.g., rosin, thermoplastic)

Sulfite binders (contain lignin, produced in the paper pulp process)

Water-soluble gums, resins, and organic chemicals

Protein binders (containing nitrogen):*

Glue

Casien

Other binders:

Portland cement†

Pitch (a coal-tar product)*†

Molasses (usually applied in water as a spray)

Cements (e.g., rubber cement)†

Sodium silicate (water glass, CO_2 hardening binders)†

* Harden by baking.

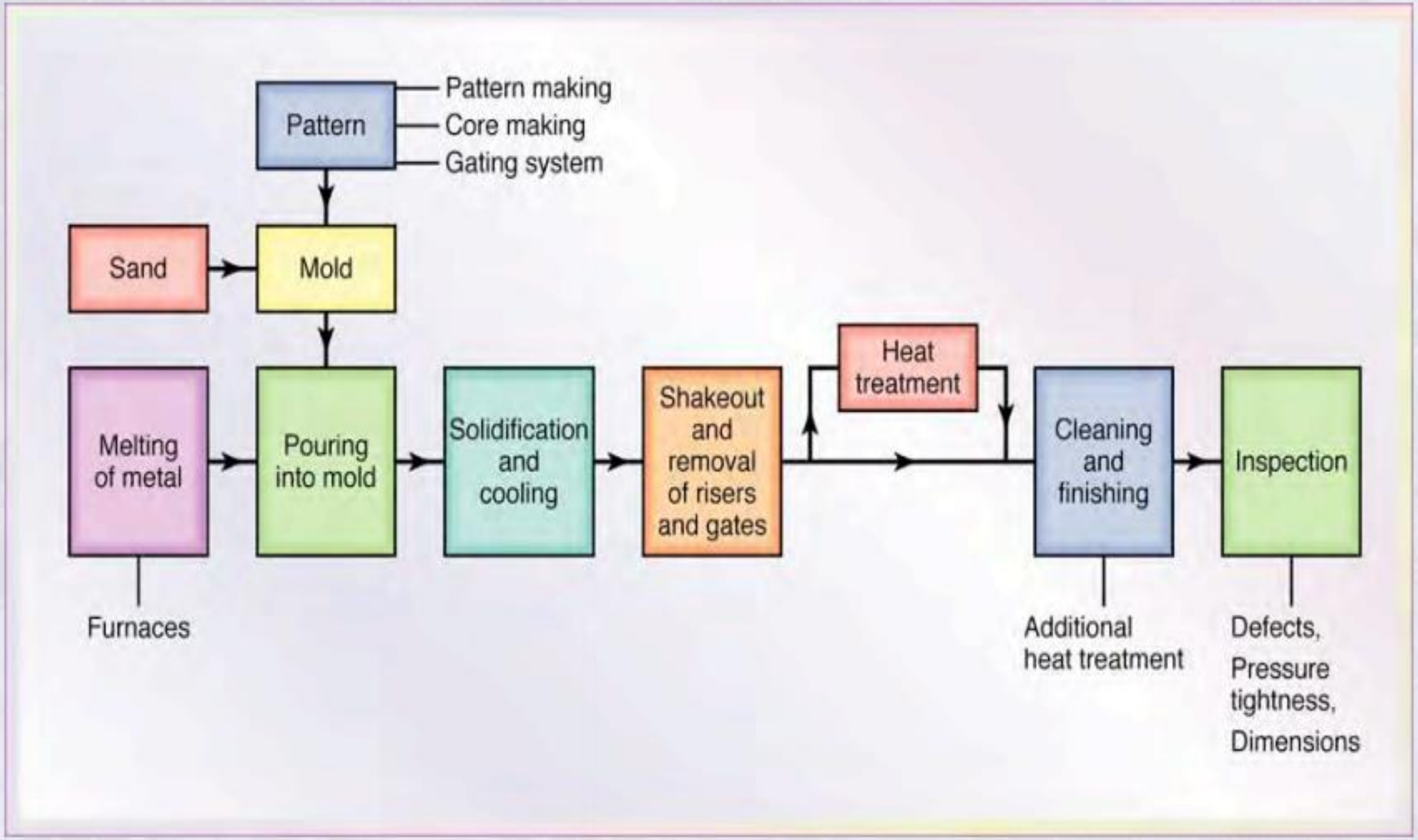
† Harden at room temperature.

‡ Available as either a liquid or a dry powder.

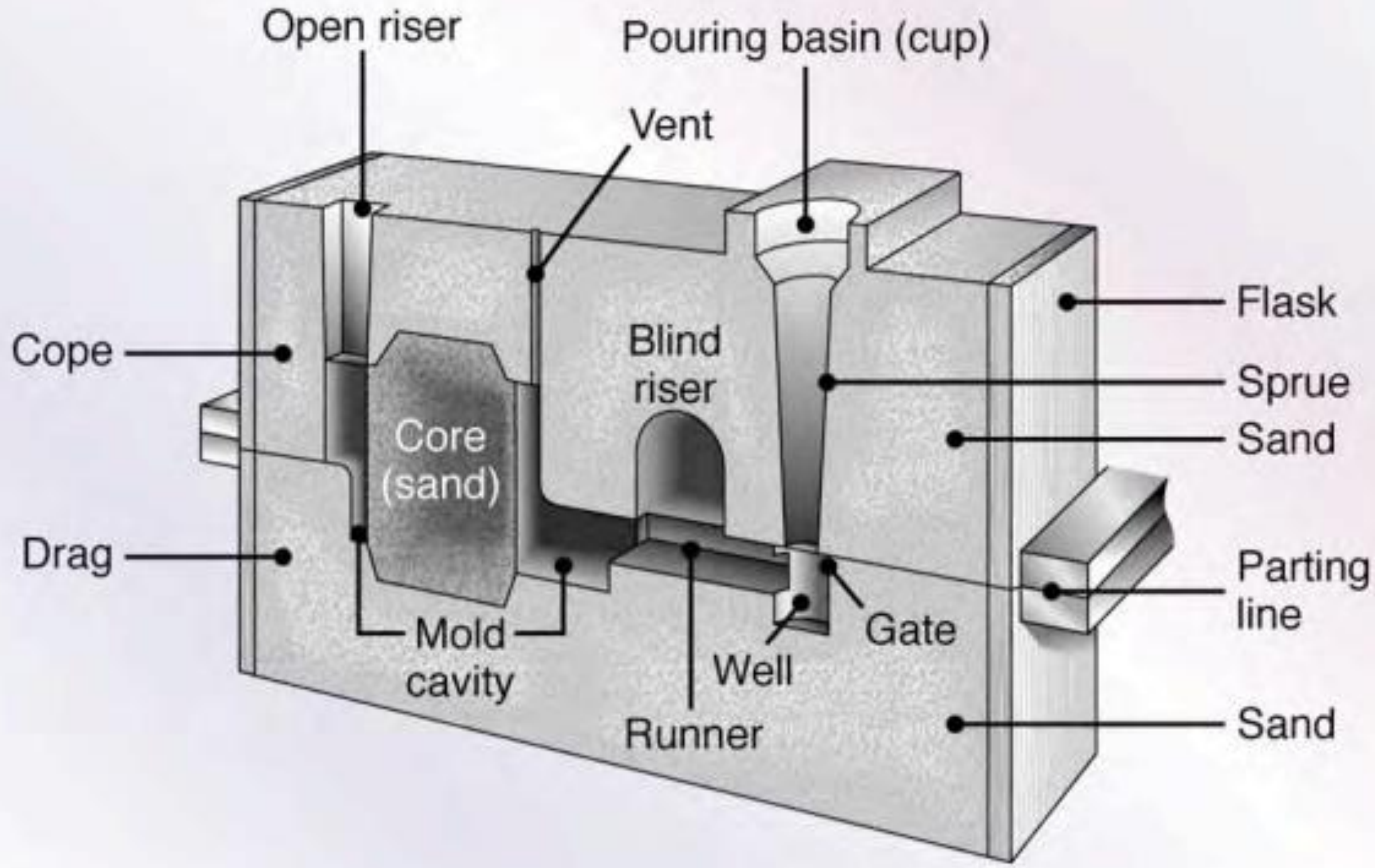
CASTING PROCESS

1. EXPENDABLE-MOLD PERMANENT-PATTERN CASTING PROCESSES
2. EXPENDABLE-MOLD EXPENDABLE-PATTERN CASTING PROCESSES
3. PERMANENT MOLD CASTING PROCESSES
4. COMPOSITE MOLD CASTING PROCESSES

Production Steps in Sand-Casting

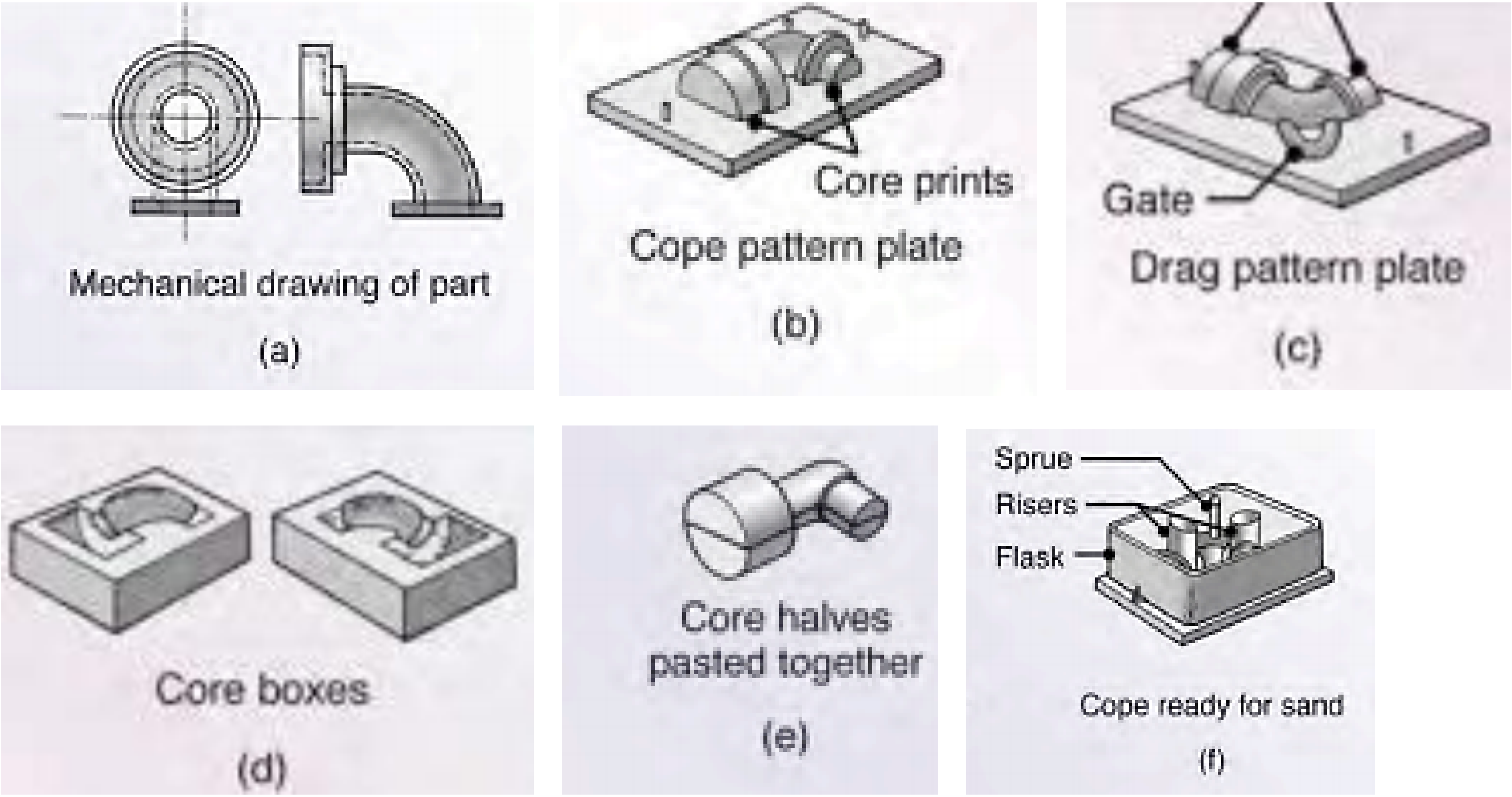


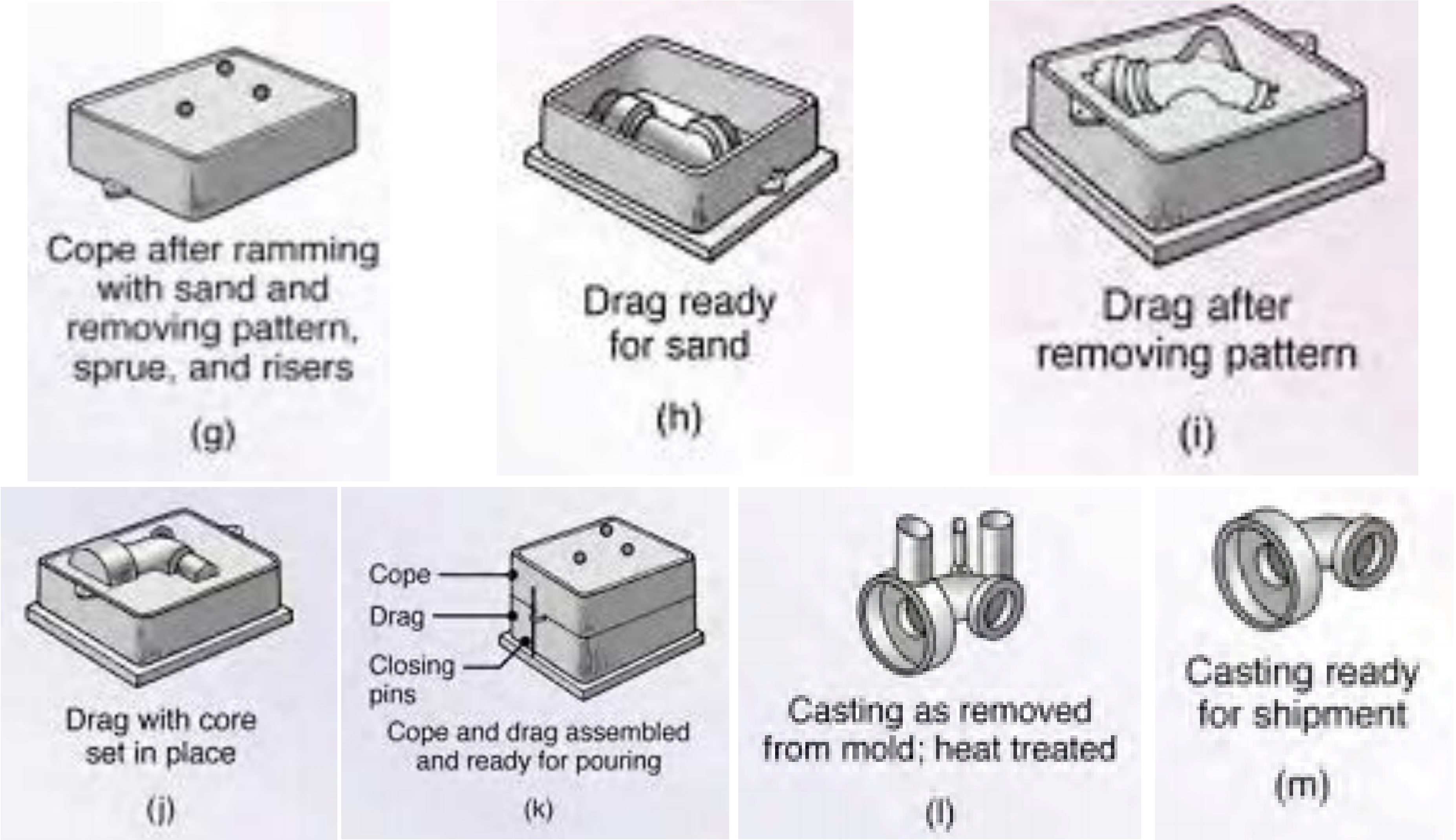
Sand Mold



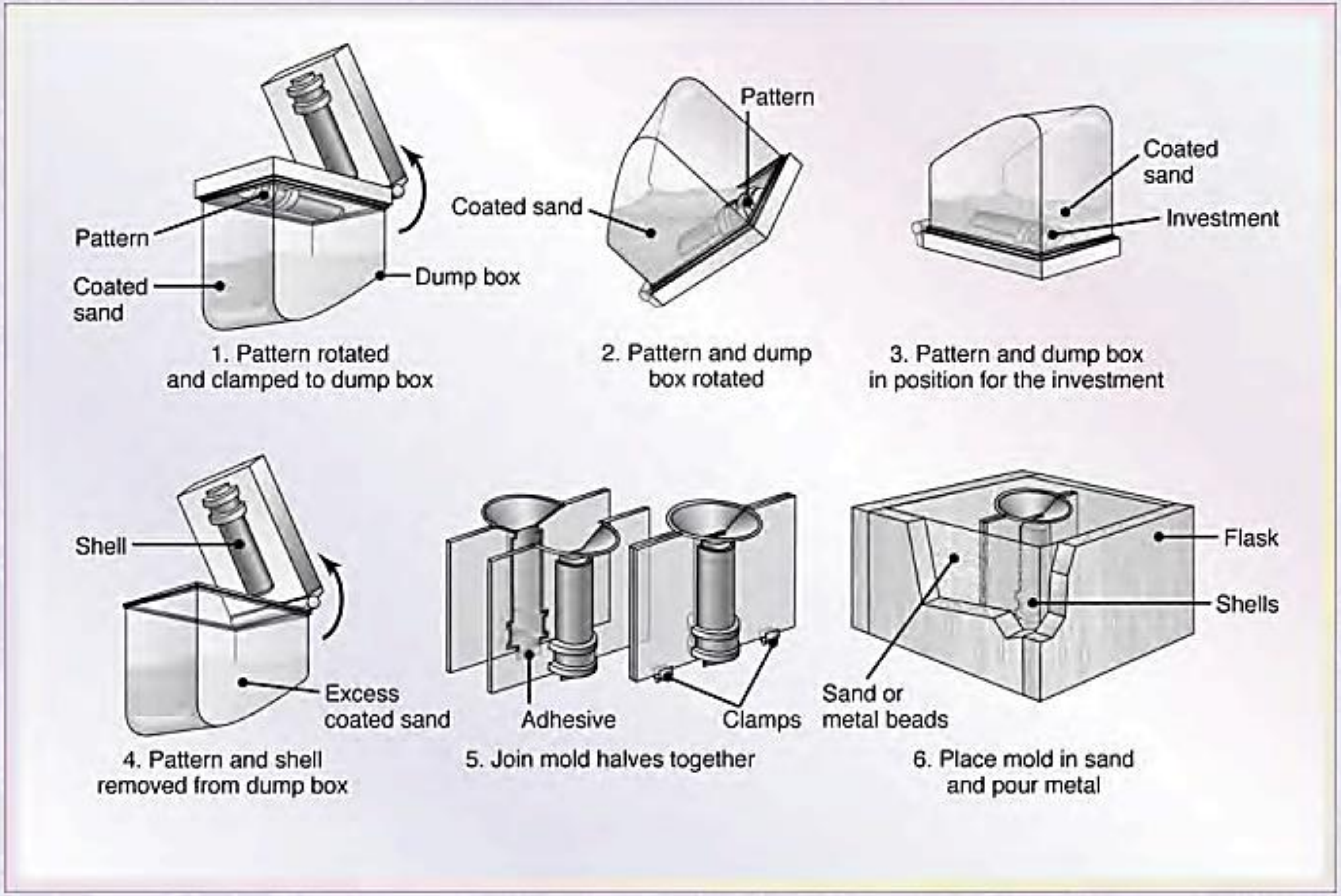
Open riser
Pouring basin (cup)
Vent
Cope
Blind riser
Core (sand)
Flask
Sprue
Sand
Drag
Parting line
Mold cavity
Well
Gate
Runner
Sand

SEQUENCE OF OPERATIONS FOR SAND CASTING




Cope after ramming with sand and removing pattern, sprue, and risers
(g)
Drag ready for sand
(h)
Drag after removing pattern
(i)
Drag with core set in place
(j)
Cope
Drag
Closing pins
Cope and drag assembled and ready for pouring
(k)
Casting as removed from mold; heat treated
(l)
Casting ready for shipment
(m)

Shell-Molding Process



A mounted pattern made of a ferrous metal or aluminum is

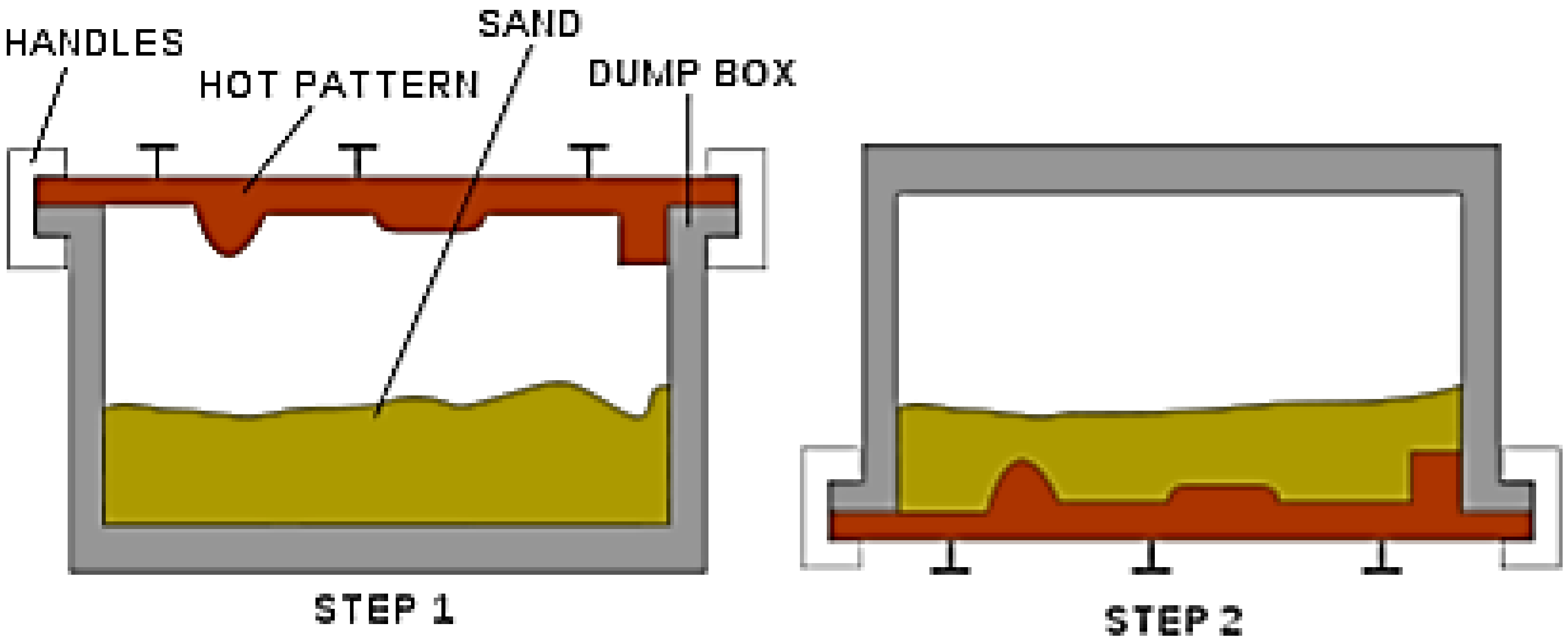
(a) heated to a range of 175° to 370°C,

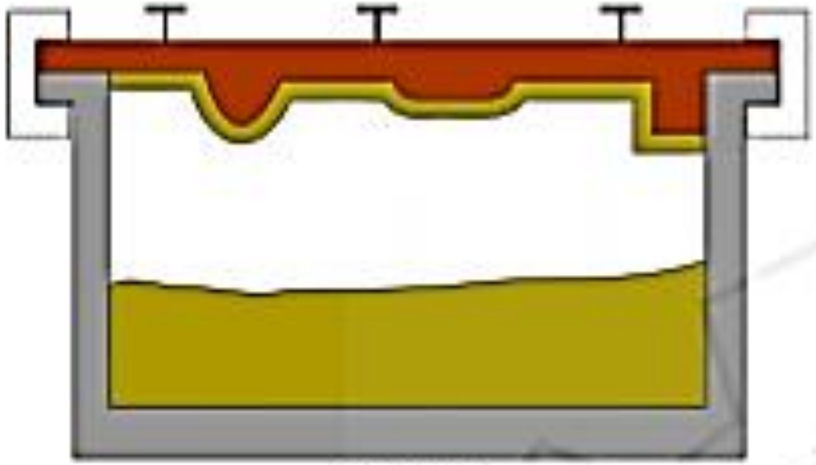
(b) coated with a parting agent (such as silicone)

(c) clamped to a box or chamber.

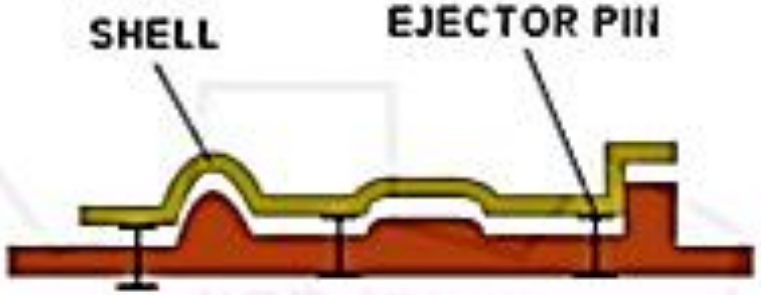
Box contains fine sand, mixed with 2.5 to 4% of a thermosetting resin binder (such as phenol-formaldehyde) that coats the sand particles

SHELL MOULDING

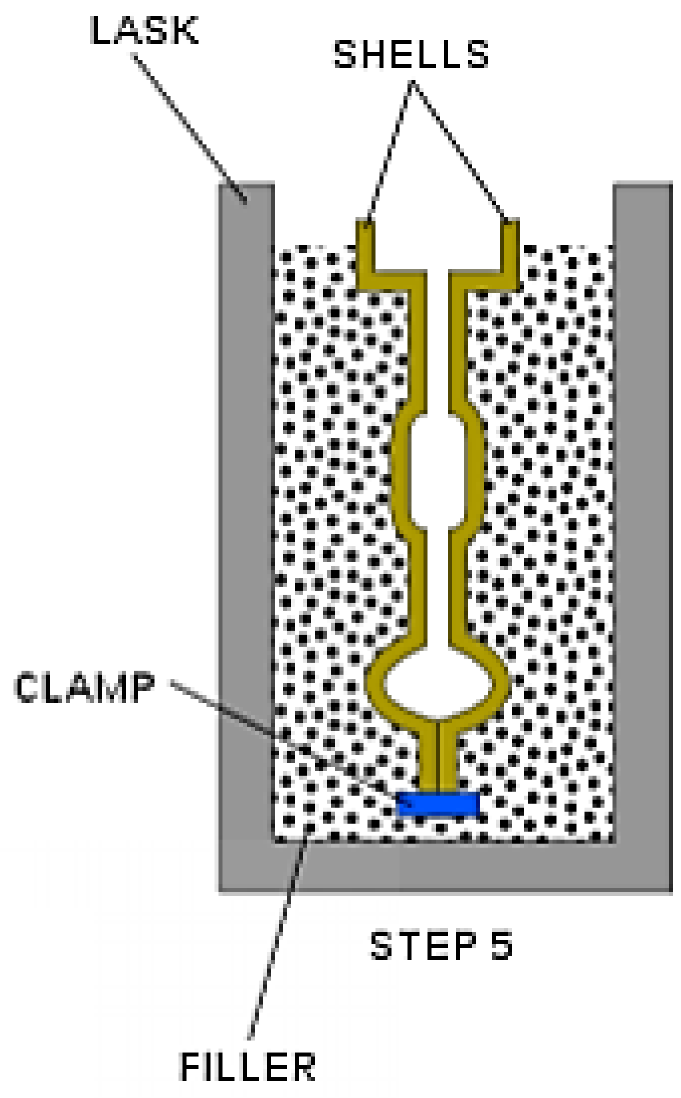




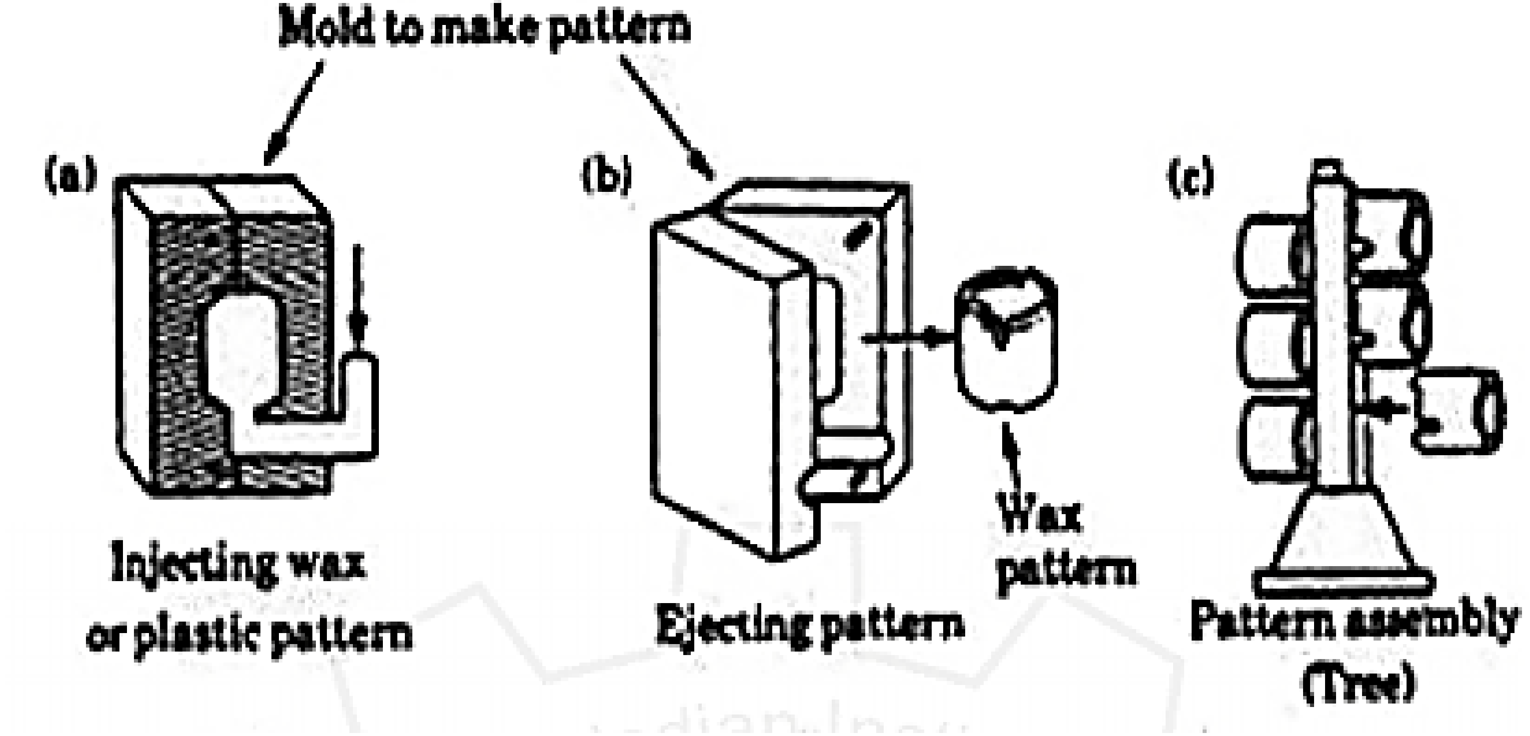
STEP 3

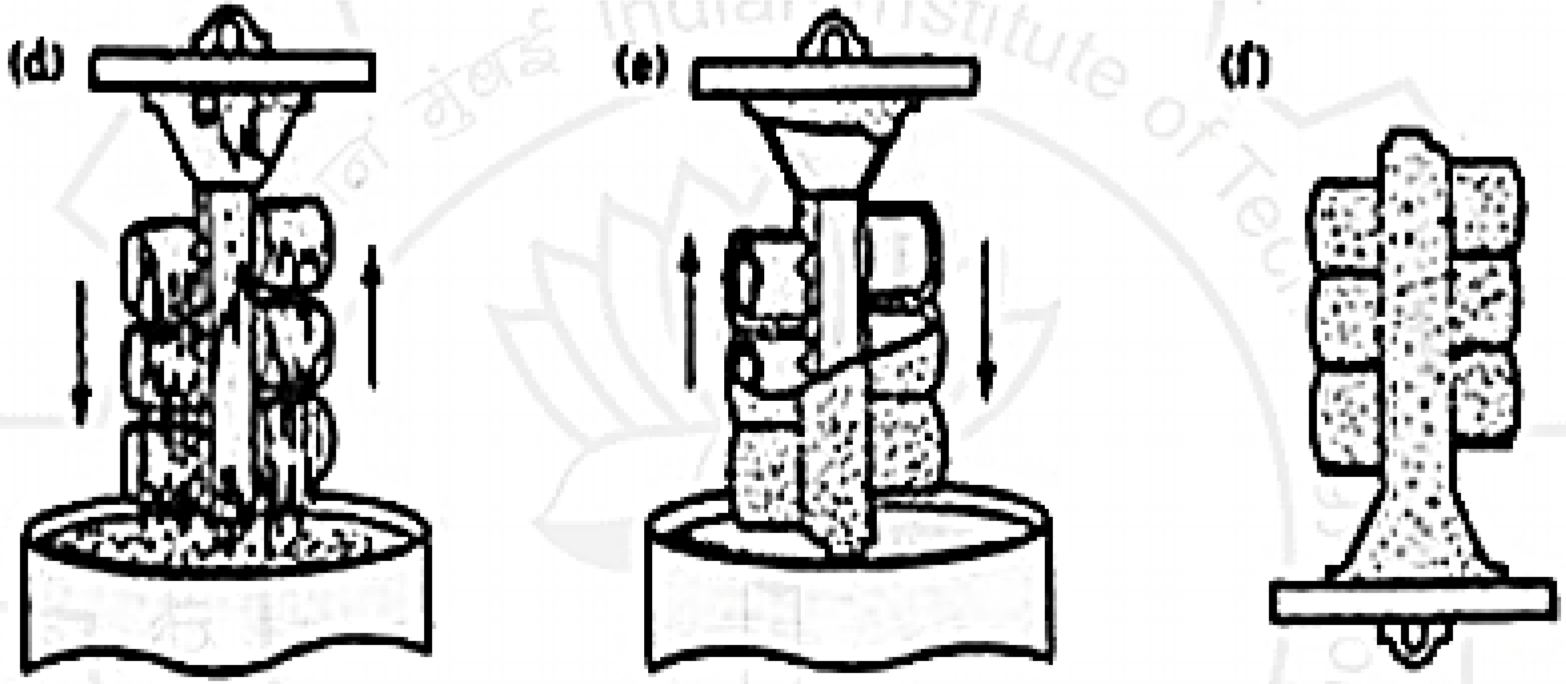


STEP 4

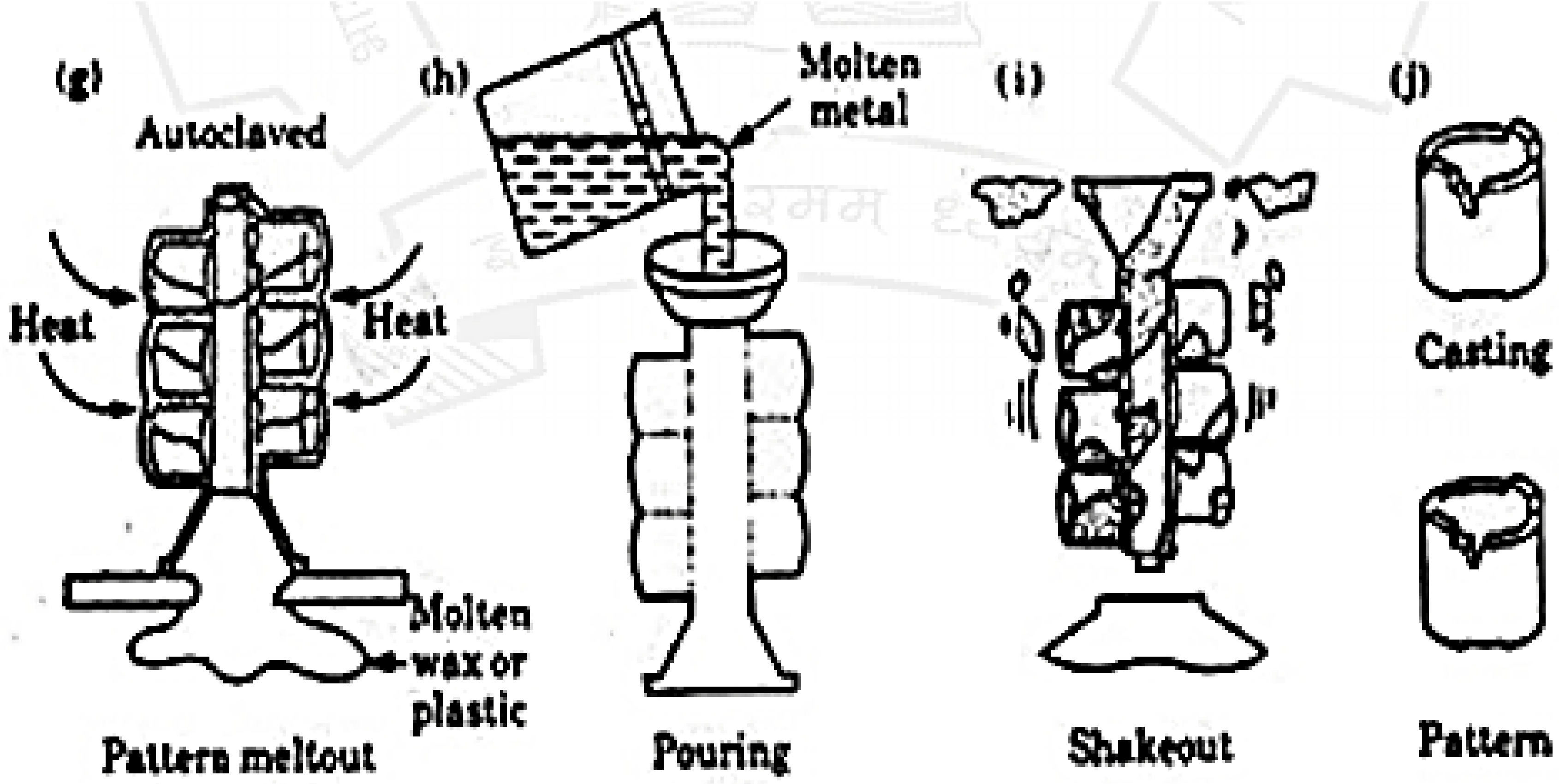

LASK
SHELLS
CLAMP
STEP 5
FILLER

INVESTMENT CASTING



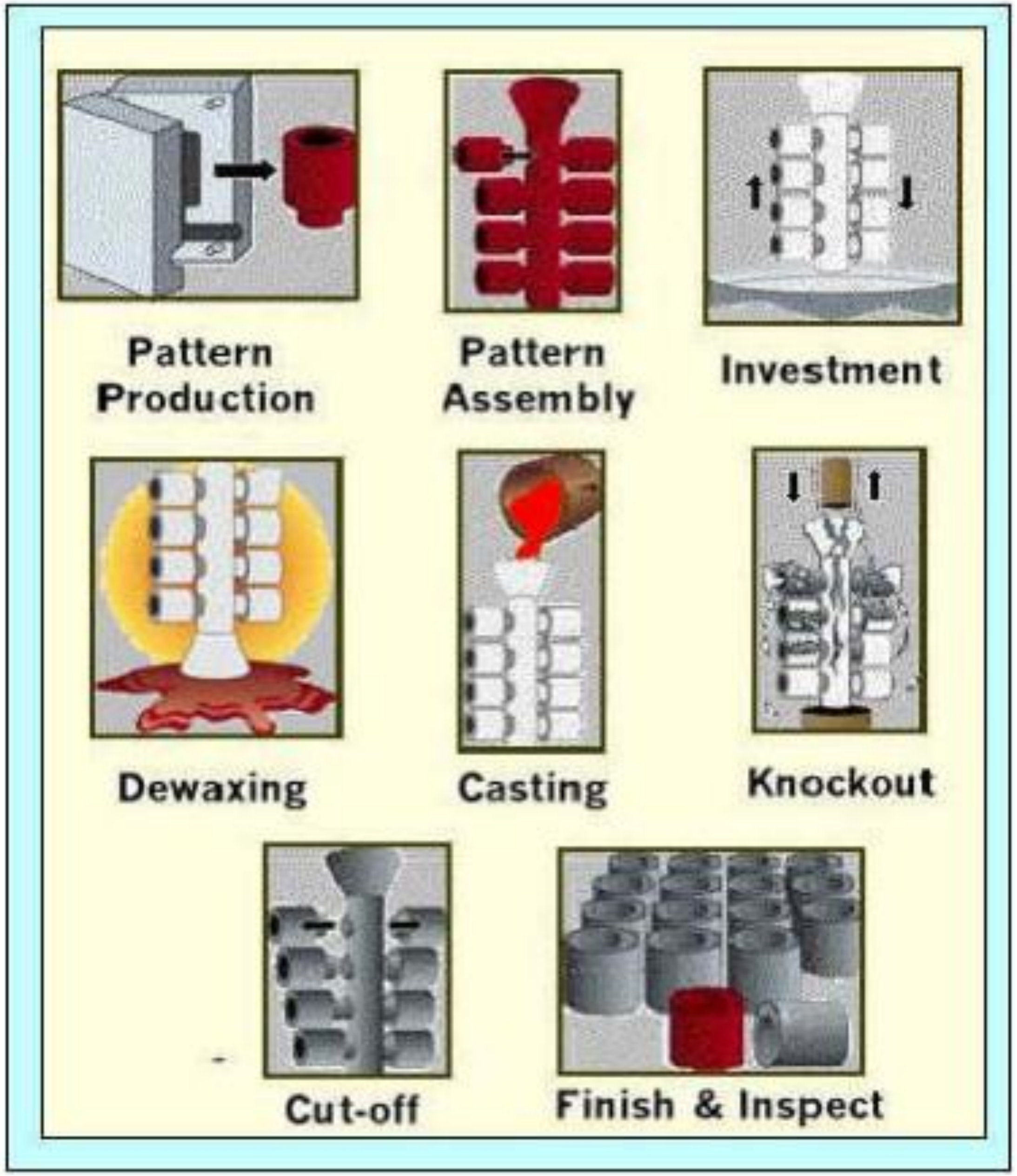


Slurry coating Stucco coating Completed mold



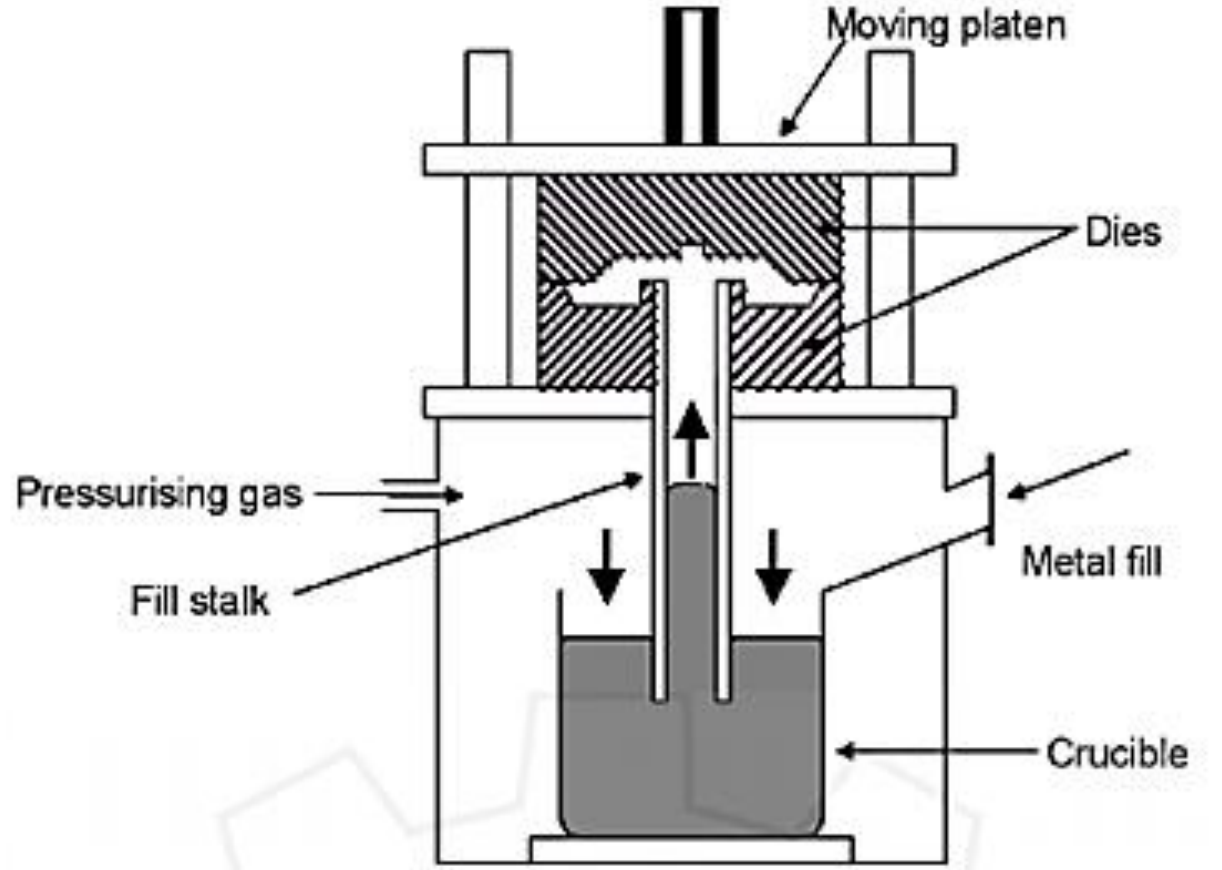
(g)
Autoclaved
Heat
Heat
Molten
wax or
plastic
Pattern meltout
(h)
Molten
metal
Pouring
(i)
Shakeout
(j)
Casting
Pattern

INVESTMENT CASTING

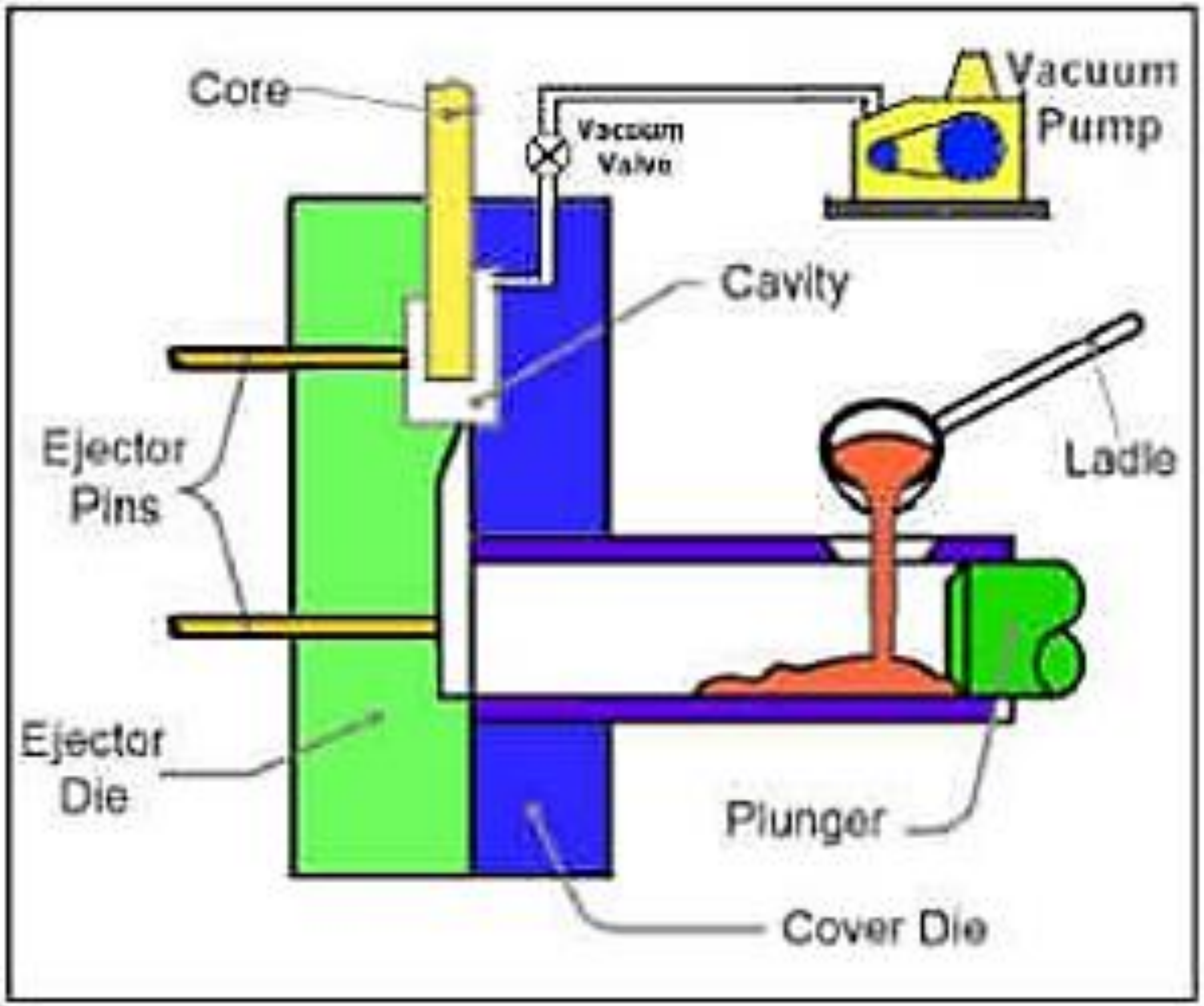


Investment (Lost Wax) Casting

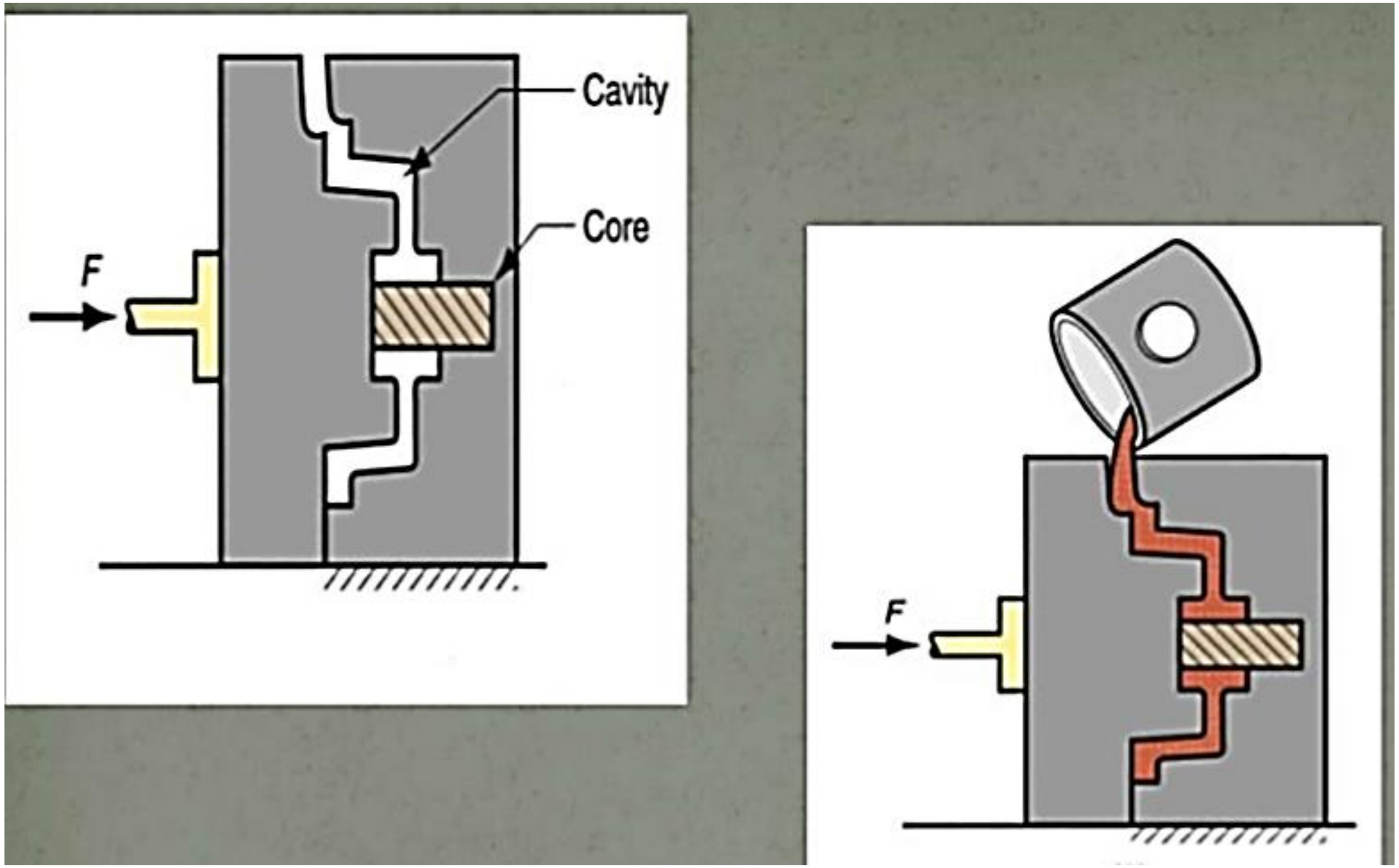
VACCUM CASTING



VACCUM DIE CASTING



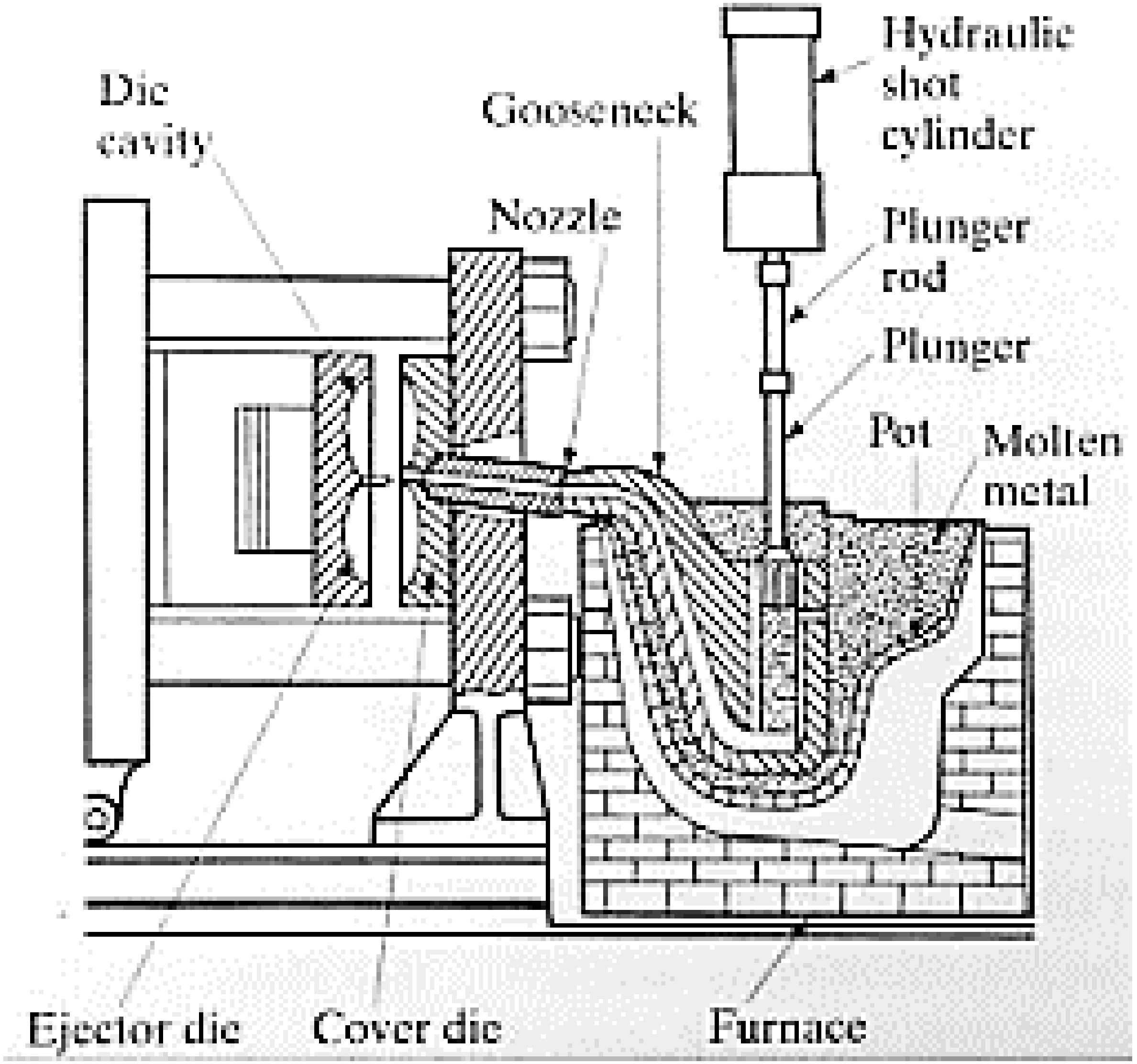
PERMANENT MOULD CASTING



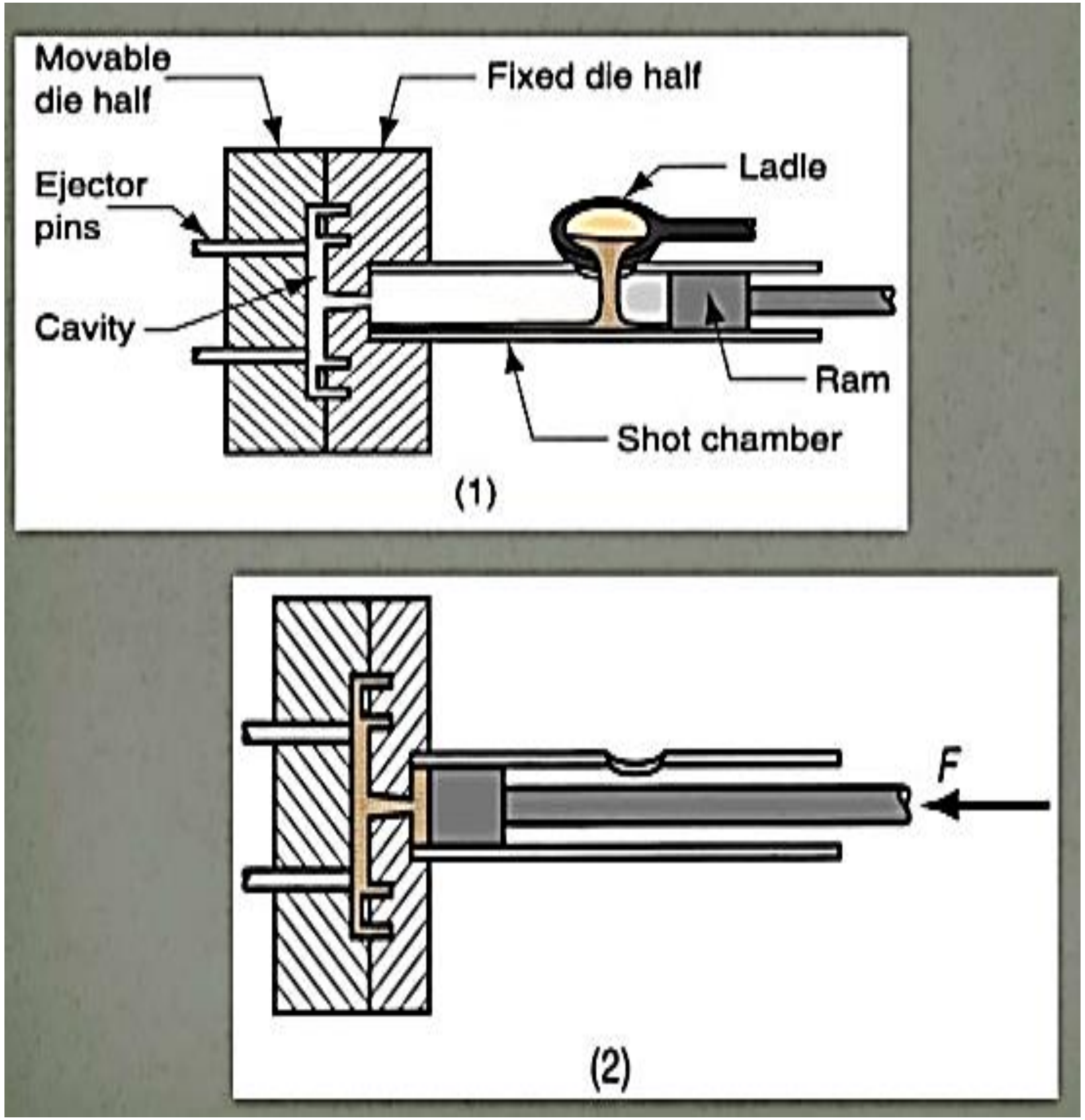
DIE CASTING

DIE CASTING IS THE PROCESS OF FORCING MOLTEN METAL UNDER HIGH PRESSURE (10-210 Mpa OR 1450-30500 PSI) INTO THE CAVITIES OF REUSABLE STEEL MOLDS

HOT CHAMBER DIE CASTING



COLD CHAMBER DIE CASTING



Die Casting

Metal: Aluminum
Process: Die Cast
Weight: 20 lb
Size: Large(over 12X12)
Market: Automotive

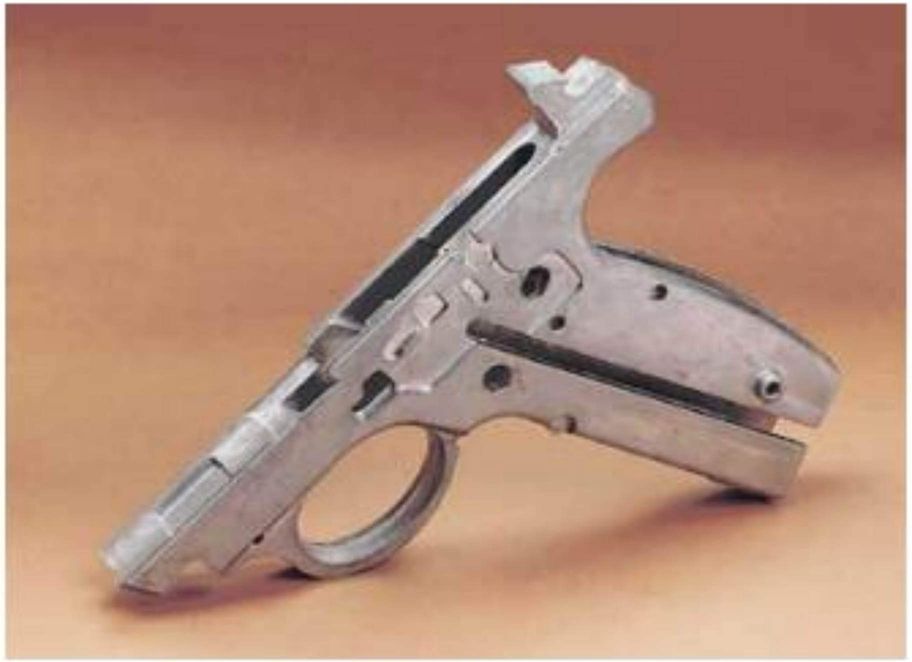
Description: Rear Sub-frame

Metal: Zinc
Process: Die Cast
Weight: xx
Size: Large(over 12X12)
Market: Automotive

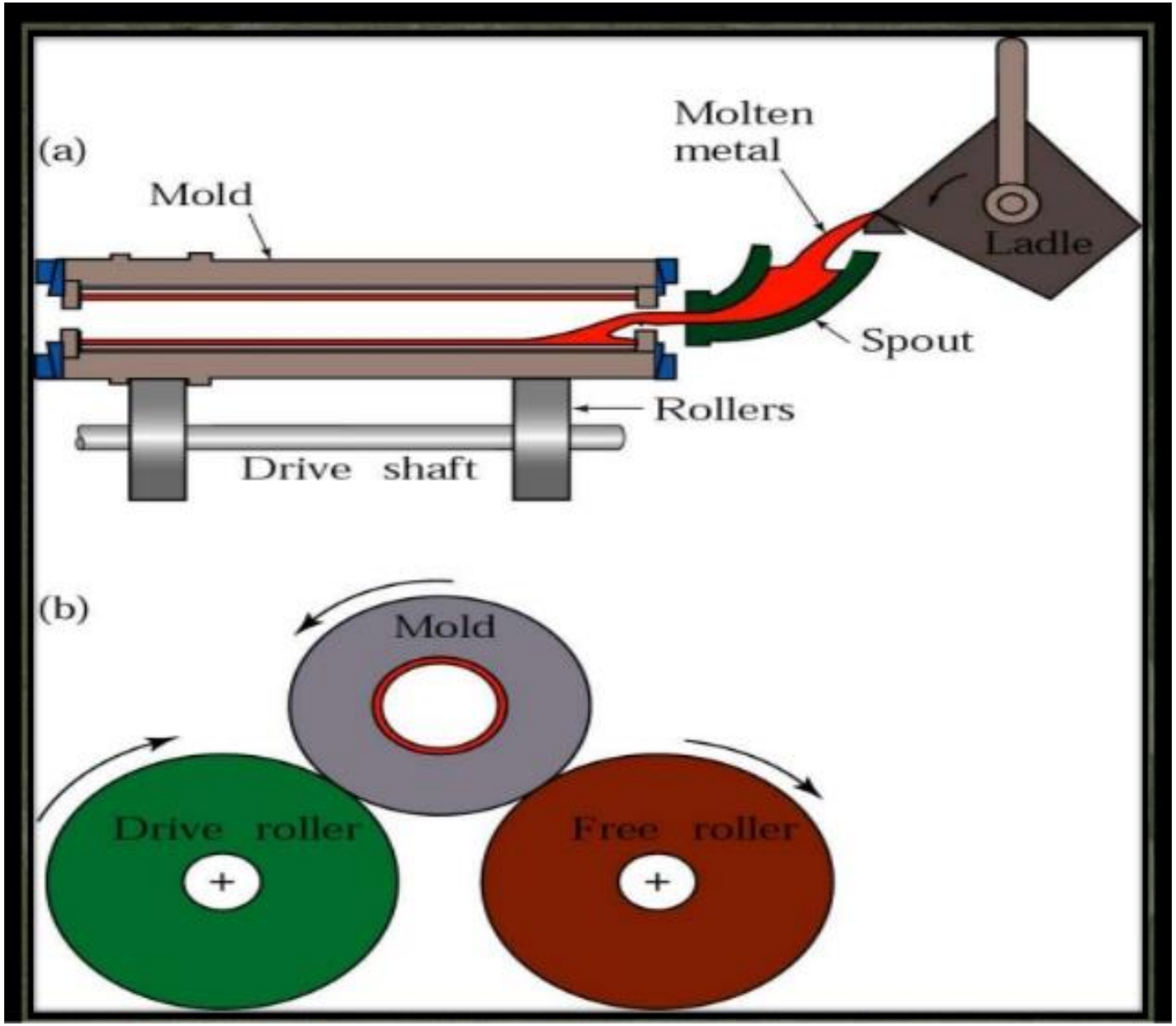
Description: 1974 Pontiac radiator grill

Metal: Aluminum
Process: Die Cast
Weight: 0.35 lb
Size: Medium(3X3 to 12X12)
Market: Sports/Recreation

Description: Pistol frame



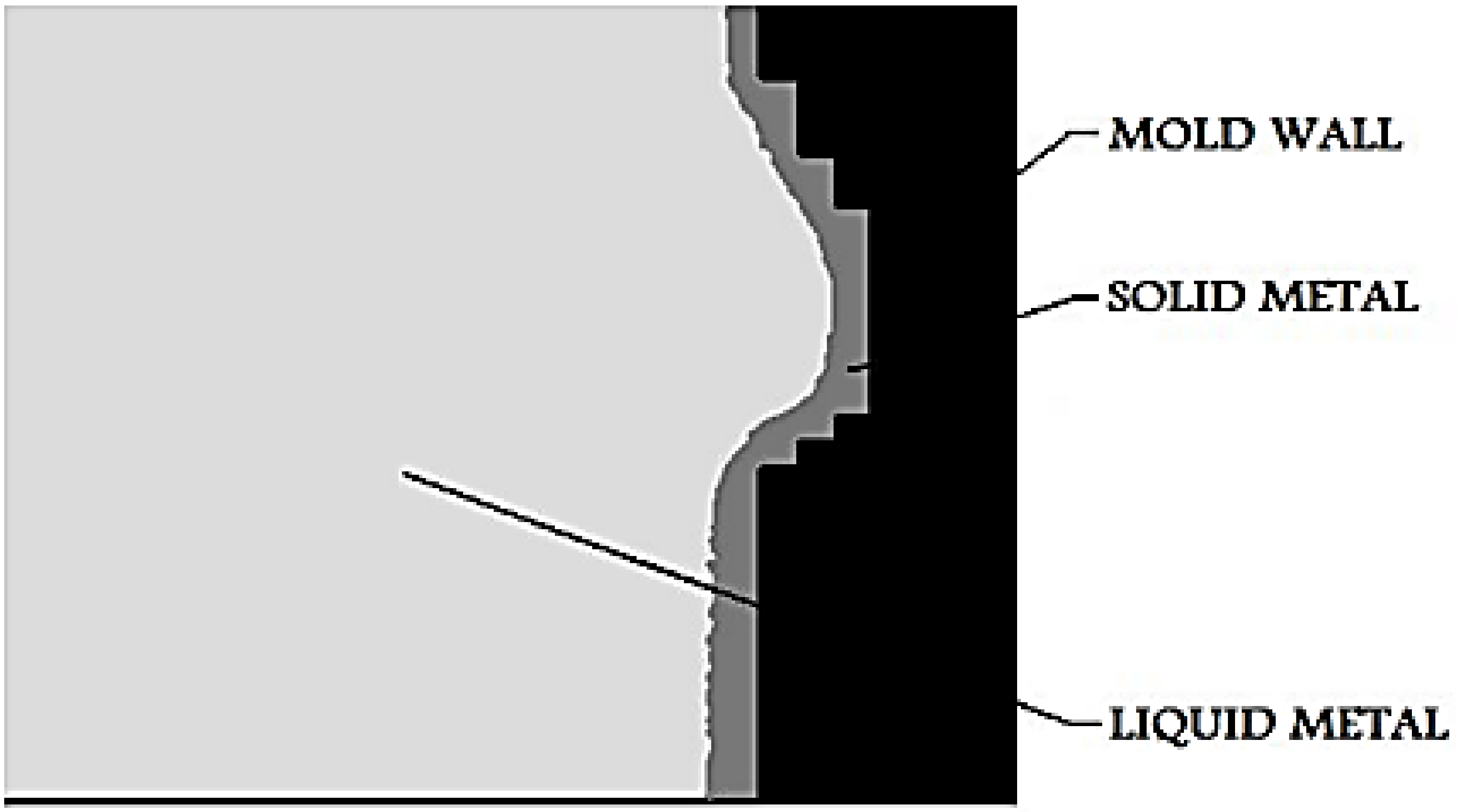
CENTRIFUGAL CASTING



Process	Advantages	Disadvantages	Examples
Sand	Wide range of metals, sizes, shapes, low cost	poor finish, wide tolerance	engine blocks, cylinder heads
Shell mold	better accuracy, finish, higher production rate	limited part size	connecting rods, gear housings
Expendable pattern	Wide range of metals, sizes, shapes	patterns have low strength	cylinder heads, brake components
Plaster mold	complex shapes, good surface finish	non-ferrous metals, low production rate	prototypes of mechanical parts
Ceramic mold	complex shapes, high accuracy, good finish	small sizes	impellers, injection mold tooling
Investment	complex shapes, excellent finish	small parts, expensive	jewellery
Permanent mold	good finish, low porosity, high production rate	Costly mold, simpler shapes only	gears, gear housings
Die	Excellent dimensional accuracy, high production rate	costly dies, small parts, non-ferrous metals	precision gears, camera bodies, car wheels
Centrifugal	Large cylindrical parts, good quality	Expensive, limited shapes	pipes, boilers, flywheels

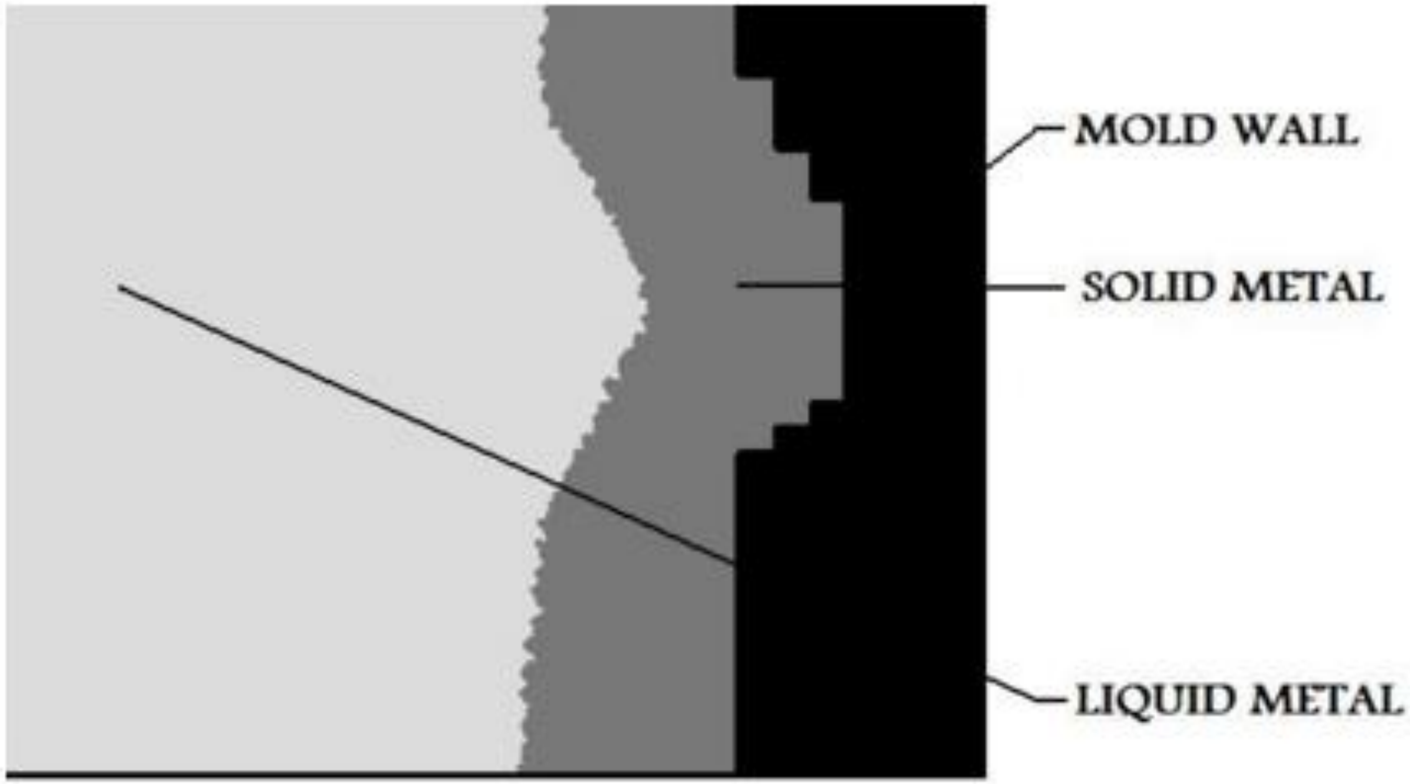
SLUSH CASTING

MOLD FOR SLUSH CASTING
READY TO BE POURED



SECTION OF CASTING NEAR MOLD WALL
SHORT TIME AFTER POURING

SOLIDIFICATION CAN BE SEEN TO START AT INTERFACE BETWEEN MOLTEN METAL AND MOLD SURFACES



SECTION OF CASTING NEAR MOLD WALL
LONGER TIME AFTER POURING

SOLIDIFICATION PROGRESSES FROM MOLD-CASTING
INTERFACE TOWARRDS INNER REGIONS OF THE MATERIAL
THICKNESS OF THIS SOLID SECTION INCREASES WITH TIME

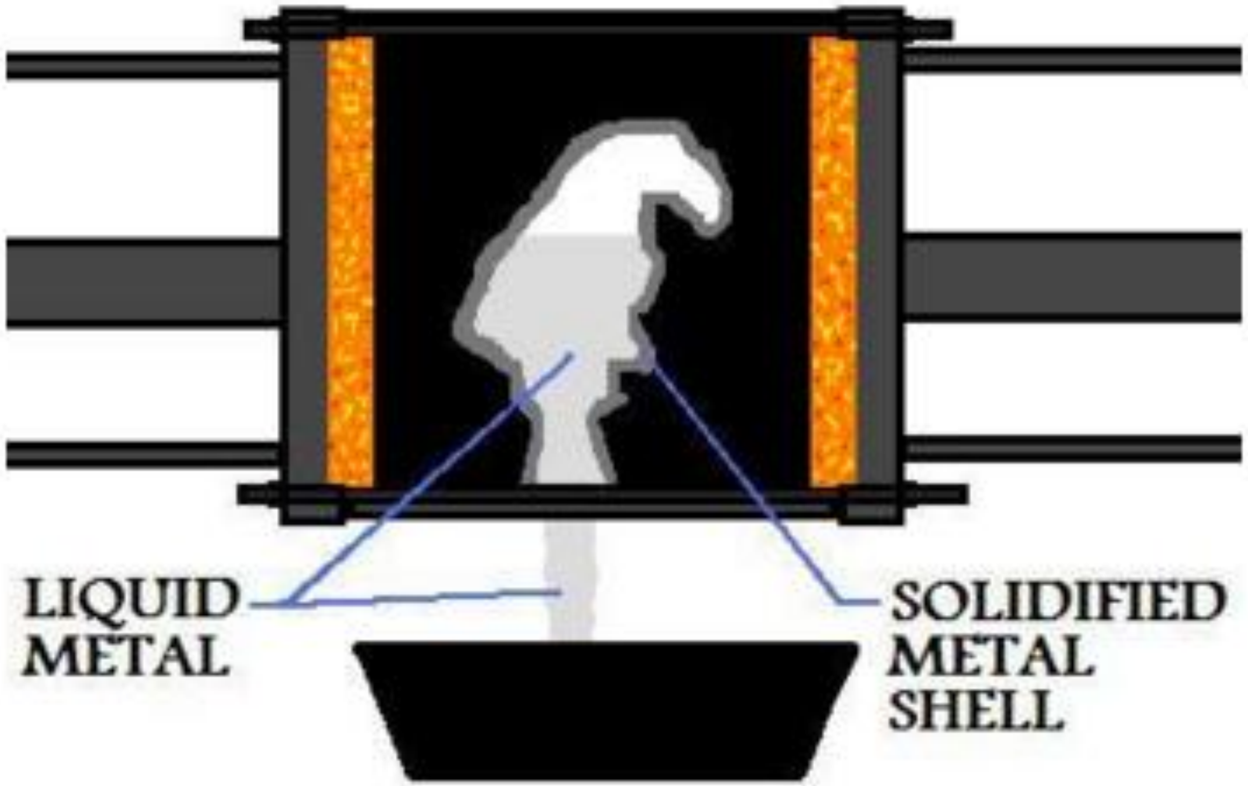
MOLD FOR SLUSH CASTING
IMMEDIATELY AFTER POURING

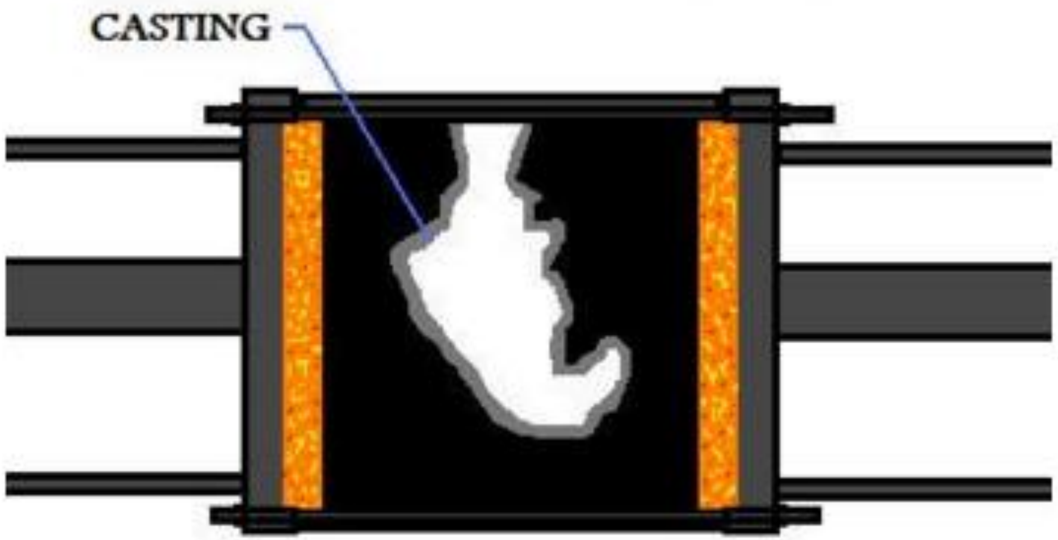
MOLD FOR SLUSH CASTING CROSS SECTIONAL VEIW OF INSIDE OF CASTING A CERTAIN AMOUNT OF TIME (T_1) AFTER POURING

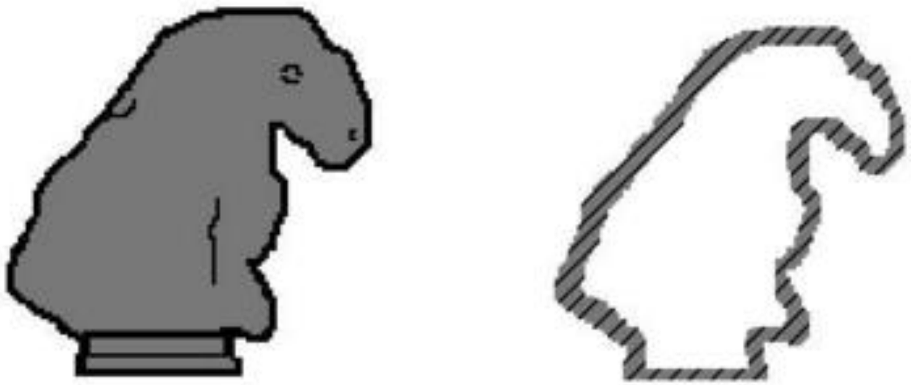
MOLD FOR SLUSH CASTING CROSS SECTIONAL VEIW OF INSIDE OF CASTING A CERTAIN AMOUNT OF TIME (T_2) AFTER POURING
ALSO NOTE ($T_2 > T_1$)

MOLD FOR SLUSH CASTING CROSS SECTIONAL VEIW OF INSIDE OF CASTING A CERTAIN AMOUNT OF TIME (T_3) AFTER POURING
ALSO NOTE ($T_3 > T_2$)

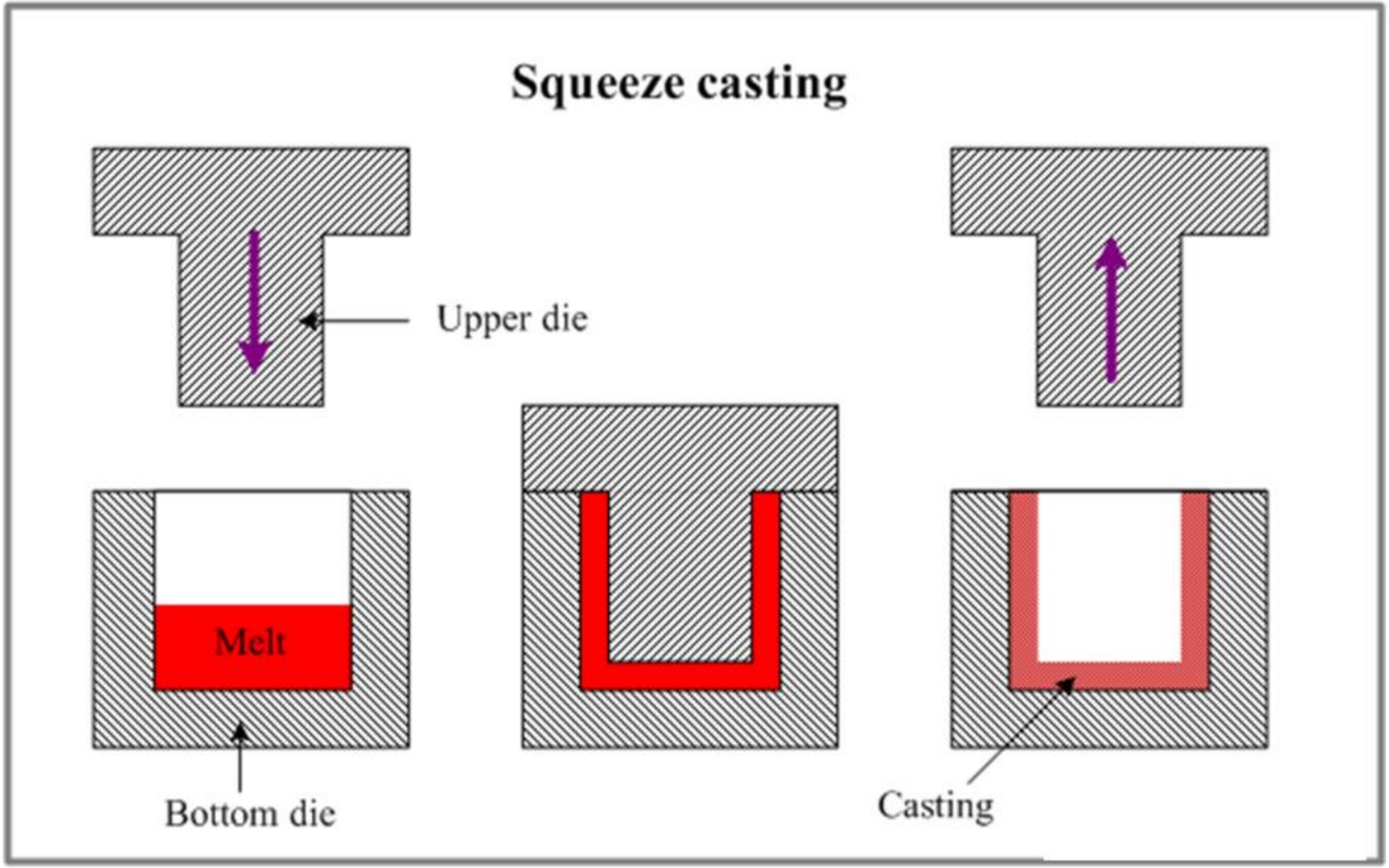
THE LIQUID METAL FROM THE INTERIOR OF THE CASTING IS POURED OUT BEFORE THE ENTIRE MASS OF MOLTEN MATERIAL CAN HARDEN. LEAVING ONLY THE SOLIDIFIED OUTER SHELL.



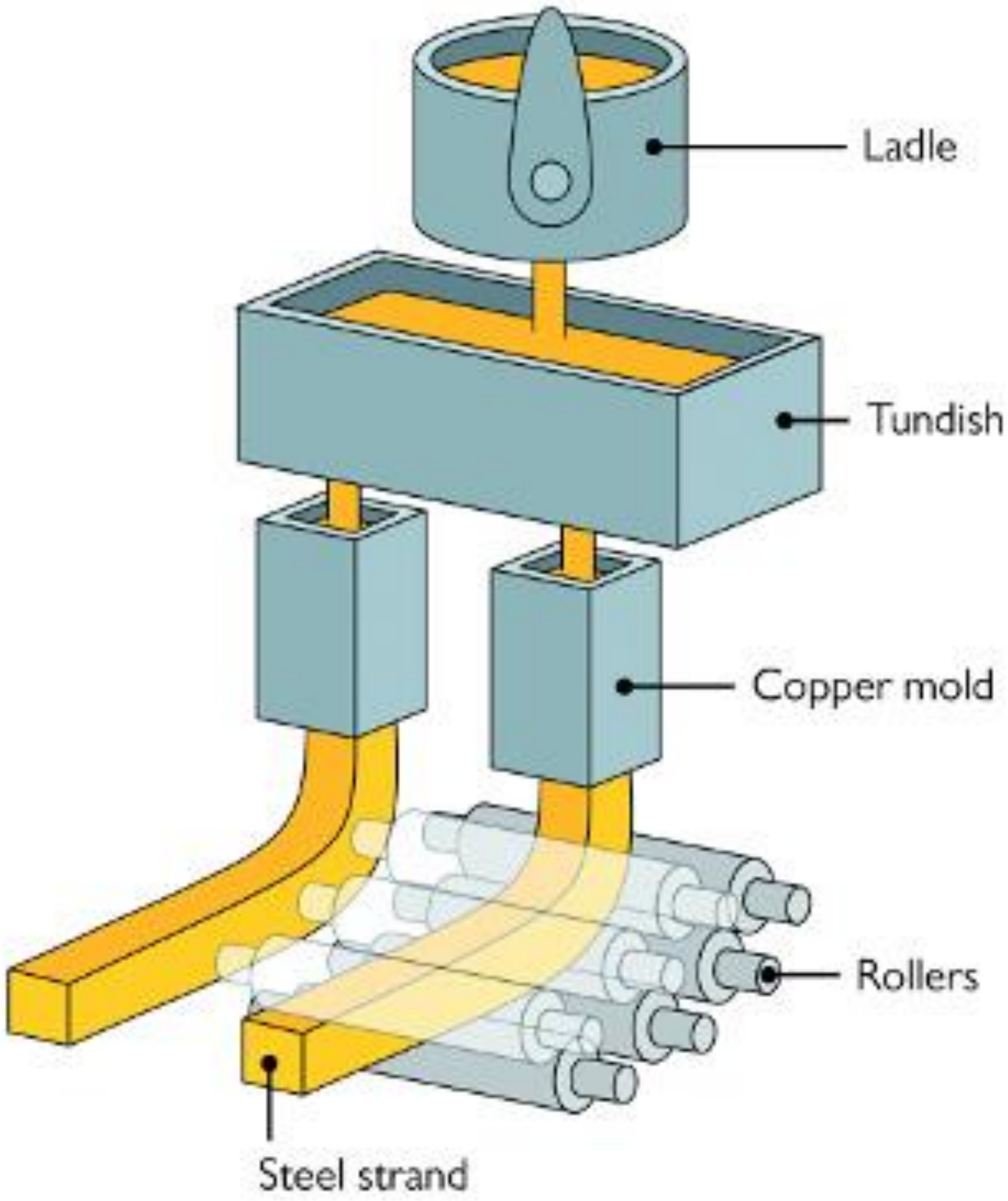


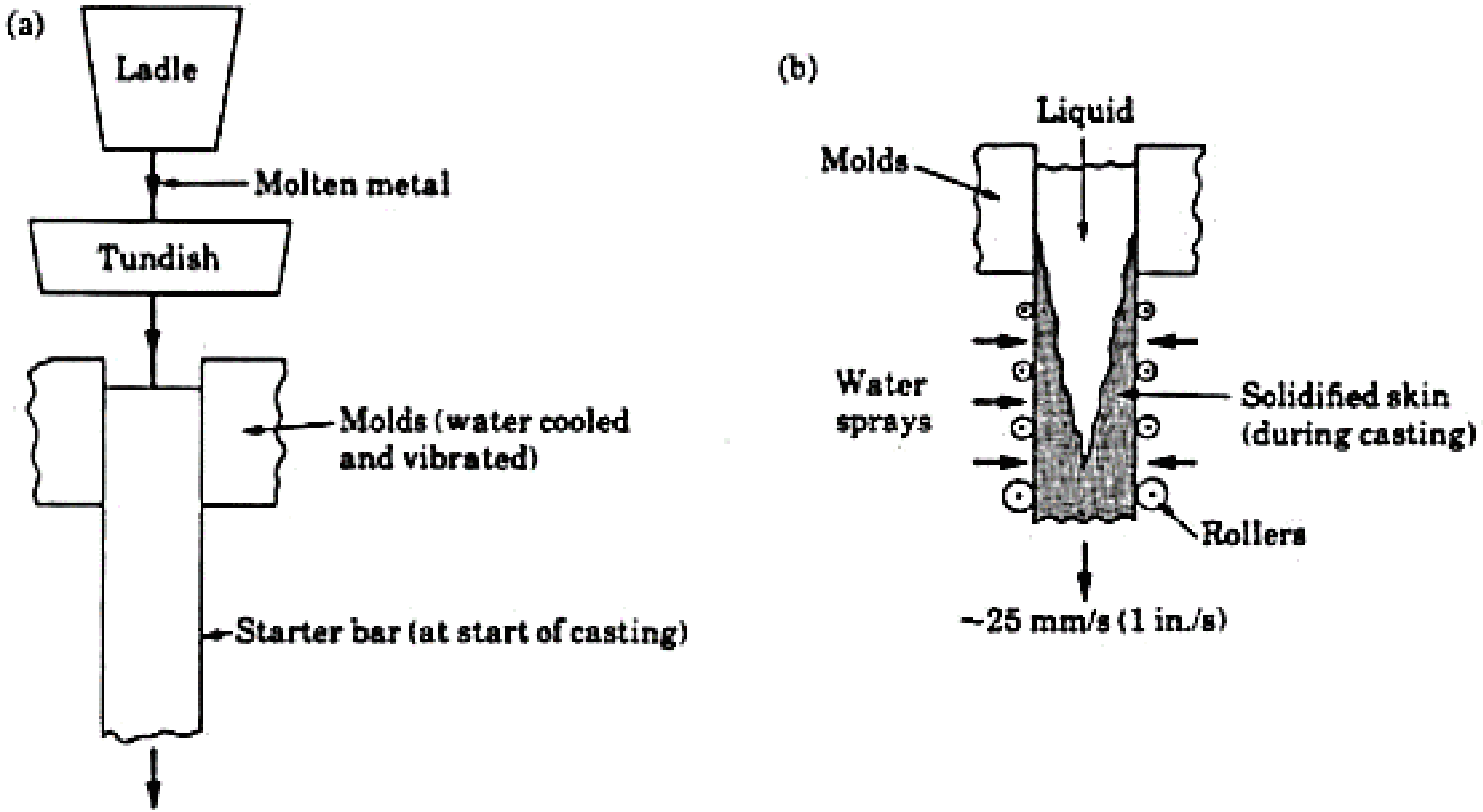


FINAL PRODUCT OF SLUSH CASTING
PROCESS; SHOWN WITH SECTION VIEW


Squeeze casting
Upper die
Melt
Bottom die
Casting

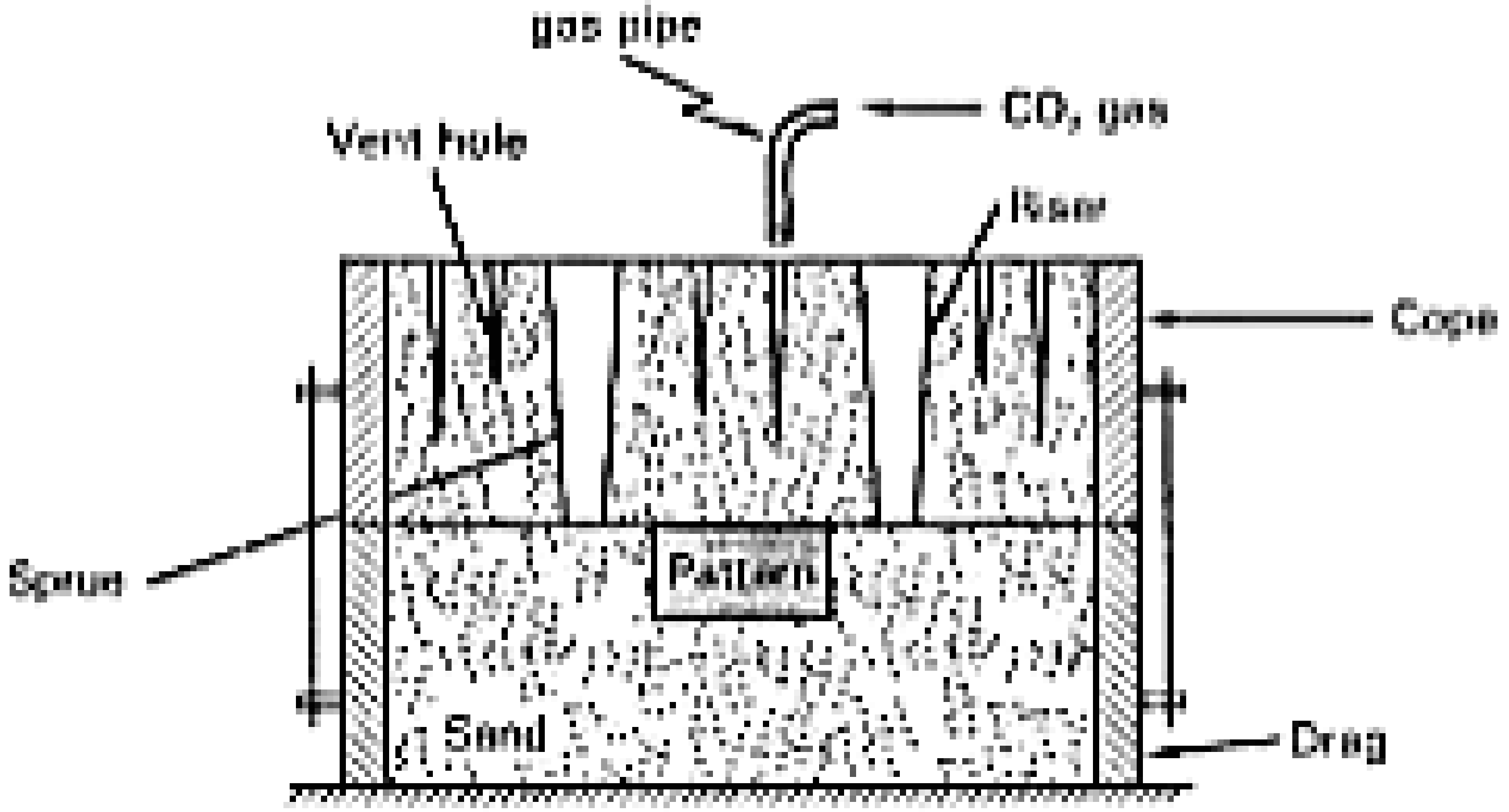
CONTINOUS CASTING





(a)
Ladle
Molten metal
Tundish
Molds (water cooled and vibrated)
Starter bar (at start of casting)
(b)
Liquid
Molds
Water sprays
Solidified skin (during casting)
Rollers
~25 mm/s (1 in./s)

CO_2 CASTING = SODIUM SILICATE PROCESS



$$Na_2SiO3 + CO_2 \rightarrow Na_2CO_3 + SiO_2$$

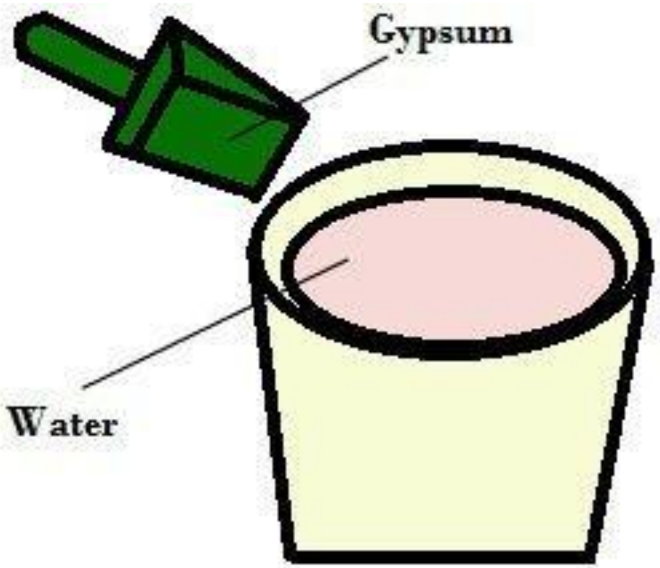
(Sodium Silicate) (silica gel)

Strength increases due to gassing

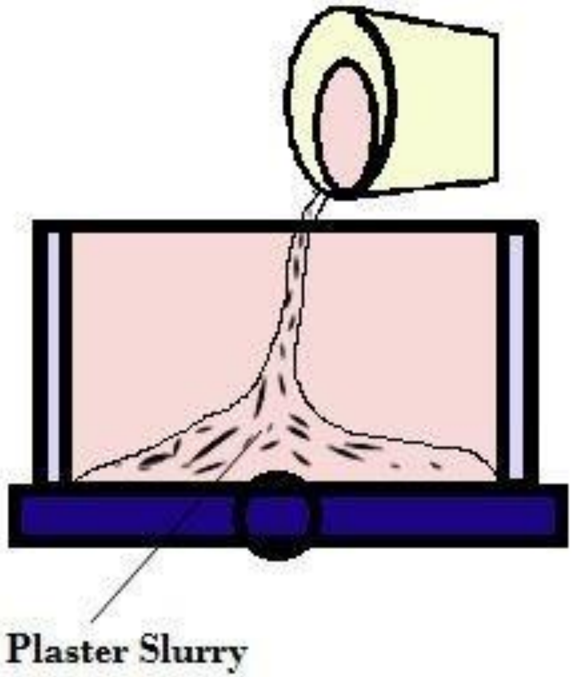
Ceramic Mold Casting

Ceramic mold casting is a casting process in which materials are combined to make a mold which has rubber like consistency. Ceramic mold casting can be used for simple home foundry casting and also complicated, intricately designed industrial castings. This casting provides attractive looks for kitchen wares.

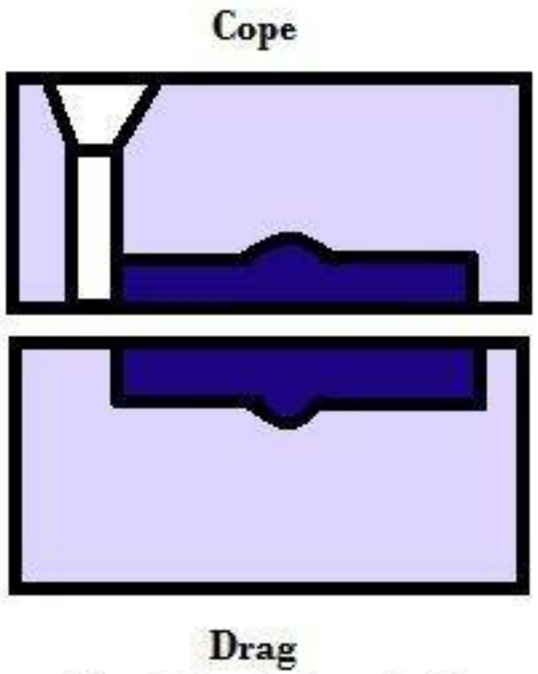
The Process: Ceramic mold casting, is an expendable process in which reusable and cheap patterns made of wood, metals, plastic or rubber are used..



Making of Plater Slurry



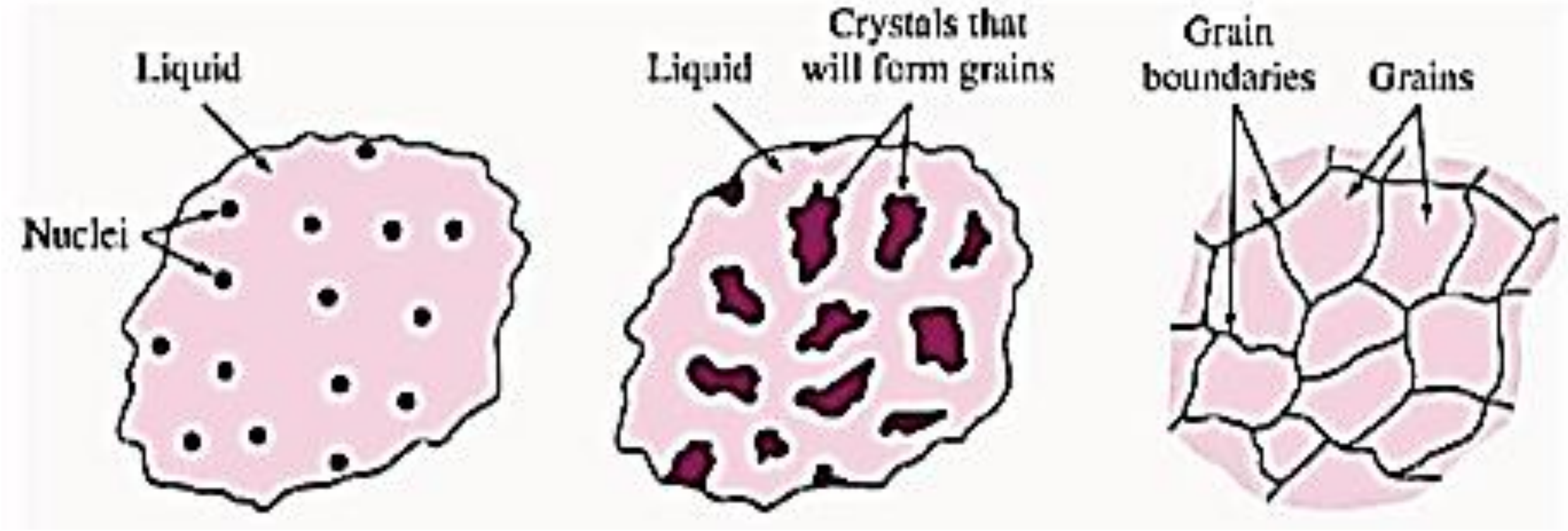
Ceramic Mould Making

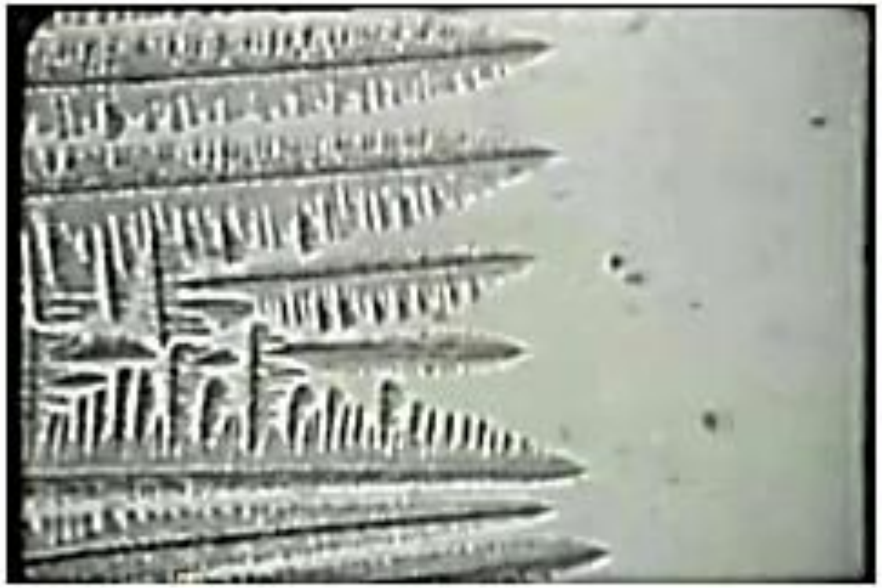


Final Part Production

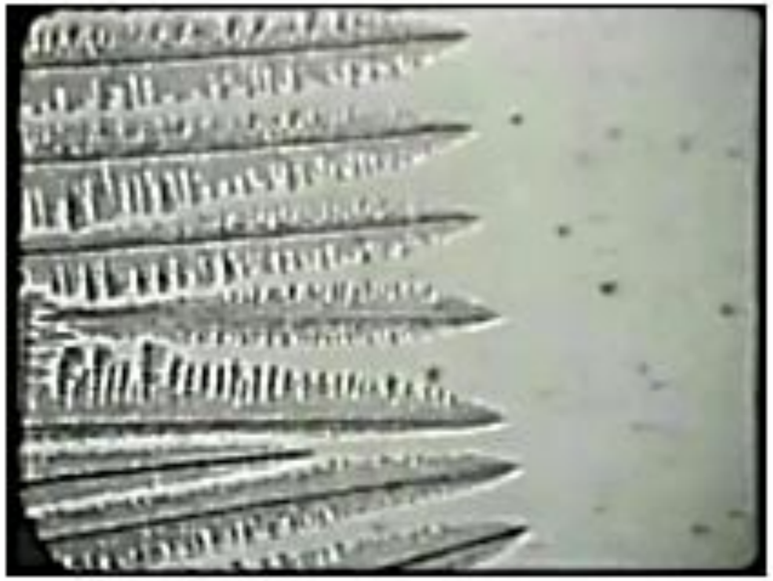
In ceramic mold casting, there are two different types of slurries used which are known as the true ceramic molding and shaw process.
Patterns are kept is a flask and aggregate is poured over the pattern. Molding material sets in a rubber like consistency around the pattern. The rubber like consistency makes it easy for the pattern to be stripped out of the mold.
The mold which is made in cope and drag form, is heated to make it harden.
The strong mold is useful for high temperature pours, which can be done when the mold is still hot.

SOLIDIFICATION



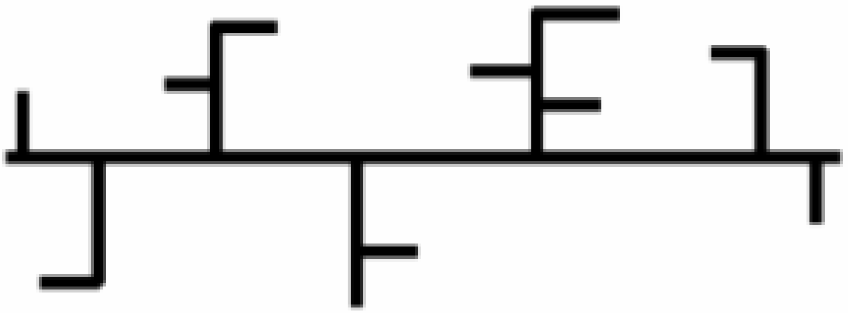


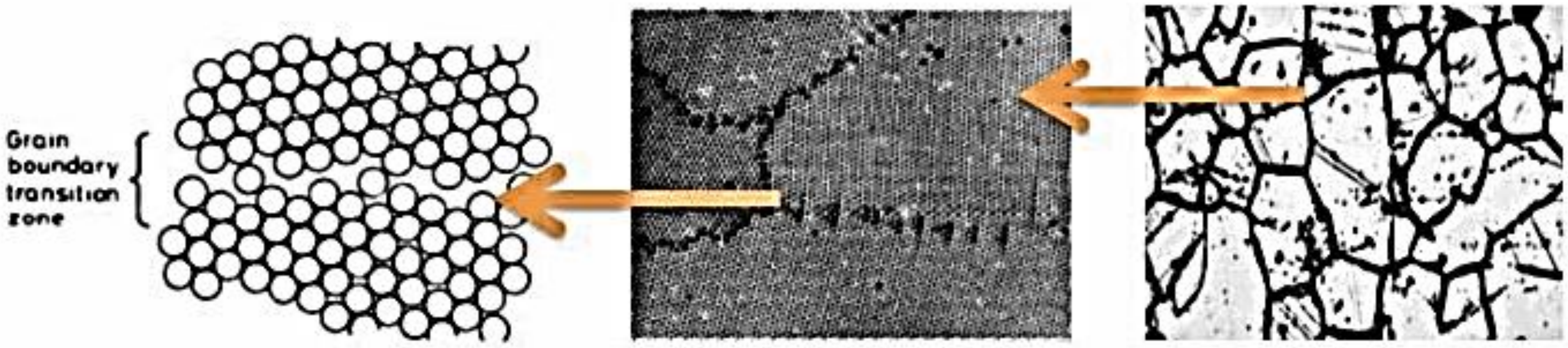
1

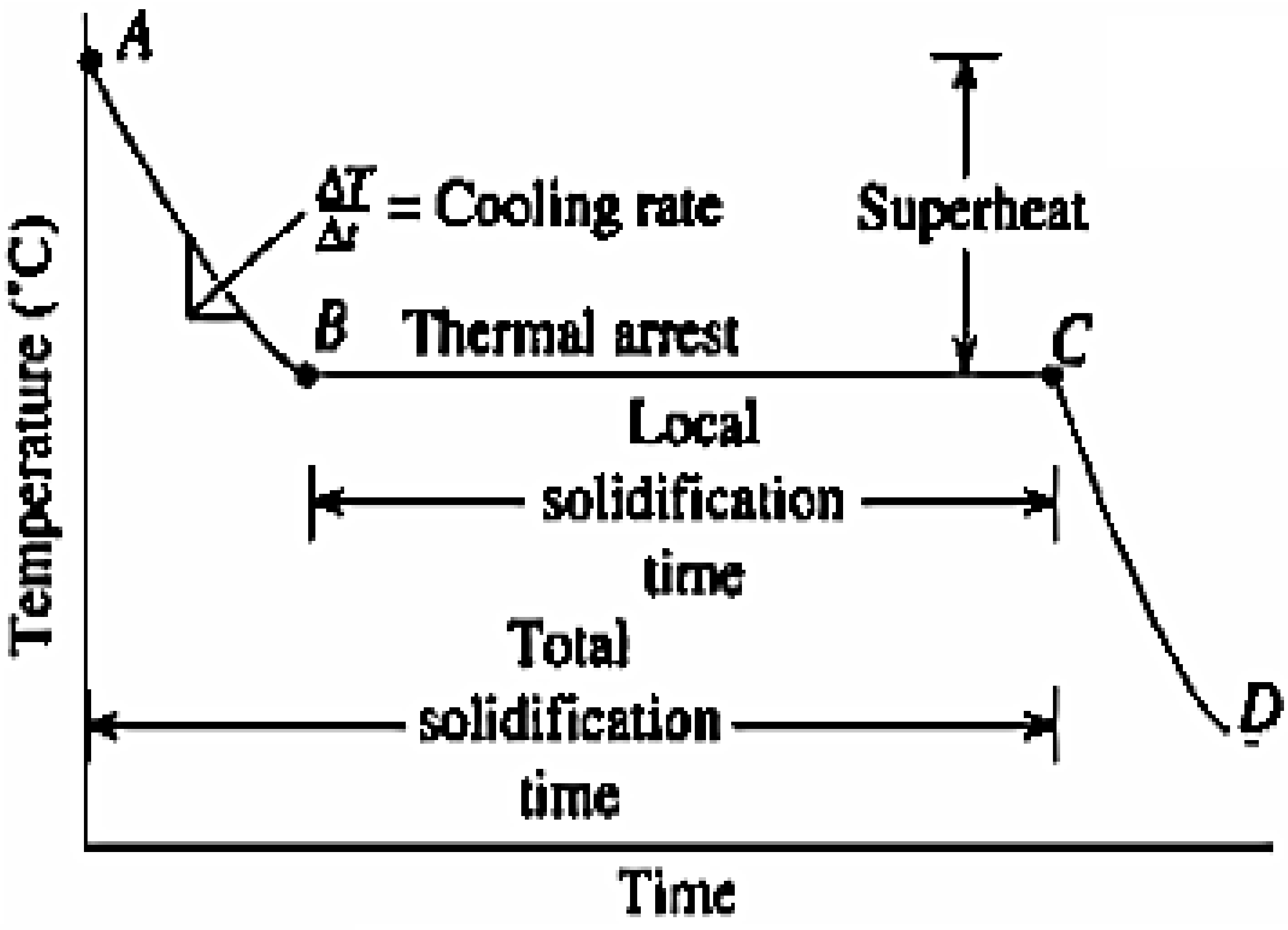


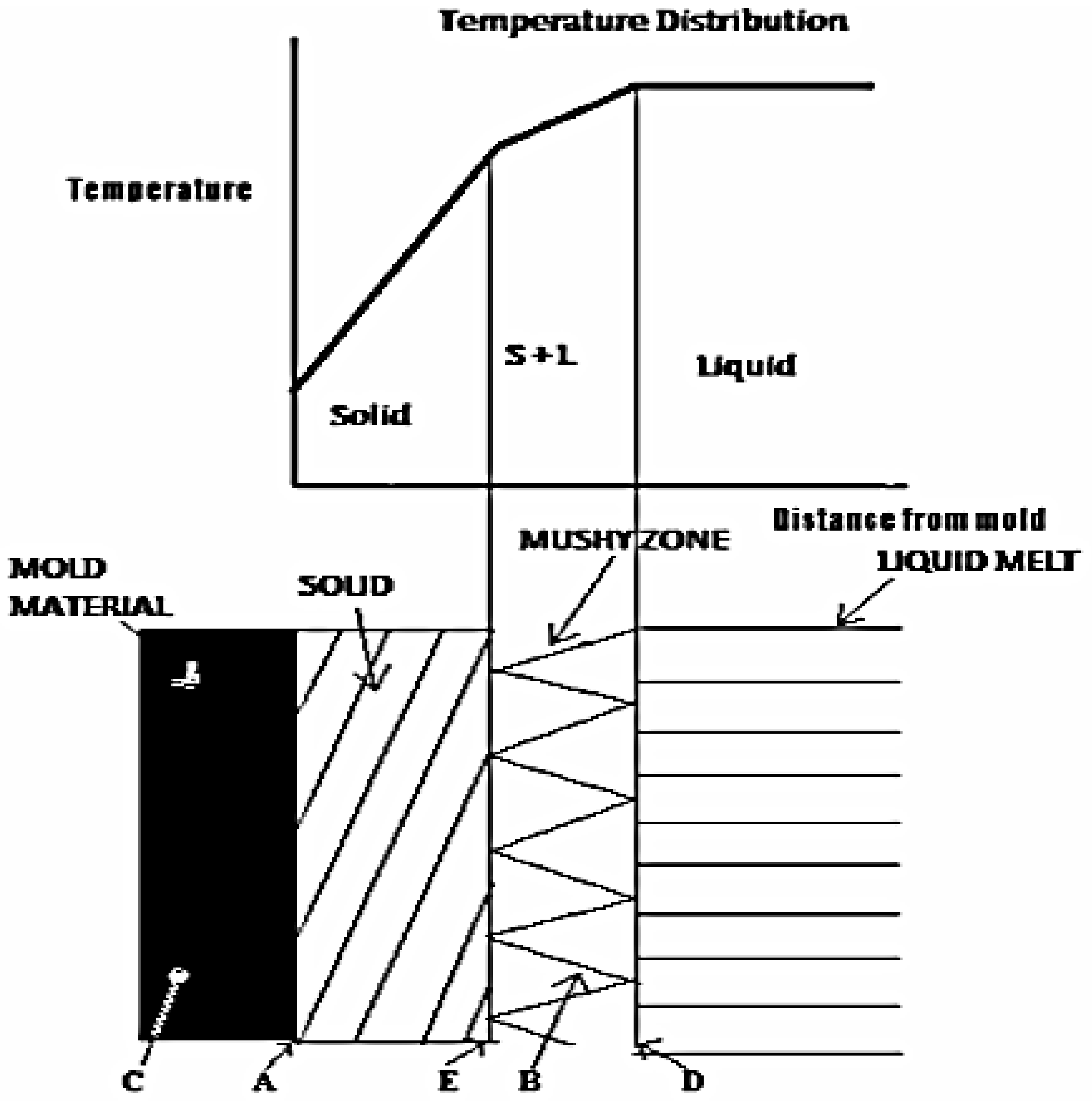
2

3




Grain
boundary
transition
zone


A
$\frac{\Delta T}{\Delta t}$ = Cooling rate
Superheat
B
Thermal arrest
C
Local
solidification
time
Total
solidification
time
D
Temperature (°C)
Time



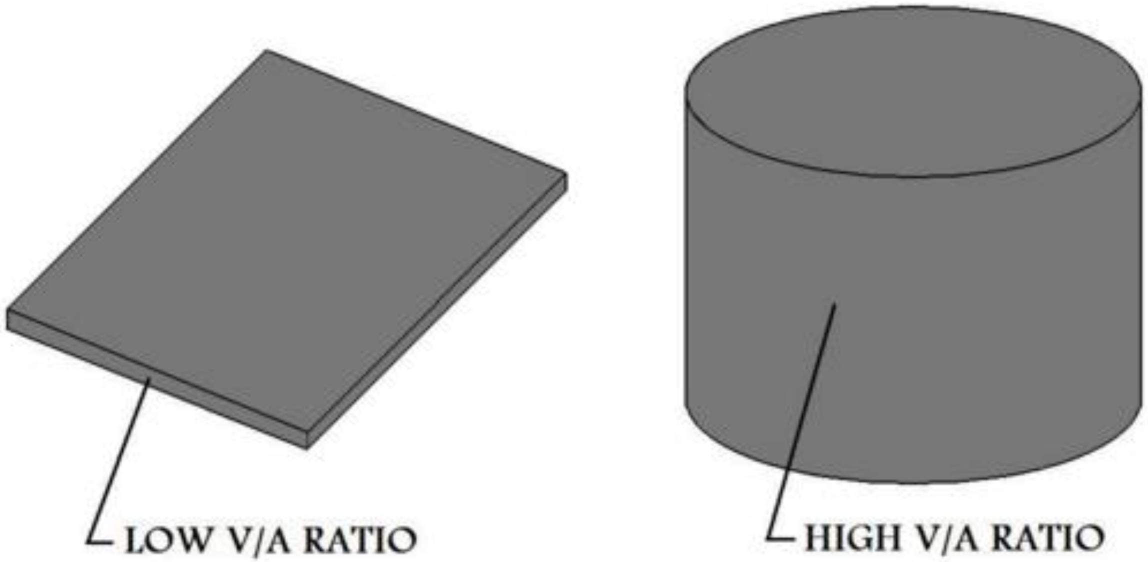
A = SURFACE OF MOLD CAVITY
B = MUSHY OR PASTY ZONE WHICH MOVES INWARD
C = HEAT FLOW DIRECTION
D =START OF SOLIDIFICATION BOUNDRY
E =END OF SOLIDIFCATION BOUNDRY

Design Considerations

V/A Ratio

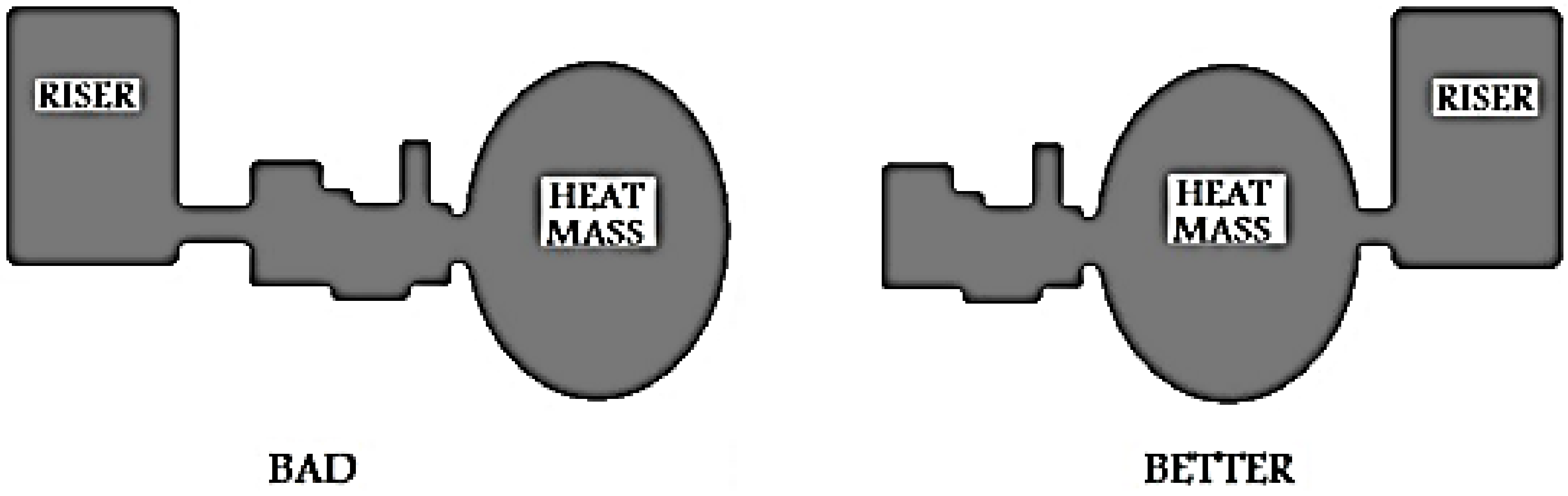
Ratio stands for volume to surface area or mathematically (volume/surface area).

V/A ratios is critical in avoiding premature solidification of the casting and the formation of vacancies.

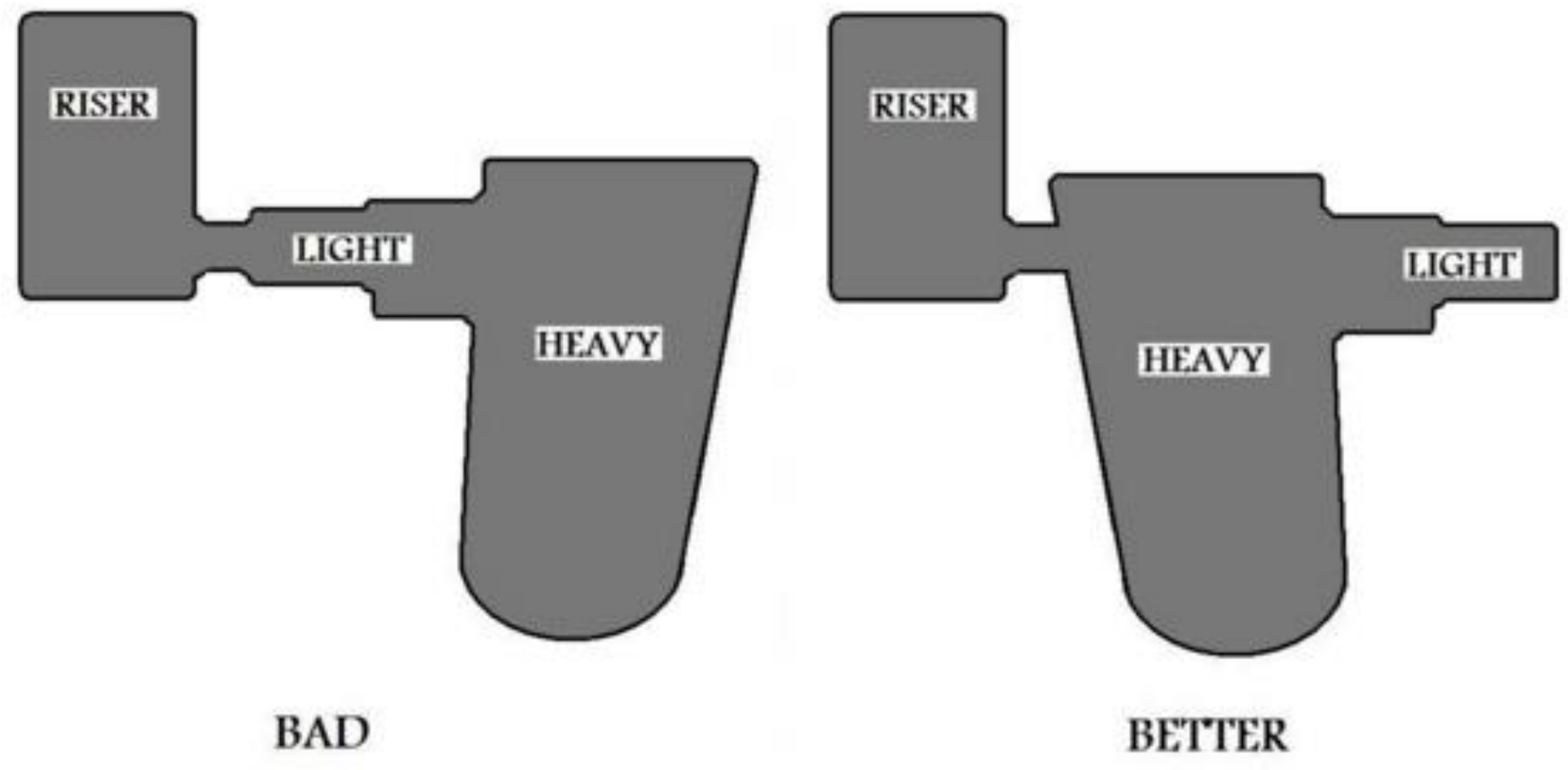


Heat Masses

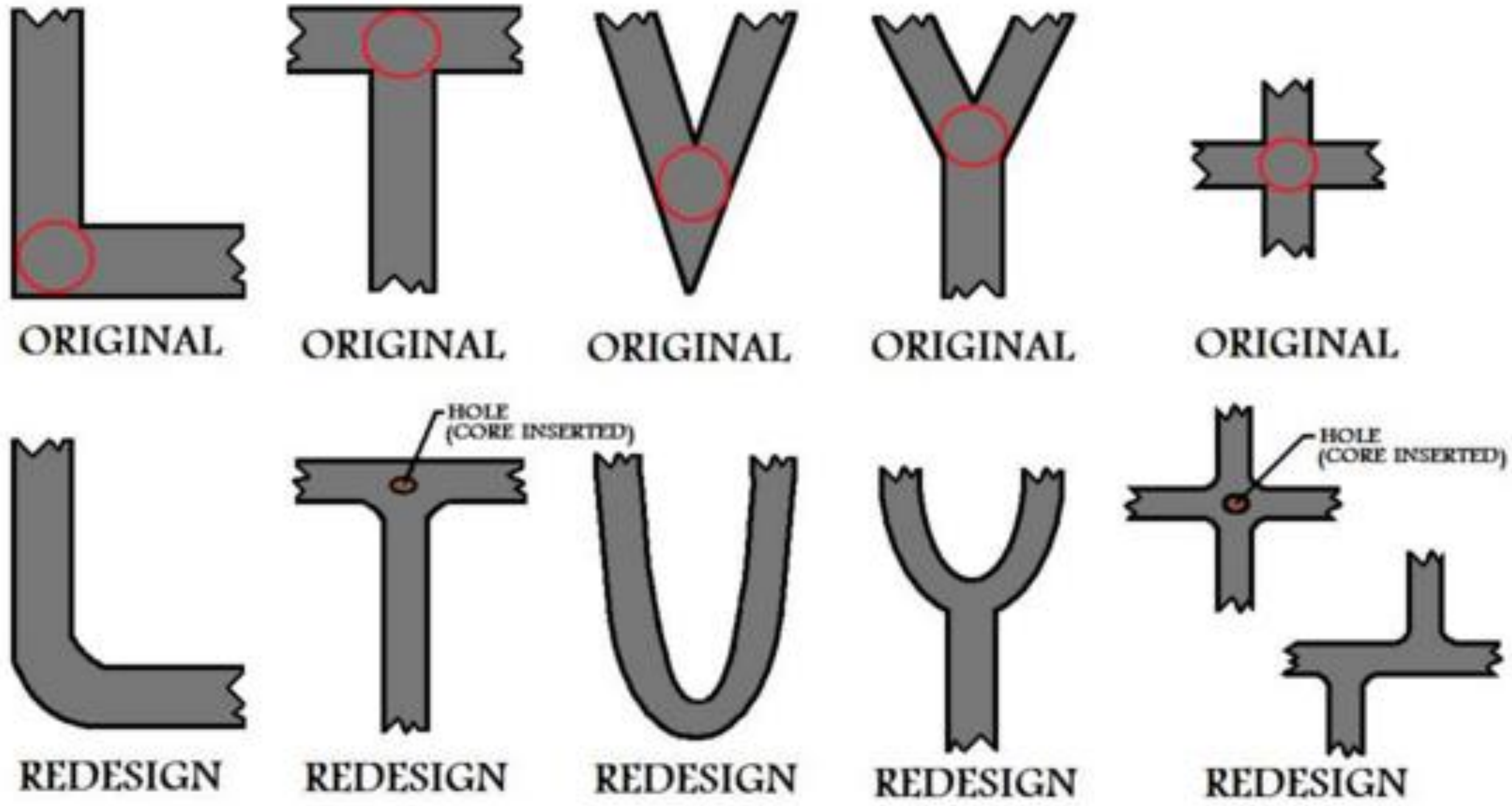
Avoid large heat masses in locations distant to risers.



Do not feed a heavy section through a lighter one.

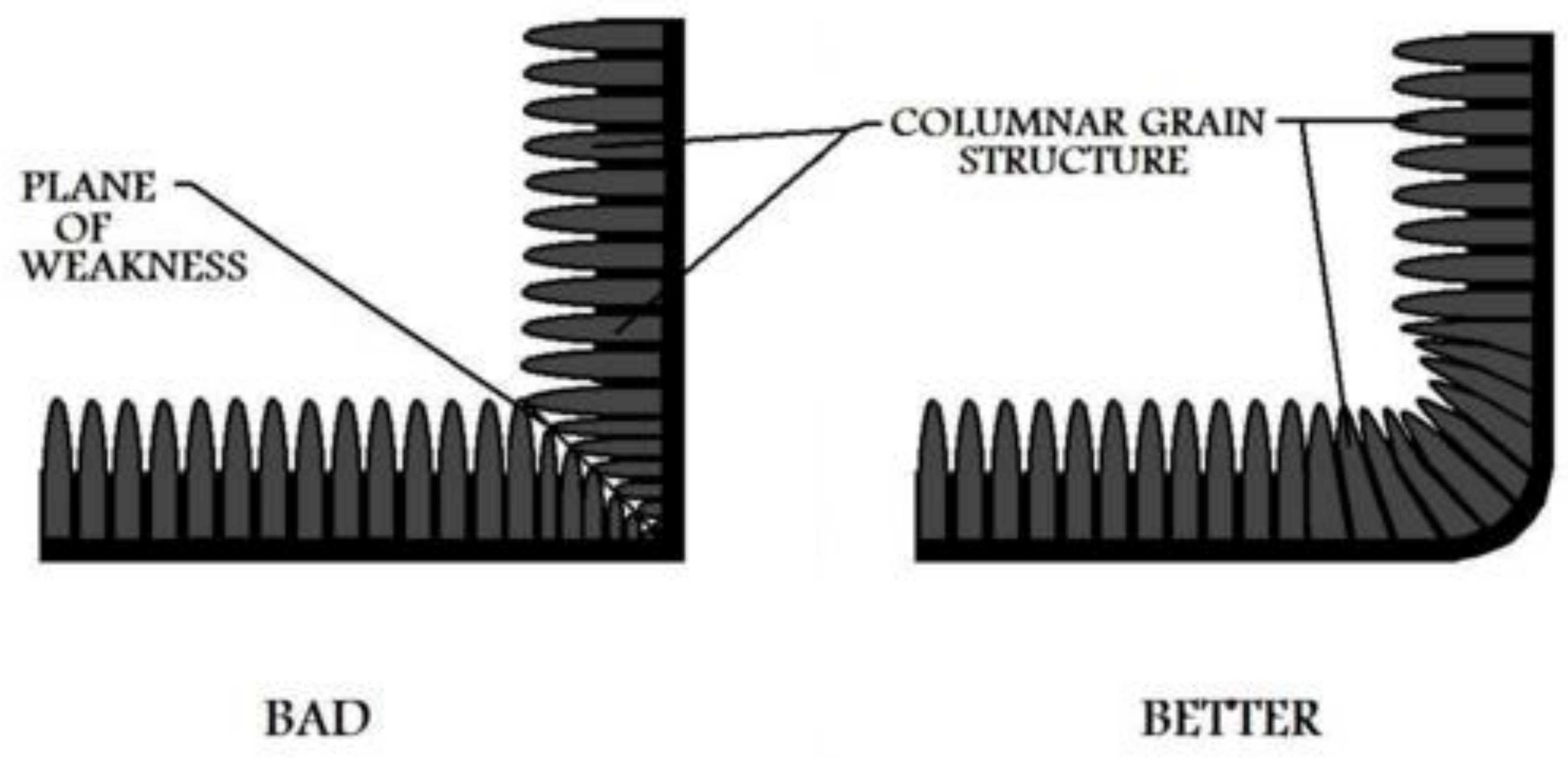


JUNCTIONS…



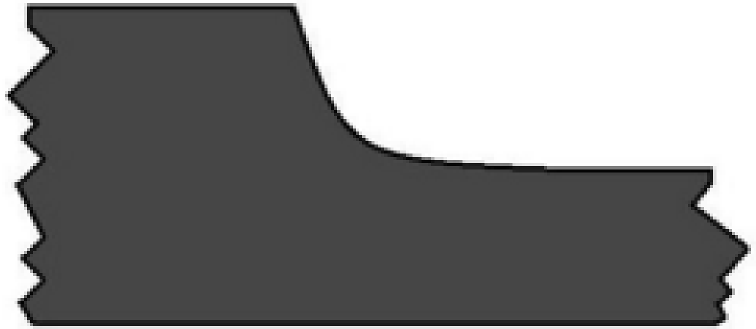
hot spots are circled in red

Prevent Planes of Weakness

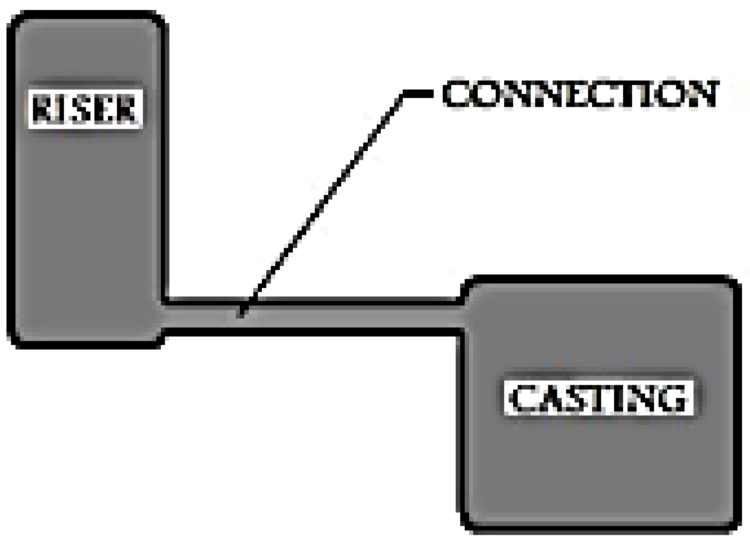


Reduce Turbulence

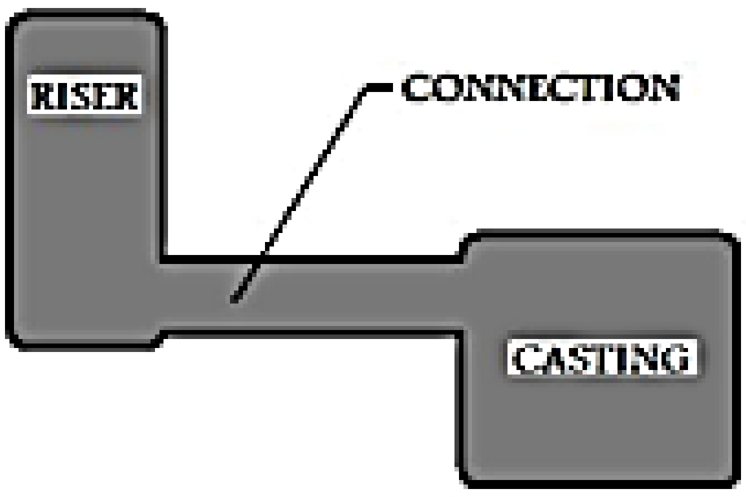
BAD



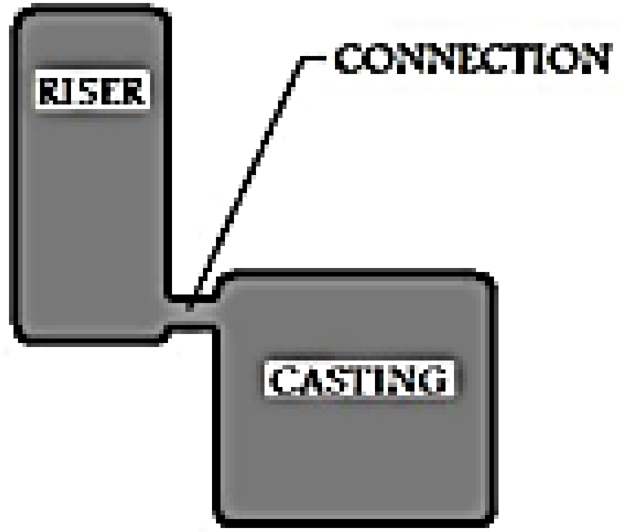
BETTER



BAD
(PASSAGE WILL FREEZE)

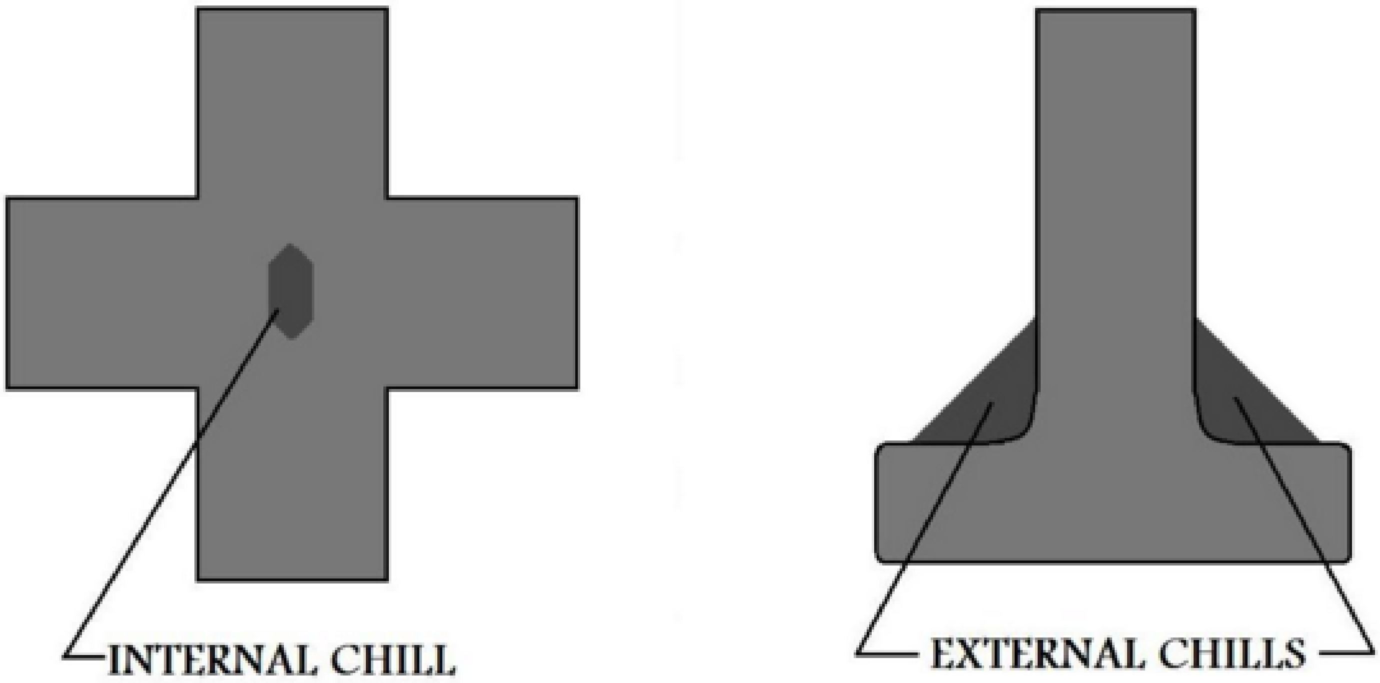


BAD
(WASTES MATERIAL)



BETTER

USAGE OF CHILLS



• **regulation of thermal gradients**

CASTING QUALITY

Basic categories of casting defects

1. Metallic projections:
   - Fins, flash or projections
2. Cavities
   - blow holes, pin holes, shrinkage cavities
3. Discontinuities
   - cracks, cold or hot tears
   - cold shuts- improper fusion of different streams of metals
   - Improper solidification can cause tears

4.Defective surface

- Surface folds ,laps, scars, adhering sand layers and oxide scales

5.Incomplete casting

- misruns (due to premature solidifications)
- insufficient metal poured
- leaks in the mold

6.Incorrect dimensions

- incorrect allowances
- deformed pattern
- pattern mounting error

7.Inclusions

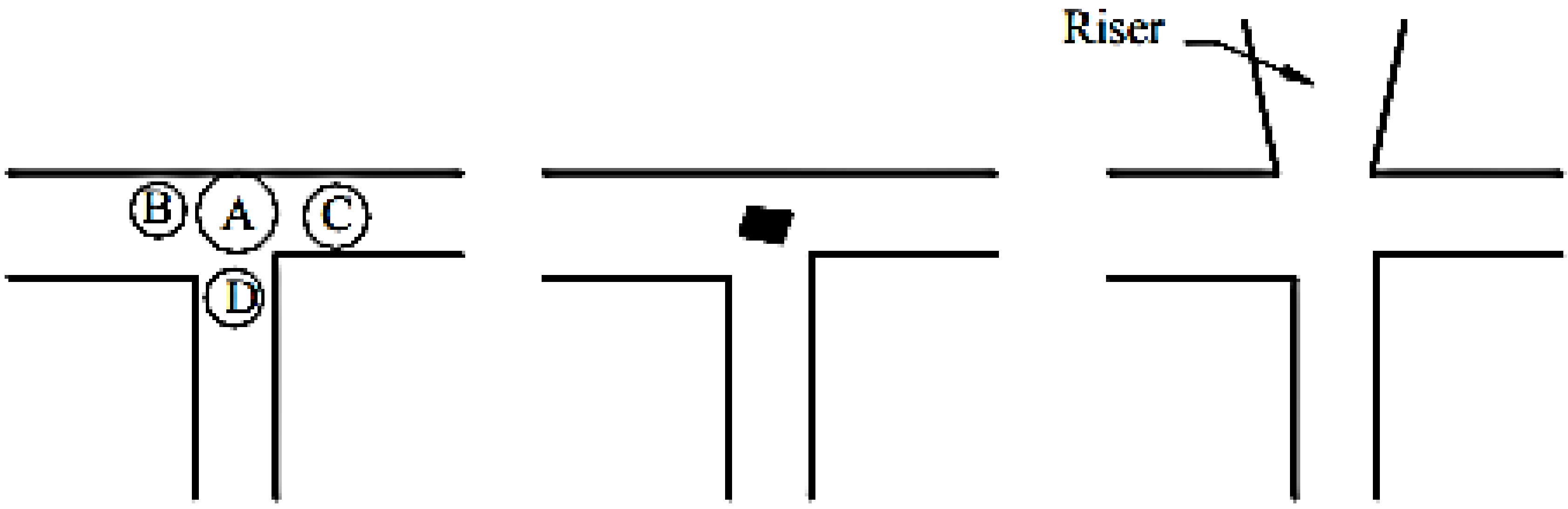
- nonmetallic particles usually
- bad for casting - acts as stress raiser
- materials from alloys, crucible ,mold etc
- sand particles, ceramic particles,
- Can be avoided using filters, good strong molds etc

BLOW HOLES

- Appears as small round voids opened to the casting surface.
- Caused by hard ramming and low permeability sands.

SHRINKAGE DEFECTS

- Caused by inadequate feeding of molten metal.



(a) (b) (c)

HOT TEARS

- Appears as external cracks or discontinuities on casting surface.
- Caused by hard ramming, too much of shrinkage of molten metal and poor design of casting.

MISRUNS

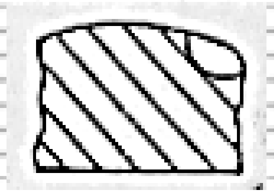
- Mould cavity remaining unfilled (casting is too thin or temperature is too cold)

- COLD SHUT
- Imperfect fusion of molten metal in the mould cavity.

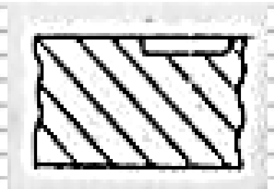
- POUR SHORT
- Mould cavity is not completely filled for the want of molten material.

- INCLUSIONS
- Foreign material present within the metal of a casting.

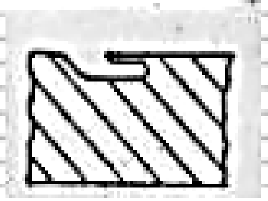
Common Casting defects



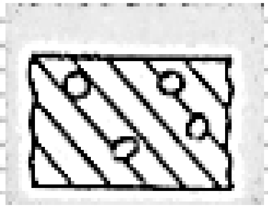
Blow



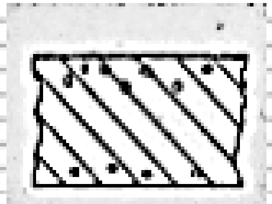
Scar



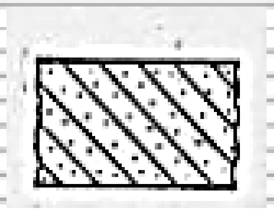
Blister



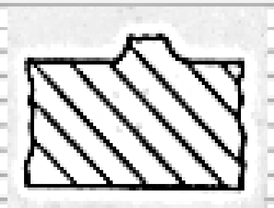
Gas holes



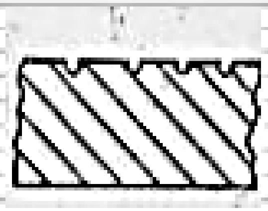
Pin holes



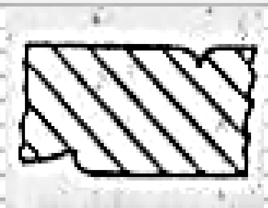
Porosity



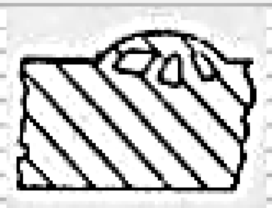
Drop



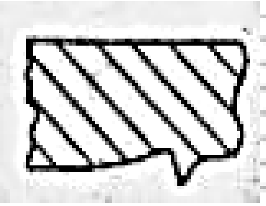
Dirt



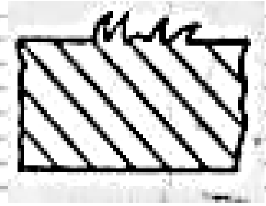
Buckle



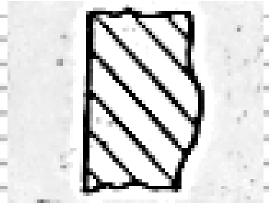
Scab



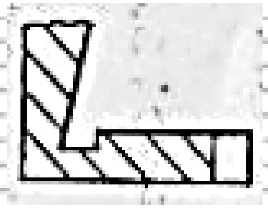
Rat tail



Penetration



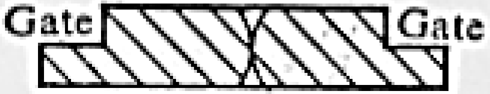
Swell



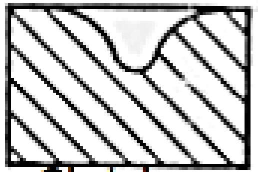
Misrun

Common Casting defects

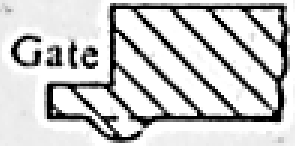
Nonmetallic inclusion



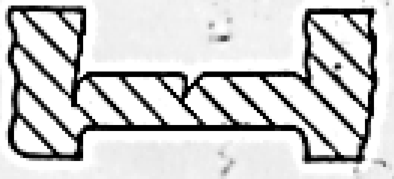
Cold shut



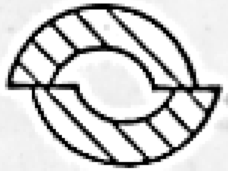
Shrinkage cavity



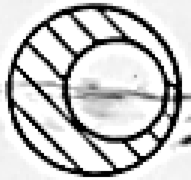
Wash



Hot tear

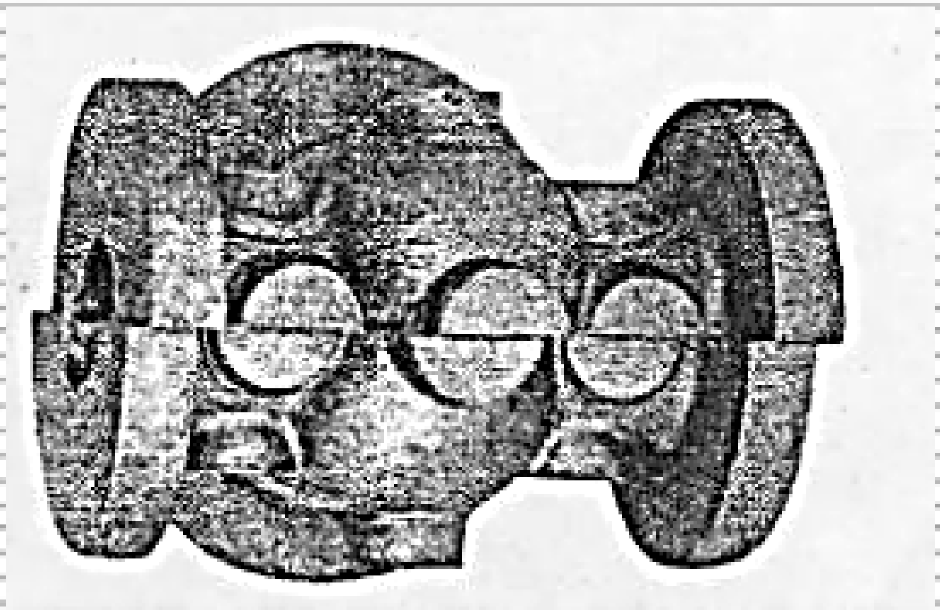


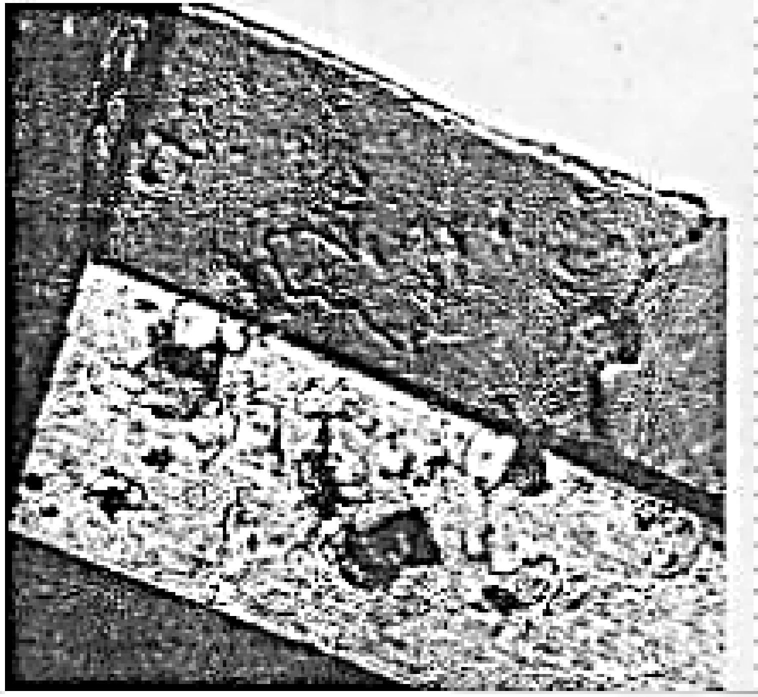
Mold shift



Core shift

Casting defects





• A crossjoint in a large gray iron valve body casting produced by mismatch of top and bottom parts of the mould

• Inclusions in spheroidal graphite cast iron.

• Part of the surface has been machined away to show the inclusions more clearly

Flash

Mold Shift

Porosity

Inclusions

Gas pockets

Short Casting

Summary of casting defects

Defect	Cause	Foundry remedy	Design remedy
Flash	Flow into mold join	Lower pouring temperature, Increase mold box clamping,	
Oxide and dross inclusion	Entrapment of foreign material	Increase care and cleanliness during pouring,	
Shrinkage cavities	Lack of sufficient feed metal	Promote directional solidification by controlling heat flow, Raise pouring temperature,	Relocate risers and ingates
Misruns	Low metal fluidity	Raise pouring temperature	Reconsider position, size and number of ingates and vents

MOULDING SAND TESTING

MOISTURE CONTENT TEST

Moisture content of the molding sand mixture may determine by drying a weighed amount of 20 to 50 grams of molding sand to a constant temperature up to 100°C in a oven for about one hour.

Then cooled to a room temperature and then reweighing the molding sand. The moisture content in molding sand is thus evaporated.

Loss in weight of molding sand due to loss of moisture, gives the amount of moisture which can be expressed as a percentage of the original sand sample.

Percentage of moisture content in the molding sand can also be determined in fact more speedily by an instrument known as a speedy moisture teller.

Instrument is based on the principle that when water and calcium carbide react, they form acetylene gas which can be measured and this will be directly proportional to the moisture content.

Instrument is provided with a pressure gauge calibrated to read directly the percentage of moisture present in the molding sand.

Clay Content Test

Amount of clay is determined by carrying out the clay content test in which clay in molding sand of 50 grams is defined as particles which when suspended in water, fail to settle at the rate of one inch per min.

Clay consists of particles less than 20 micron, per 0.0008 inch in dia.

Grain Fineness Test

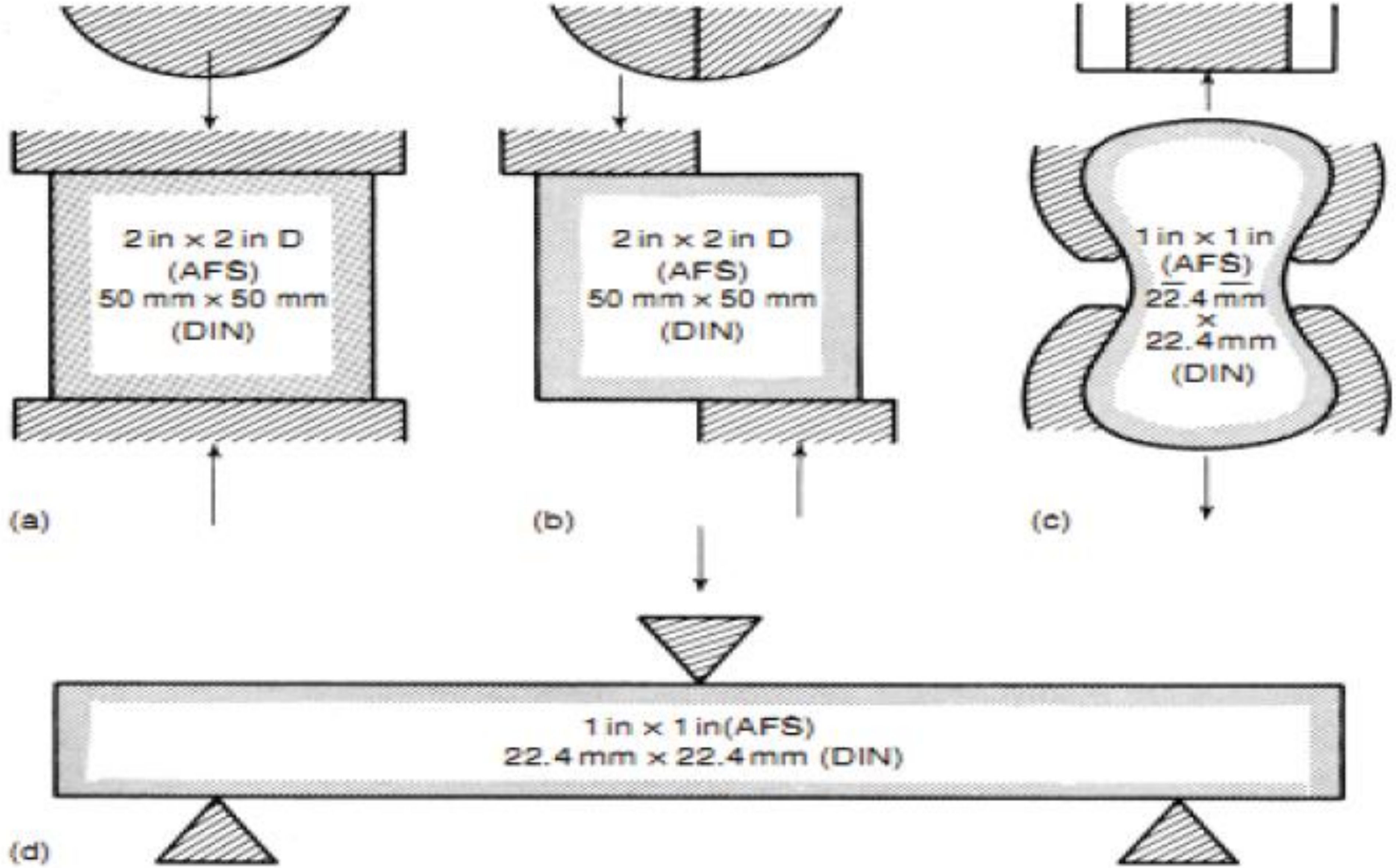
AFS Grain Fineness Number (AFS-GFN) is one means of measuring the grain fineness of a sand system.

GFN is a measure of the average size of the particles (or grains) in a sand sample. Grain fineness of molding sand is measured using a test called sieve analysis.

Test is carried out in power-driven shaker consisting of number of sieves fitted one over the other.

Sieve Analyzer

TENSILE, COMPRESSIVE, SHEAR TESTS



Permeability Test

Permeability is determined by measuring the rate of flow of air through a compacted specimen under standard conditions.

A cylinder sand sample is prepared by using rammer and die. This specimen (usually 2 inch dia & 2 inch height) is used for testing the permeability or porosity of molding and the core sand.

Test is performed in a permeability meter consisting of the balanced tank, water tank, nozzle, adjusting lever, nose piece for fixing sand specimen and a manometer. The permeability is directly measured.

Permeability number P is volume of air (in cm^3) passing through a sand specimen of 1 cm^2 cross-sectional area and 1 cm height, at a pressure difference of 1 gm/cm^2 in one minute.

$P = Vh / atp$

Where, P = permeability

v = volume of air passing through the specimen in c.c.

h = height of specimen in cm

p = pressure of air in gm/cm^2

a = cross-sectional area of the specimen in cm^2

t = time in minutes.

Refractoriness Test

The refractoriness of the molding sand is judged by heating the A.F.S standard sand specimen to very high temperatures ranges depending upon the type of sand.

The heated sand test pieces are cooled to room temperature and examined under a microscope for surface characteristics or by scratching it with a steel needle.

If the silica sand grains remain sharply defined and easily give way to the needle.

In the actual experiment the sand specimen in a porcelain boat is placed into an electric furnace. It is usual practice to start the test from 1000°C and raise the temperature in steps of 100°C to 1300°C and in steps of 50° above 1300°C till sintering of the silica sand grains
takes place.

At each temperature level, it is kept for at least three minutes and then taken out from the oven for examination under a microscope for evaluating surface characteristics or by scratching it with a steel needle.

Three metal pieces being cast have the same volume, but different shapes: One is a sphere, one a cube, and the other a cylinder with its height equal to its diameter. Which piece will solidify the fastest, and which one the slowest? Assume that $n = 2$.

Three metal pieces being cast have the same volume, but different shapes: One is a sphere, one a cube, and the other a cylinder with its height equal to its diameter. Which piece will solidify the fastest, and which one the slowest? Assume that $n = 2$.

The volume of the piece is taken as unity.

$$\text{Solidification time} \propto \frac{1}{(\text{Surface area})^2}.$$

The respective surface areas are as follows:

Sphere:

$$V = \left(\frac{4}{3}\right)\pi r^3, \; r = \left(\frac{3}{4\pi}\right)^{1/3}.$$

$$A = 4\pi r^2 = 4\pi\left(\frac{3}{4\pi}\right)^{2/3} = 4.84.$$

Cube:

$$V = a^3, a = 1, \text{ and } A = 6a^2 = 6.$$

Cylinder:

$$V = \pi r^2 h = 2\pi r^3, r = \left(\frac{1}{2\pi}\right)^{1/3},$$

$$A = 2\pi r^2 + 2\pi r h = 6\pi r^2 = 6\pi\left(\frac{1}{2\pi}\right)^{2/3} = 5.54.$$

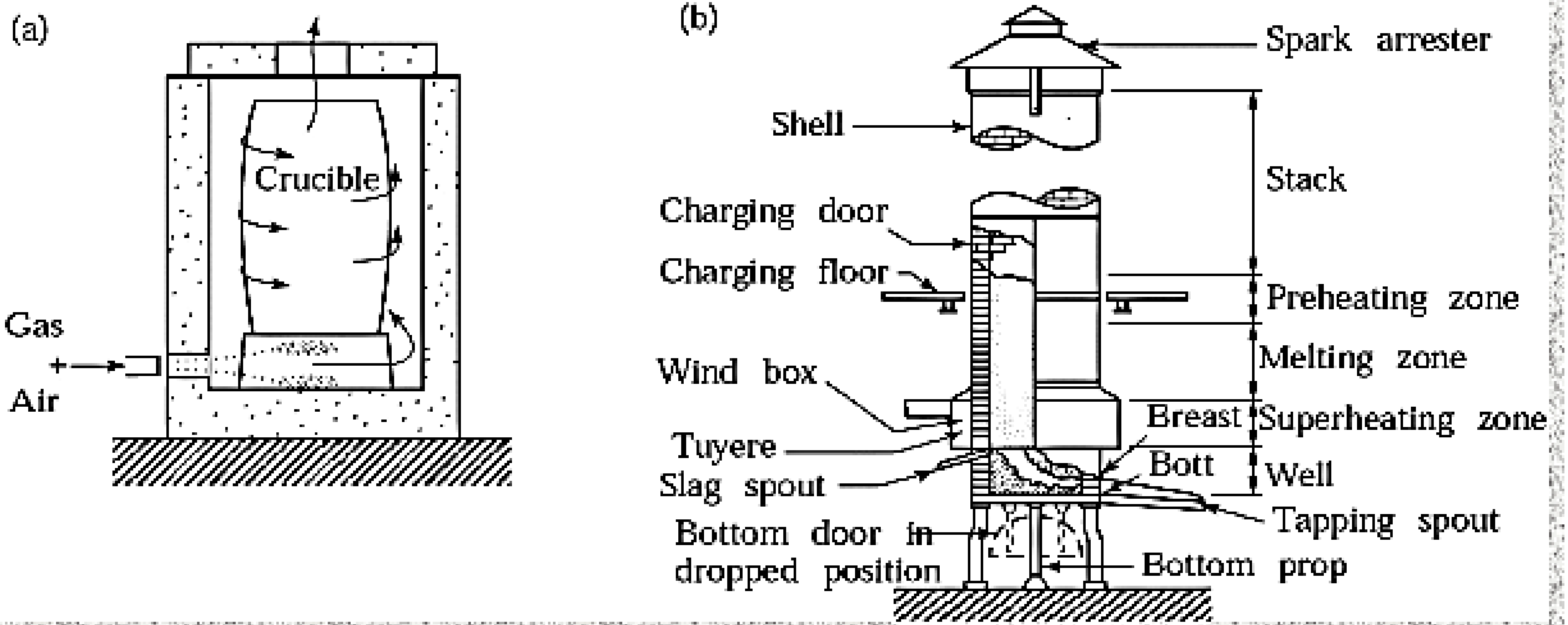
The respective solidification times are therefore

$$t_{\text{sphere}} = 0.043C, t_{\text{cube}} = 0.028C, t_{\text{cylinder}} = 0.033C.$$

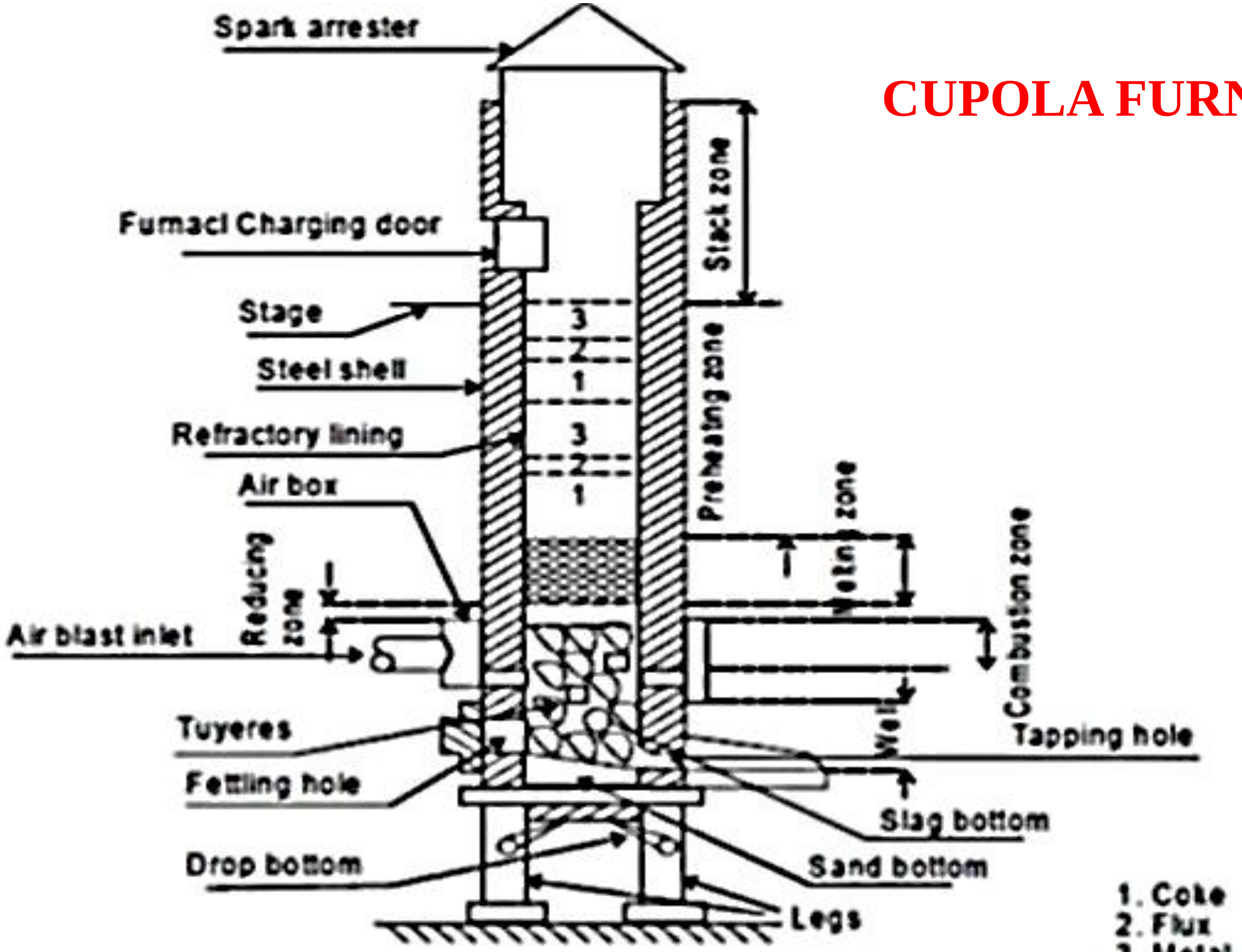
Hence, the cube-shaped piece will solidify the fastest, and the spherical piece will solidify the slowest.

Types of Melting Furnaces

Figure 11.33 Two types of melting furnaces used in foundries: (a) crucible, and (b) cupola.



CUPOLA FURNACE



Direct Fuel-Fired Furnaces

Small open-hearth in which charge is heated by natural gas fuel burners located on side of furnace

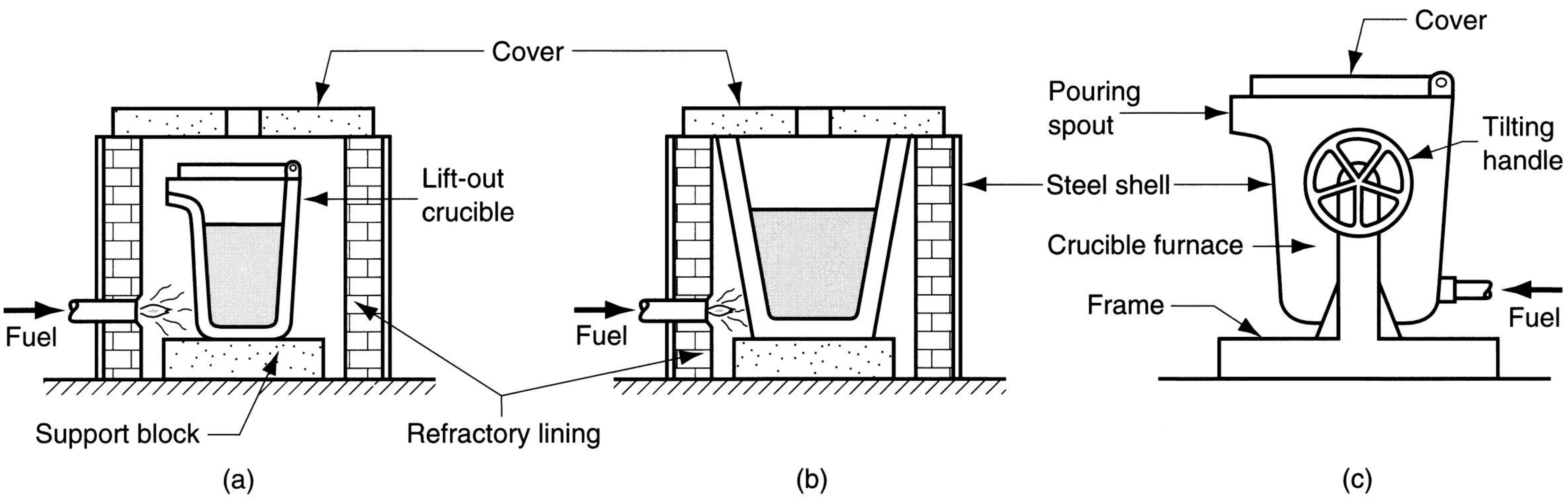
- Furnace roof assists heating action by reflecting flame down against charge
- At bottom of hearth is a tap hole to release molten metal
- Generally used for nonferrous metals such as copper-base alloys and aluminum

Crucible Furnaces

Metal is melted without direct contact with burning fuel mixture

- Sometimes called *indirect fuel-fired furnaces*
- Container (crucible) is made of refractory material or high-temperature steel alloy
- Used for nonferrous metals such as bronze, brass, and alloys of zinc and aluminum
- Three types used in foundries:

(a) lift-out type, (b) stationary, (c) tilting



Three types of crucible furnaces:

(a) lift-out crucible,

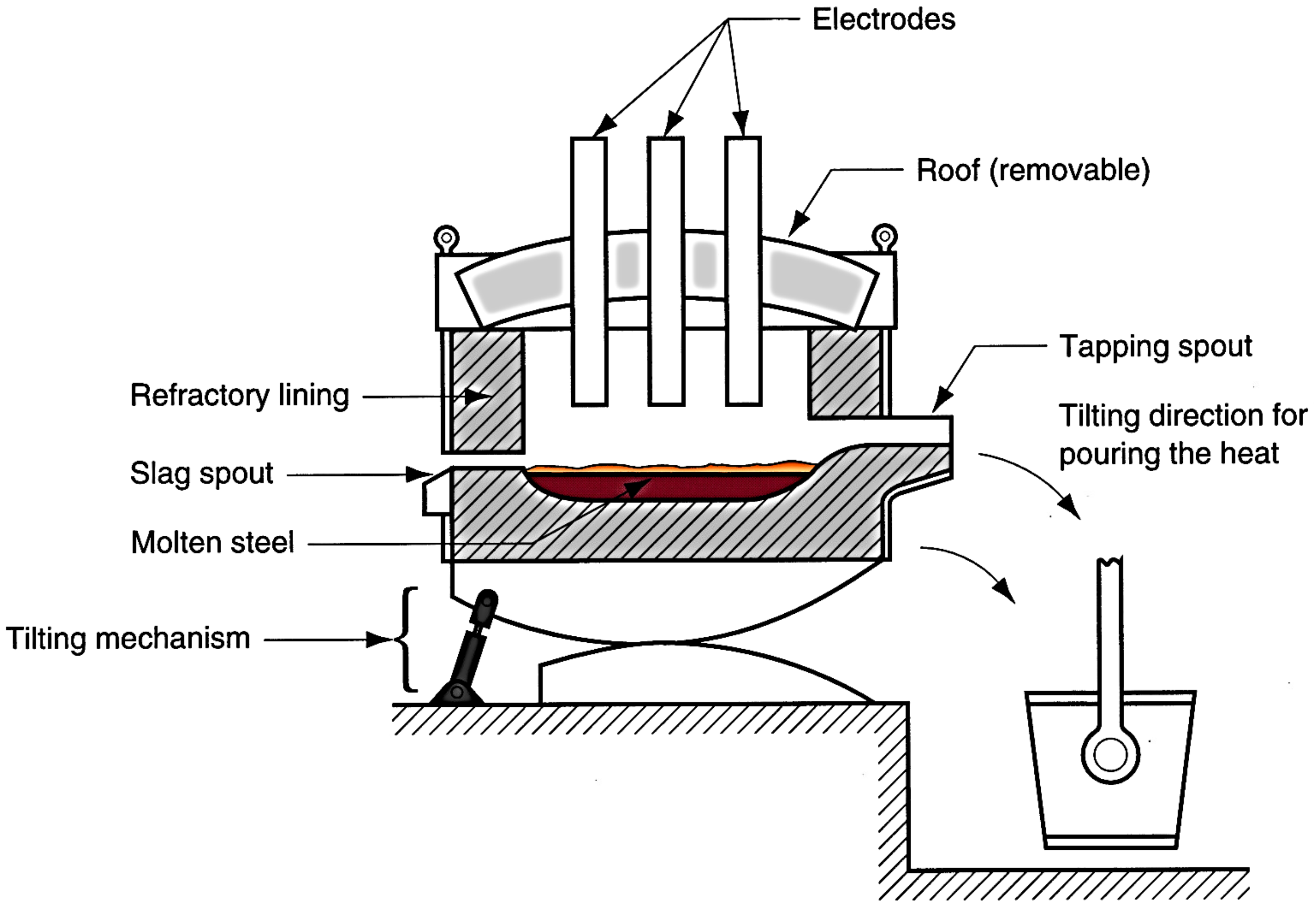
(b) stationary pot, from which molten metal must be ladled, and

(c) tilting-pot furnace

Electric-Arc Furnaces

Charge is melted by heat generated from an electric arc

- High power consumption, but electric-arc furnaces can be designed for high melting capacity
- Used primarily for melting steel

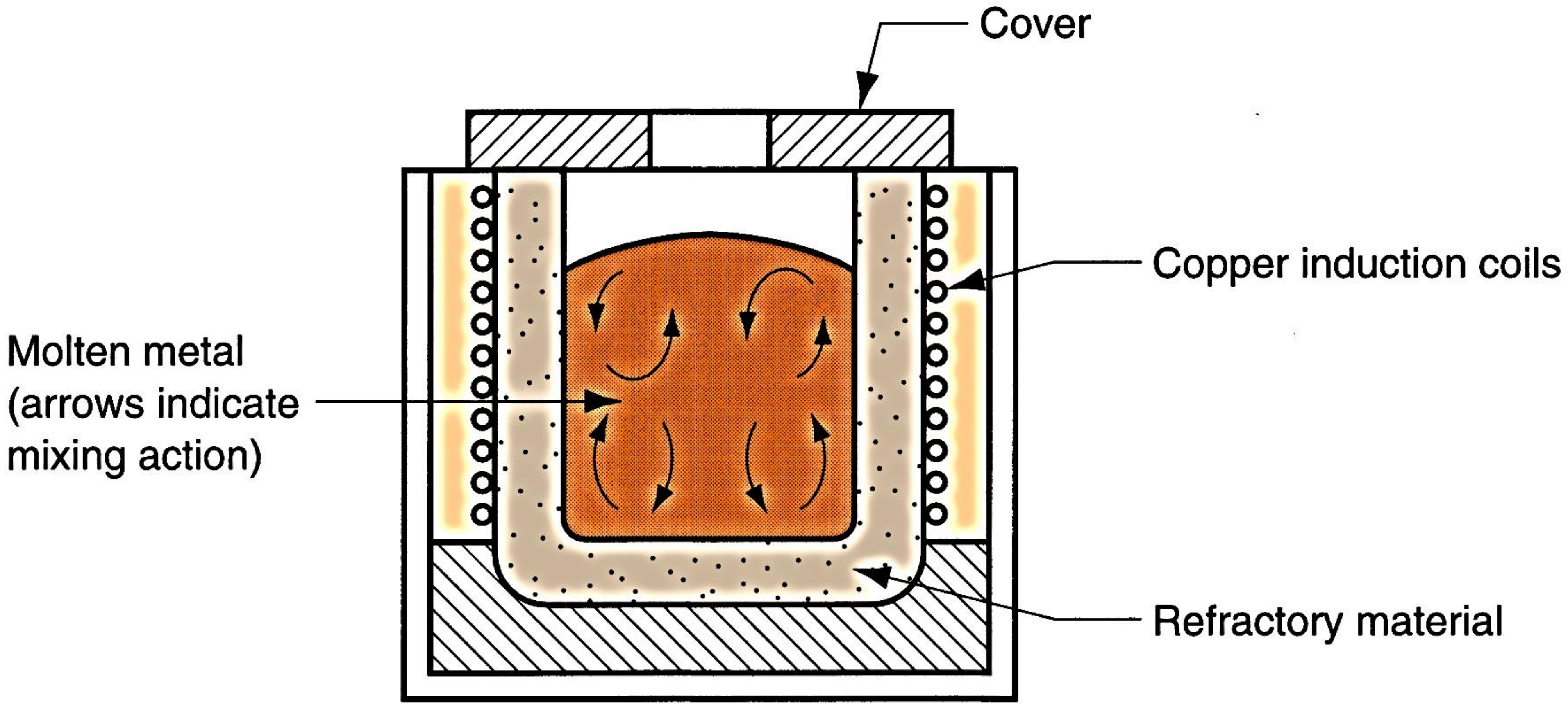


Electric arc furnace for steelmaking

Induction Furnaces

Uses alternating current passing through a coil to develop magnetic field in metal

- Induced current causes rapid heating and melting
- Electromagnetic force field also causes mixing action in liquid metal
- Since metal does not contact heating elements, the environment can be closely controlled, which results in molten metals of high quality and purity
- Melting steel, cast iron, and aluminum alloys are common applications in foundry work



Induction furnace

Additional Steps After Solidification

- Trimming
- Removing the core
- Surface cleaning
- Inspection
- Repair, if required
- Heat treatment

Inspection of casting

1. Visual Inspection
   - Most surface defects can be seen
2. Pressure test
   - The casting is filled with pressurized air after closing all the openings
   - E.g. gear boxes, pressure vessels, look for leaks by submerging in special liquids
   - Pressurized oil can also be used in some cases
3. Radiographic Examination
   - Usually x-rays or g rays
   - x-ray method is used for voids,non metallic inclusions, porosity, cracks
   - Defects appear darker than surrounding

4. Ultrasound examination

- Ultrasound across the casting
- Sound transmitted across homogenous metals
- However discontinuities reflect sound back.
- Not good for cast iron

5. Dye Penetration Inspection

- To detect invisible surface defects in non magnetic castings
- A dye of fluorescent material is sprayed or applied near the surface. The surface is then wiped and viewed in darkness
- Cracks will be visible

6. Magnetic Particle inspection

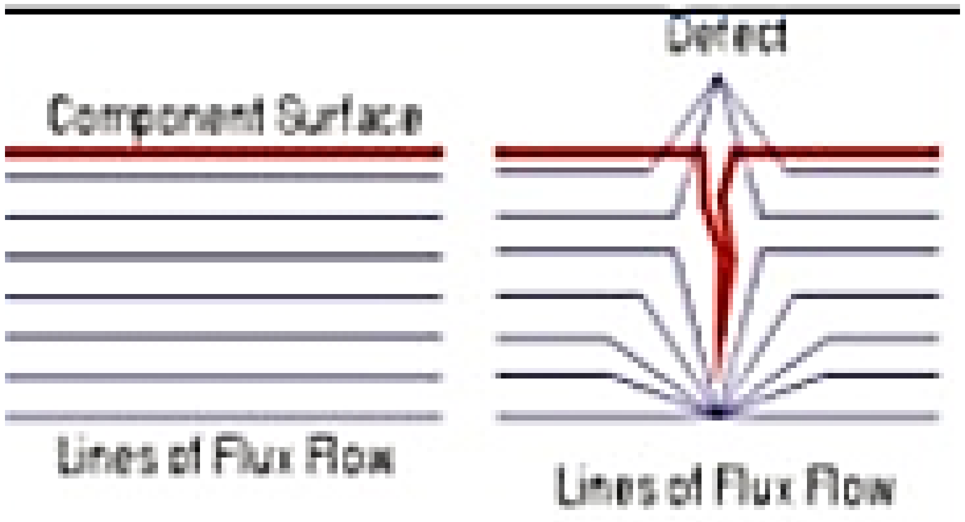
- Induce magnetic field through section under inspection
- Powdered Ferro-magnetic magnetic material is spread onto the surface
- Voids or cracks result in abrupt changes in permeability of material – leads to leakage in magnetic field
- Particles concentrate on the disrupted field or on the crack.

Liquid penetrant test

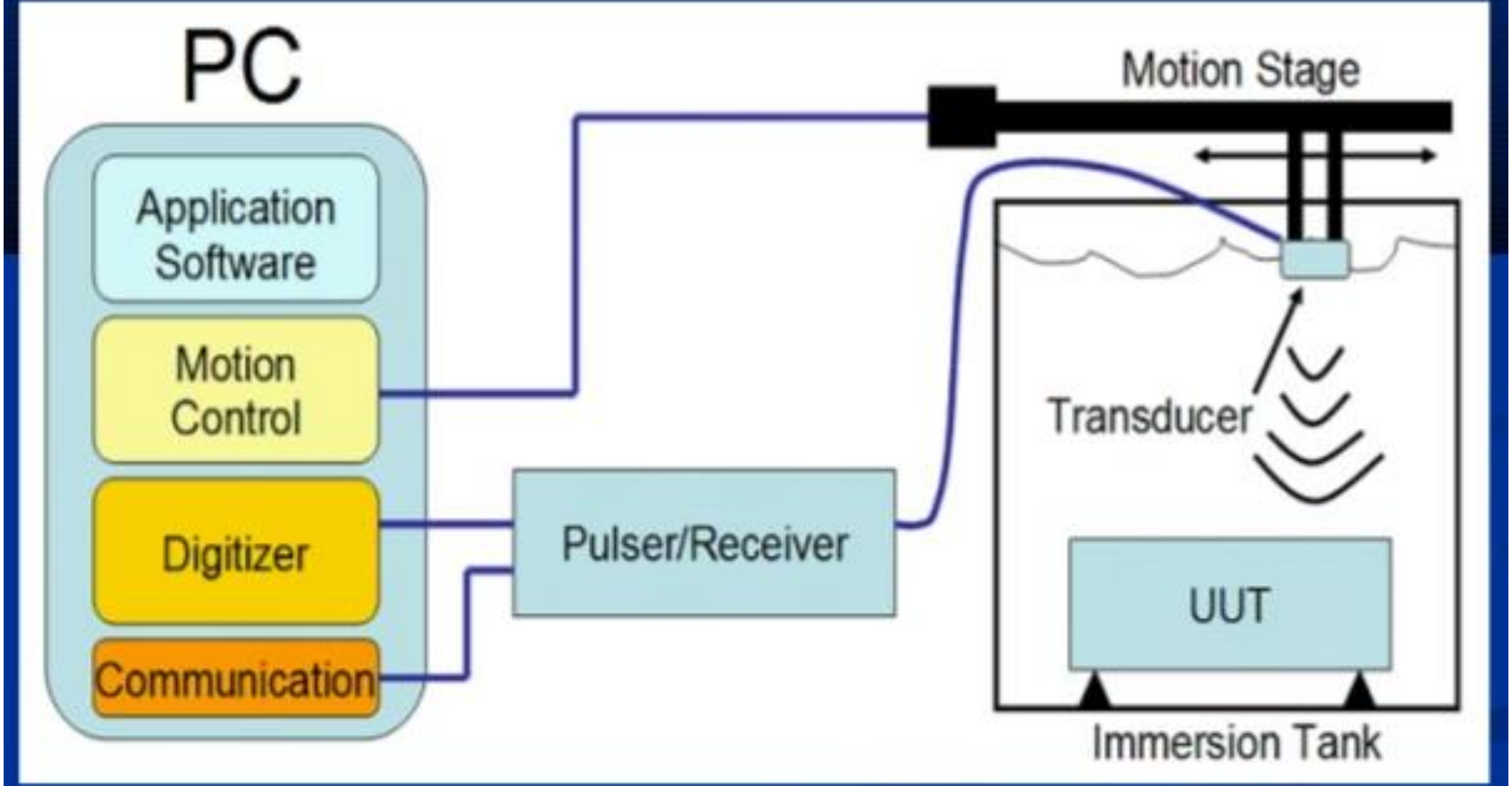
- Surface preparation
- Penetrant application
- Penetrant dwell
- Excess Penetrant removal
- Developer application
- Indication development
- Inspection
- Clean surface.

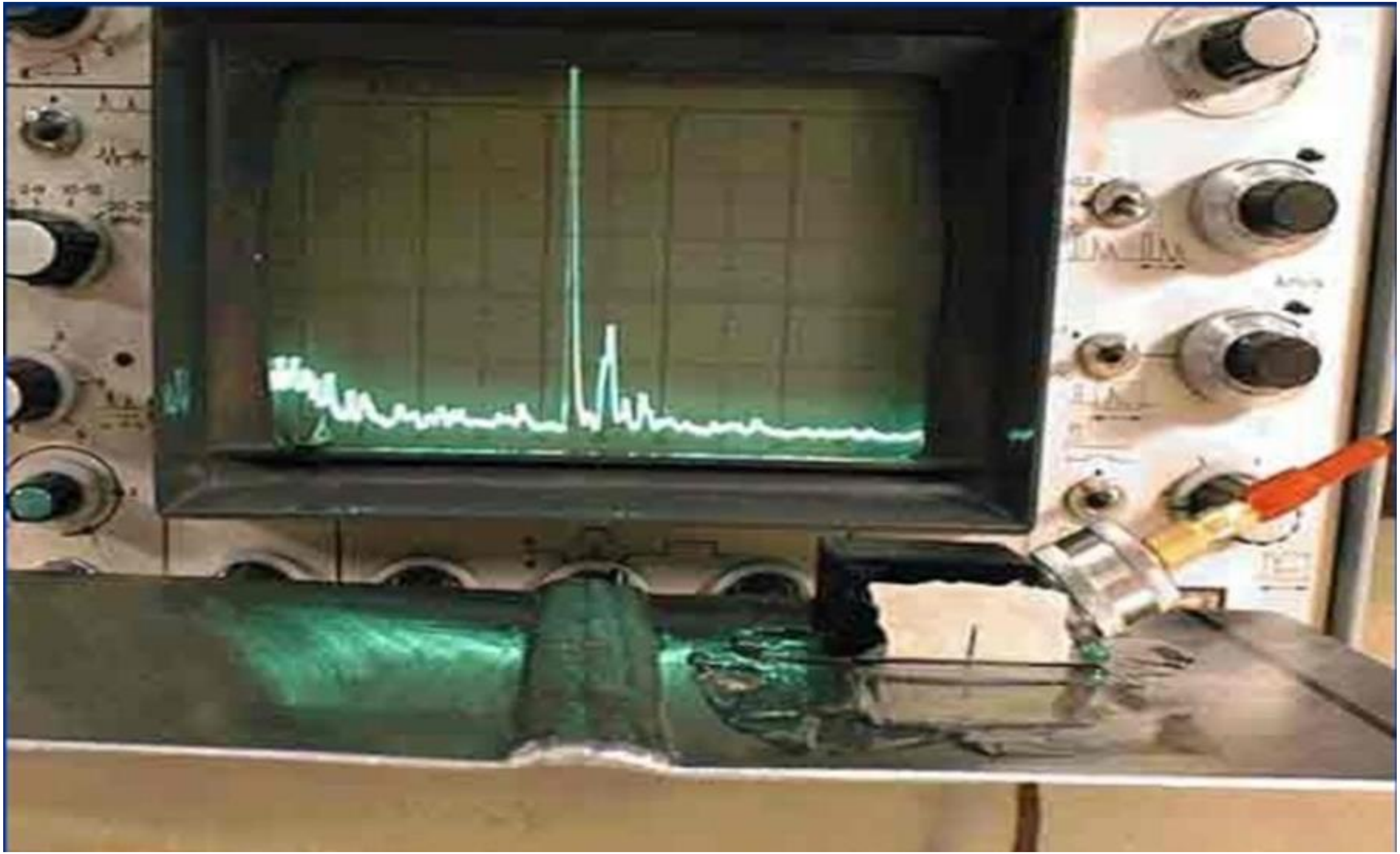
Principle - MPI

- When a metal placed in magnetic field, magnetic flux are intersected by the defect – magnetic poles are induced on either side of discontinuity.
- Abrupt change in path of flux – local leakage
- This can detected when magnetic particles are attracted towards defective region.
- Magnetic particles piles up in defective region.



UT arrangement





GATING SYSTEM & RISERING SYSTEM

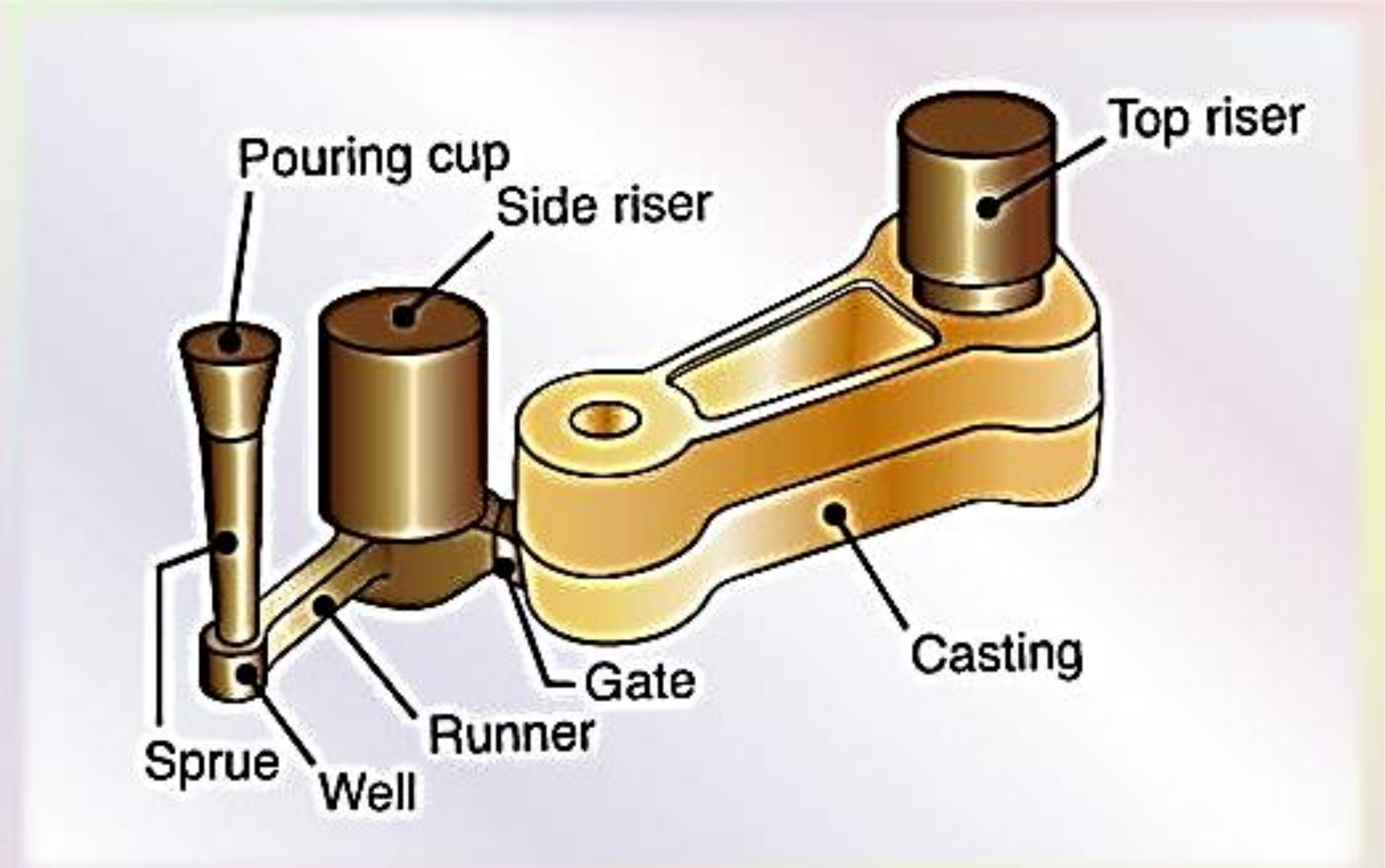
- A good gating design should ensure proper distribution of molten metal without excessive temperature loss, turbulence, gas entrapping and slags.

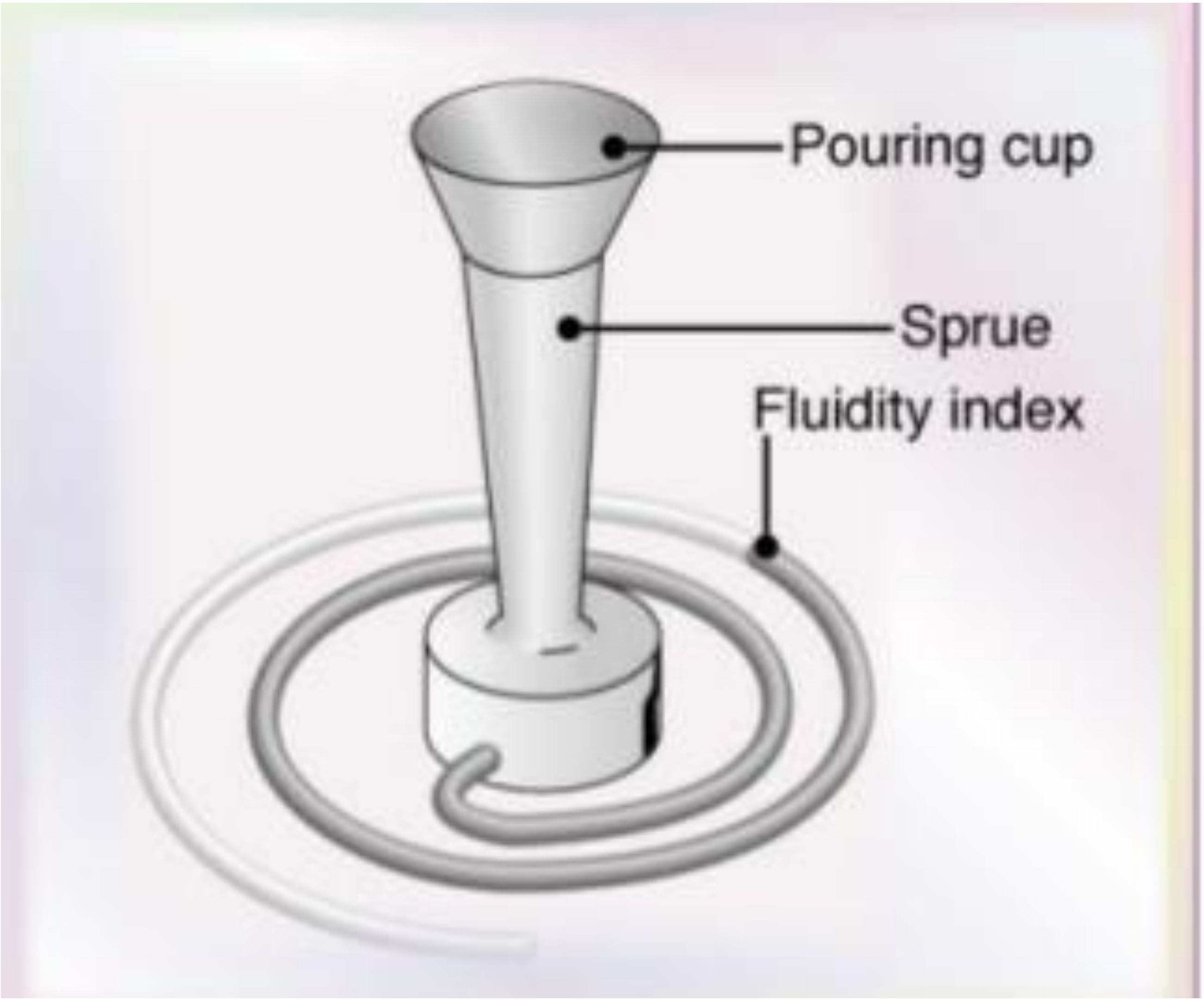
- Very slow pouring, require longer filling time and solidification will start even before filling of mould.

This can be restricted by using **super heated metal**, but in this case **gas solubility will be a problem.**

- Faster pouring can erode the mould cavity.

- So gating design is important and it depends on the metal and molten metal composition. For example, aluminium can get oxidized easily.


Pouring cup
Side riser
Top riser
Sprue
Well
Runner
Gate
Casting



TEST METHOD FOR TESTING FLUIDITY

FLUIDITY INDEX – Length of solidified metal in the spiral passage. Greater the length of the solidified metal, greater is its fluidity

Gating systems refer to **all those elements** which are connected with the **flow of molten metal** from the ladle to the mould cavity.

- Pouring Basin
- Sprue
- Sprue Base Well
- Runner
- Runner Extension
- Gate or Ingate
- Riser

The purpose of gating system is to deliver the molten metal to mold.

A gating system should be able to do the following:

1. Permit complete filling of the mold cavity
2. Requires minimum time to fill the mold cavity
3. Minimum turbulence so as to minimize gas pickup
4. Regulate rate at which molten metal enters the mold cavity
5. Prevent unwanted material from entering mould cavity
6. Establish suitable temperature gradients

7. No mould erosion

8. Simple and economical design

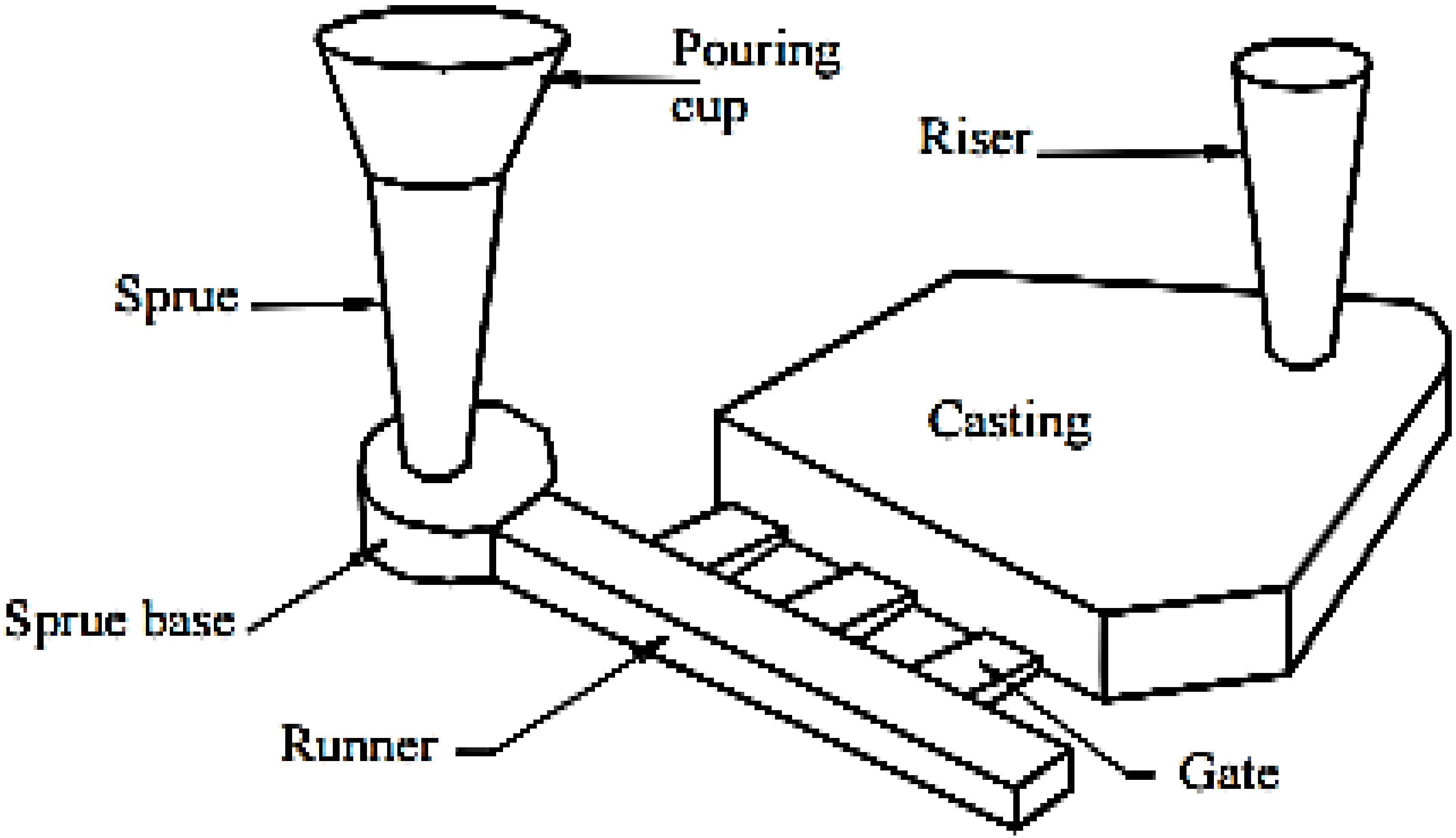
9. Easy to implement and remove after solidification

10. Maximum casting yield

Casting yield

$$C_y = \frac{W_c}{W_c + W_g} \times 100\%$$

GATING SYSTEM



1. **Pouring basin** : This is otherwise called as bush or cup. It is circular or rectangular in shape. It collects the molten metal, which is poured, from the ladle.

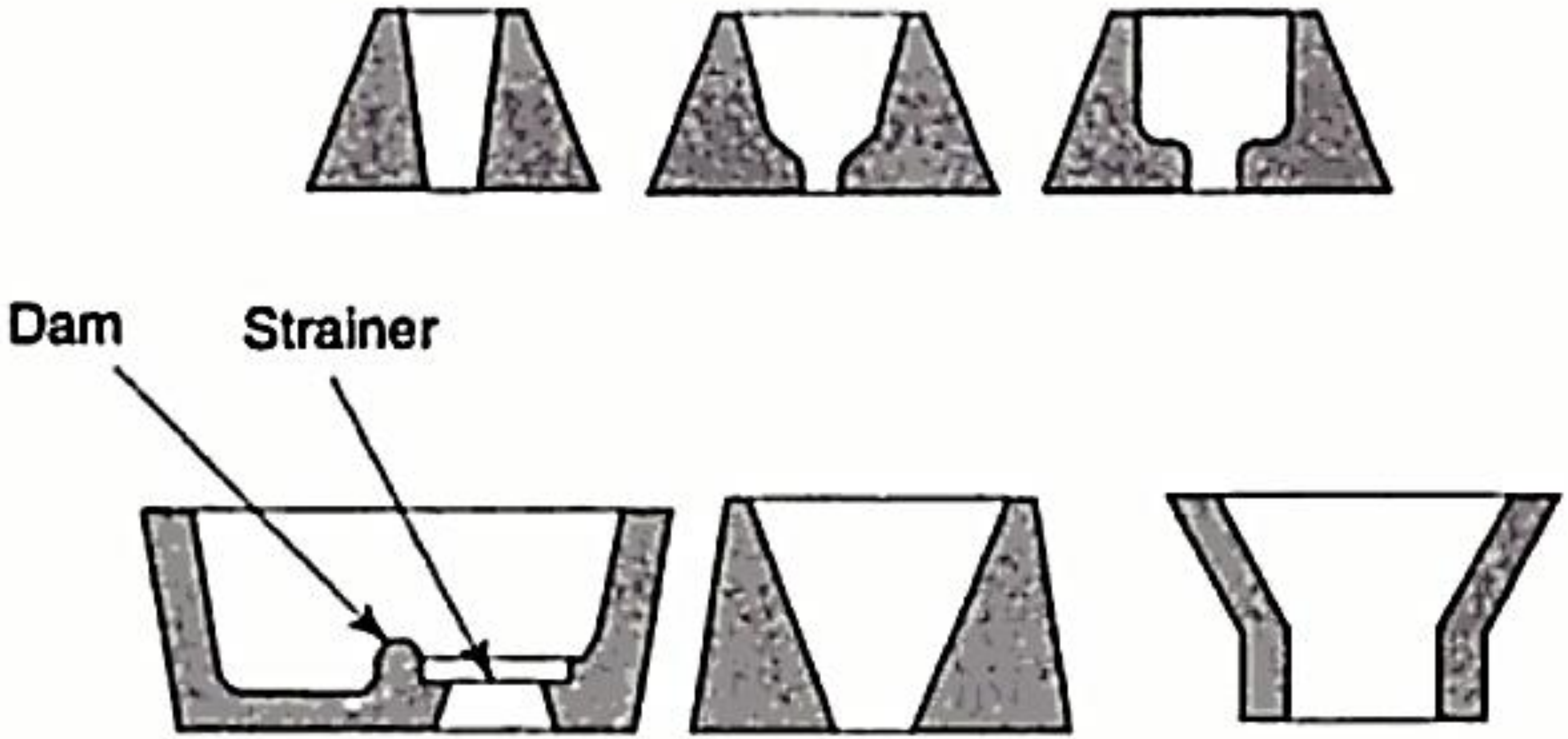
2. **Sprue** : It is circular in cross section. It leads the molten metal from the pouring basin to the sprue well.

3. **Sprue Well** : It changes the direction of flow of the molten metal to right angle and passes it to the runner.

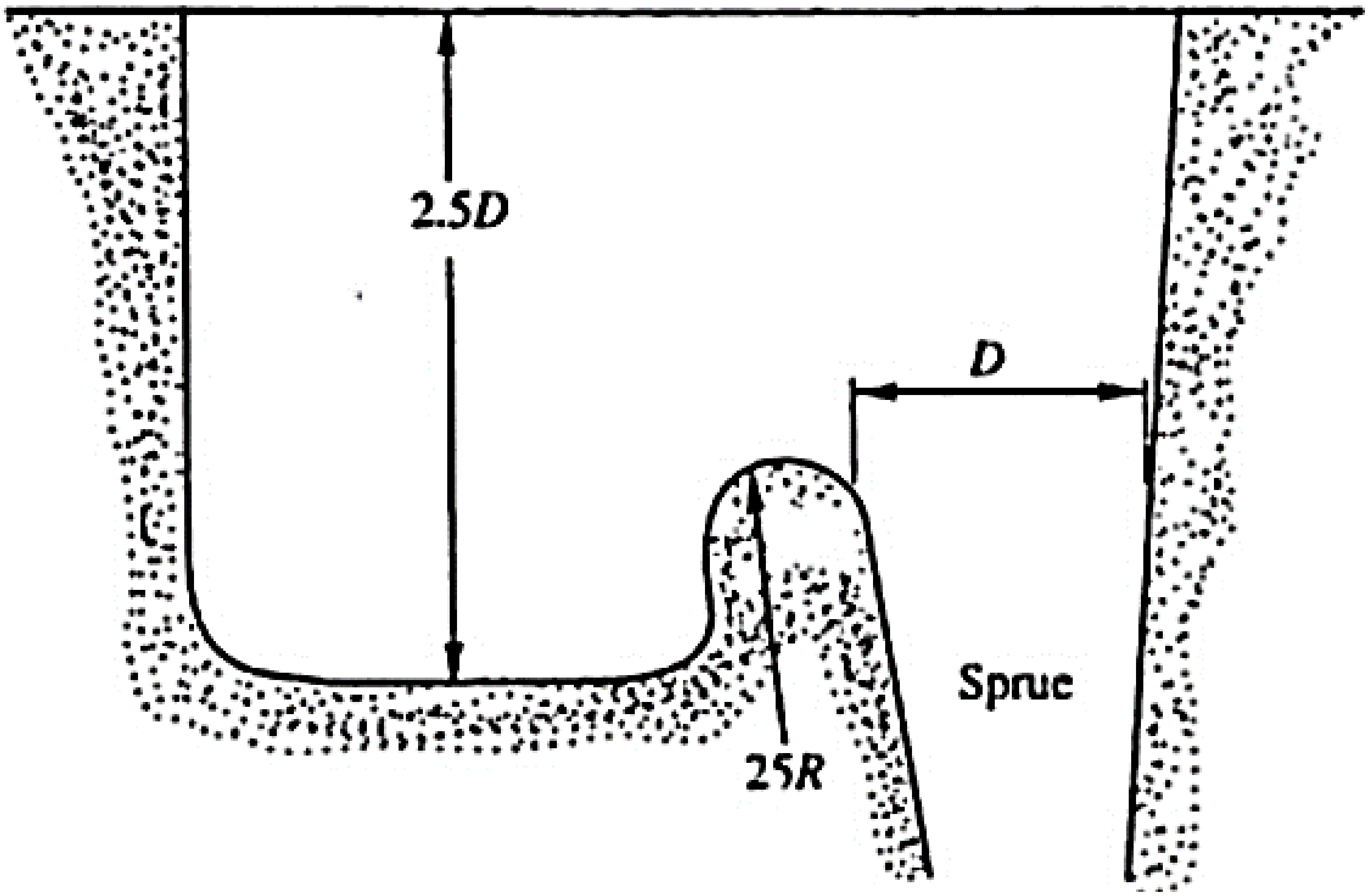
4. **Runner** : The runner takes the molten metal from sprue to the casting. Ingate: This is the final stage where the molten metal moves from the runner to the mold cavity.

5. **Slag trap** : It filters the slag when the molten metal moves from the runner and ingate. It is also placed in the runner

TYPES OF POURING BASINS

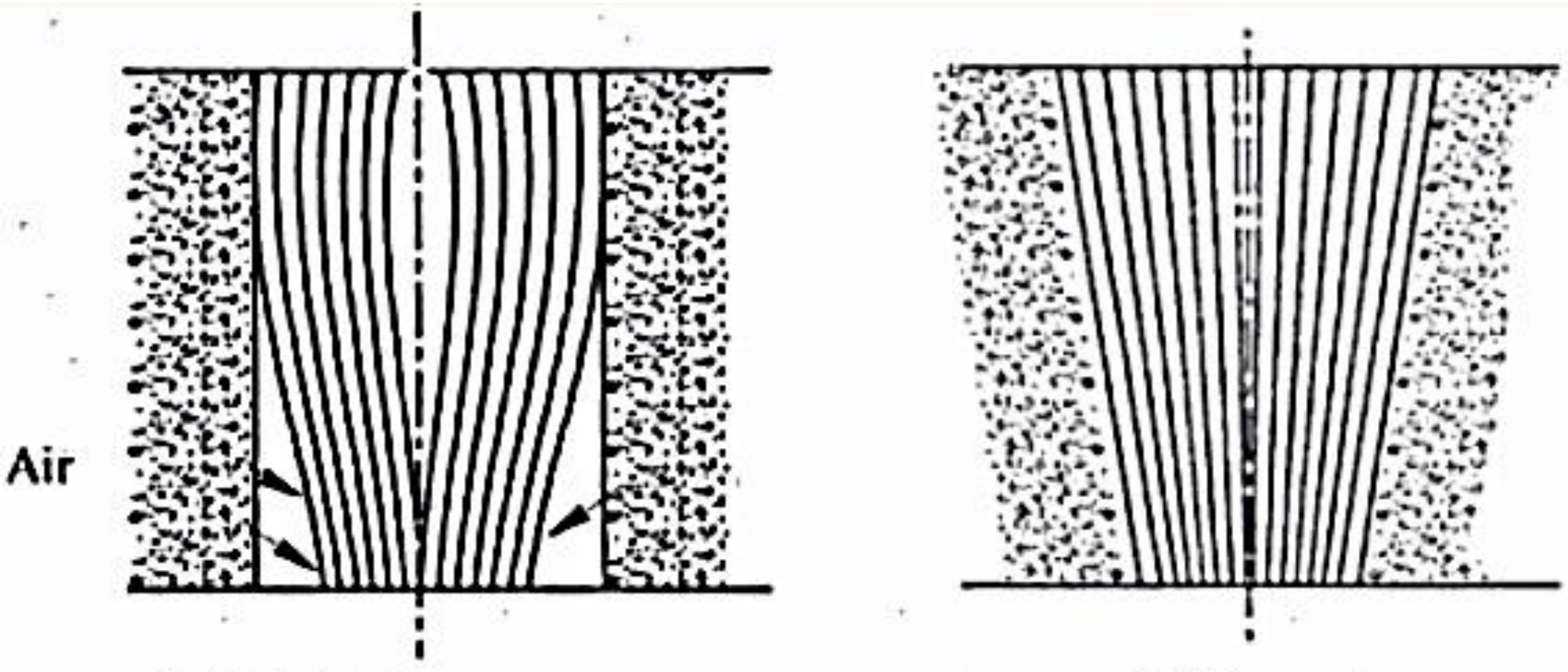


POURING BASIN DESIGN



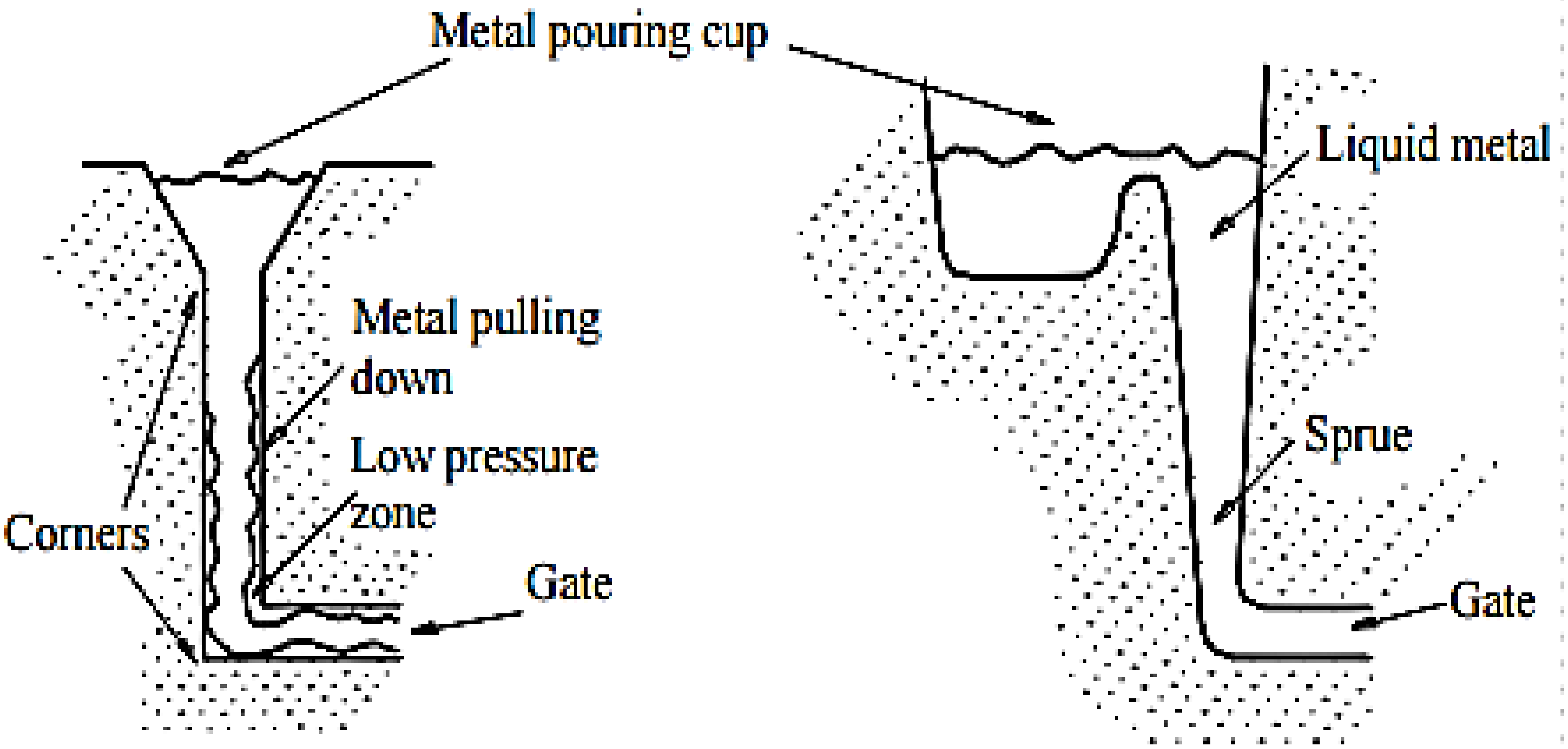
- **Sprue** : It is circular in cross section. It leads the molten metal from the pouring basin to the sprue well.

- **Sprue Well** : It changes the direction of flow of the molten metal to right angle and passes it to the runner.



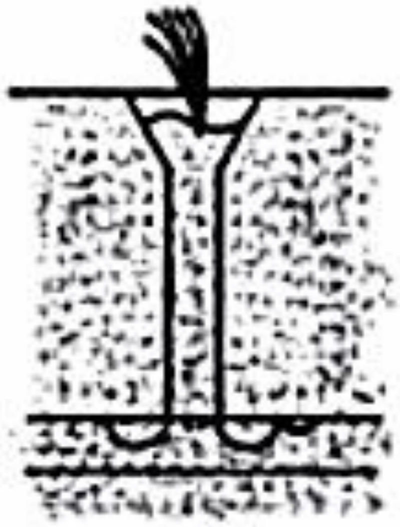
(a) Straight sprue (b) Tapered

SPRUE

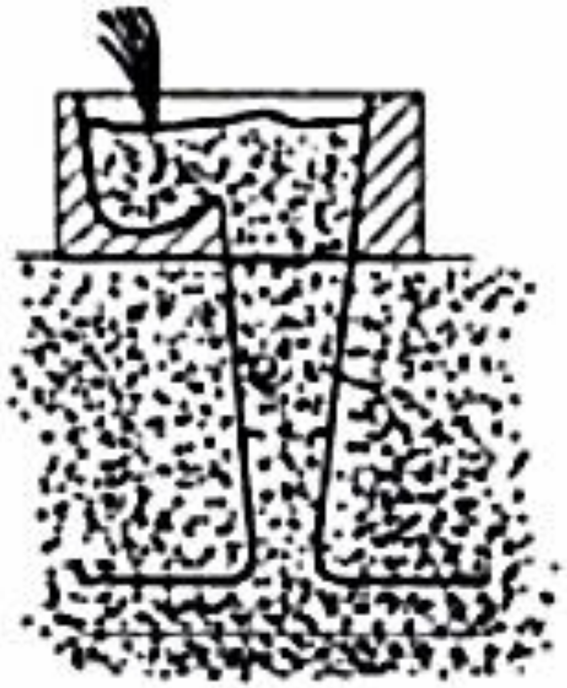


(a) Straight sprue

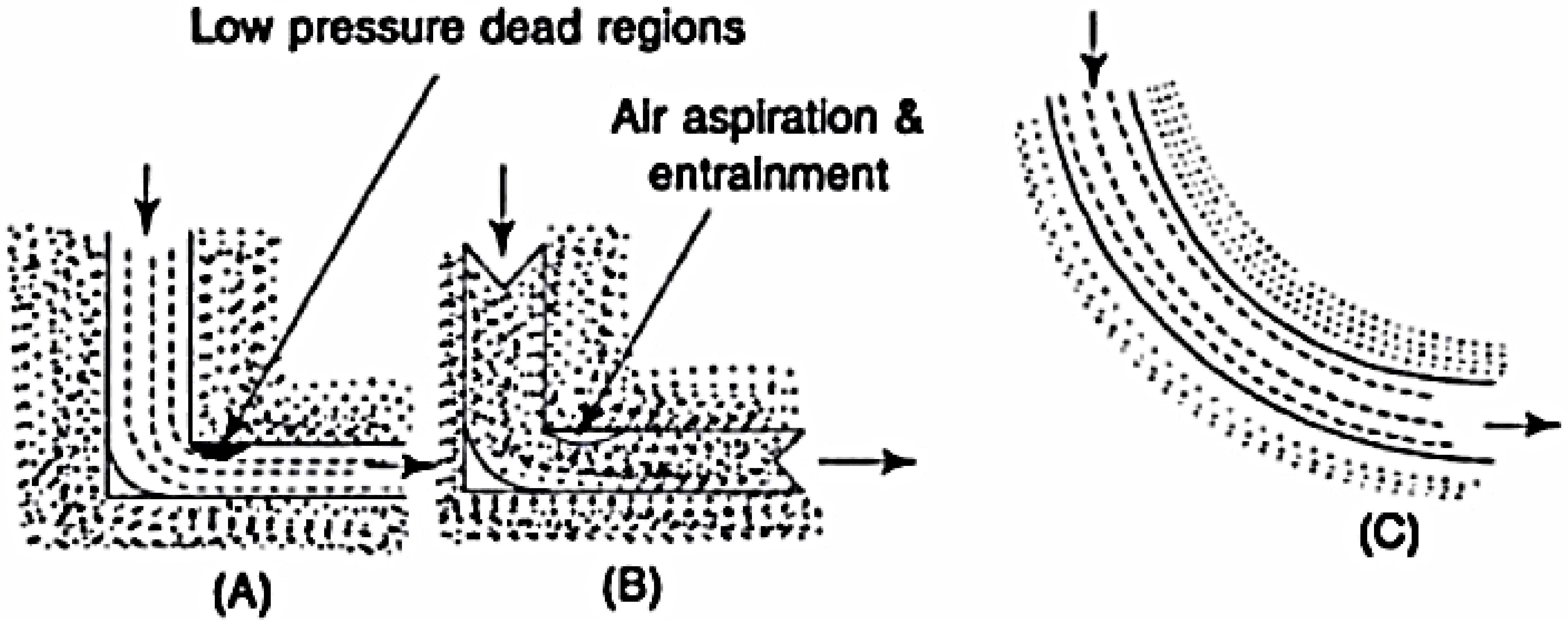
(b) Tapered sprue



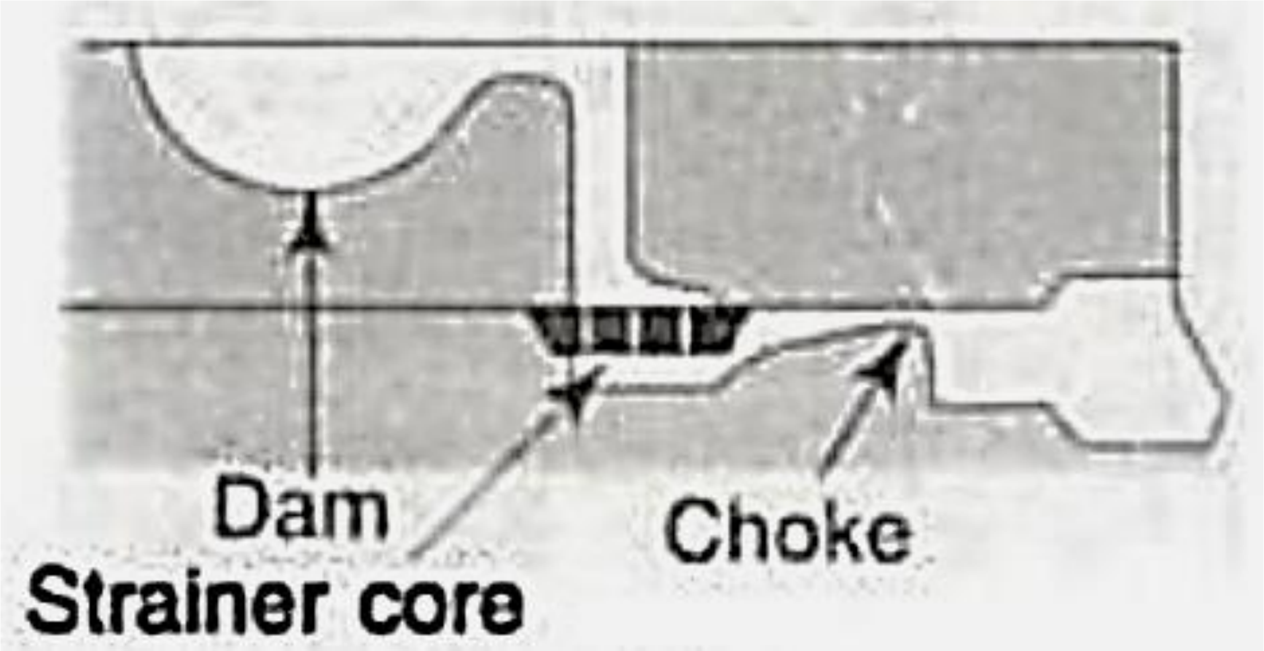
(A)



(B)


Low pressure dead regions
Air aspiration &
entrainment
(A)
(B)
(C)

- **Slag trap** : It filters the slag when the molten metal moves from the runner and ingate.



- **Runner** : The runner takes the molten metal from sprue to the Ingates of casting.

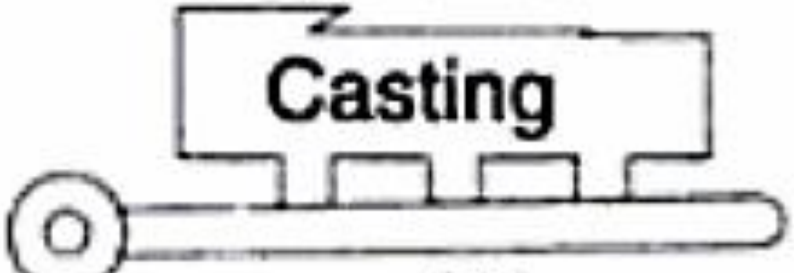
    a) Straight runner

    b) Tapered runner

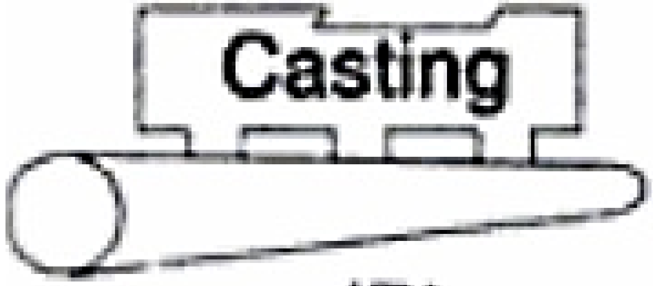
    c) Step gate (may also act as feeder)

    d) Uniform size runner

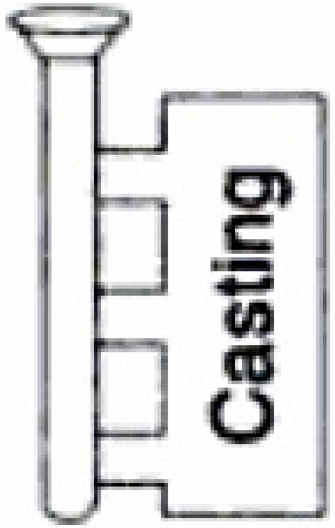
    e) Runner for even distribution of metal



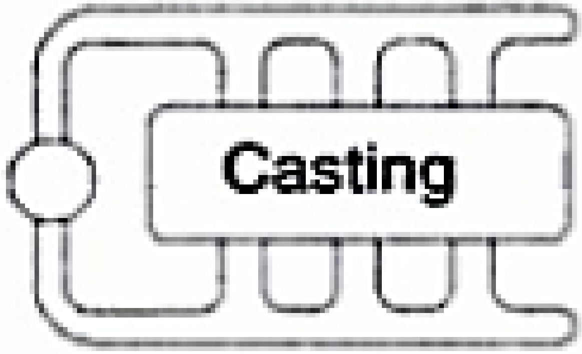
(A)



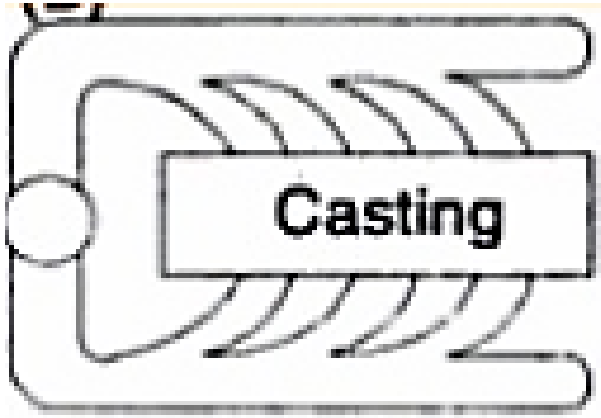
(B)



(C)

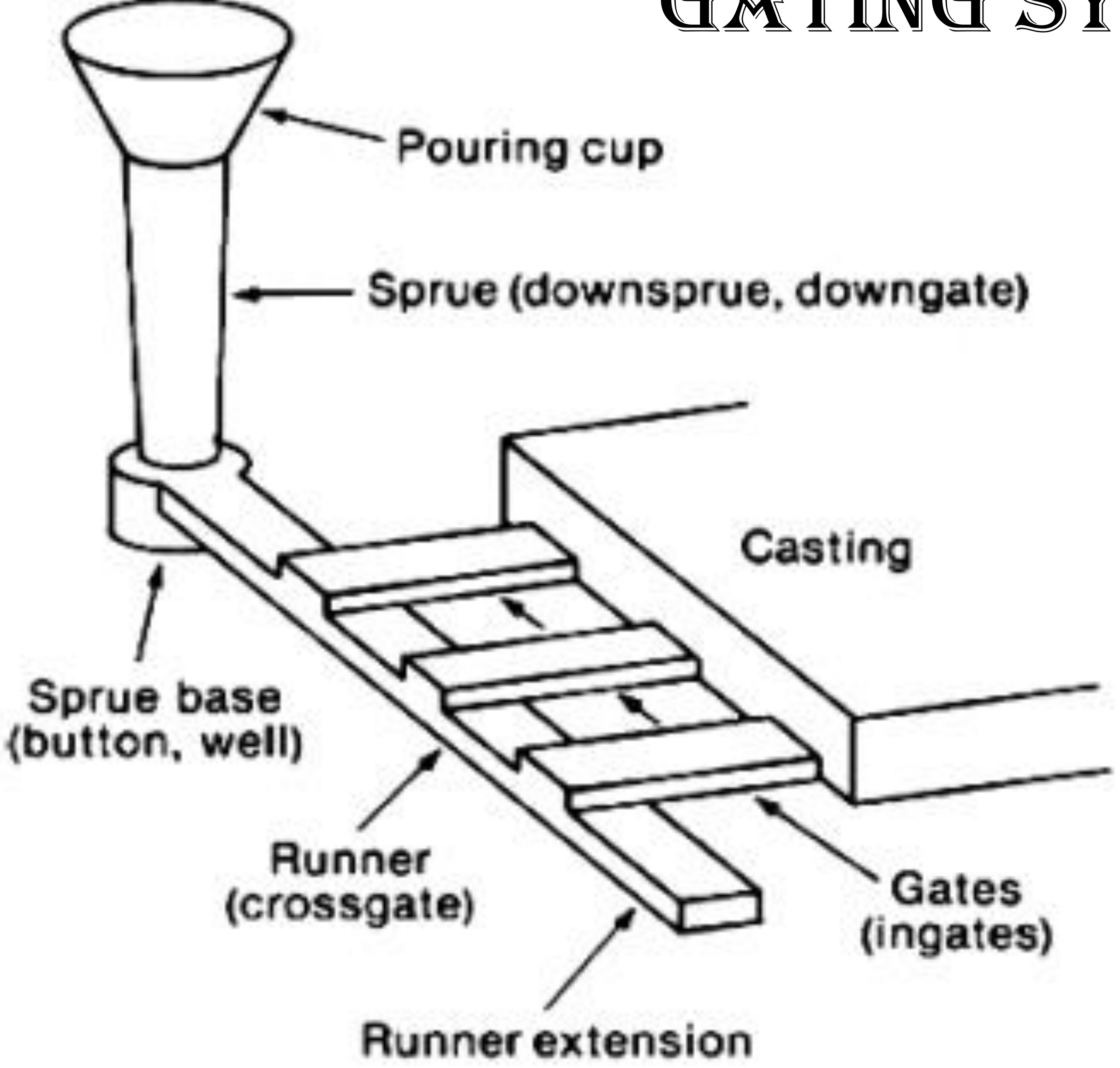


(D)



(E)

Gating System



Basic elements of gating system

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

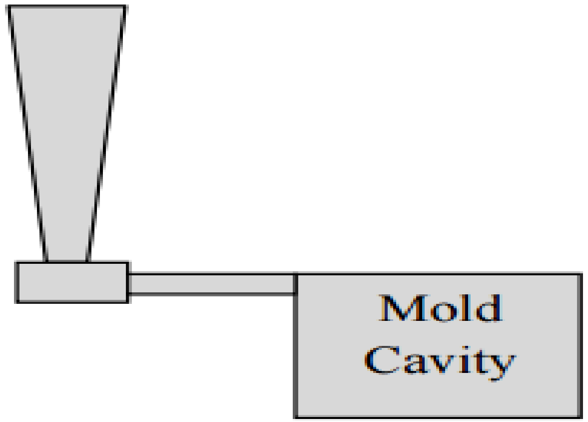
✓ Runner

✓ Gates

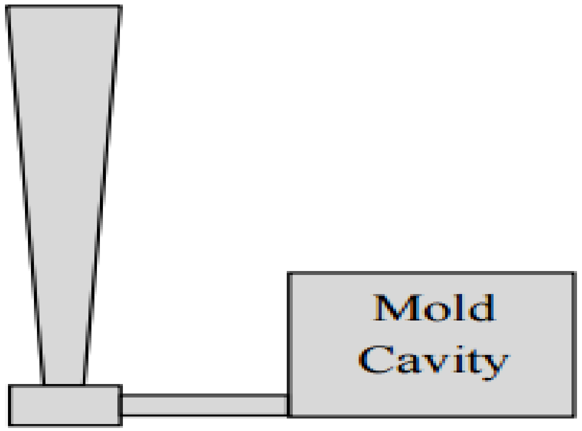
✓ Risers

TYPES OF GATES

- **Down gates or sprue**
- **Cross gates or runners**
- **Ingates or gates**

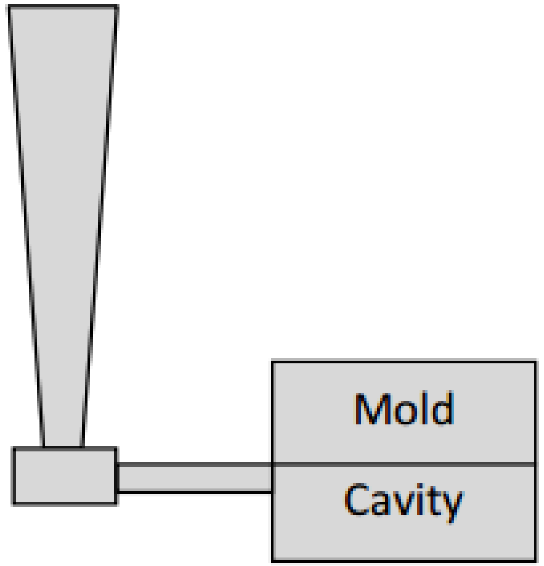


(a) Top gating



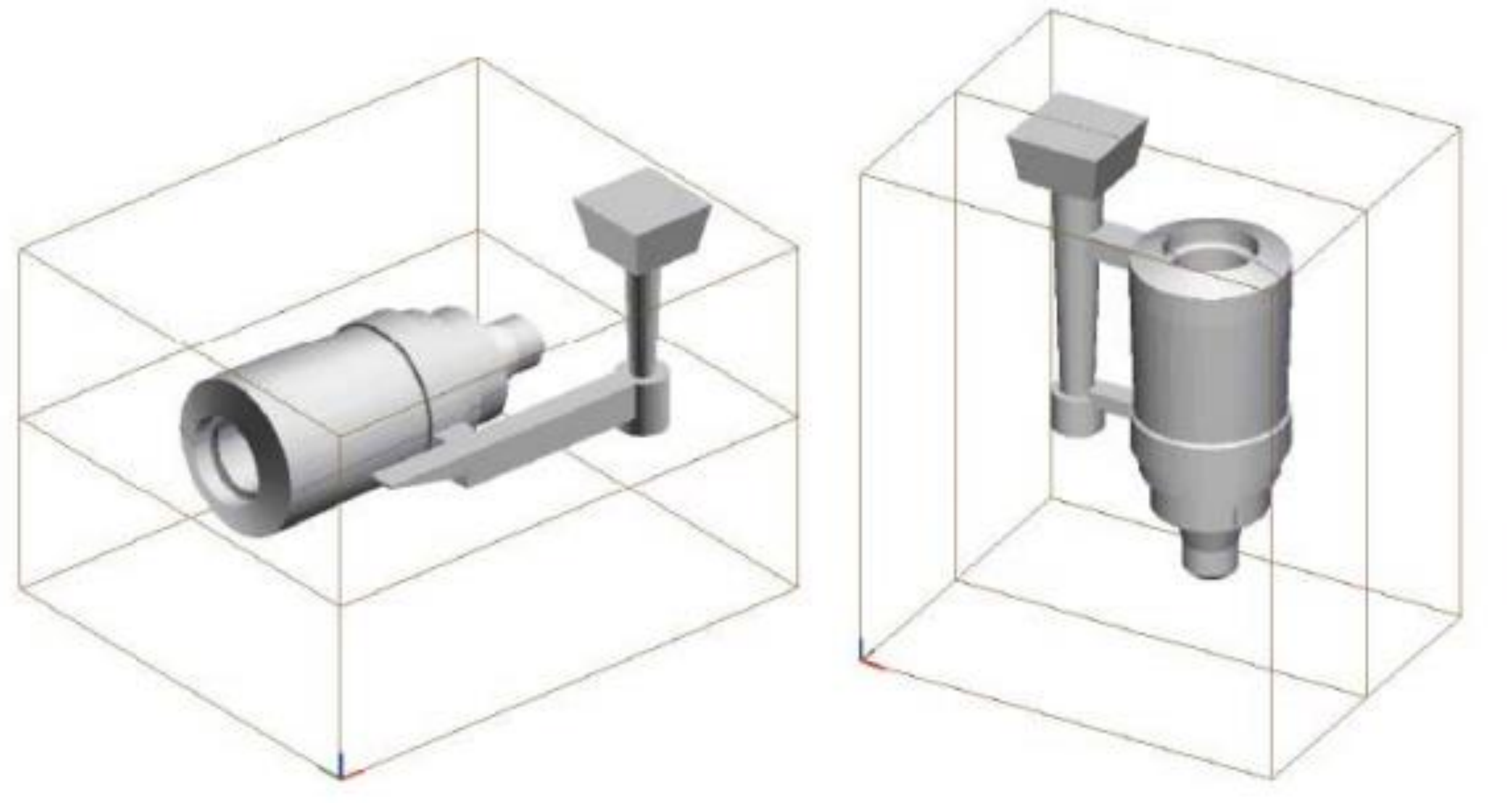
(b) Bottom gating

Depending upon the position of ingate(s)



(c) Parting line gating

Depending upon the orientation of the parting plane



(a) Horizontal gating system (b) Vertical gating system

Depending on the ratio of total cross sectional area of sprue exit, runner and ingate

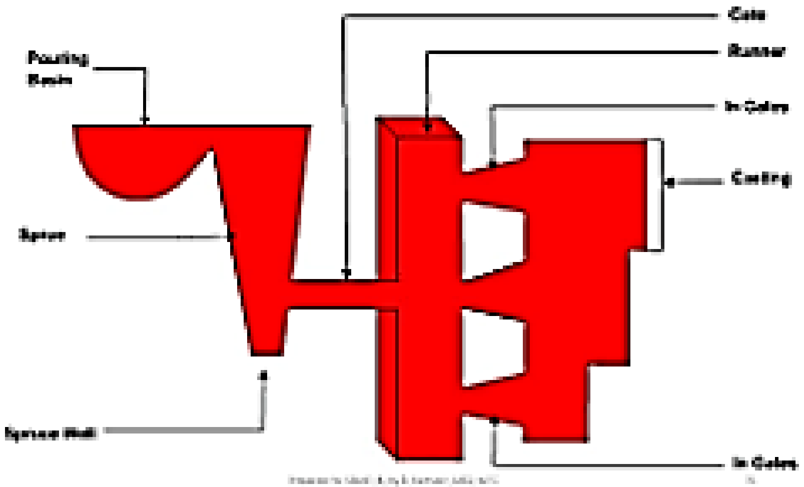
1. Pressurized gating system

2. Un-pressurized gating system

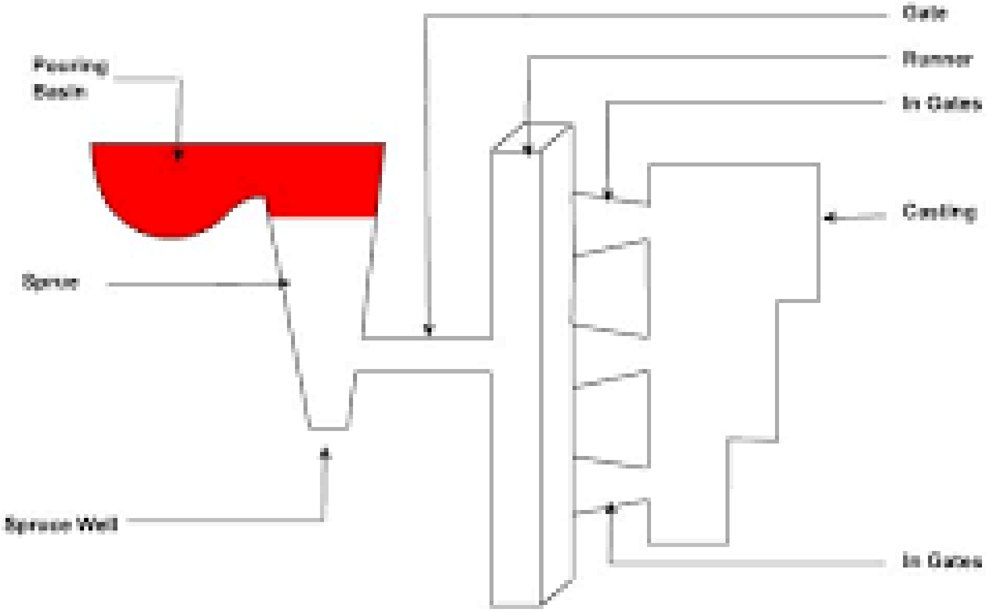
Pressurized Gating System

1. The total cross sectional area decreases towards the mold cavity
2. Back pressure is maintained by the restrictions in the metal flow
3. Flow of liquid (volume) is almost equal from all gates
4. Back pressure helps in reducing the aspiration as the sprue always runs full
5. Because of the restrictions the metal flows at high velocity leading to more turbulence and chances of mold erosion

Un-pressurized gating system



Pressurized



Un-Pressurized Gating System

1. The total cross sectional area increases towards the mold cavity

2. Restriction only at the bottom of sprue

3. Flow of liquid (volume) is different from all gates

4. aspiration in the gating system as the system never runs full

5. Less turbulence

The goals for the gating system are

1. To minimize turbulence to avoid trapping gasses into the mold
2. To get enough metal into the mold cavity before the metal starts to solidify
3. To avoid shrinkage
4. Establish the best possible temperature gradient in the solidifying casting so that the shrinkage if occurs must be in the gating system not in the required cast part.
5. Incorporates a system for trapping the non-metallic inclusions

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.

Hydraulic Principles used in the Gating System

Reynold’s No.,

$$R_N = \frac{VD\rho}{\mu}$$

Reynold's Number

Nature of flow in the gating system can be established by calculating Reynold's number

V	=	Mean Velocity of flow		
D	=	diameter of tubular flow		
m	=	Kinematics Viscosity	=	Dynamic viscosity / Density
r	=	Fluid density		

1. Inclusion of dross or slag
2. Air aspiration into the mold
3. Erosion of the mold walls

$$h + \frac{P}{\rho g} + \frac{v^2}{2g} = \text{const.}$$

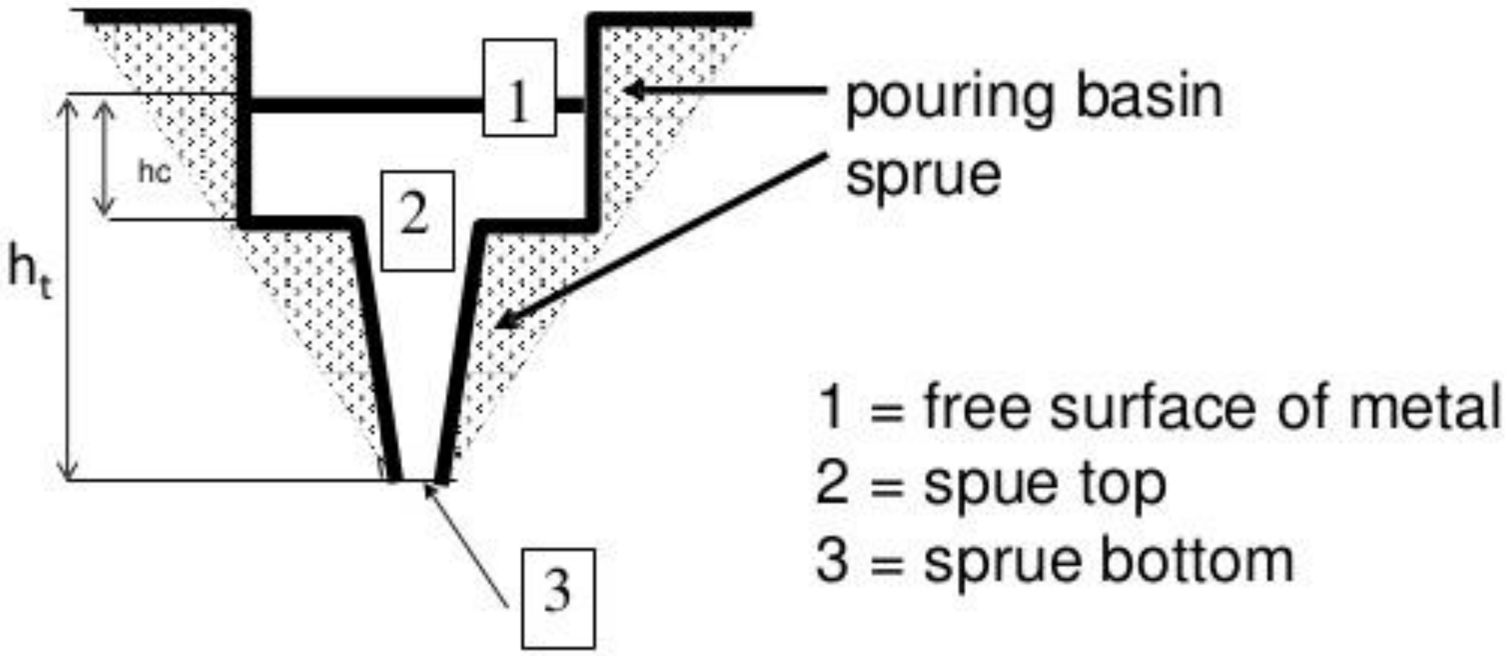
Bernoulli's Equation

h = height of liquid
P = Static Pressure
n = metal velocity
g = Acceleration due to gravity
r = Fluid density

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

DESIGN OF SPRUE



- 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.

- 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

K

POURING TIME

- 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

Functions of Risers

1. Provide extra metal to compensate for the volumetric shrinkage
2. Allow mold gases to escape
3. Provide extra metal pressure on the solidifying mold to reproduce mold details more exact

Design Requirements of Risers

1. Riser size: For a sound casting riser must be last to freeze. The ratio of (volume / surface area)^2 of the riser must be greater than that of the casting.

   When this condition does not meet the metal in the riser can be kept in liquid state by heating it externally or using exothermic materials in the risers.

2. Riser placement: the spacing of risers in the casting must be considered by effectively calculating the feeding distance of the risers.

3. Riser shape: cylindrical risers are recommended for most of the castings as spherical risers.

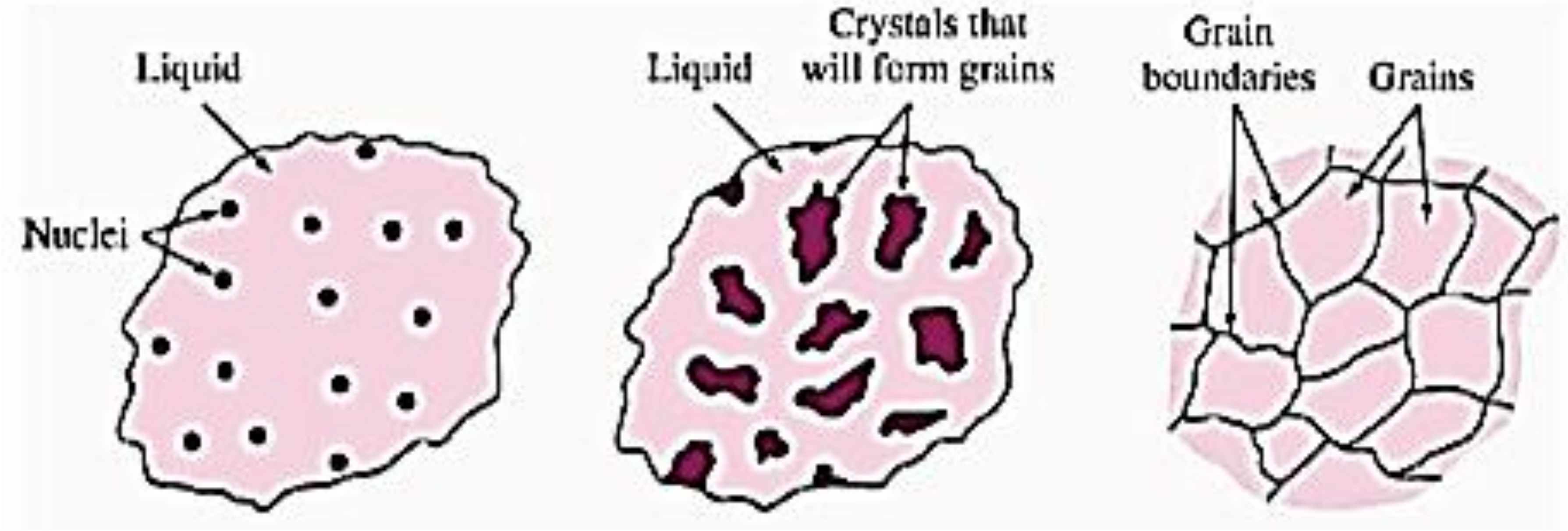
   To increase volume/surface area ratio the bottom of the riser can be shaped as hemisphere.

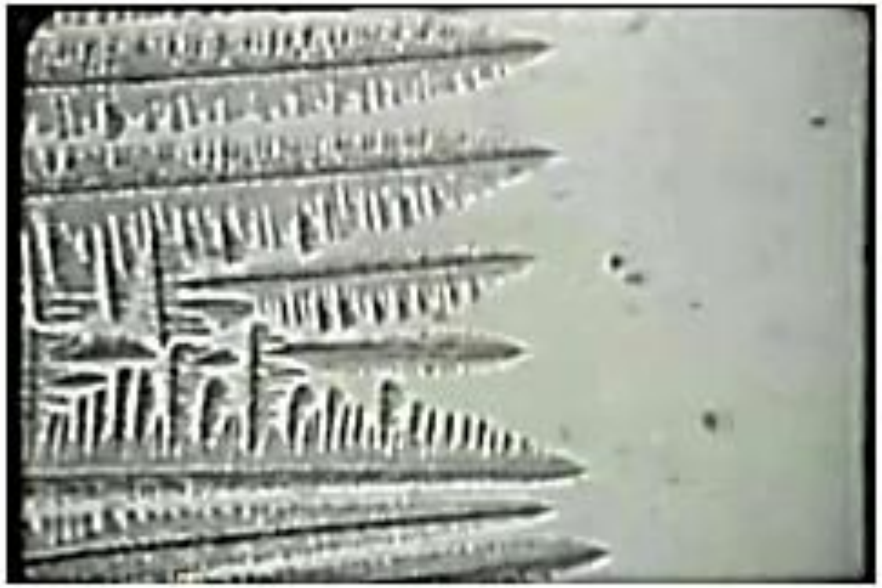
DESIGN FOR RUNNER AND GATES

GATING RATIO

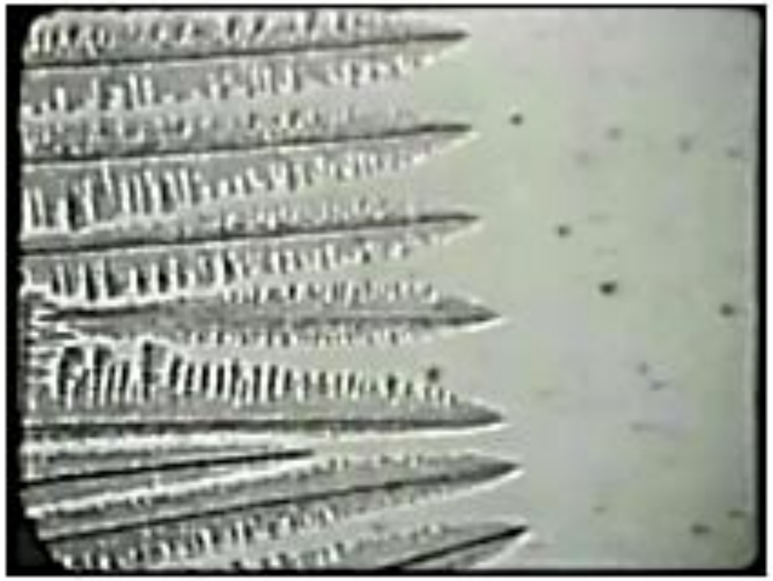
- Gating ratio= a:b:c where,
- a= cross-sectional area of sprue
- b= cross-sectional area of runner
- c= total cross-sectional area of ingates.
- Gating ratio reveals-
- whether the total cross- section decreases towards the mould cavity. This provides a choke effect which pressurizes the liquid metal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

SOLIDIFICATION



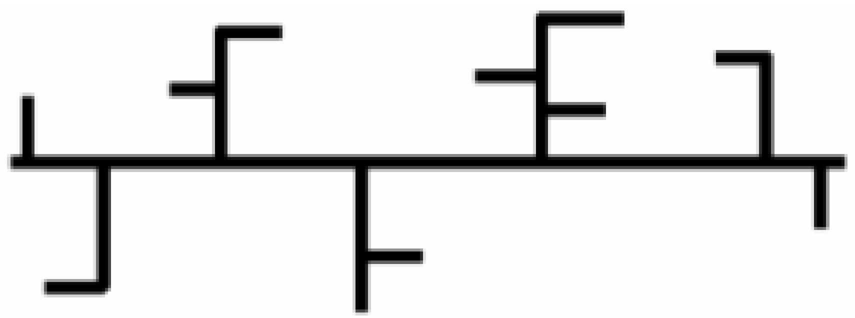


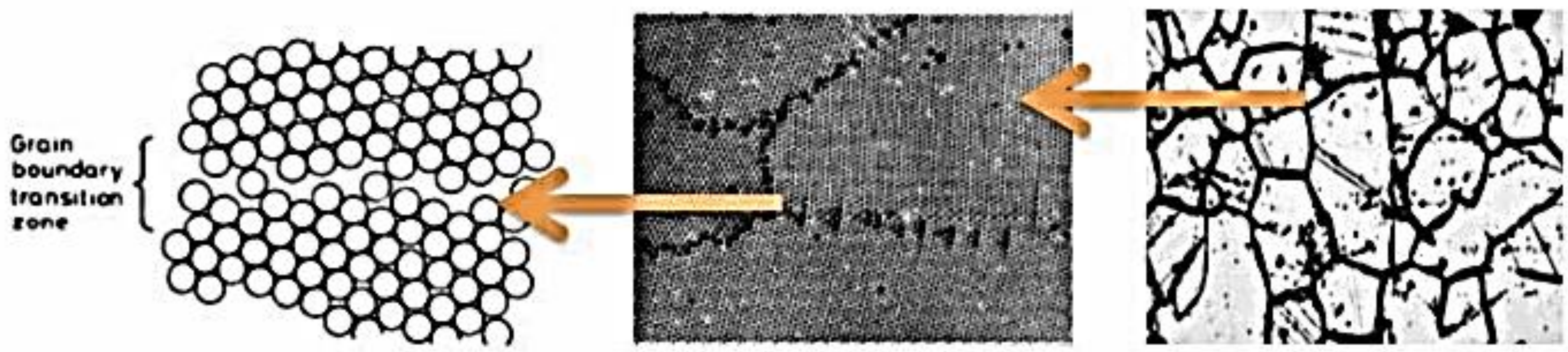
1

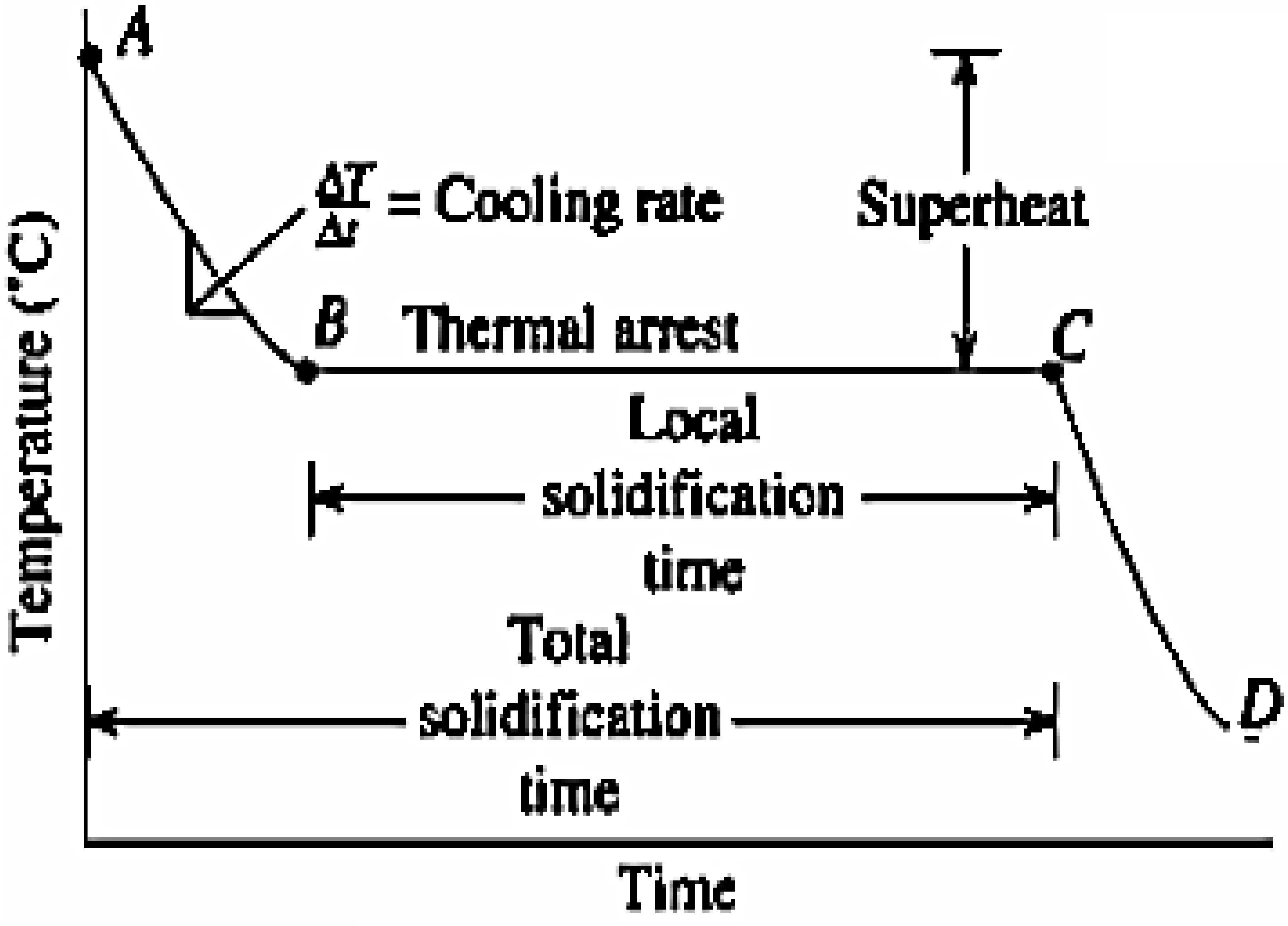


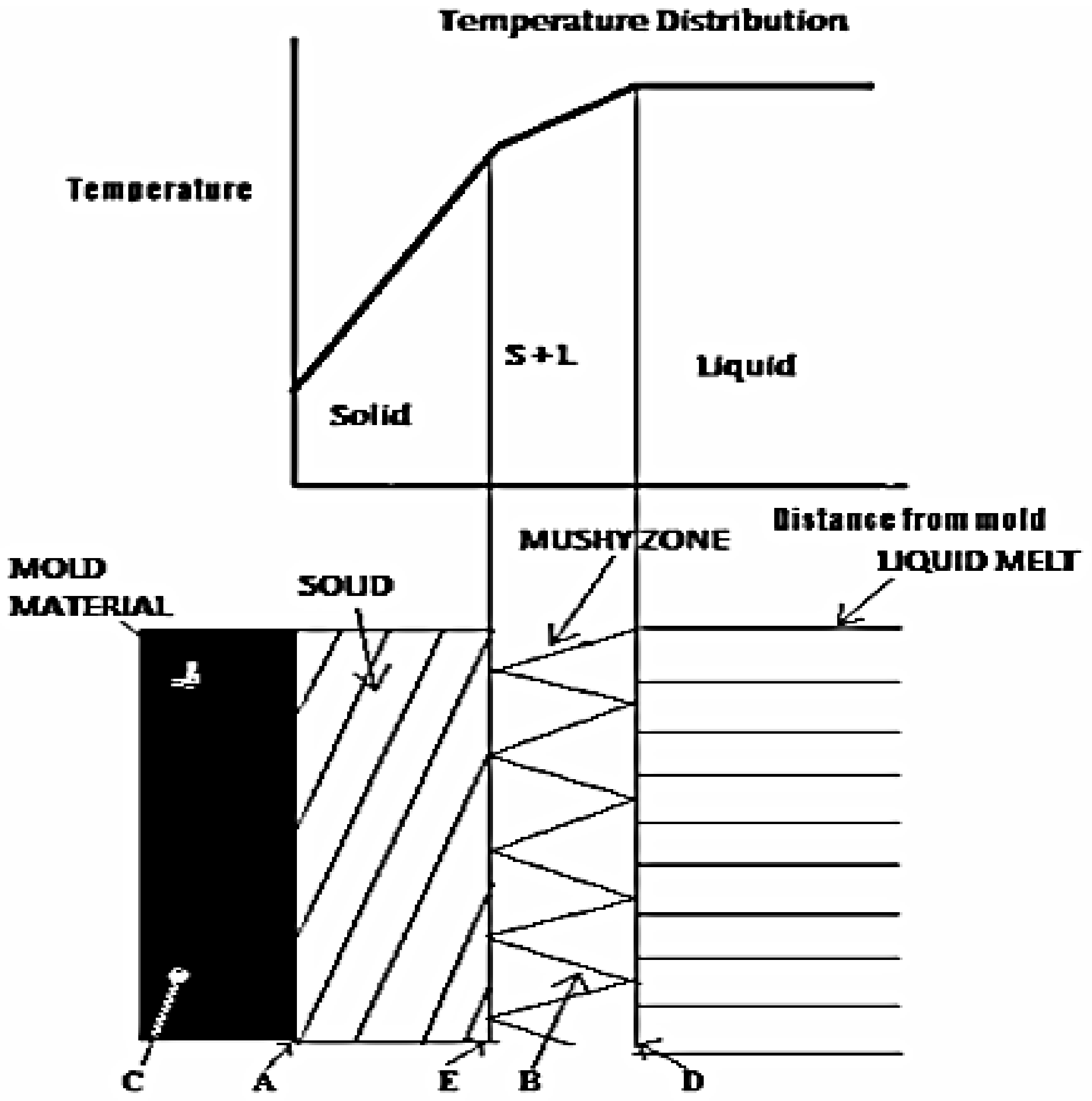
2

3




Grain
boundary
transition
zone


A
$\frac{\Delta T}{\Delta t}$ = Cooling rate
Superheat
B
Thermal arrest
C
Local
solidification
time
Total
solidification
time
D
Temperature (°C)
Time



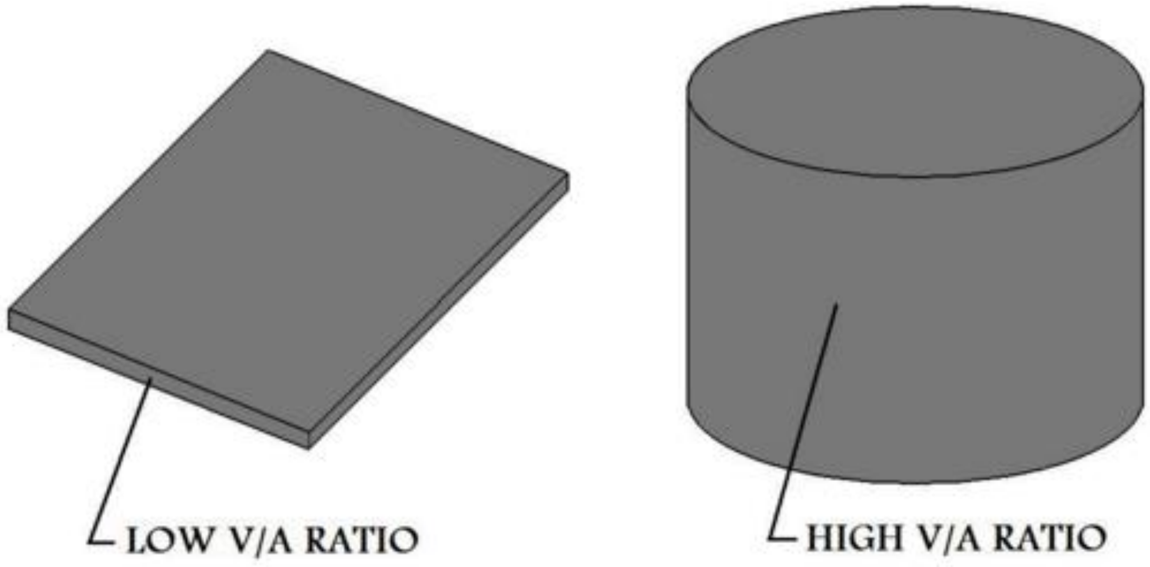
A = SURFACE OF MOLD CAVITY
B = MUSHY OR PASTY ZONE WHICH MOVES INWARD
C = HEAT FLOW DIRECTION
D =START OF SOLIDIFICATION BOUNDRY
E =END OF SOLIDIFCATION BOUNDRY

Design Considerations

V/A Ratio

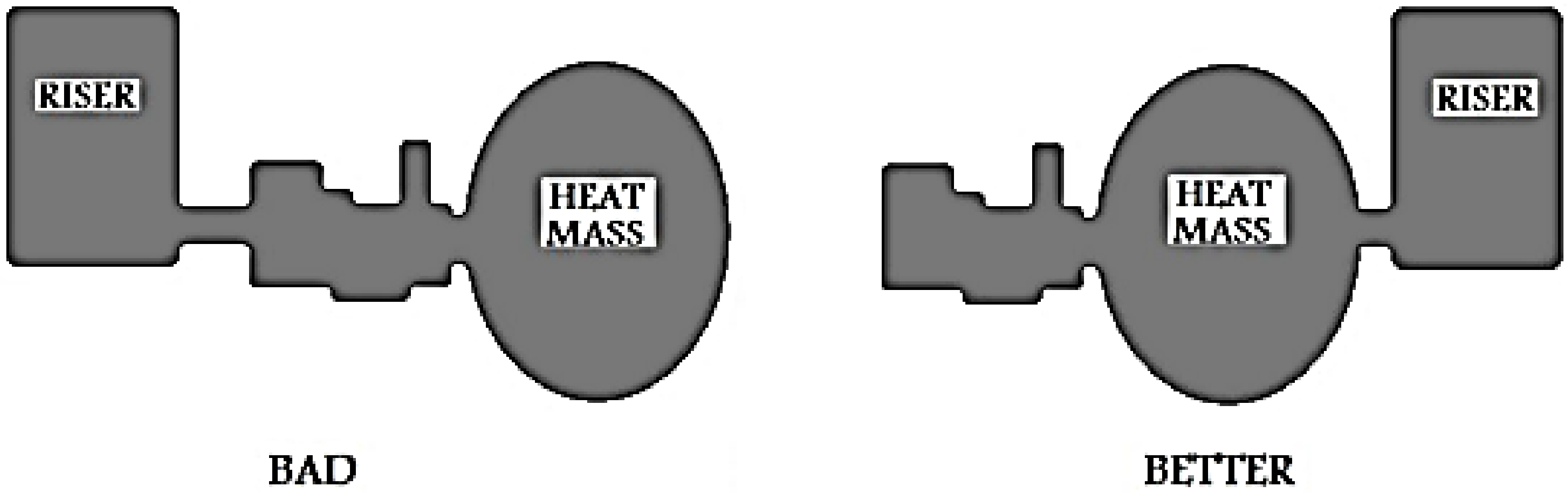
Ratio stands for volume to surface area or mathematically (volume/surface area).

V/A ratios is critical in avoiding premature solidification of the casting and the formation of vacancies.

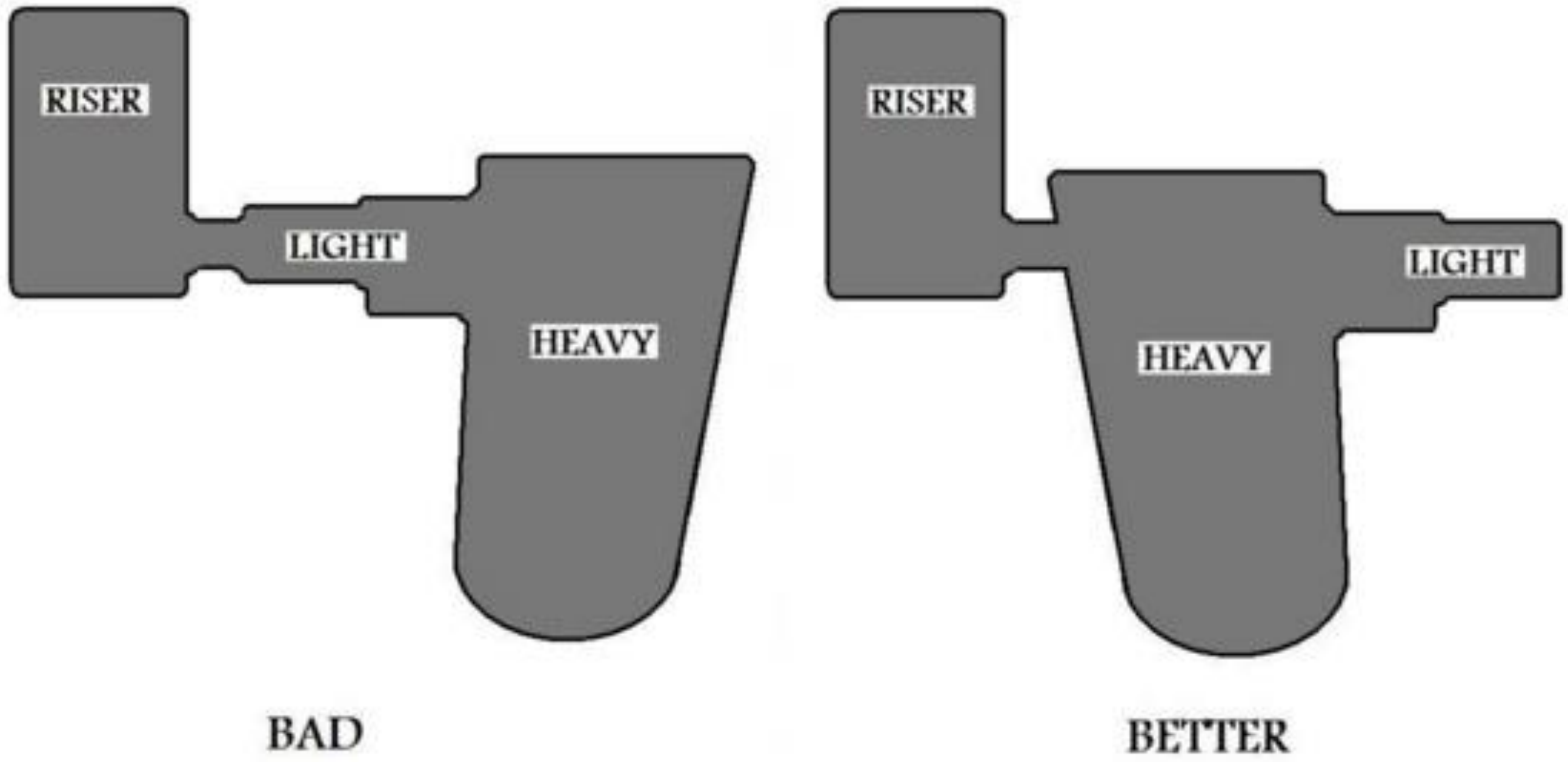


Heat Masses

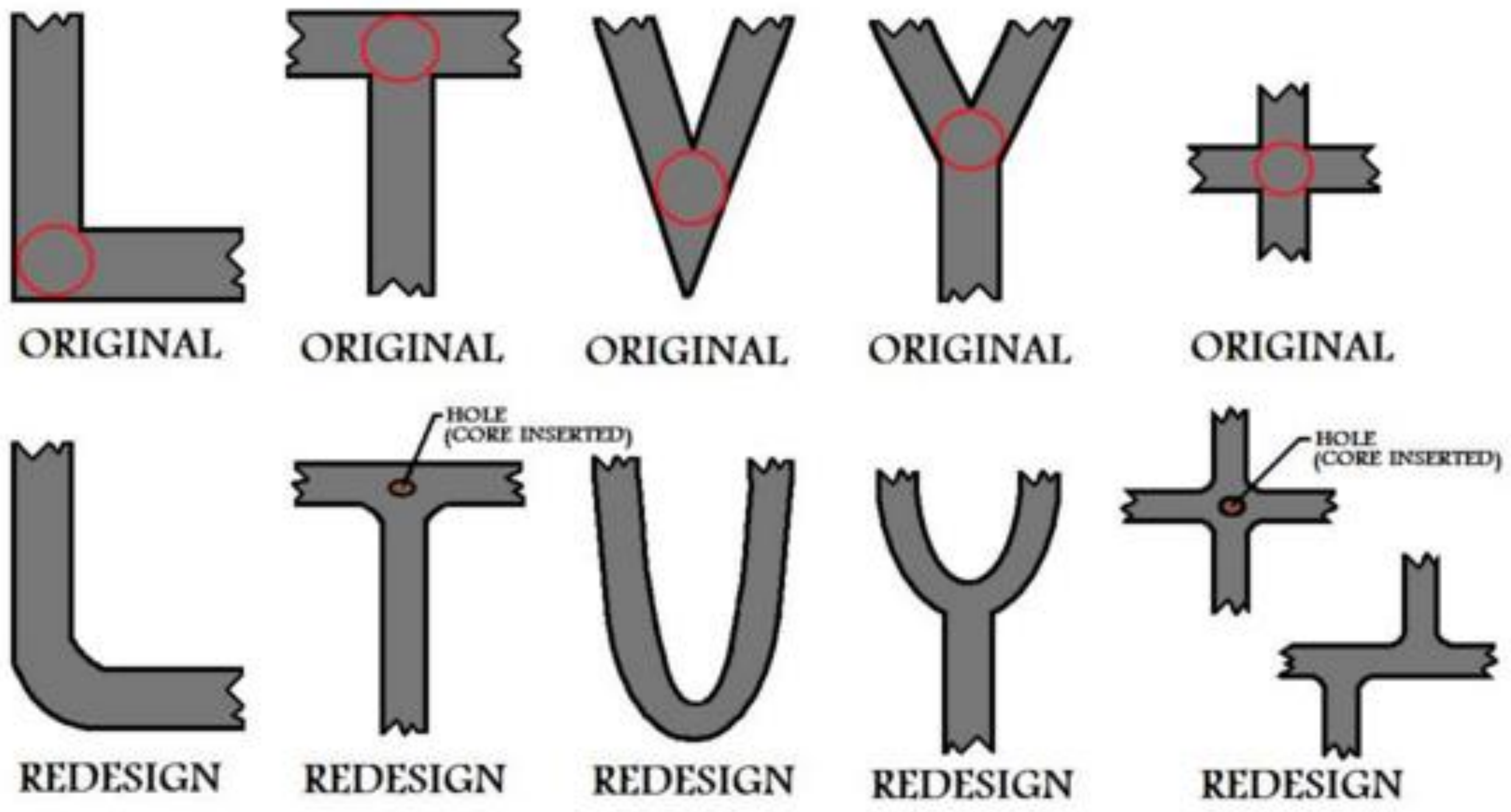
Avoid large heat masses in locations distant to risers.



Do not feed a heavy section through a lighter one.

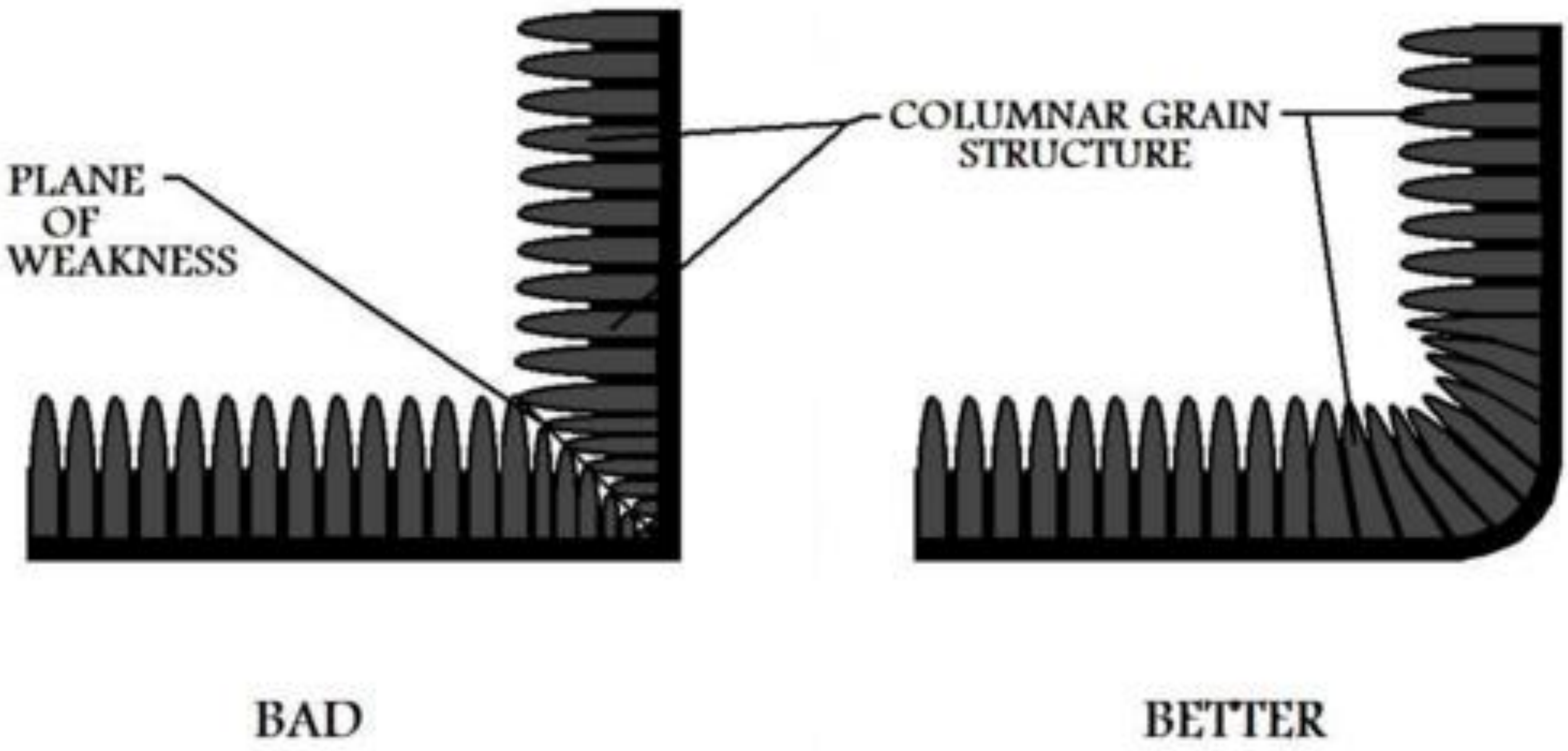


JUNCTIONS…

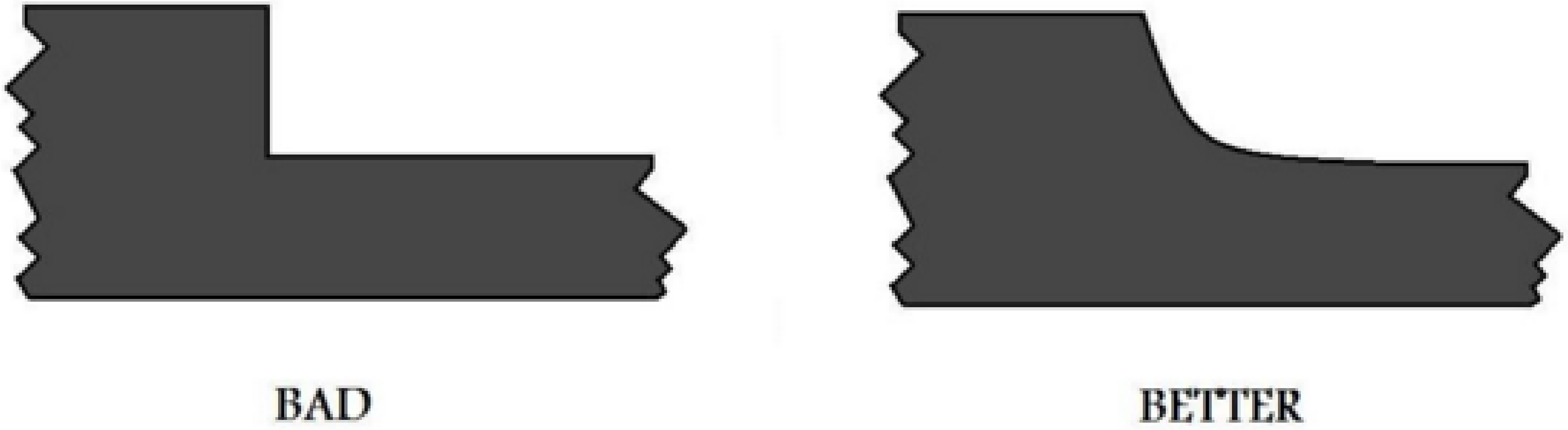


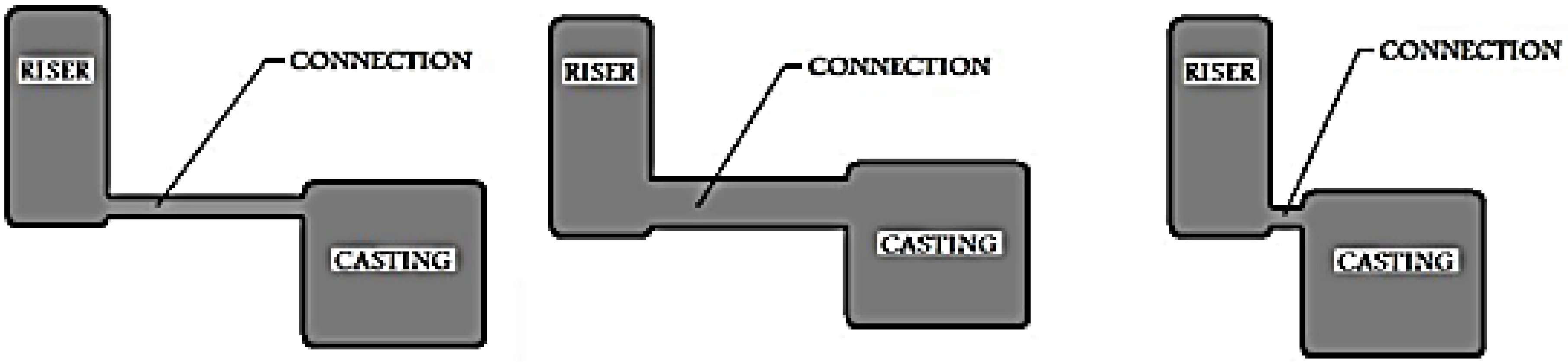
hot spots are circled in red

Prevent Planes of Weakness



Reduce Turbulence



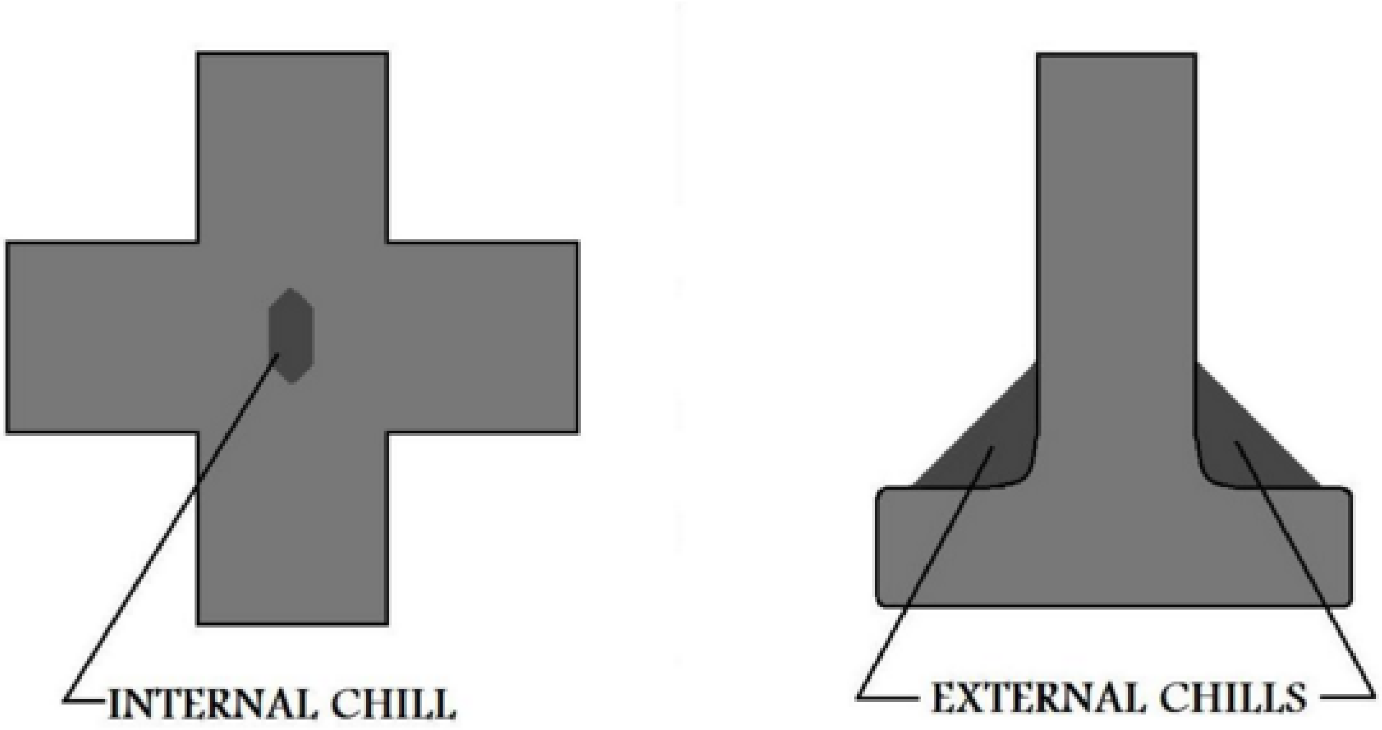


BAD
(PASSAGE WILL FREEZE)

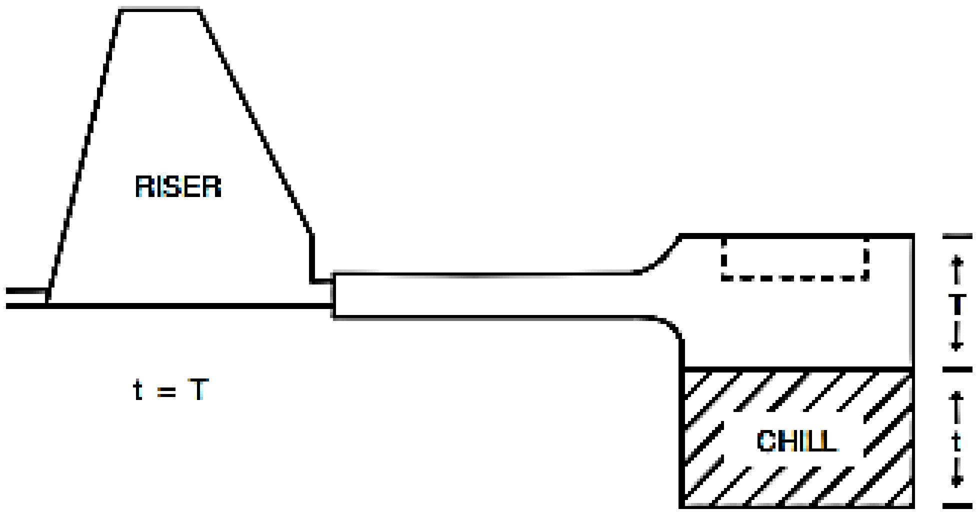
BAD
(WASTES MATERIAL)

BETTER

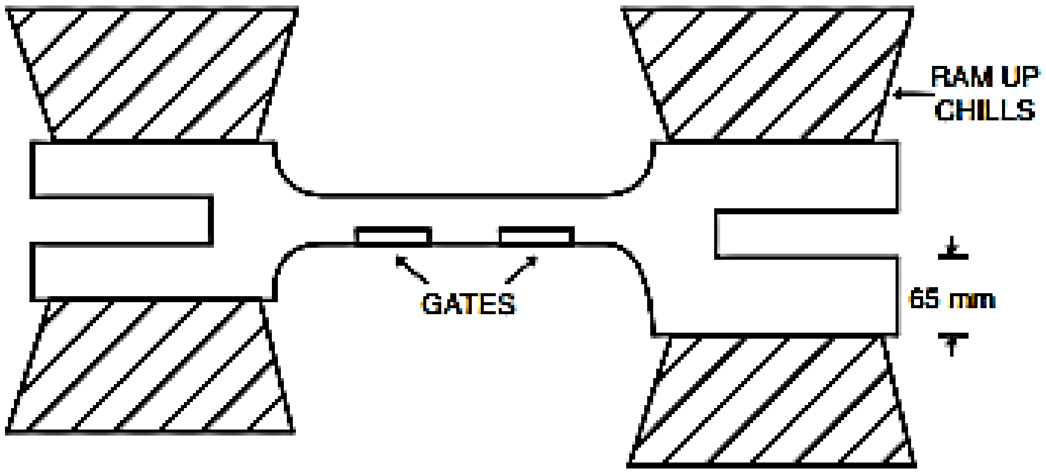
USAGE OF CHILLS



- **regulation of thermal gradients**



Reduce section modulus with chill(s).



Eliminate risers by using chills (minimum modulus > 1 in (25 mm)).

CASTING QUALITY

Basic categories of casting defects

1. Metallic projections:
   - Fins, flash or projections
2. Cavities
   - blow holes, pin holes, shrinkage cavities
3. Discontinuities
   - cracks, cold or hot tears
   - cold shuts- improper fusion of different streams of metals
   - Improper solidification can cause tears

4. Defective surface

- Surface folds ,laps, scars, adhering sand layers and oxide scales

5. Incomplete casting

- misruns (due to premature solidifications)
- insufficient metal poured
- leaks in the mold

6. Incorrect dimensions

- incorrect allowances
- deformed pattern
- pattern mounting error

7.Inclusions

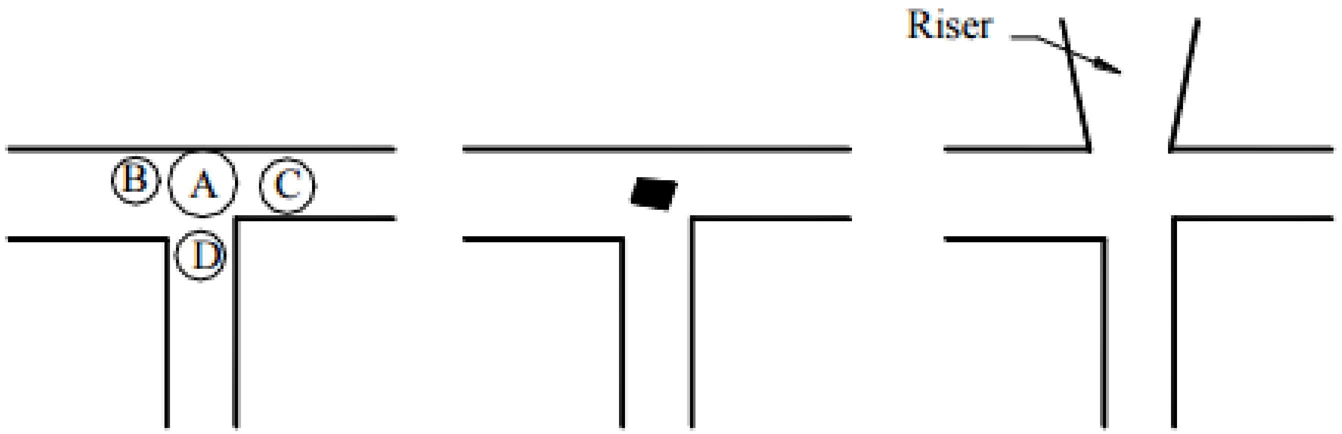
- nonmetallic particles usually
- bad for casting - acts as stress raiser
- materials from alloys, crucible ,mold etc
- sand particles, ceramic particles,
- Can be avoided using filters, good strong molds etc

BLOW HOLES

- Appears as small round voids opened to the casting surface.
- Caused by hard ramming and low permeability sands.

SHRINKAGE DEFECTS

- Caused by inadequate feeding of molten metal.



(a) (b) (c)

HOT TEARS

- Appears as external cracks or discontinuities on casting surface.
- Caused by hard ramming, too much of shrinkage of molten metal and poor design of casting.

MISRUNS

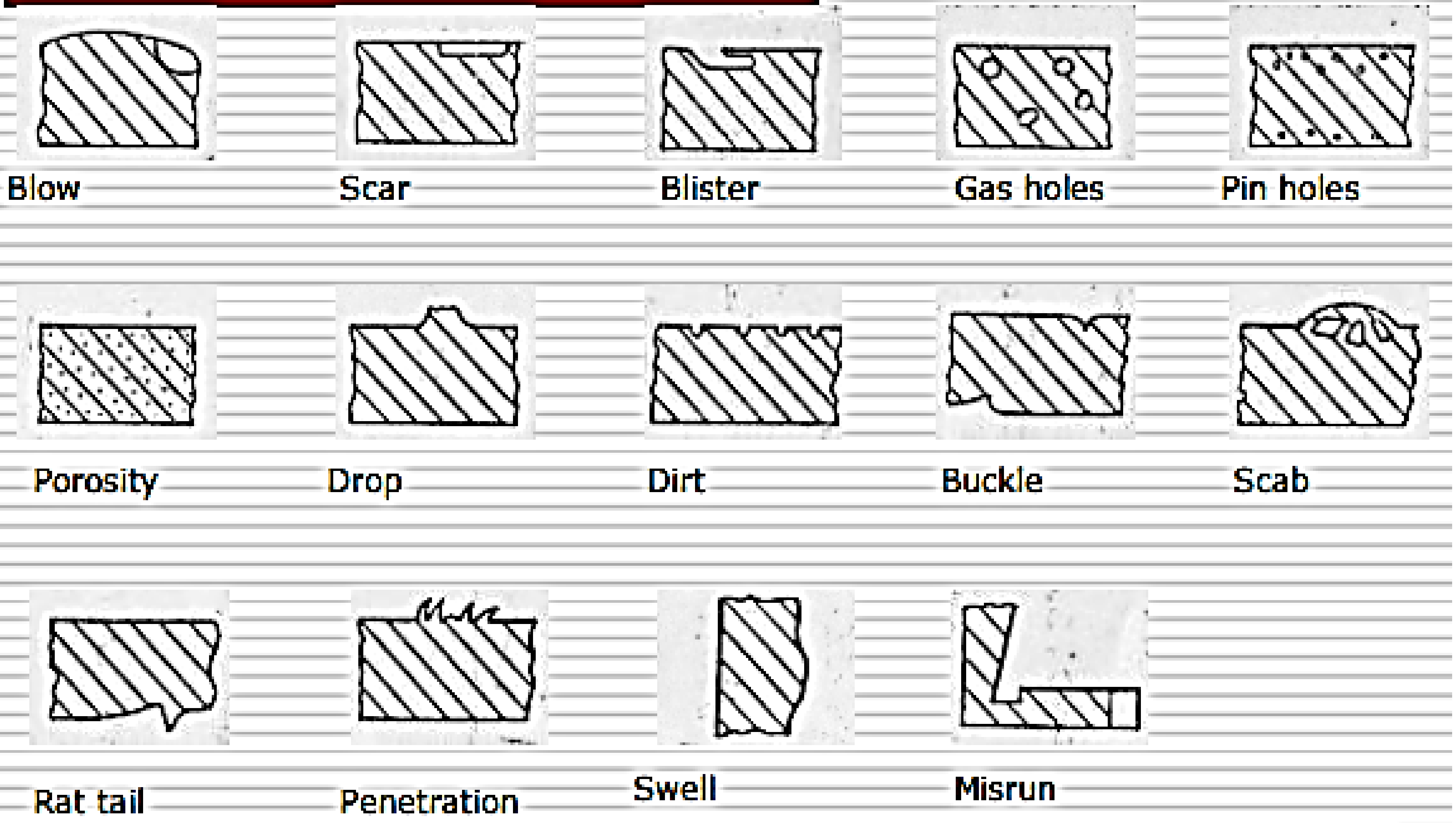
- Mould cavity remaining unfilled (casting is too thin or temperature is too cold)

- COLD SHUT
- Imperfect fusion of molten metal in the mould cavity.

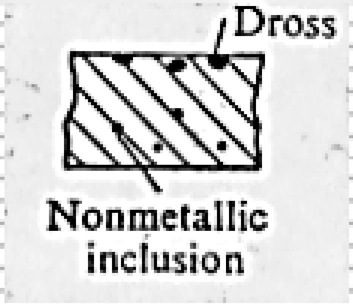
- POUR SHORT
- Mould cavity is not completely filled for the want of molten material.

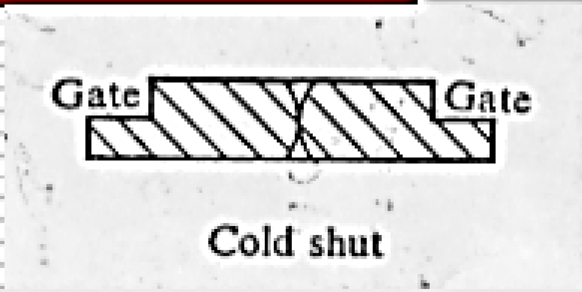
- INCLUSIONS
- Foreign material present within the metal of a casting.

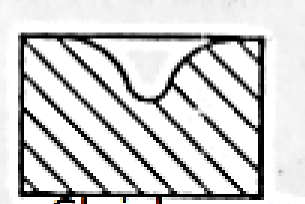
Common Casting defects

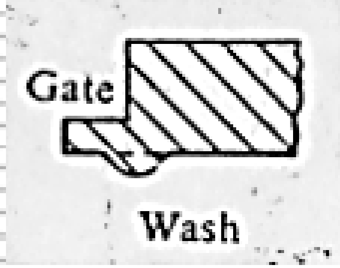


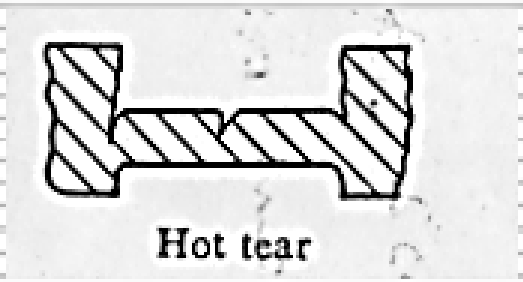
Common Casting defects

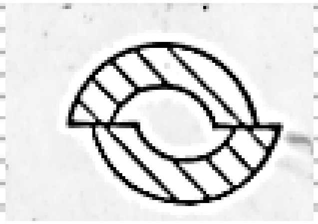


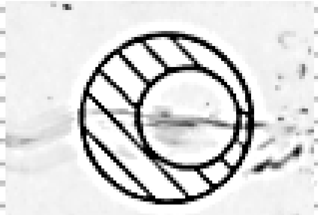



Shrinkage cavity

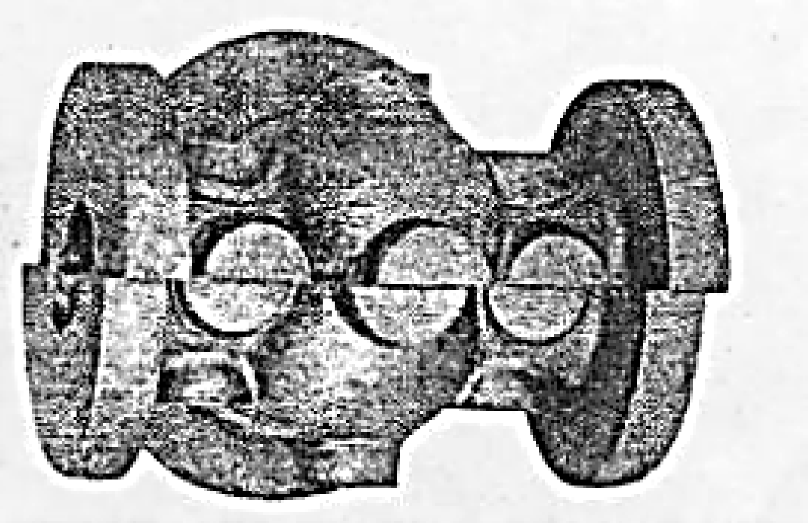


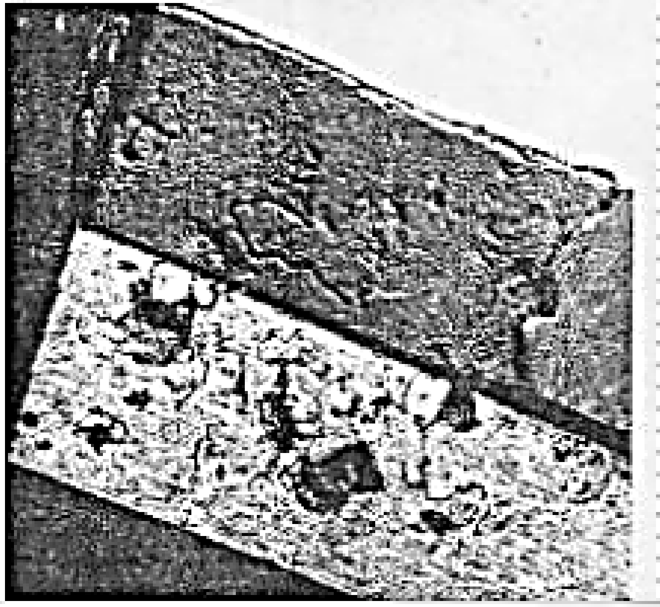



Mold shift


Core shift

Casting defects





- A crossjoint in a large gray iron valve body casting produced by mismatch of top and bottom parts of the mould

- Inclusions in spheroidal graphite cast iron.
- Part of the surface has been machined away to show the inclusions more clearly

Flash

Mold Shift

Porosity

Inclusions

Gas pockets

Short Casting

Summary of casting defects

Defect	Cause	Foundry remedy	Design remedy
Flash	Flow into mold join	Lower pouring temperature, Increase mold box clamping,	
Oxide and dross inclusion	Entrapment of foreign material	Increase care and cleanliness during pouring,	
Shrinkage cavities	Lack of sufficient feed metal	Promote directional solidification by controlling heat flow, Raise pouring temperature,	Relocate risers and ingates
Misruns	Low metal fluidity	Raise pouring temperature	Reconsider position, size and number of ingates and vents

PROPERTIES OF MOULDING SAND

MOISTURE CONTENT TEST

Moisture content of the molding sand mixture may determine by drying a weighed amount of 20 to 50 grams of molding sand to a constant temperature up to 100°C in a oven for about one hour.

Then cooled to a room temperature and then reweighing the molding sand. The moisture content in molding sand is thus evaporated.

Loss in weight of molding sand due to loss of moisture, gives the amount of moisture which can be expressed as a percentage of the original sand sample.

Percentage of moisture content in the molding sand can also be determined in fact more speedily by an instrument known as a speedy moisture teller.

Instrument is based on the principle that when water and calcium carbide react, they form acetylene gas which can be measured and this will be directly proportional to the moisture content.

Instrument is provided with a pressure gauge calibrated to read directly the percentage of moisture present in the molding sand.

Clay Content Test

Amount of clay is determined by carrying out the clay content test in which clay in molding sand of 50 grams is defined as particles which when suspended in water, fail to settle at the rate of one inch per min.

Clay consists of particles less than 20 micron, per 0.0008 inch in dia.

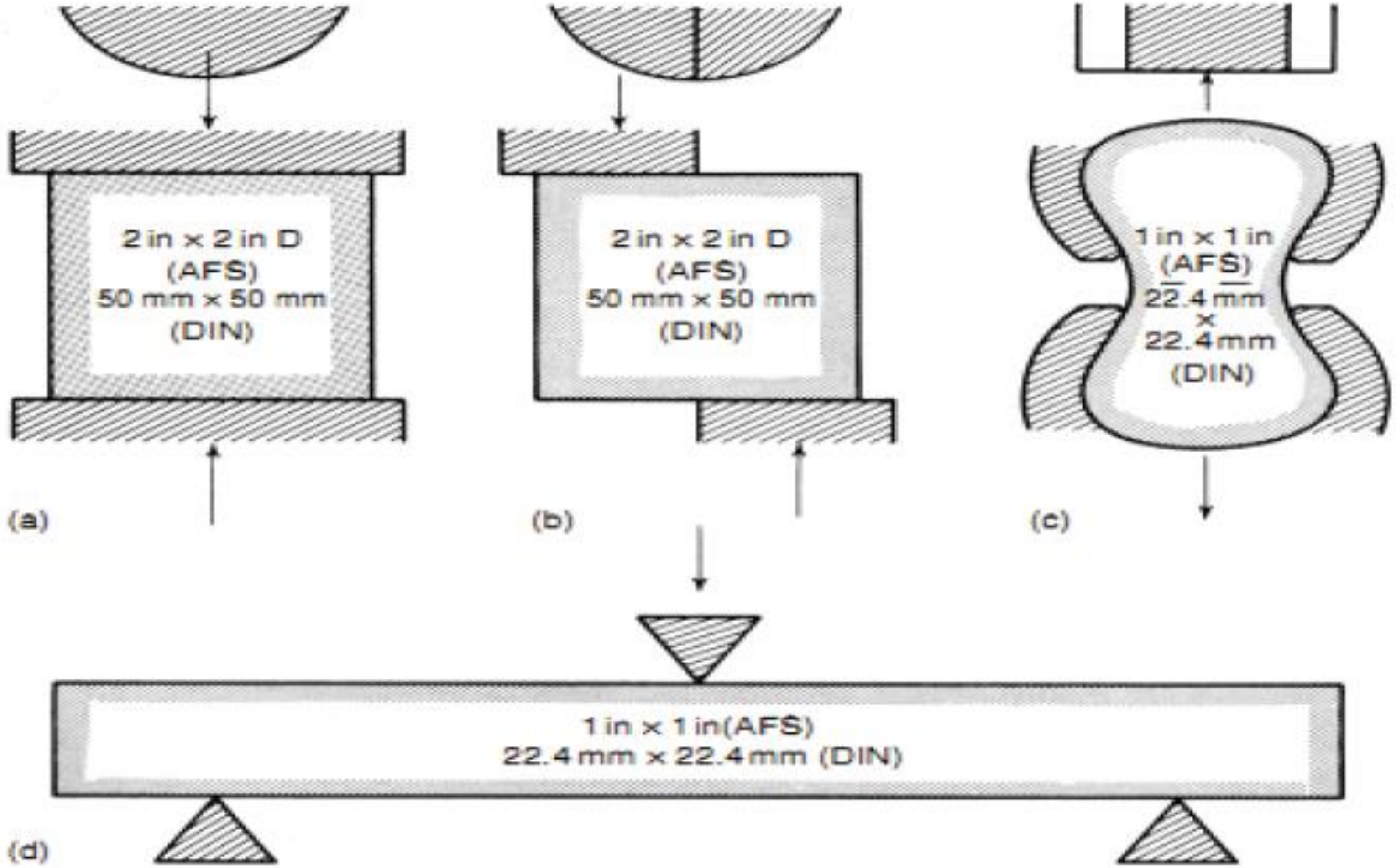
Grain Fineness Test

AFS Grain Fineness Number (AFS-GFN) is one means of measuring the grain fineness of a sand system.

GFN is a measure of the average size of the particles (or grains) in a sand sample. Grain fineness of molding sand is measured using a test called sieve analysis.

Test is carried out in power-driven shaker consisting of number of sieves fitted one over the other.

Sieve Analyzer



2 in × 2 in D
(AFS)
50 mm × 50 mm
(DIN)
(a)
2 in × 2 in D
(AFS)
50 mm × 50 mm
(DIN)
(b)
1 in × 1 in
(AFS)
22.4 mm
×
22.4 mm
(DIN)
(c)
1 in × 1 in(AFS)
22.4 mm × 22.4 mm (DIN)
(d)

Permeability Test

Permeability is determined by measuring the rate of flow of air through a compacted specimen under standard conditions.

A cylinder sand sample is prepared by using rammer and die. This specimen (usually 2 inch dia & 2 inch height) is used for testing the permeability or porosity of molding and the core sand.

Test is performed in a permeability meter consisting of
the balanced tank, water tank, nozzle, adjusting lever, nose piece for fixing sand specimen and a manometer. The permeability is directly measured.

Permeability number P is volume of air (in cm^3) passing through a sand specimen of 1 cm^2 cross-sectional area and 1 cm height, at a pressure difference of 1 gm/cm^2 in one minute.

$$\mathbf{P = Vh / atp}$$

Where, P = permeability
v = volume of air passing through the specimen in c.c.
h = height of specimen in cm
p = pressure of air in gm/cm^2
a = cross-sectional area of the specimen in cm^2
t = time in minutes.

Refractoriness Test

The refractoriness of the molding sand is judged by heating the A.F.S standard sand specimen to very high temperatures ranges depending upon the type of sand.

The heated sand test pieces are cooled to room temperature and examined under a microscope for surface characteristics or by scratching it with a steel needle.

If the silica sand grains remain sharply defined and easily give way to the needle.

In the actual experiment the sand specimen in a porcelain boat is placed into an electric furnace. It is usual practice to start the test from l000°C and raise the temperature in steps of 100°C to 1300°C and in steps of 50° above 1300°C till sintering of the silica sand grains
takes place.

At each temperature level, it is kept for at least three minutes and then taken out from the oven for examination under a microscope for evaluating surface characteristics or by scratching it with a steel needle.

Three metal pieces being cast have the same volume, but different shapes: One is a sphere, one a cube, and the other a cylinder with its height equal to its diameter. Which piece will solidify the fastest, and which one the slowest? Assume that $n = 2$.

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The volume of the piece is taken as unity.

$$\text{Solidification time} \propto \frac{1}{(\text{Surface area})^2}.$$

The respective surface areas are as follows:

Sphere:

$$V = \left(\frac{4}{3}\right)\pi r^3, \; r = \left(\frac{3}{4\pi}\right)^{1/3}.$$

$$A = 4\pi r^2 = 4\pi\left(\frac{3}{4\pi}\right)^{2/3} = 4.84.$$

Cube:

$$V = a^3, a = 1, \text{ and } A = 6a^2 = 6.$$

Cylinder:

$$V = \pi r^2 h = 2\pi r^3, r = \left(\frac{1}{2\pi}\right)^{1/3},$$

$$A = 2\pi r^2 + 2\pi r h = 6\pi r^2 = 6\pi\left(\frac{1}{2\pi}\right)^{2/3} = 5.54.$$

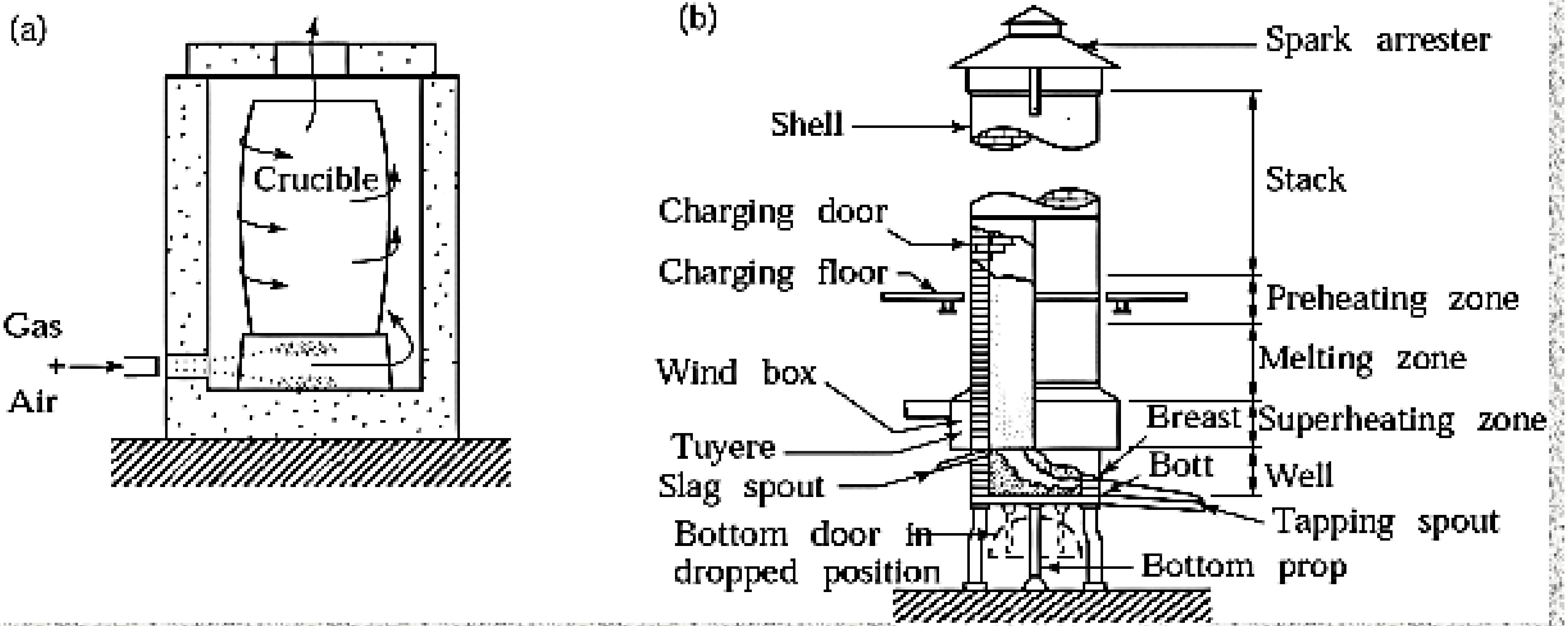
The respective solidification times are therefore

$$t_{\text{sphere}} = 0.043C, t_{\text{cube}} = 0.028C, t_{\text{cylinder}} = 0.033C.$$

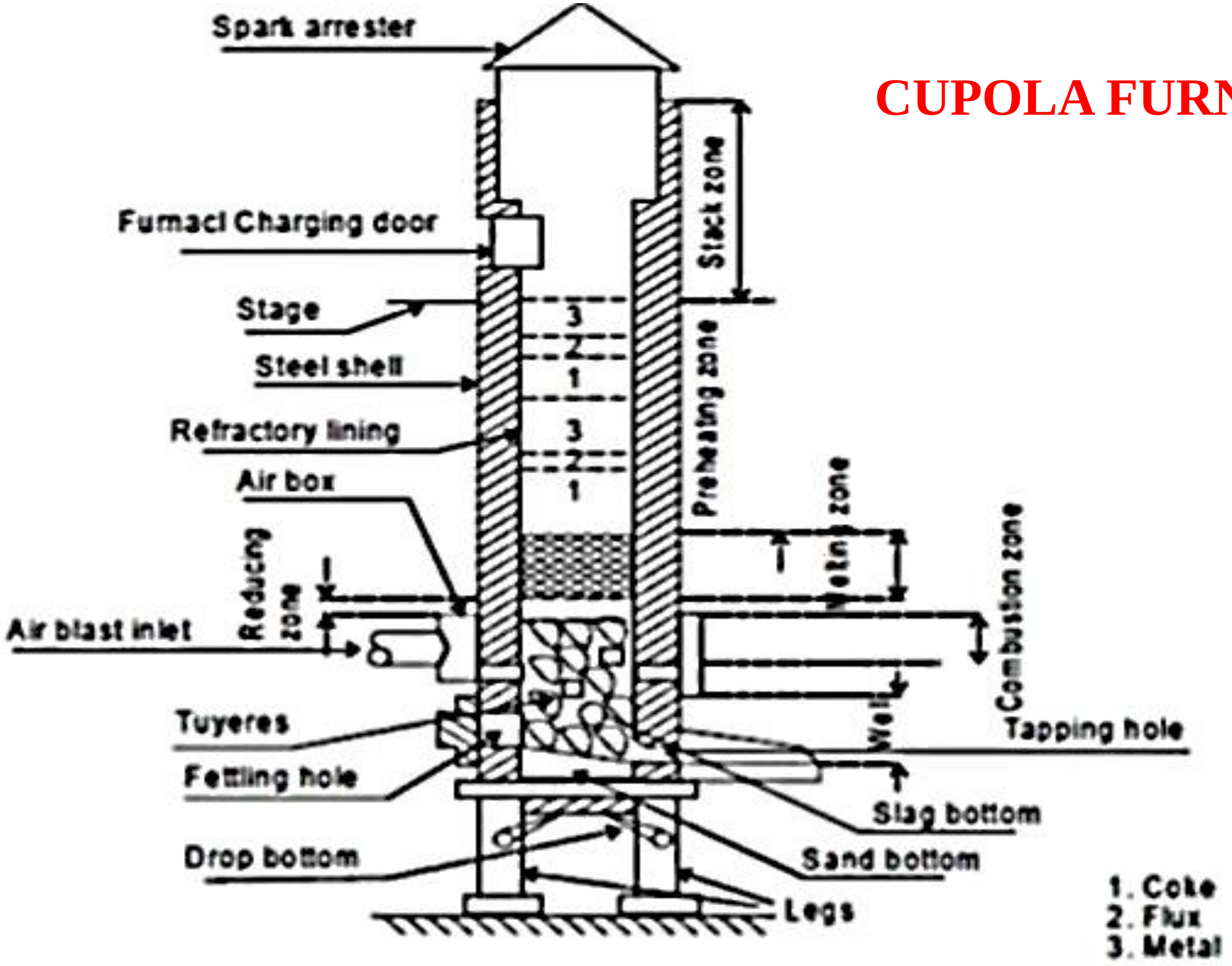
Hence, the cube-shaped piece will solidify the fastest, and the spherical piece will solidify the slowest.

Types of Melting Furnaces

Figure 11.33 Two types of melting furnaces used in foundries: (a) crucible, and (b) cupola.



CUPOLA FURNACE



Direct Fuel-Fired Furnaces

Small open-hearth in which charge is heated by natural gas fuel burners located on side of furnace

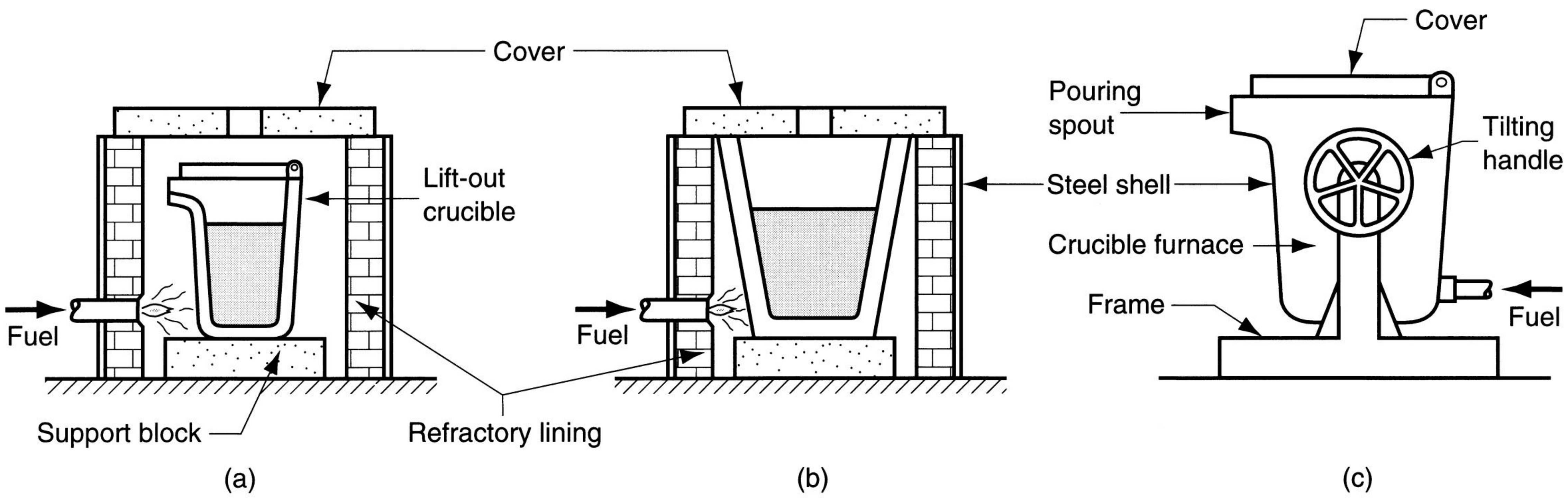
- Furnace roof assists heating action by reflecting flame down against charge
- At bottom of hearth is a tap hole to release molten metal
- Generally used for nonferrous metals such as copper-base alloys and aluminum

Crucible Furnaces

Metal is melted without direct contact with burning fuel mixture

- Sometimes called *indirect fuel-fired furnaces*
- Container (crucible) is made of refractory material or high-temperature steel alloy
- Used for nonferrous metals such as bronze, brass, and alloys of zinc and aluminum
- Three types used in foundries:

(a) lift-out type, (b) stationary, (c) tilting



Three types of crucible furnaces:

(a) lift-out crucible,

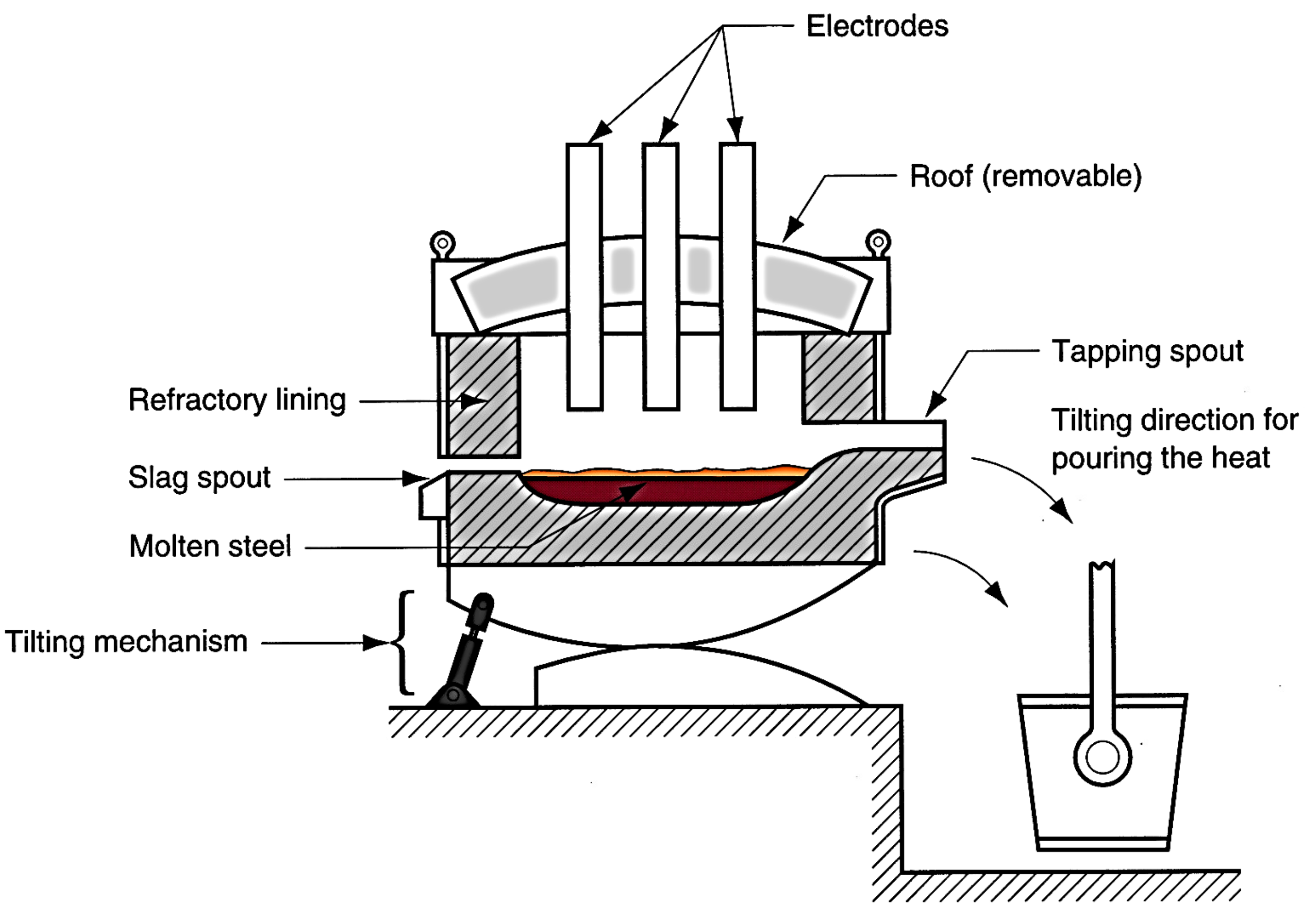
(b) stationary pot, from which molten metal must be ladled, and

(c) tilting-pot furnace

Electric-Arc Furnaces

Charge is melted by heat generated from an electric arc

- High power consumption, but electric-arc furnaces can be designed for high melting capacity
- Used primarily for melting steel

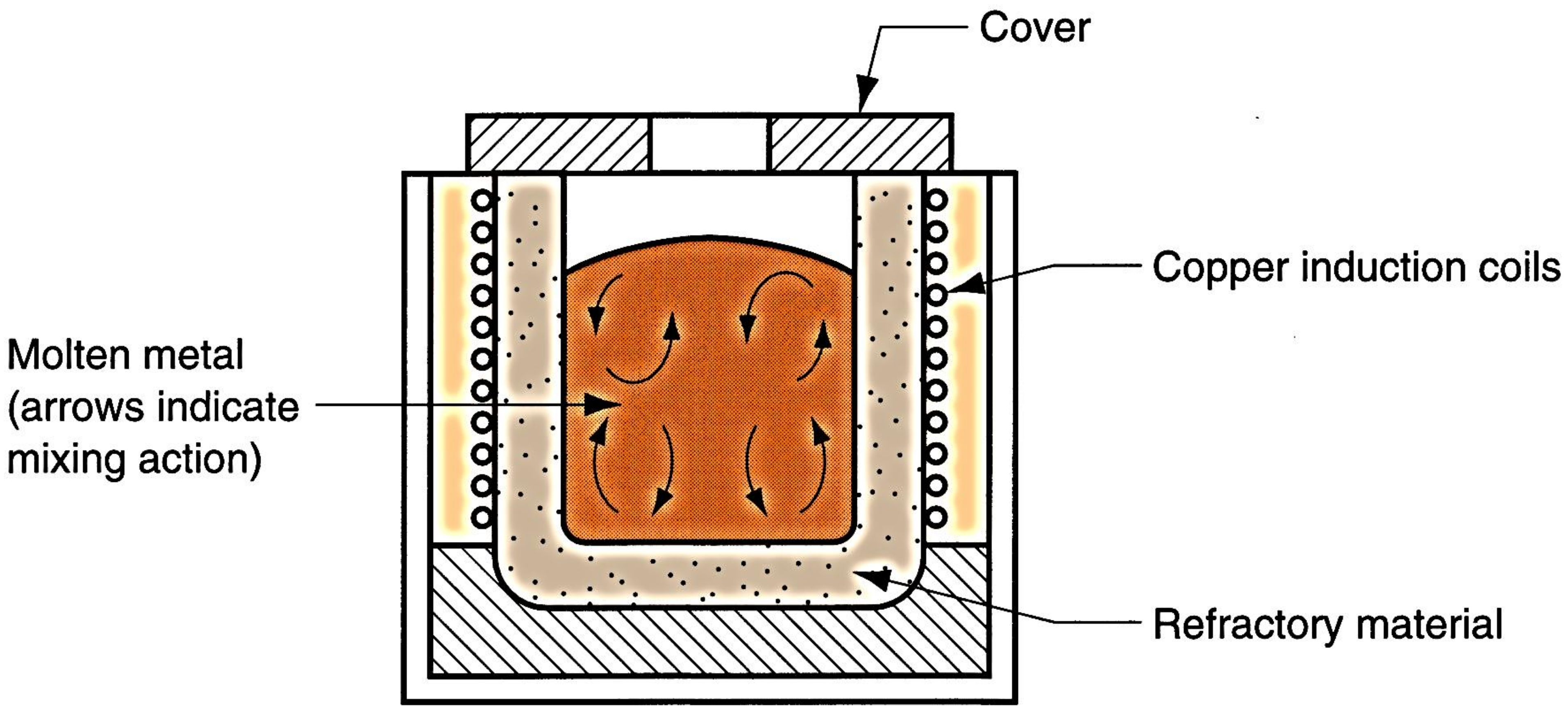


Electric arc furnace for steelmaking

Induction Furnaces

Uses alternating current passing through a coil to develop magnetic field in metal

- Induced current causes rapid heating and melting
- Electromagnetic force field also causes mixing action in liquid metal
- Since metal does not contact heating elements, the environment can be closely controlled, which results in molten metals of high quality and purity
- Melting steel, cast iron, and aluminum alloys are common applications in foundry work



Induction furnace

Additional Steps After Solidification

- Trimming
- Removing the core
- Surface cleaning
- Inspection
- Repair, if required
- Heat treatment

Inspection of casting

1. Visual Inspection
   - Most surface defects can be seen
2. Pressure test
   - The casting is filled with pressurized air after closing all the openings
   - E.g. gear boxes, pressure vessels, look for leaks by submerging in special liquids
   - Pressurized oil can also be used in some cases
3. Radiographic Examination
   - Usually x-rays or g rays
   - x-ray method is used for voids,non metallic inclusions, porosity, cracks
   - Defects appear darker than surrounding

4. Ultrasound examination

- Ultrasound across the casting
- Sound transmitted across homogenous metals
- However discontinuities reflect sound back.
- Not good for cast iron

5. Dye Penetration Inspection

- To detect invisible surface defects in non magnetic castings
- A dye of fluorescent material is sprayed or applied near the surface. The surface is then wiped and viewed in darkness
- Cracks will be visible

6. Magnetic Particle inspection

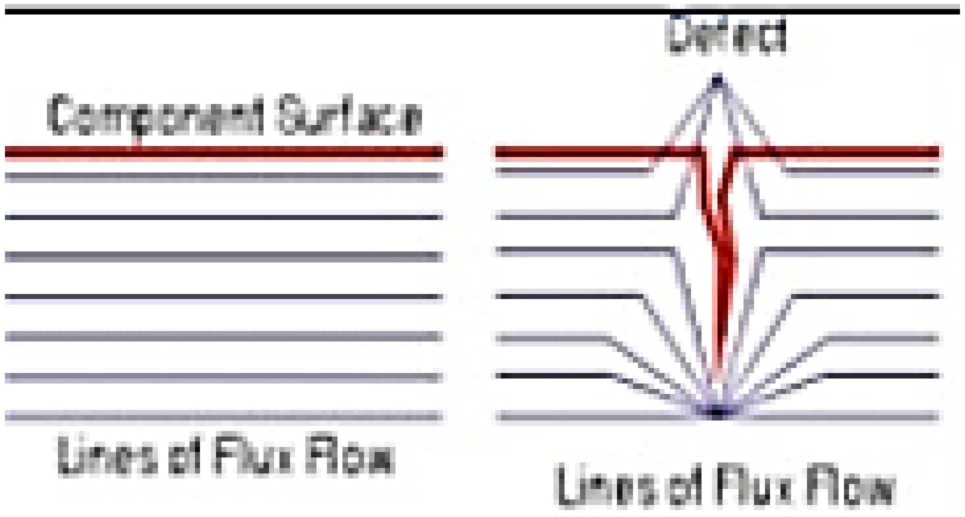
- Induce magnetic field through section under inspection
- Powdered Ferro-magnetic magnetic material is spread onto the surface
- Voids or cracks result in abrupt changes in permeability of material – leads to leakage in magnetic field
- Particles concentrate on the disrupted field or on the crack.

Liquid penetrant test

- Surface preparation
- Penetrant application
- Penetrant dwell
- Excess Penetrant removal
- Developer application
- Indication development
- Inspection
- Clean surface.

Principle - MPI

- When a metal placed in magnetic field, magnetic flux are intersected by the defect – magnetic poles are induced on either side of discontinuity.
- Abrupt change in path of flux – local leakage
- This can detected when magnetic particles are attracted towards defective region.
- Magnetic particles piles up in defective region.



UT arrangement