

Chapter Three

**Focused science of this unit is called
Fundamental of Casting:**

- Introduction
- Types and classification, patterns,
- Types and classification, mold materials,
- Molding sand properties,
- Core sand elements of gating systems,
- Casting design(gating systems: rise, runner, etc.),
- Melting practice, cupola furnace, defects in casting.

3,FUNDAMENTALS OF METAL CASTING

1. Overview of Casting Technology
2. Heating and Pouring
3. Solidification and Cooling

3.1 Introduction to Casting

Casting process

- Material is melted
- Heated to proper temperature
- Treated to modify its chemical makeup
- Molten material is poured into a mold
- Solidifies

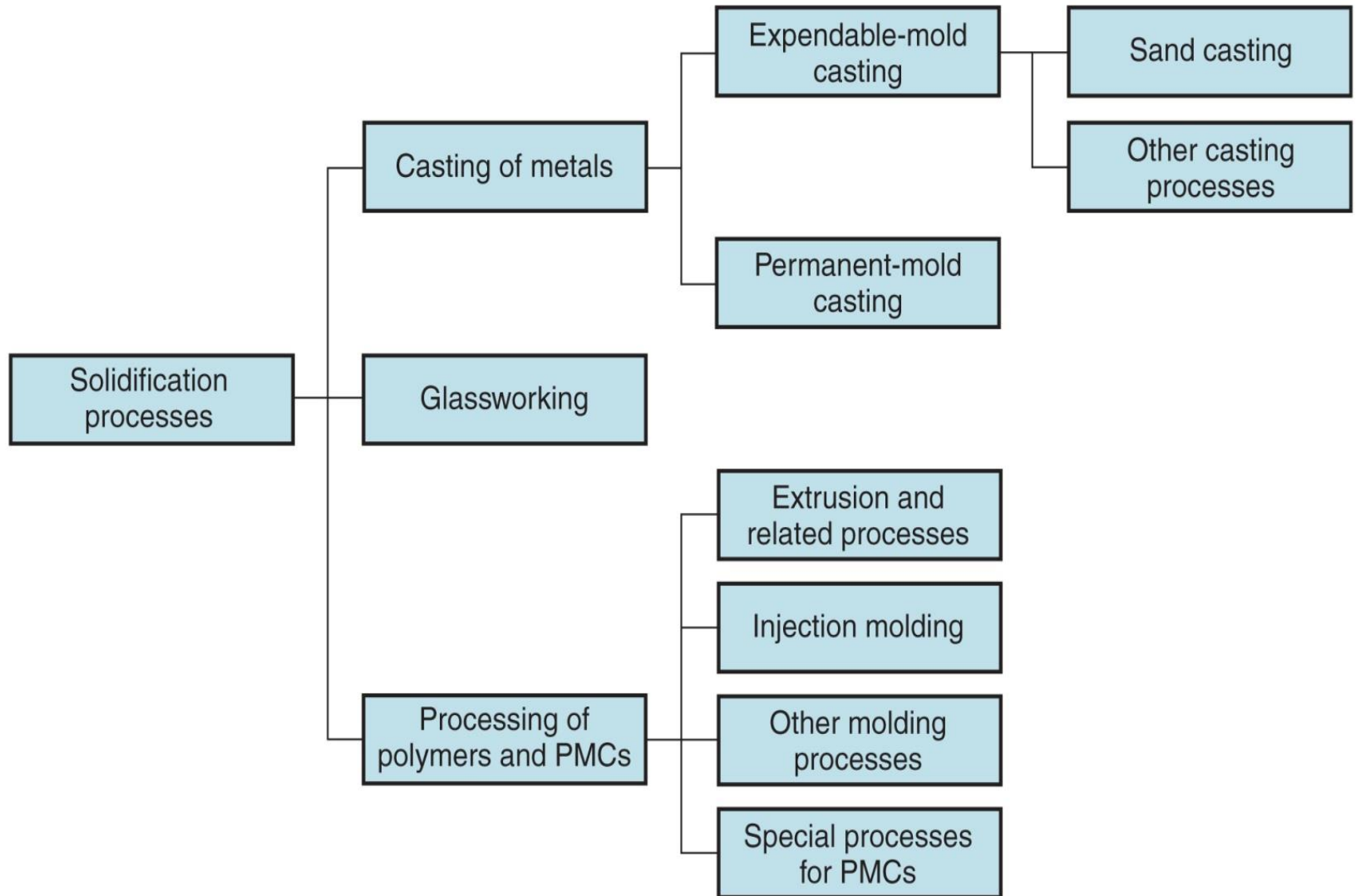
Casting can produce a large variety of parts

Solidification Processes

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

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

Classification of solidification processes



Casting of Metals

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

- The term *casting* also applies to the part made in the process
- Steps in casting seem simple: Melt the metal
 1. Pour it into a mold
 2. Let it freeze

Advantages of Casting

- Complex shapes
- Parts can have hollow sections or cavities
- Very large parts
- Intricate shaping of metals that are difficult to machine
- Different mold materials can be used
 - Sand, metal, or ceramics
- Different pouring methods

Disadvantages of Casting

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

Parts Made by Casting

- Big parts
 - Engine blocks and heads for automotive vehicles, wood burning stoves, machine frames, railway wheels, pipes, church bells, big statues, pump housings
- Small parts
 - Dental crowns, jewelry, small statues, frying pans

Overview of Casting Technology

- Casting is usually performed in a foundry

Foundry = factory equipped for making molds, melting and handling molten metal, performing the casting process, and cleaning the finished casting

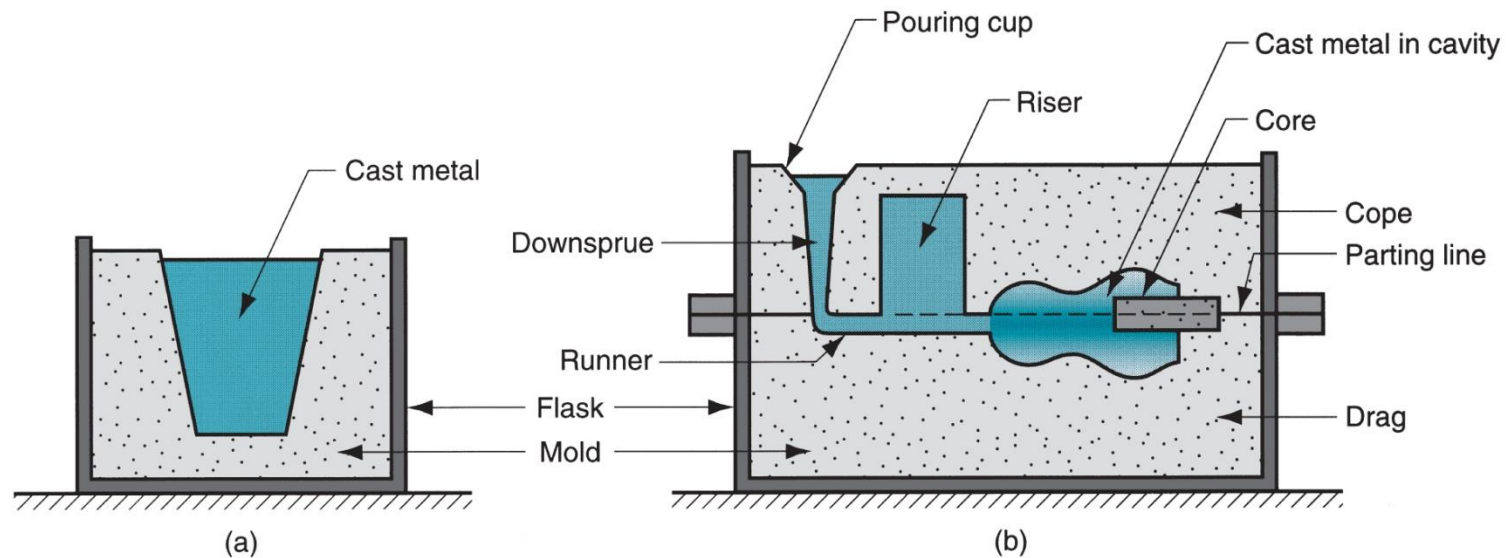
- Workers who perform casting are called foundry men

The Mold in Casting

- Contains cavity whose geometry determines part shape
 - Actual size and shape of cavity must be slightly enlarged to allow for shrinkage of metal during solidification and cooling
 - Molds are made of a variety of materials, including sand, plaster, ceramic, and metal

Open Molds and Closed Molds

Two forms of mold: (a) open mold and (b) closed mold for more complex mold geometry with gating system leading into the cavity



Two Categories of Casting Processes

1. Expendable mold processes – use an expendable mold which must be destroyed to remove casting
 - Mold materials: sand, plaster, and similar materials, plus binders
2. Permanent mold processes – use a permanent mold which can be used to produce many castings
 - Made of metal (or, less commonly, a ceramic refractory material)

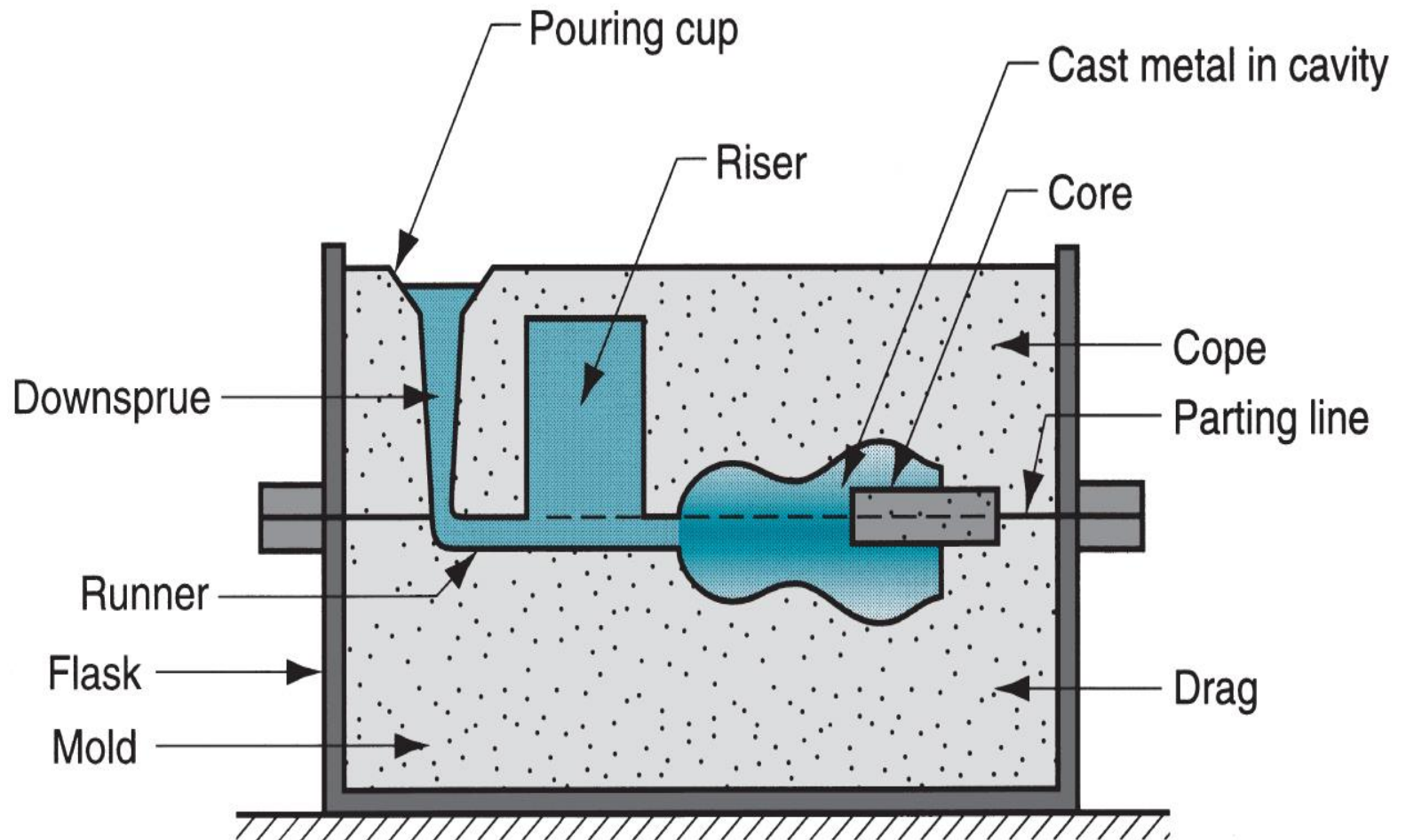
Advantages and Disadvantages CP

More intricate geometries are possible with expendable mold processes

Part shapes in permanent mold processes are limited by the need to open the mold

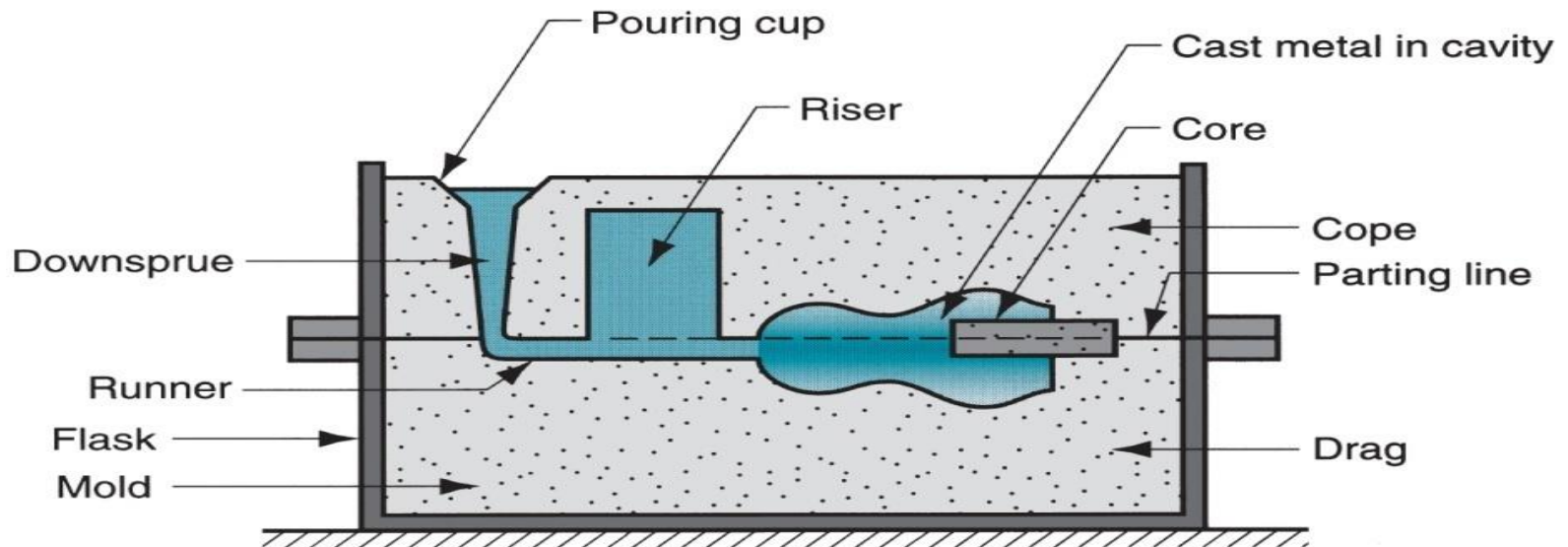
Permanent mold processes are more economic in high production operations

Sand Casting Mold



Terminology for Sand Casting Mold

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



Forming the Mold Cavity in Sand Casting

- Mold cavity is formed by packing sand around a pattern, which has the shape of the part
- When the pattern is removed, the remaining cavity of the packed sand has desired shape of cast part
- The pattern is usually oversized to allow for shrinkage of metal during solidification and cooling
- Sand for the mold is moist and contains a binder to maintain its shape

Use of a Core in the Mold Cavity

- The mold cavity provides the external surfaces of the cast part
- In addition, a casting may have internal surfaces, determined by a core, placed inside the mold cavity to define the interior geometry of part
- In sand casting, cores are generally made of sand

Basic Requirements of Casting Processes

- Six basic steps of casting
 - 1. Mold cavity is produced having the desired shape and size of the part
 - Takes shrinkage into account
 - Single-use or permanent mold
 - 2. Melting process
 - Provides molten material at the proper temperature
 - 3. Pouring technique
 - Molten metal is poured into the mold at a proper rate to ensure that erosion and or defects are minimized

- 4. Solidification process
 - Controlled solidification allows the product to have desired properties
 - Mold should be designed so that shrinkage is controlled
- 5. Mold removal
 - The casting is removed from the mold
 - Single-use molds are broken away from the casting
 - Permanent molds must be designed so that removal does not damage the part
- 6. Cleaning, finishing, and inspection operations
 - Excess material along parting lines may have to be machined

Casting Terminology

- Pattern- approximate duplicate of the part to be cast
- Molding material- material that is packed around the pattern to provide the mold cavity
- Flask- rigid frame that holds the molding aggregate
- Cope- top half of the pattern or mold
- Drag- bottom half of the pattern or mold
- Core- sand or metal shape that is inserted into the mold to create internal features

- Mold cavity- combination of the mold material and cores
- Riser-additional void in the mold that provides additional metal to compensate for shrinkage
- Gating system- network of channels that delivers the molten metal to the mold
- Pouring cup- portion of the gating system that controls the delivery of the metal
- Sprue- vertical portion of the gating system
- Runners- horizontal channels
- Gates- controlled entrances

- Parting line- separates the cope and drag
- Draft- angle or taper on a pattern that allows for easy removal of the casting from the mold
- Casting- describes both the process and the product when molten metal is poured and solidified

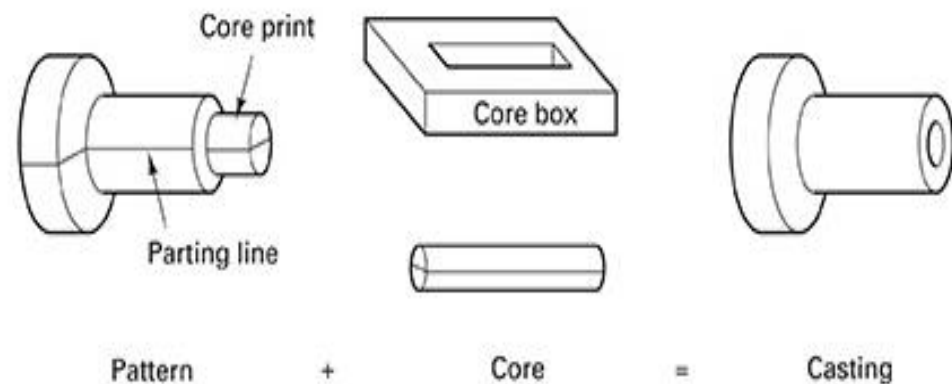
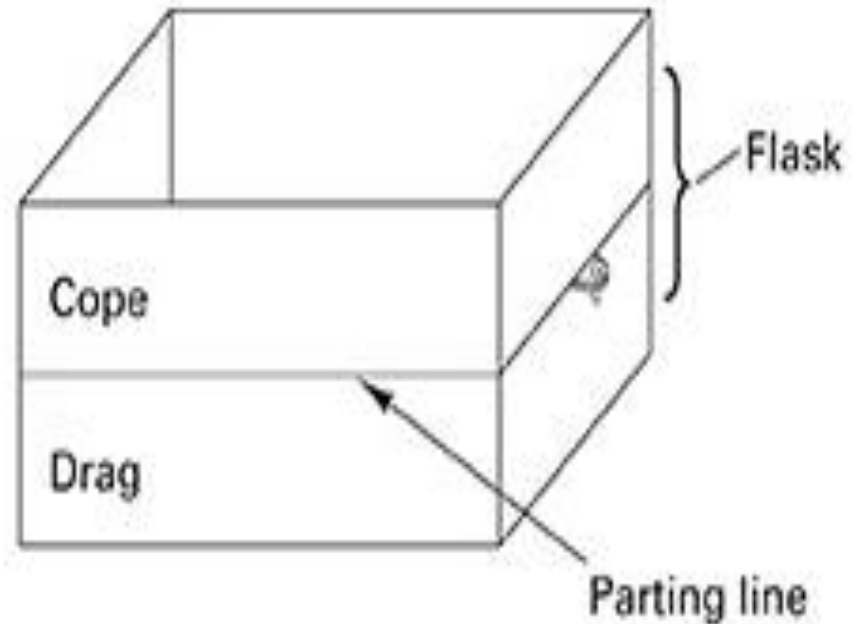


Figure that show Cross section of a typical two-part sand mold, indicating various mold components and terminology.

Cross Section of a Mold

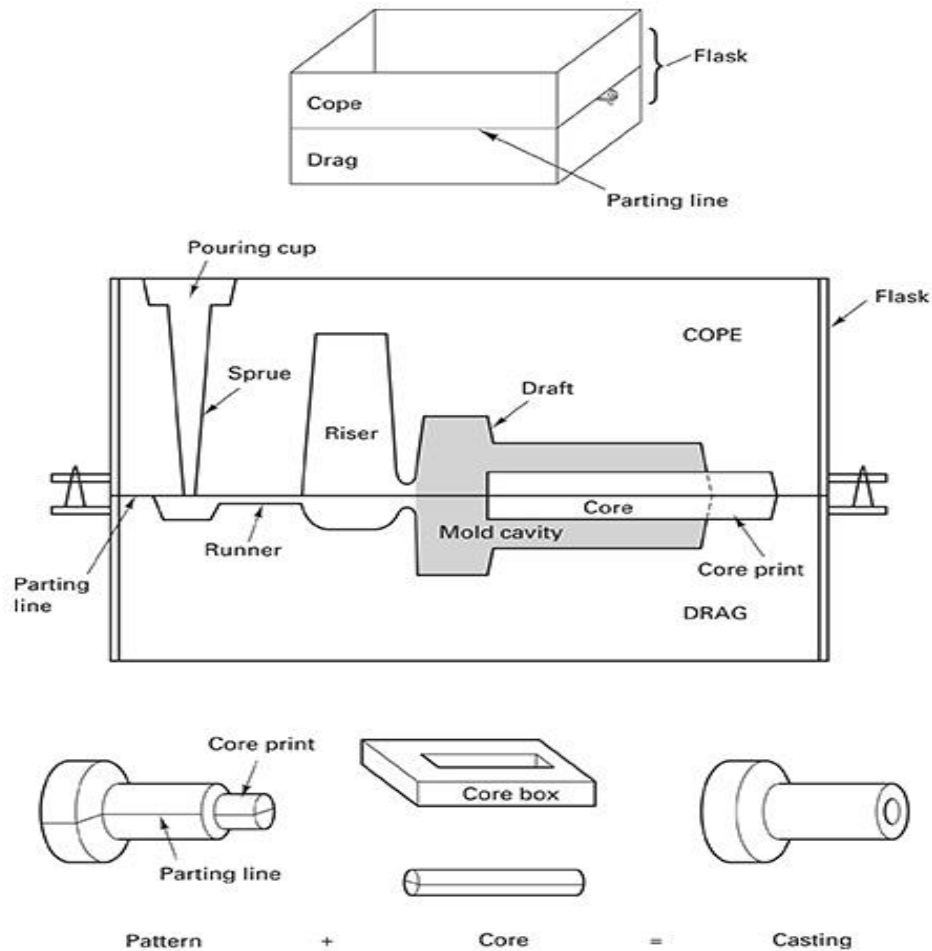


Figure 11-2

The Solidification Process

- Molten material is allowed to solidify into the final shape
- Casting defects occur during solidification
 - Gas porosity
 - Shrinkage
- Two stages of solidification
 - Nucleation
 - Growth

Nucleation

- Stable particles form from the liquid metal
- Occurs when there is a net release of energy from the liquid Under cooling is the difference between the melting point and the temperature at which nucleation occurs
- Each nucleation event produces a grain
 - Nucleation is promoted (more grains) for enhanced material properties
 - Inoculation or grain refinement is the process of introducing solid particles to promote nucleation

Grain Growth

- Occurs as the heat of fusion is extracted from the liquid
- Direction, rate, and type of growth can be controlled
 - Controlled by the way in which heat is removed
 - Rates of nucleation and growth control the size and shape of the crystals
 - Faster cooling rates generally produce finer grain sizes

Cast Structure

- Three distinct regions or zones
 - Chill zone
 - Rapid nucleation that occurs when the molten metal comes into contact with the cold walls of the mold
 - Forms a narrow band of randomly oriented crystals on the surface of a casting
 - Columnar zone
 - Rapid growth perpendicular to the casting surface
 - Long and thin
 - Highly directional
 - Equiaxed zone
 - Crystals in the interior of the casting
 - Spherical, randomly oriented crystals

Molten Metal Problems

- Chemical reactions can occur between molten metal and its surroundings
- Reactions can lead to defects in the final castings
 1. Metal oxides may form when molten metal reacts with oxygen
 2. Dross or slag is the material that can be carried with the molten metal during pouring and filling of the mold
 - Affects the surface finish, machinability, and mechanical properties

3. Gas porosity

- Gas that is not rejected from the liquid metal may be trapped upon solidification
- Several techniques to prevent gas porosity
 - Prevent the gas from initially dissolving in the liquid
 - Melting can be done in a **vacuum**
 - Melting can be done in environments with **low-solubility gases**
 - **Minimize turbulence**
 - **Vacuum degassing** removes the gas from the liquid before it is poured into the castings
 - Gas flushing- passing **inert gases** or reactive gases through the liquid metal

Fluidity and Pouring Temperature

- Metal should flow into all regions of the mold cavity and then solidify
- **Fluidity** is the ability of a metal to flow and fill a mold
 - Affects the minimum section thickness, maximum length of a thin section, fineness of detail, ability to fill mold extremities
 - Dependent on the composition, freezing temperature, freezing range, and surface tension
- Most important controlling factor is **pouring temperature**

Consideration for selecting a casting process

- Required quality of the casting surface
- Required dimensional accuracy of the casting
- Number of castings required per order
- Type of pattern and core box equipment needed
- Cost of making the mold(s)
- How the selected process will affect the design of the casting

3.2 Type and classification, patterns

What is **pattern**?

A pattern is a model or the replica of the object (to be casted). It is embedded in molding sand and suitable ramming of molding sand around the pattern is made. The pattern is then withdrawn for generating cavity (known as mold) in molding sand. Thus it is a mould forming tool.

Objective of a pattern

- Pattern prepares a mould cavity
- Pattern possesses core prints
- It establishes the parting line
- parting surfaces in the mould.
- Runner, gates and riser may form a part of the pattern.
- minimize overall cost of the casting , and
- Pattern may help in establishing locating pins on the mould and therefore on the surface then.

Common pattern material

The common materials used for making patterns are

1. wood patterns material
2. metal patterns material
3. plastic patterns material
4. plaster patterns material
5. wax patterns material
6. mercury patterns material

Advantages of wooden patterns

- Wood can be easily worked.
- It is light in weight.
- It is easily available.
- It is very cheap.
- It is easy to join.
- It is easy to obtain good surface finish.
- Wooden laminated patterns are strong.
- It can be easily repaired.

Disadvantage of wooden pattern

- 1 It is susceptible to moisture.
- 2 It tends to warp.
- 3 It wears out quickly due to sand abrasion.
- 4 It is weaker than metallic patterns.

Metal pattern material

Advantage

1. It is cheap
2. It is easy to file and fit
3. It is strong
4. It has good resistance against sand abrasion
5. Good surface finish

Disadvantage

- 1 It is heavy
- 2 It is brittle and hence it can be easily broken
- 3 It may rust

Brasses and Bronzes pattern

Advantages

1. Better surface finish than cast iron.
2. Very thin sections can be easily casted.

Disadvantages

1. It is costly
2. It is heavier than cast iron.

Aluminum Alloys

Advantages

1. Aluminum alloys pattern does not rust.
2. They are easy to cast.
3. They are light in weight.
4. They can be easily machined.

Disadvantages

1. They can be damaged by sharp edges.
2. They are softer than brass and cast iron.
3. Their storing and transportation needs proper care.

Plastic pattern material

- Plastics are getting more popularity now a days because the patterns made of these materials are lighter, stronger, moisture and wear resistant, non sticky to molding sand, durable and they are not affected by the moisture of the molding sand. Moreover they impart very smooth surface finish on the pattern surface.

Plaster pattern material

- This material belongs to gypsum family which can be easily cast and worked with wooden tools and preferable for producing highly intricate casting. The main advantages of plaster are that it has high compressive strength and is of high expansion setting type which compensate for the shrinkage allowance of the casting metal.

Wax pattern material

Patterns made from wax are excellent for investment casting process. The materials used are blends of several types of waxes, and other additives which act as polymerizing agents, stabilizers, etc. The commonly used waxes are paraffin wax, shellac wax, bees-wax, cerasin-wax, and micro-crystalline wax.

Factors effecting selection of pattern material

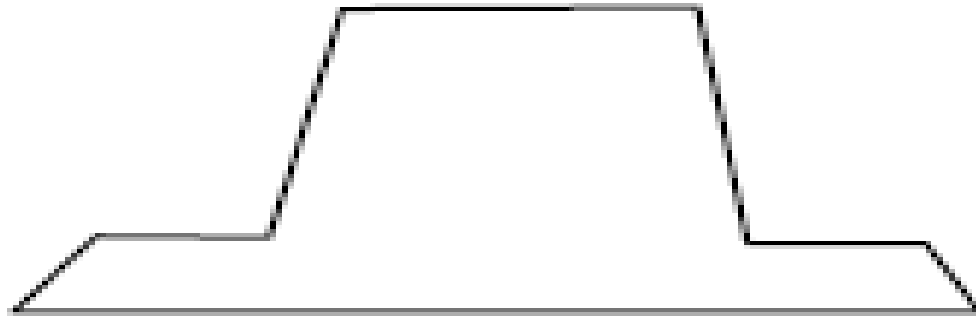
1. Metal pattern are preferred.
2. Type of mould material used.
3. Kind of molding process.
4. Method of molding (hand or machine).
5. Degree of dimensional accuracy
6. surface finish required.
7. Minimum thickness required.
8. Shape, complexity and size of casting.
9. Cost of pattern and chances of repeat orders of the pattern

3.2.1 Type of pattern

1. One piece or solid pattern
2. Two piece or split pattern
3. Cope and drag pattern
4. Three-piece or multi- piece pattern
5. Loose piece pattern
6. Match plate pattern
7. Follow board pattern
8. Gated pattern
9. Sweep pattern
10. Skeleton pattern , and Segmental or part pattern

1. Single-piece or solid pattern

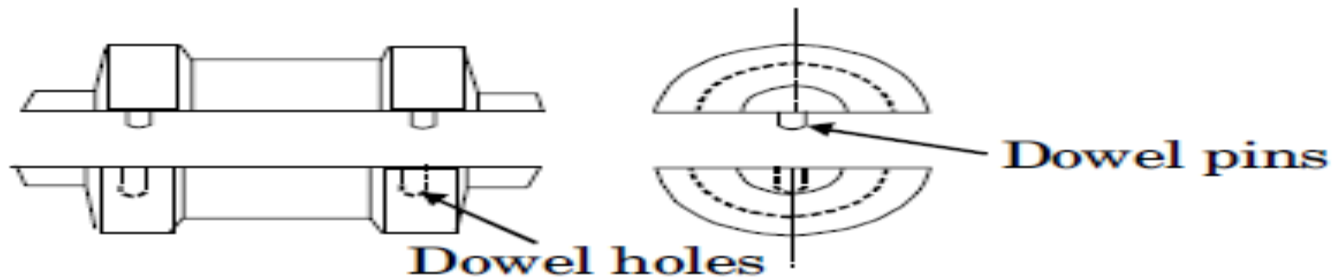
Solid pattern is made of single piece without joints, partings lines or loose pieces. It is the simplest form of the pattern. Typical single piece pattern is shown in Fig here below.



Single piece pattern

2. Two-piece or split pattern

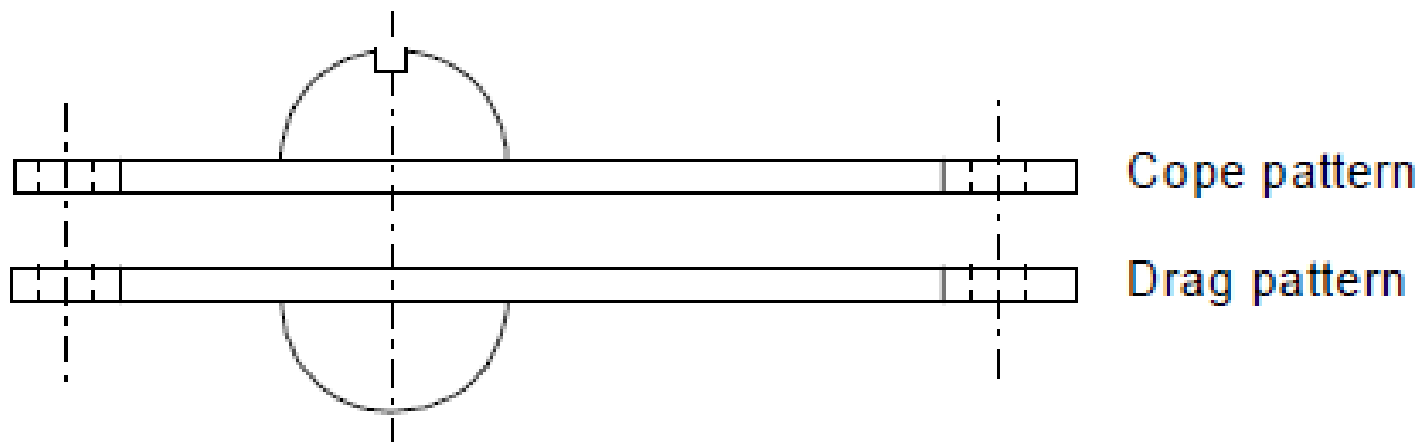
- When solid pattern is difficult for withdrawal from the mold cavity, then solid pattern is **split** in two parts. Split pattern is made in two pieces which are joined at the parting line by means of dowel pins. The splitting at the parting line is done to facilitate the withdrawal of the pattern. A typical example is shown in here below.



Two piece pattern

3.Cope and drag pattern

- In this case, cope and drag part of the mould are prepared separately. This is done when the complete mould is too heavy to be handled by one operator. The pattern is made up of two halves, which are mounted on different plates. A typical example of match plate pattern is shown here below.



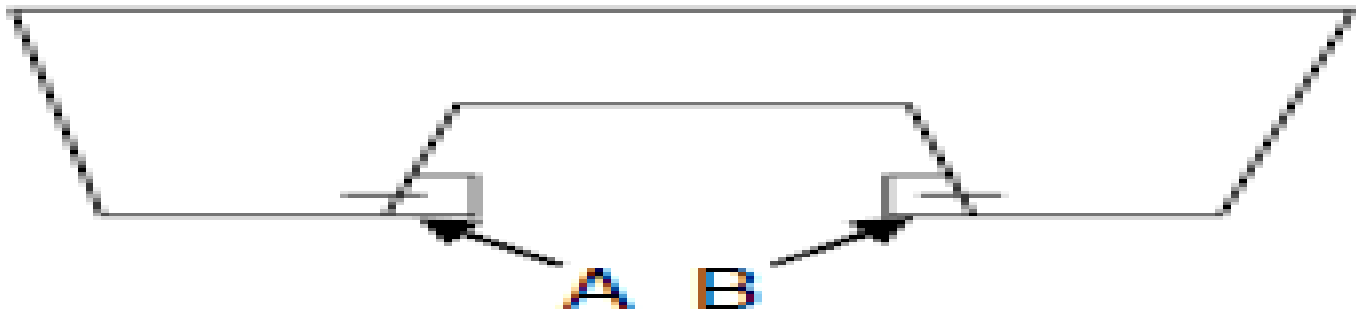
Cope and drag pattern

4.Three-piece or multiple pattern

Some patterns are of complicated kind in shape and hence can not be made in one or two pieces because of difficulty in withdrawing the pattern. Therefore these patterns are made in either three pieces or in multi-pieces. Multi molding flasks are needed to make mold from these patterns.

5. Loose-piece pattern

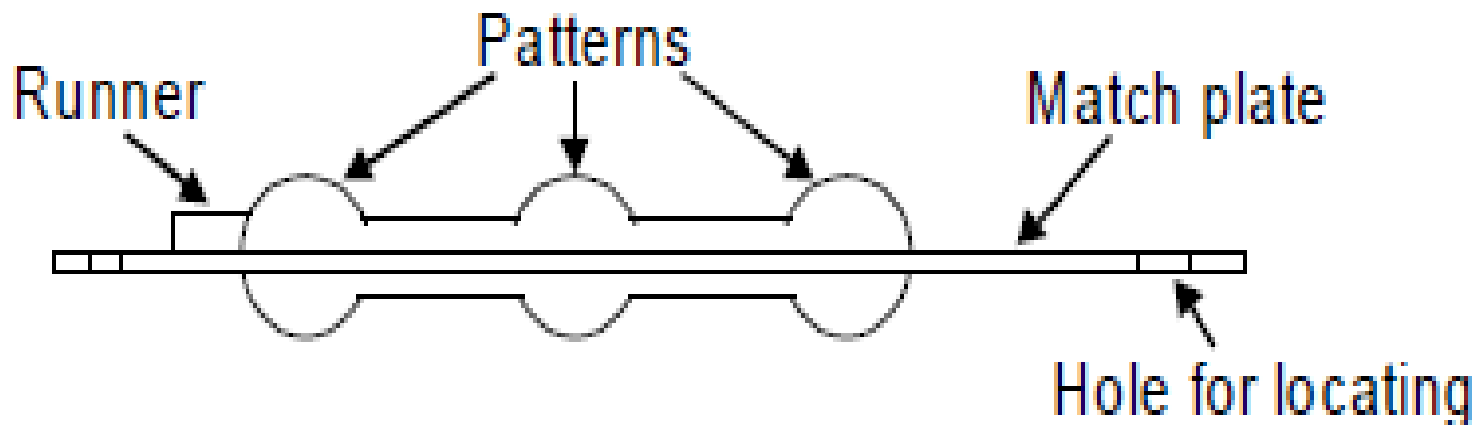
Loose piece pattern Fig below is used when pattern is difficult for with drawl from the mould. Loose pieces are provided on the pattern and they are the part of pattern. The main pattern is removed first leaving the loose piece portion of the pattern in the mould. Finally the loose piece is withdrawal separately leaving the intricate mould.



Loose piece pattern

6.Match plate pattern

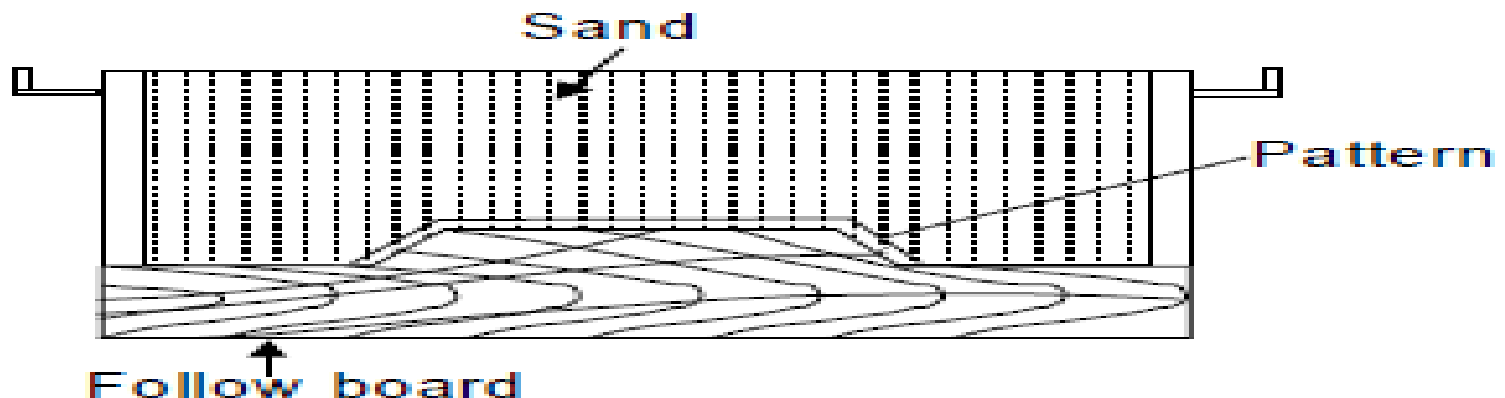
This pattern is made in two halves and is mounted on the opposite sides of a wooden or metallic plate, known as match plate. The gates and runners are also attached to the plate. This pattern is used in machine molding. A typical example of match plate pattern is shown below.



Match plate pattern

7. Follow board pattern

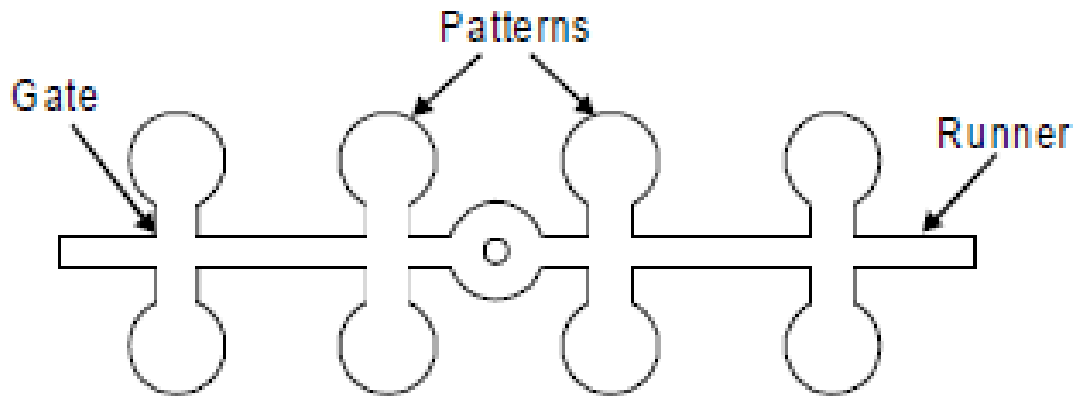
When the use of solid or split patterns becomes difficult, a contour corresponding to the exact shape of one half of the pattern is made in a wooden board, which is called a follow board and it acts as a molding board for the first molding operation as shown in Fig below.



Follow board pattern look like above drawing

8.Gated pattern

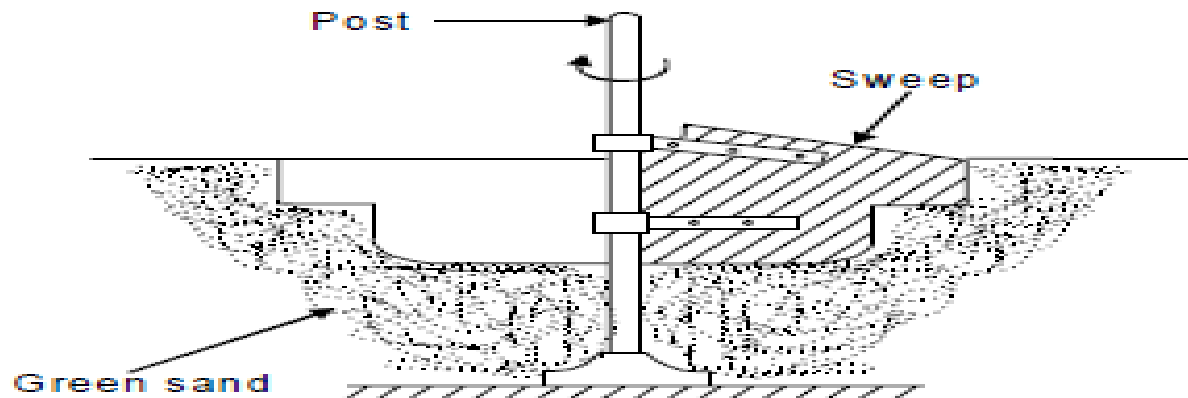
In the mass production of casings, multi cavity moulds are used. Such moulds are formed by joining a number of patterns and gates and providing a common runner for the molten metal, as shown in Figure below. These patterns are made of metals, and metallic pieces to form gates and runners are attached to the pattern.



Gated pattern look like above figure

9.Sweep pattern

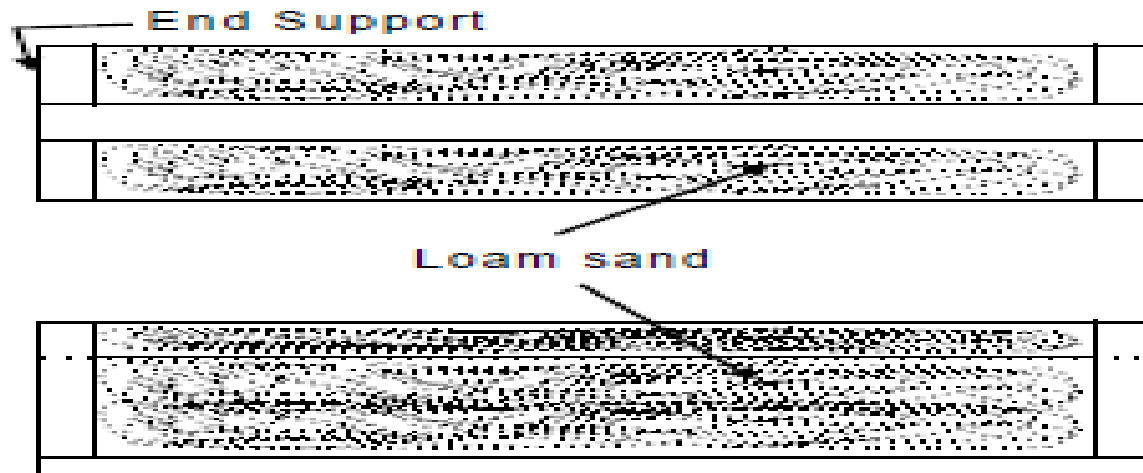
Sweep patterns are used for forming large circular moulds of symmetric kind by revolving a sweep attached to a spindle as shown below. Actually a sweep is a template of wood or metal and is attached to the spindle at one edge and the other edge has a contour depending upon the desired shape of the mould. The pivot end is attached to a stake of metal in the center of the mould.



Sweep pattern look like above figure

10.Skeleton pattern

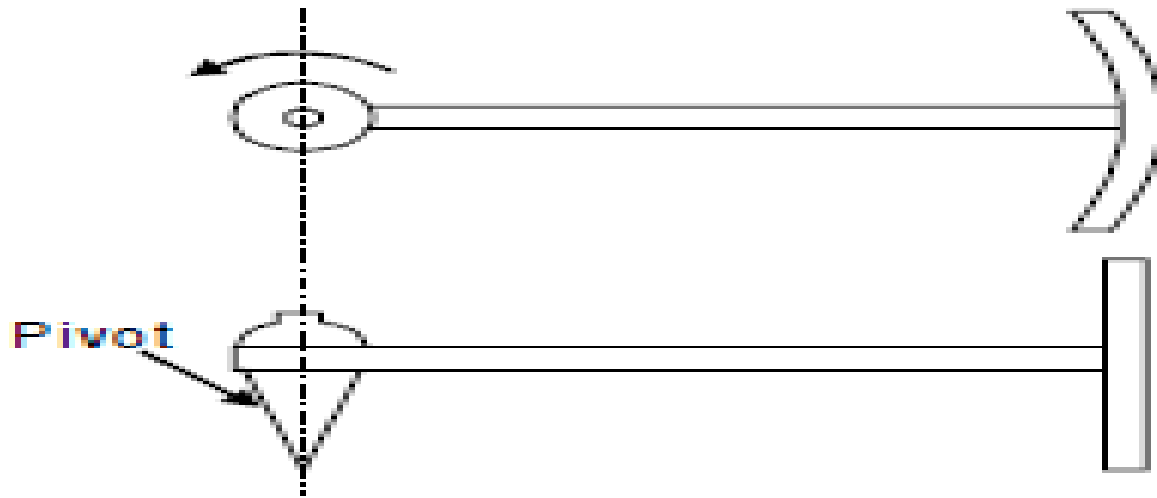
- When only a small number of large and heavy castings are to be made, it is not economical to make a solid pattern. In such cases, however, a skeleton pattern may be used. This is a ribbed construction of wood which forms an outline of the pattern to be made. This framework work is filled with loam sand and rammed. The surplus sand is removed by stickle board.



Skeleton pattern look like above figure

11.Segmental pattern

Patterns of this type are generally used for circular castings, for example wheel rim, gear blank etc. Such patterns are sections of a pattern so arranged as to form a complete mould by being moved to form each section of the mould. The movement of segmental pattern is guided by the use of a central pivot.



Segmental pattern look like above figure

Pattern allowances

1. Shrinkage Allowance
2. Machining Allowance
3. Draft or Taper Allowance
4. Rapping or Shake Allowance
5. Distortion Allowance
6. Mold wall Movement Allowance

The general tools and equipment used in the pattern making shop are given as under

1. Measuring and Layout Tools

look here for Example ;- Wooden or steel scale or rule
Dividers ,Calipers ,Try square ,Caliper rule ,Flexible rule ,Marking gauge ,T-bevel, Combination square.

2. Sawing Tools

look here for Example ;- Compass saw ,Rip saw ,Coping saw, Dovetail saw ,Back saw ,Panel saw ,Miter saw

3. Planning Tools

Jack plane Circular plane Router plane Rabbet plane
Block plane Bench plane , Core box plane

4. Boring Tools

Hand operated drills, Machine operated drills,
Twist drill, Countersunk Brace Auger bit,. Bit
gauge

5. Clamping Tools

Bench vice , C-clamp, Bar clamp, Hand screw,
Pattern maker's vice, Pinch dog

6. Miscellaneous Tools

Screw Driver, Various types of hammers, Chisel,
Rasp, File, Nail set, Screw driver, Bradawl,
Brad pusher, Cornering tool

Design consideration in pattern making

1. All Abrupt changes in section of the pattern should be avoided as far as possible.
2. Parting line should be selected carefully, so as to allow as small portion of the pattern as far as possible in the cope area
3. The thickness and section of the pattern should be kept as uniform as possible.
4. Sharp corners and edges should be supported by suitable fillets or otherwise rounded of.
5. Surfaces of the casting which are specifically required to be perfectly sound and clean should be so designed that they will be molded in the drag because the possible defects due to lose sand and inclusions will occur in the cope.

3.4 Molding sand Properties

1. **Composition**
2. **Particle size distribution**
3. **Surface Texture**
4. **Roundness and Sphericity**

1.Composition

While sand typically is made up of Quartz (SiO_2) it can in fact be composed of almost any mineral or combination of minerals or even sand sized fragments of rocks

2.Particle Size and Distribution

The source rock and weathering and transportation history of a sand usually results in a particle size distribution that can be characteristic of a sample

3.Surface Texture

The surface of a sand grain can vary between being smooth to frosted Smooth surface indicates chemical reaction Frosted surface indicates wind action

4.Roundness and Sphericity

- Sand is ubiquitous. It makes up most beach and river deposits
- Sand is concentrated by selective transport
- Sand is left at beaches as the finer clay particles are washed out to sea
- A medium sized river takes about a million years to transport a sand grain 100 miles downstream
- Transport does not do much to change the roundness and sphericity of the sand grains

3.5Core sand element of gating systems

- Introduction
- Functions of gating systems
- Elements of gating systems
- Classifications of gating systems
- Controlling factors in gating system
- Surface tension controlled filling in gating systems

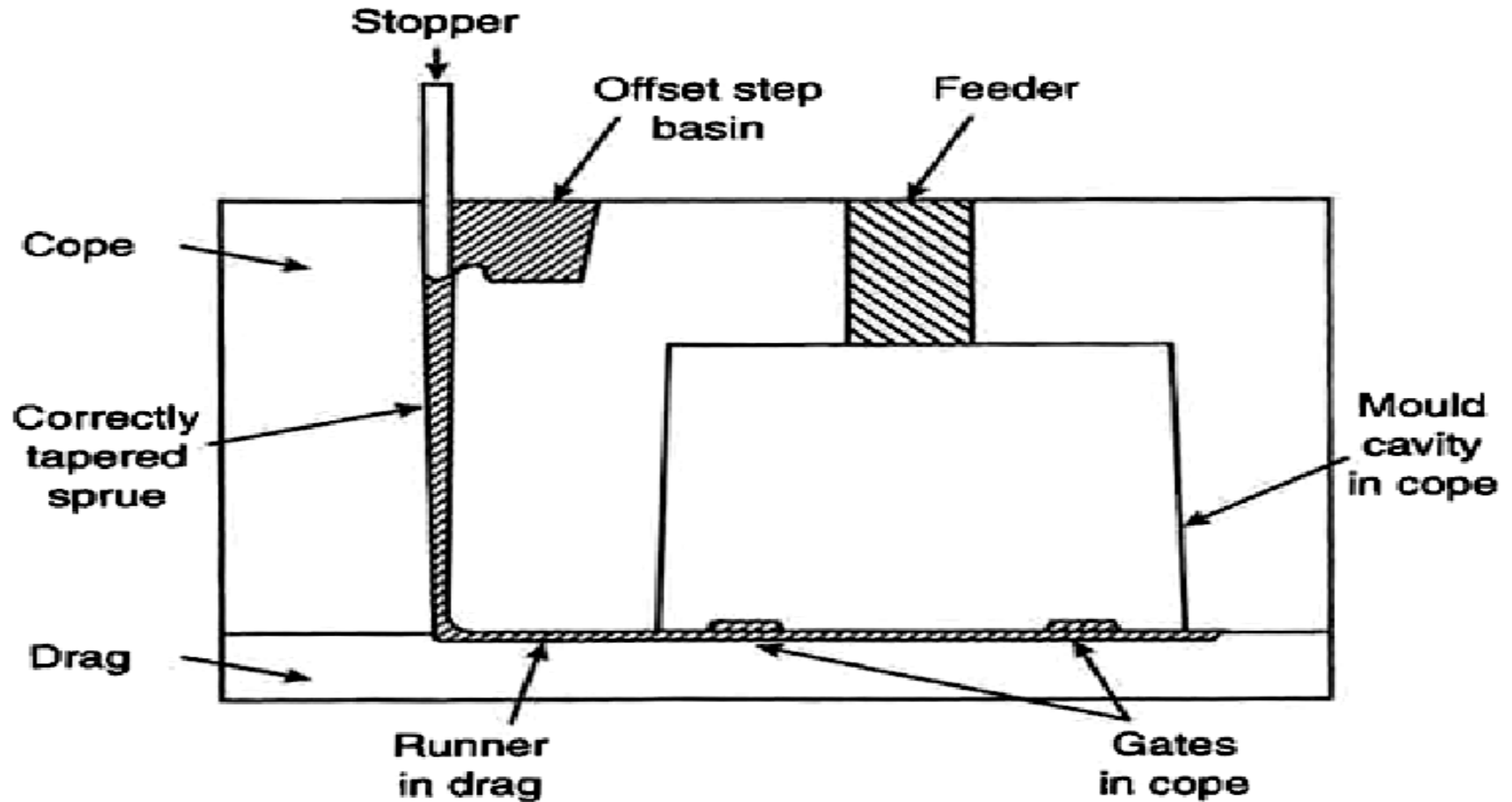
Introduction gating systems

- Getting the liquid metal out of crucible and into the mould cavity is a critical step
- Recent work observing the liquid metal as it travel through the filing system indicates that most of the damage is done to castings by poor filling system design
- The series of funnels, pipes and channels used to guide liquid metal from the ladle into the mould cavity is known as the gating system or the running system Leaving its design to chance or even to the patternmaker is a risk not to be recommended

Functions of gating systems

1. Economy of size
2. The filling of mould at the required speed for most castings, this roughly equals 0.5 m/s
3. The delivery of only liquid metal into the mould cavity no other phases such as slag, oxide, sand, air or other gases
4. The elimination of surface turbulence
5. Establish proper temperature gradient
6. Ease of removal

Elements of gating systems

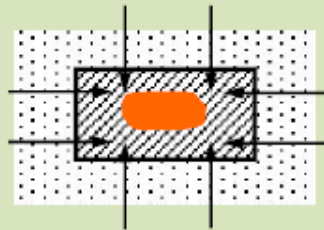


Additional Features of gating system

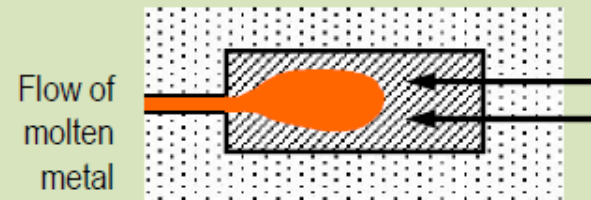
- Core
- Riser or feeder
- Skim core, strainer, delay screen, sprue plug
- Filter, dross trap

Progressive and directional solidification

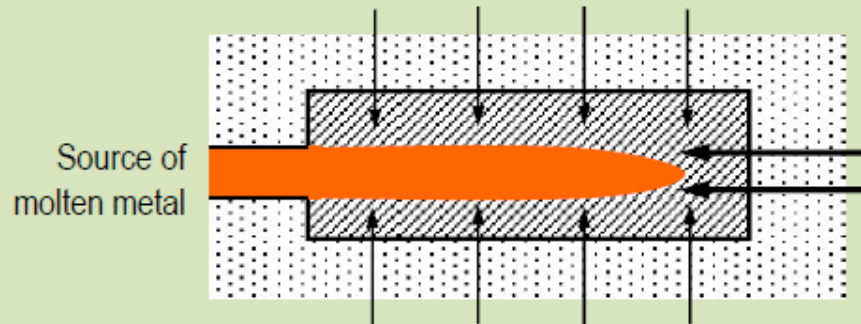
Progressive vs. directional solidification



progressive solidification



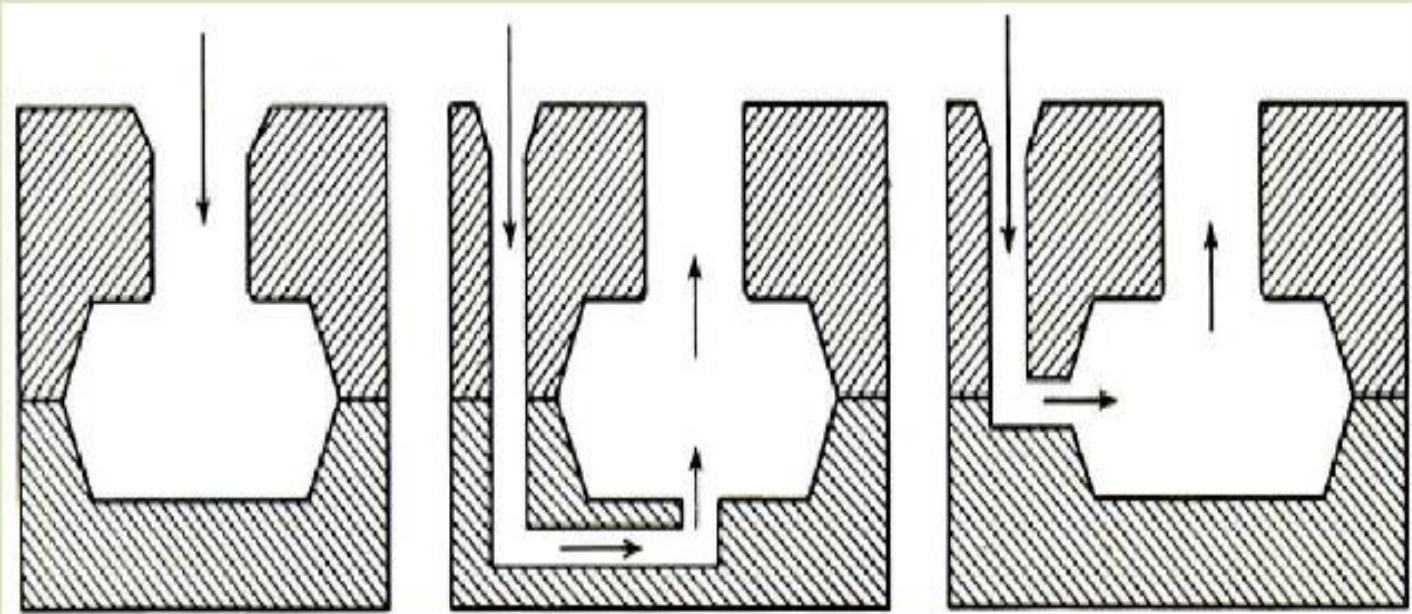
directional solidification



combination of progressive and directional solidifications

Classifications of gating systems

1. Top Pouring vs. Bottom Pouring Systems



(a) Top pouring system, (b) Bottom pouring system, (c) Side pouring system

Top pouring and bottom pouring

Top pouring

Faster pouring rate,
less fluidity requirement

Severe splashing and mould
erosion

Oxidation of liquid metal
resulted

Favourable temperature
gradient

Bottom pouring

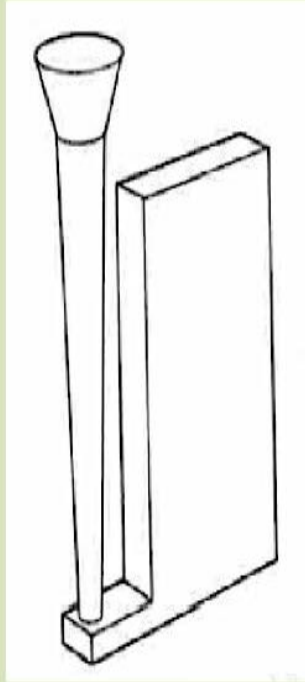
Filling against gravity,
quiet entry to mould cavity

Elimination of splashing
and mould erosion

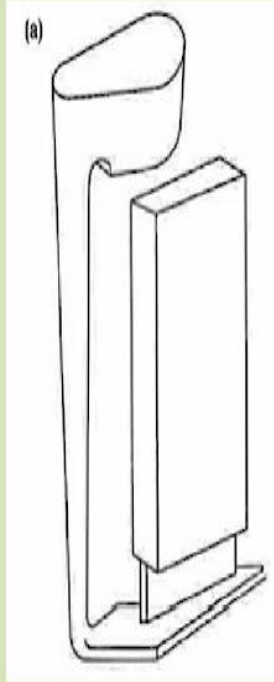
Less turbulence,
less oxide formation

Unfavourable temperature
gradient

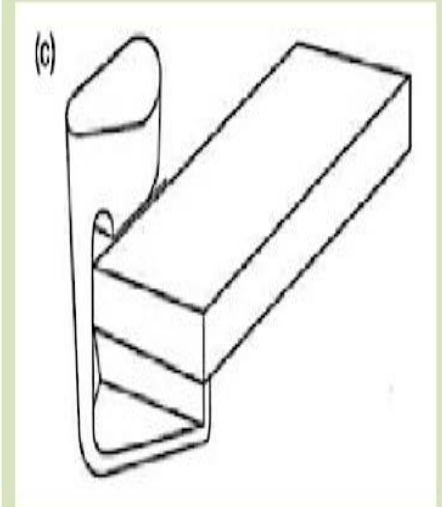
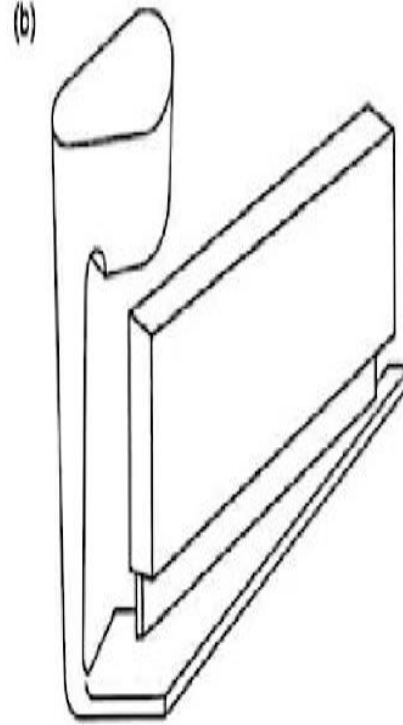
Top pouring and bottom pouring



a poor bottom-gated filling system
because of direct entry of high velocity
liquid into the mould cavity



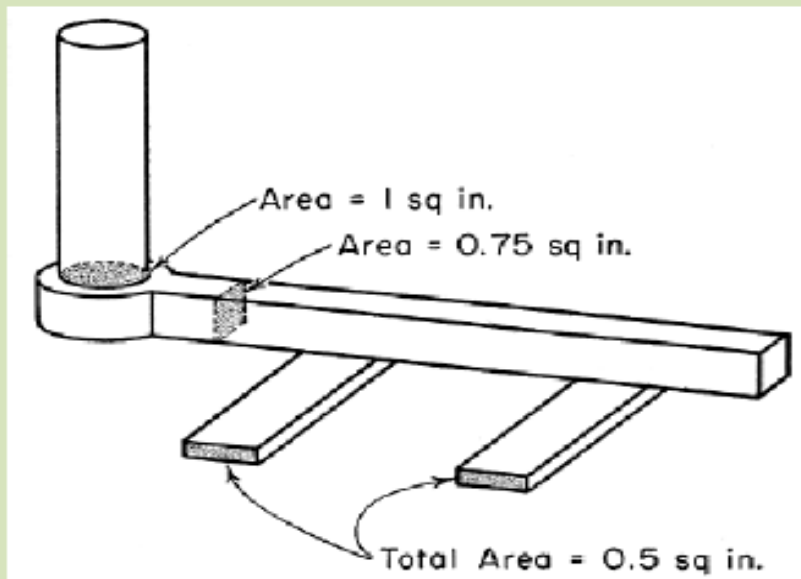
(a) an improved version of the previous
bottom-gated filling system



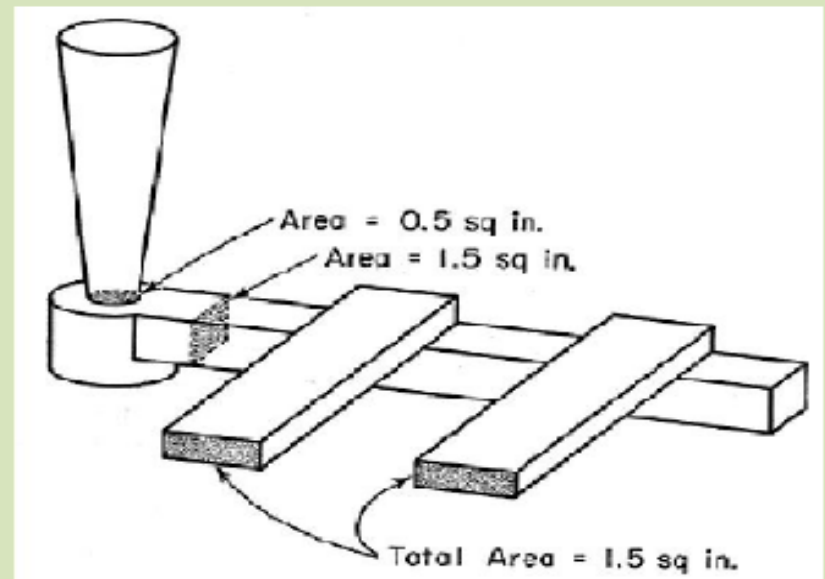
further improvements of the previous bottom-gated filling system by height reduction

2. pressurized system and unpressurised system

2. Pressurized vs. Unpressurized Systems



pressurised system



unpressurised system

D/nc pressurized system and unpressurised system

Pressurised system	Unpressurised system
Gate is used as choke	Sprue base is used as choke
Velocity increases as the liquid flows from sprue to runner to gate	Velocity decreases as liquid flows from sprue to runner to gate
Turbulence resulted	Turbulence minimised
Gating system is kept full due to back pressure	Careful design is required to keep gating system full
Velocity in each of multiple gates (of equal area) is equal	Obtaining equal flow in multiple gates is difficult
Volume of gating system is smaller producing high casting yield	High volume of gating system producing low casting yield

Controlling factors gating system

1. Type of gating system
 - (top / bottom pouring, pressurized / unpressurised system)
1. Pouring temperature (fluidity of metal)
2. Type of pouring equipment
 - (ladle / pouring cup / pouring basin)
1. Rate of pouring
2. Size and type of runner and sprue
3. Size, number and location of ingates

3.6 casting design

Introduction to casting design

- Successful casting practice requires the proper control of a large number of variables: characteristics of the metals (or alloys) casts, method of casting, mold/die materials, mold/die design, and various process parameters.
- The **flow** of the molten metal in the mold cavities, the **gating** systems, the **rate** of cooling, and the **gases** evolved all influence the quality of a casting.
- This chapter describes general design considerations and guidelines for metal casting and presents suggestions for avoiding defects.

Design Considerations in Casting

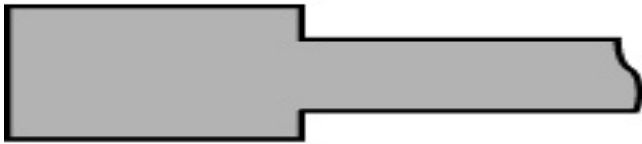
1. Design the part so that the shape is cast easily.
2. Select a casting process and material suitable for the part, size, mechanical properties, etc.
3. Locate the parting line of the mold in the part.
4. Locate and design the gates to allow uniform feeding of the mold cavity with molten metal.
5. Select an appropriate runner geometry for the system.
6. Locate mold features such as sprue, screens and risers, as appropriate.
7. Make sure proper controls and good practices are in place.

Design Considerations in Casting - Design of cast parts

- **Corners, angles and section thickness**: avoid using sharp corners and angles (act as stress raisers) and may cause cracking and tearing during solidification. Use fillets with radii ranging from 3 to 25 mm

Design Considerations in Casting - Design of cast parts

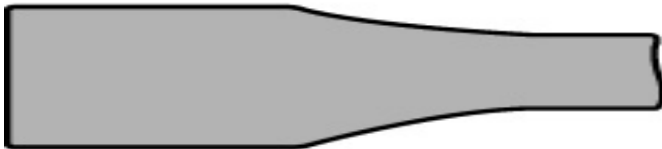
(a)



(b)



Poor



Good

Figure That illustrate above suggested design modifications to avoid defects in castings. Note that sharp corners are avoided to reduce stress concentrations.

Design Considerations in Casting - Design of cast parts

- Sections changes in castings should be blended smoothly into each other. Location of the largest circle that can be inscribed in a particular region is critical so far as shrinkage cavities are concerned (a & b). Because the cooling rate in regions with large circles is lower, they are **called hot spots**. These regions can develop shrinkage cavities and porosity (c & d).
- Cavities at hot spots can be eliminated by using small cores (e). It is important to maintain (as much as possible) uniform cross sections and wall thicknesses throughout the casting to avoid or minimize shrinkage cavities. Metal chills in the mold can eliminate or minimize hot spots.

Design Considerations in Casting - Design of cast parts

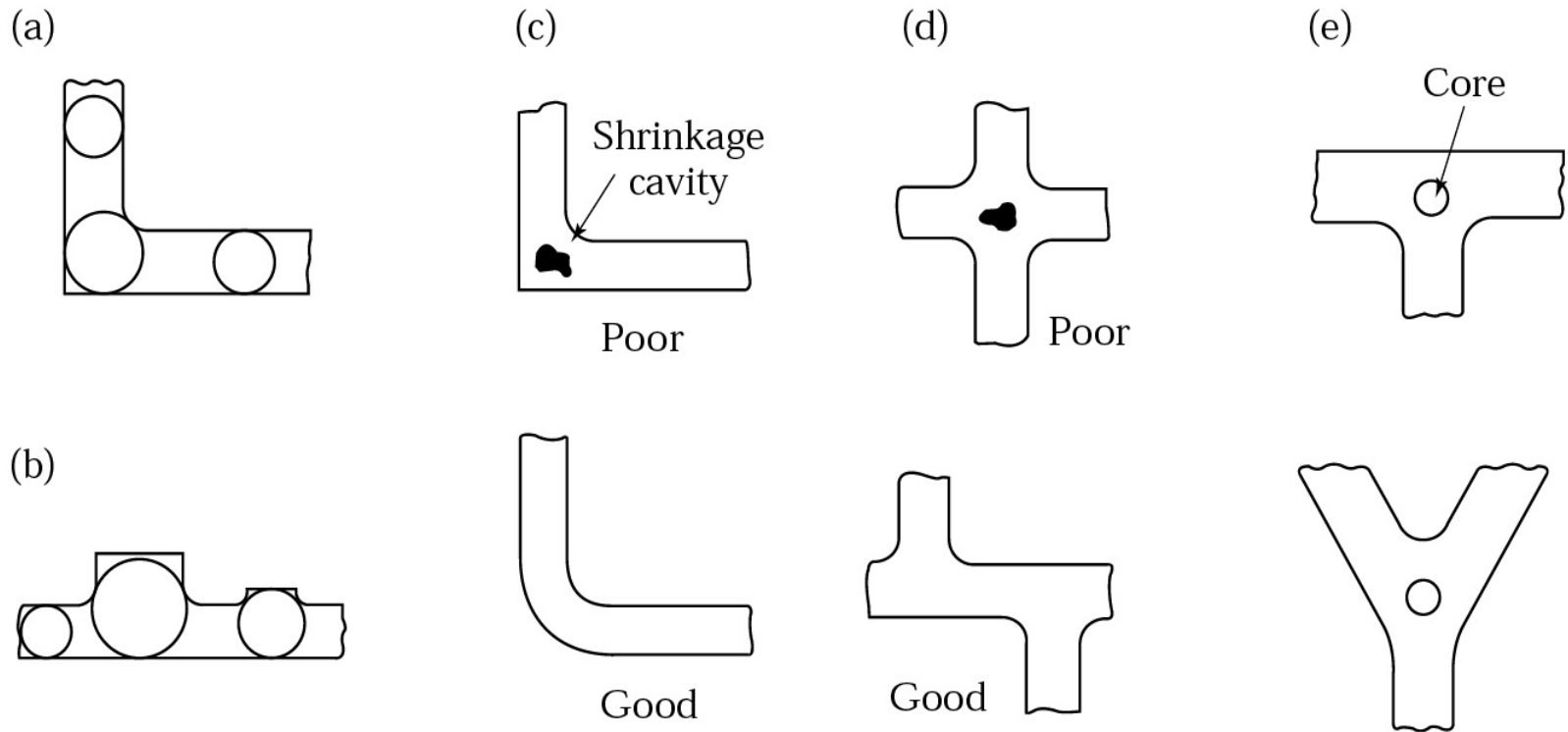


Figure That illustrate above suggested of designs showing the importance of maintaining uniform cross-sections in castings to avoid hot spots and shrinkage cavities.

Elimination of Hot Spots

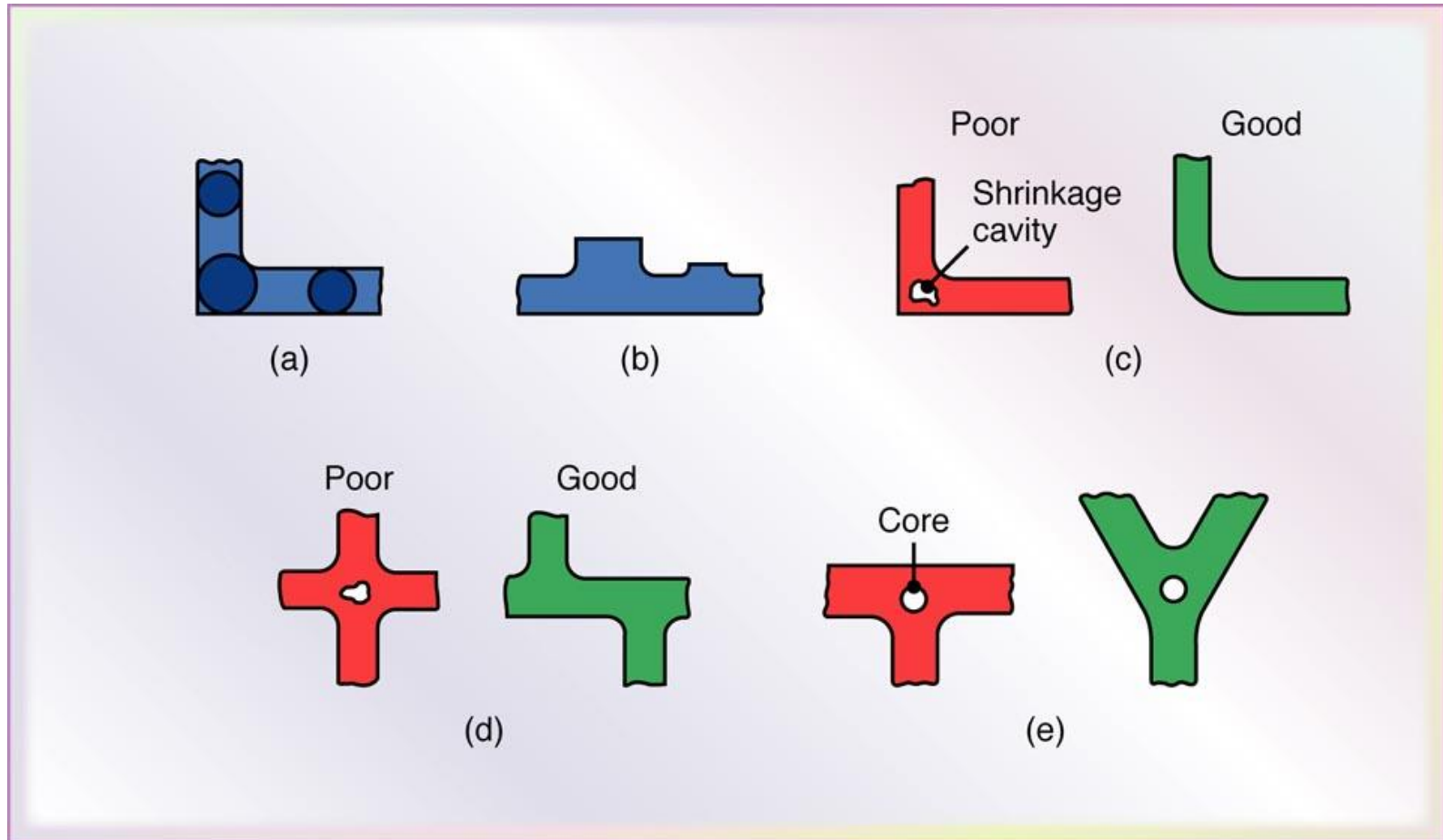


Figure above that designs showing the importance of maintaining uniform cross-sections in castings to avoid hot spots and shrinkage cavities.

Design Considerations in Casting - Design of cast parts

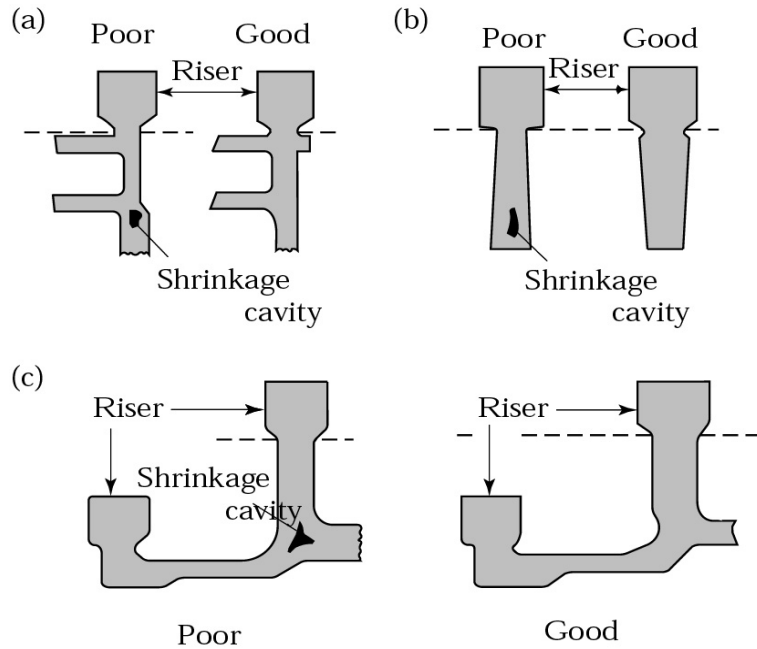


Figure 1 Examples of design modifications to avoid shrinkage cavities in castings.

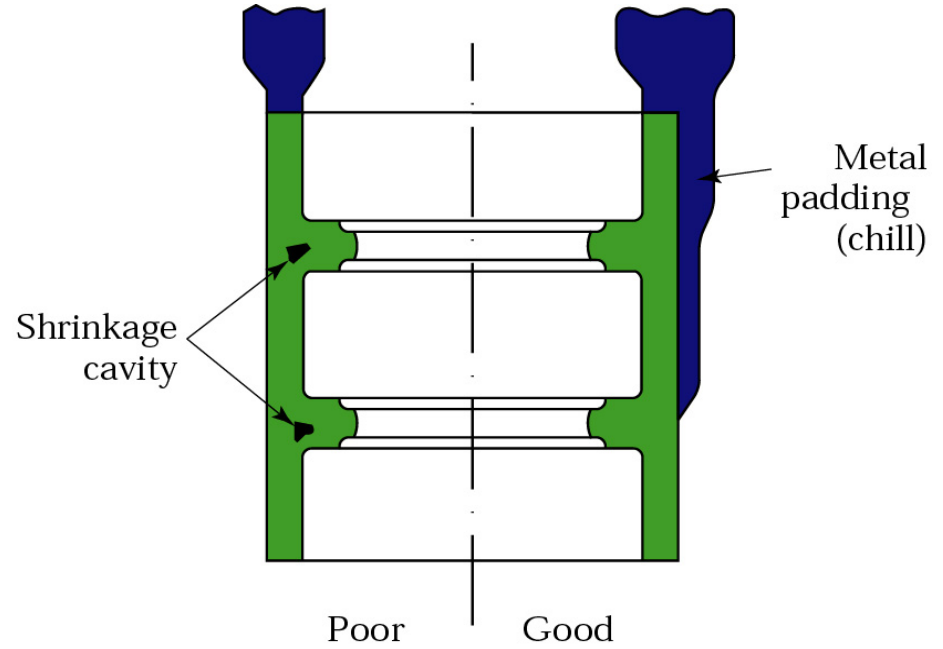


Figure 2 The use of metal padding (chills) to increase the rate of cooling in thick regions in a casting to avoid shrinkage cavities

Design Considerations in Casting - Design of cast parts

- **Flat areas**: large flat areas (plain surfaces) should be avoided, since they may warp during cooling because of temperature gradients, or they develop poor surface finish because of uneven flow of metal during pouring.

Note;-To resolve this one can break up flat surfaces with staggered ribs.

- **Shrinkage**: pattern dimensions also should allow for shrinkage of the metal during solidification and cooling.
- Allowances for shrinkage, known as **patternmaker's shrinkage** allowances, usually range from about 10 to 20 mm/m..

Design Considerations in Casting - Design of cast parts

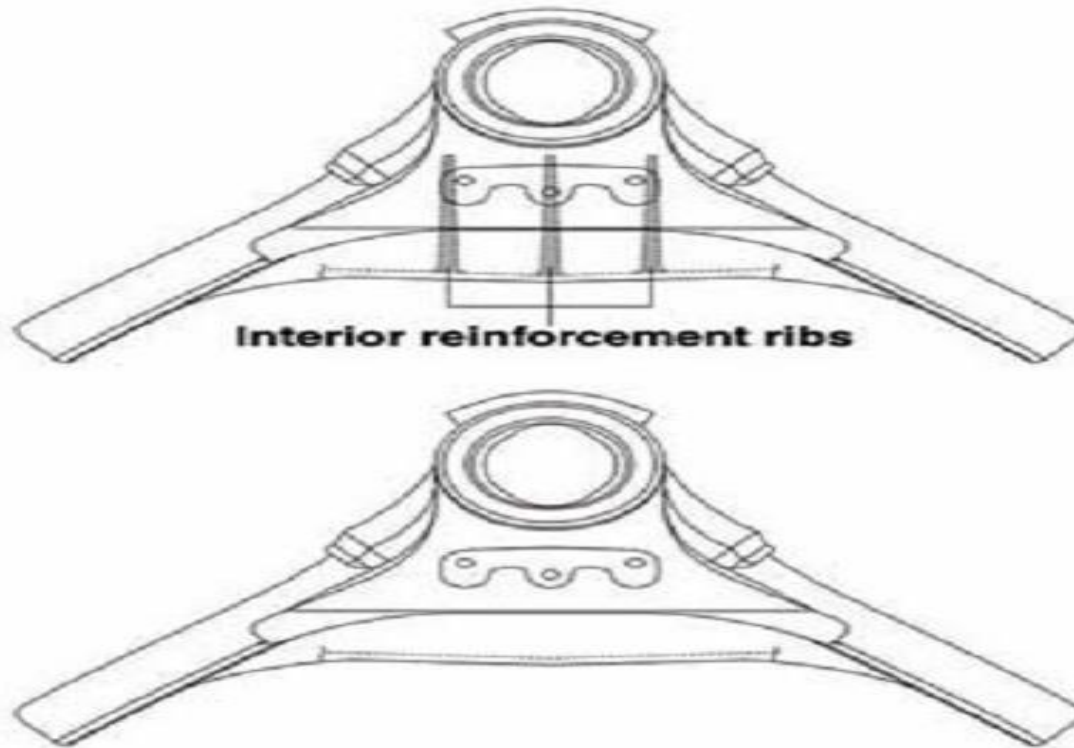


Figure: Adding ribs to flat region decreases warping and increases stiffness against bending moments

Design Considerations in Casting - Design of cast parts

- **Draft**: a small draft (taper) typically is provided in sand mold pattern to enable removal of the pattern without damaging the mold. Drafts generally range from 5 to 15 mm/m. Depending on the quality of the pattern, draft angles usually range from 0.5° to 2° .
- **Dimensional tolerances**: tolerances should be as wide as possible, within the limits of good part performance; otherwise, the cost of the casting increases. In commercial practices, tolerances are usually in the range of ± 0.8 mm for small castings. For large castings, tolerances may be as much as ± 6 mm.

Design Considerations in Casting - Design of cast parts

- **Lettering and markings**: it is common practice to include some form of part identification (such as lettering or corporate logos) in castings. These features can be sunk into the casting or protrude from the surface.
- **Machining and finishing operations**: should be taken into account. For example, a hole to be drilled should be on a flat surface not a curved one. Better yet, should incorporate a small dimple as a starting point. Features to be used for clamping when machining.

Design Considerations in Casting - Locating the parting line

- A part should be oriented in a mold so that the large portion of the casting is relatively low and the height of the casting is minimized.
- The parting line is line or plane separating the upper (cope) and lower (drag) halves of mold. In general, the parting line should **be along a flat plane** rather than be contoured.
- The parting line should be placed as low as possible relative to the casting for less dense metal (such as aluminum alloys) and located at around mid-height for denser metals (such as steels).

Design Considerations in Casting - Locating the parting line

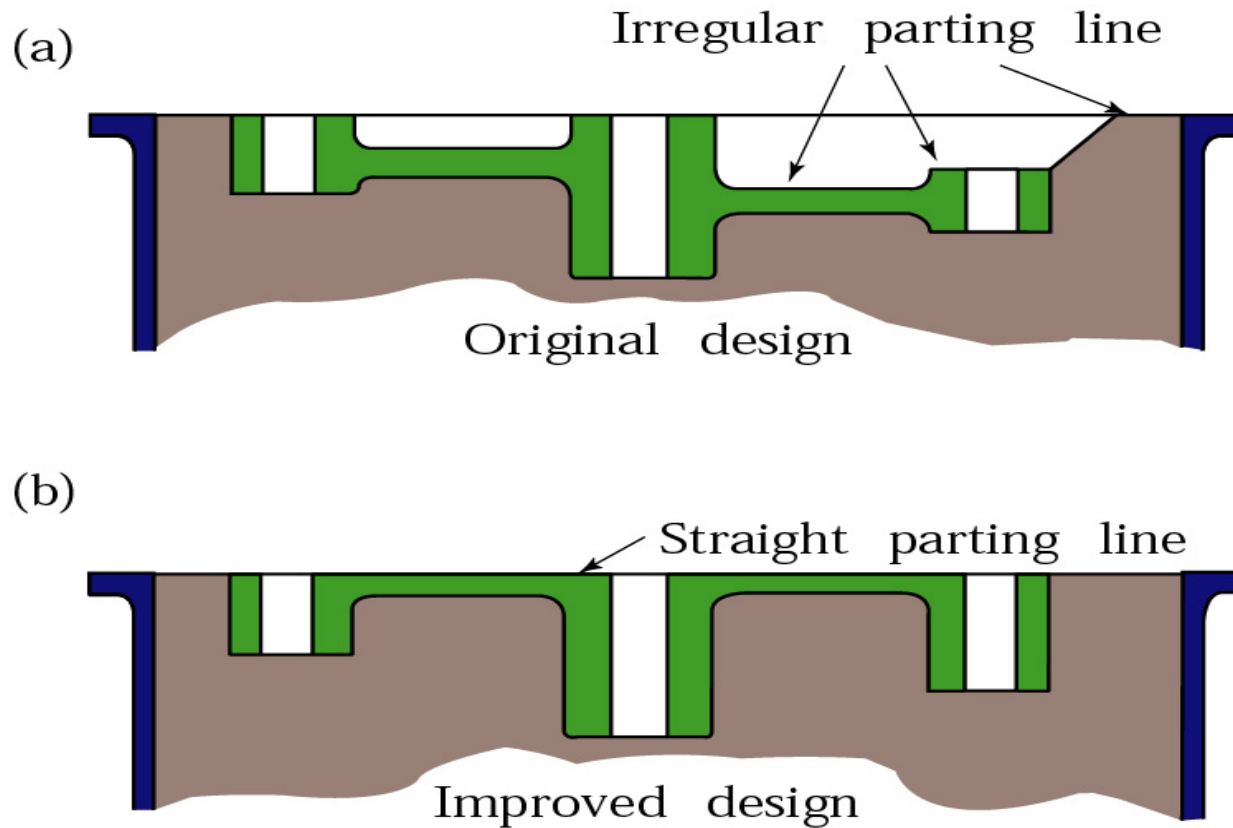


Figure 12.5 Redesign of a casting by making the parting line straight to avoid defects.

Design Considerations in Casting - Locating and designing gates

- The gates are connections between the runners and the part cavity. Some of the considerations in designing gating systems are:
- Multiple gates often are preferable and are necessary for large parts.
- Gates should feed into thick sections of castings.
- A fillet should be used where a gate meets a casting; this feature produces less turbulence than abrupt junctions.
- The gate closest to the Sprue should be placed sufficiently far away so that the gate can be easily removed. This distance may be as small as a few mm for small casting and up to 500 mm for large parts.

Design Considerations in Casting - Locating and designing gates

- The minimum gate length should be three to five times the gate diameter, depending on the metal being cast. The cross-section should be large enough to allow the filling of the mold cavity and should be smaller than the runner cross-section.
- Curved gates should be avoided, but when necessary, a straight section in the gate should be located immediately adjacent to the casting.

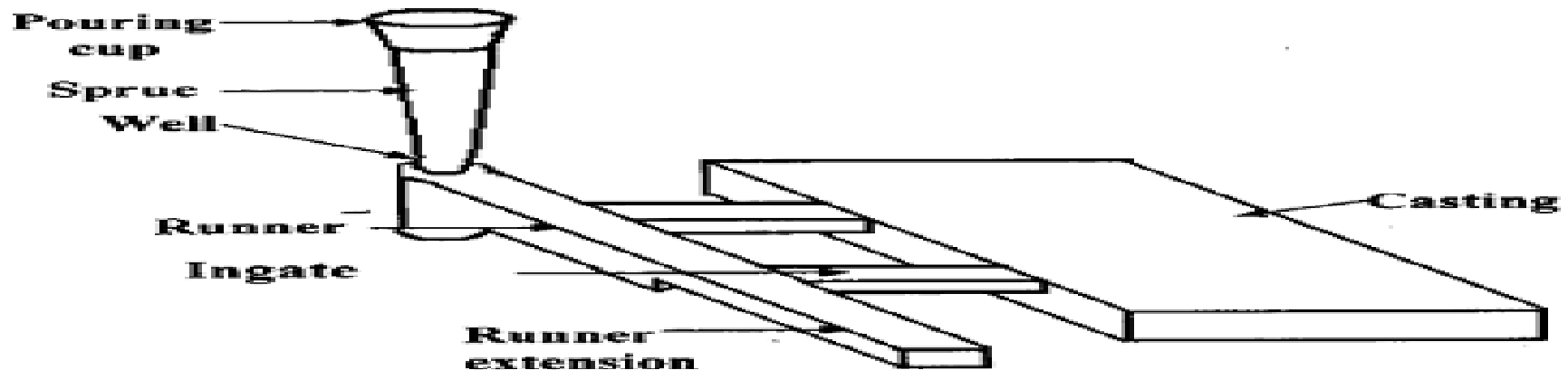


Figure 1: Gating system

Design Considerations in Casting - Runner design

- The runner is a horizontal distribution channel that accepts the molten metal from the Sprue and delivers it to the gates.
- One runner is used for simple parts, but two runner systems can be specified for more complicated castings.
- The runners are used to trap dross (dross is a mixture of oxide and metal and forms on the surface of the metal) and keep it from entering the gates and the mold cavity.
- Commonly, dross traps are placed at the ends of the runners, and the runner projects above the gates to ensure that the metal in the gates is trapped below the surface.

Design Considerations in Casting - Designing other mold features

- The main goal in designing a Sprue is to achieve the required metal flow rates while preventing excessive dross formation.
- Flow rates are determined such that **turbulence is avoided**, but the **mold is filled quickly compared to the solidification time required**.
- A pouring basin can be used to ensure that **the metal flow into the Sprue is uninterrupted**; also, if the molten metal is maintained in the pouring basin during pouring, then the dross will float and will not enter the mold cavity.
- **Filters** are used to trap large contaminants and to slow metal velocity and make the flow more laminar.
- **Chills** can be used to speed solidification of the metal in a particular region of a casting.

Design Considerations in Casting - Establishing good practices

Some **quality control** procedures are necessary:

- Starting with a **high-quality molten** metal is essential for producing superior castings. Pouring temperature, metal chemistry, gas entrainment, and handling procedures all can affect the quality of the metal being poured into a mold.
- The pouring of the metal should **not be interrupted**, since it can lead to dross entrainment and turbulence.
- The different cooling rates within the body of a casting cause residual stresses. Stress relieving, thus may necessary to avoid distortions of castings in critical applications.

Design for expendable-mold casting

A.Mold layout.

- One of the most important goals in mold layout is to have solidification initiate at one end of the mold and progress in a uniform front across the casting with ***risers solidifying last***.
- Traditionally, this depends on experience and consideration of fluid flow and heat transfer.
- More recently, commercial computer programs based on finite-difference algorithms have become available.

Design for expendable-mold casting

B. Riser design.

Risers (size and location) are extremely useful in affecting-front progression across a casting and are essential feature in the mold layout. ***Blind risers*** are good design features and maintain heat longer than open risers.

Risers are designed according to six basic rules:

1. The riser **must not solidify** before the casting.
2. The riser volume must be **large enough** to provide a sufficient amount of liquid metal to **compensate for shrinkage** in the cavity.

Design for expendable-mold casting- Riser design

- Risers are designed according to six basic rules:
3. Junctions between casting and feeder should not develop a hot spot where shrinkage porosity can occur.
 4. Risers must be placed so that the liquid metal can be delivered to locations where it is **most needed**.
 5. There must be **sufficient pressure** to drive the liquid metal into locations in the mold where it is most needed.
 6. The pressure head from the riser should **suppress** cavity formation and encourage complete cavity filling.

Design for expendable-mold casting

C. Machining allowance

- Machining allowances, which are included in pattern dimensions, depend on the type of casting and increase with size and thickness of the casting.
- Allowances usually range from about **2 to 5 mm** for small castings to more than **25 mm** for large castings.

Design for permanent-mold casting

Poor and good designs in permanent-Mold and Die casting

- a. Lower portion of the design has a thin wall which may fracture under high forces. The good design eliminates this problem and also may simplify die and mold manufacturing.
- b. Large flat surfaces may warp and develop uneven surfaces. We may break up the surfaces with ribs and serrations (dents) on the reverse side of the casting.
- c. It is difficult to produce sharp internal radii or corners. Placement of a small radius at the corners at the bottom of the part
- d. This part may represent a knob to be gripped and rotated. The casting die for the good design is easier to manufacture.
- e. Poor design has sharp fillets. Good design prevents the die edges from chipping off.
- f. The poor design has threads reaching the right face of the casting. The good design uses an offset on the threaded rod, eliminating this problem.

Examples of Good and Poor Designs

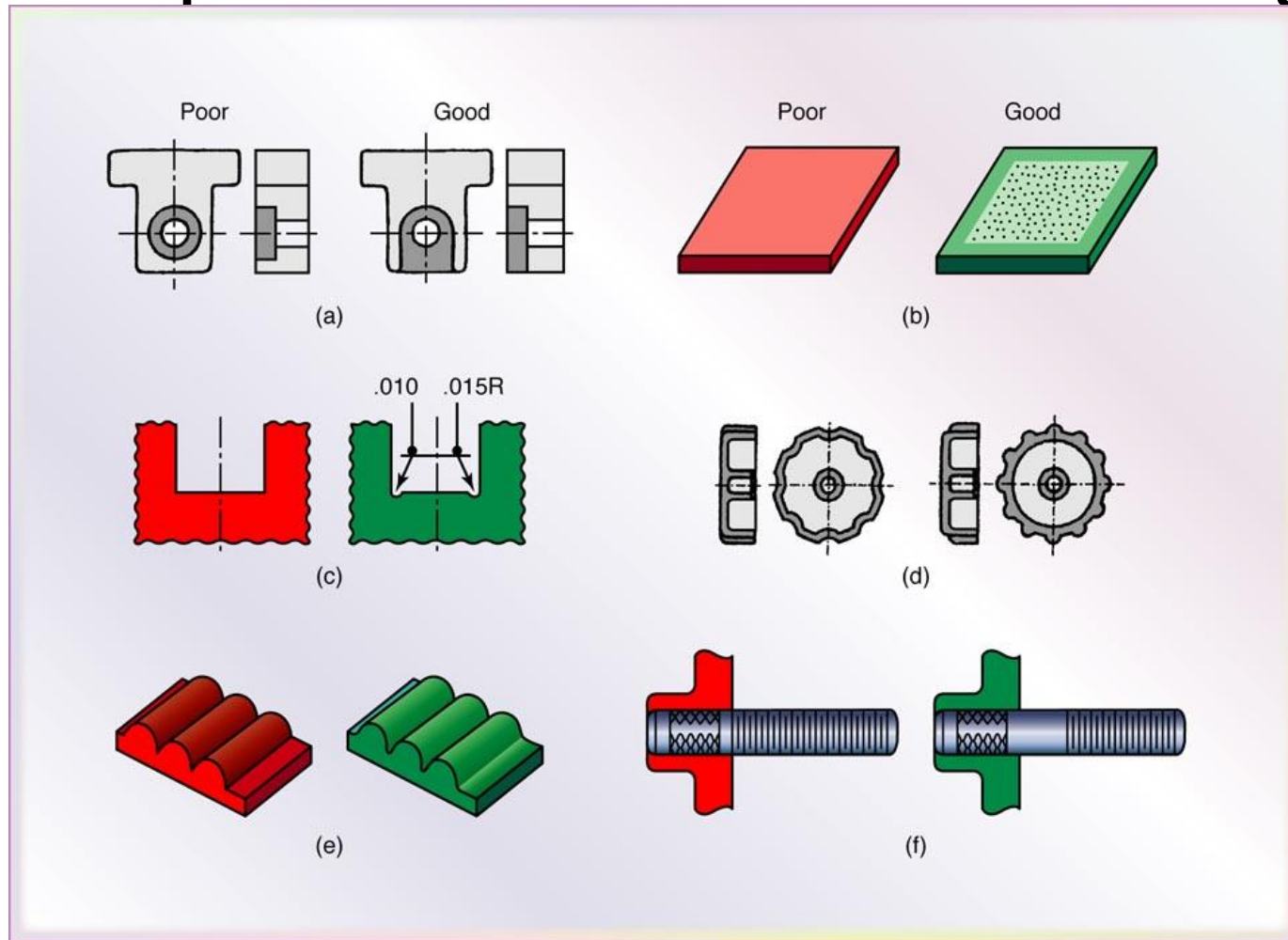


Figure that already show is Examples of undesirable (poor) and desirable (good) casting designs

Computer modeling of casting processes

- Rapid advances in computers and modeling analysis led innovations in **modeling** different aspects of casting including: fluid flow, heat transfer, and microstructures developed during solidification; under various casting-process conditions.
- **Specifically, software may provide:**
 - Modeling fluid flow in molds (Bernoulli's and continuity). Predict velocity and pressure of the molten metal in the gating system all the way into the mold cavity.
 - Modeling of heat transfer in casting.
 - Fluid flow and heat transfer (with surface conditions, thermal properties of materials) are coupled.
 - Modeling the development of microstructure in casting.

Computer modeling of casting processes

The benefits of such user-friendly software are to increase productivity, improve quality, and easily plan and estimate cost. Also quicker response to design changes.

Several commercial software programs now are available for modeling of casting processes:

1. Magma soft,
2. Precast,
3. Solidia, and
4. AFSsolid.

Casting Applications and Characteristics

TABLE 12.2

Typical Applications for Castings and Casting Characteristics

Type of alloy	Typical applications	Castability*	Weldability*	Machinability*
Aluminum	Pistons, clutch housings, intake manifolds	E	F	G-E
Copper	Pumps, valves, gear blanks, marine propellers	F-G	F	F-G
Ductile iron	Crankshafts, heavy-duty gears	G	D	G
Gray iron	Engine blocks, gears, brake disks and drums, machine bases	E	D	G
Magnesium	Crankcase, transmission housings	G-E	G	E
Malleable iron	Farm and construction machinery, heavy-duty bearings, railroad rolling stock	G	D	G
Nickel	Gas turbine blades, pump and valve components for chemical plants	F	F	F
Steel (carbon and low-alloy)	Die blocks, heavy-duty gear blanks, aircraft undercarriage members, railroad wheels	F	E	F
Steel (high-alloy)	Gas-turbine housings, pump and valve components, rock-crusher jaws	F	E	F
White iron	Mill liners, shot-blasting nozzles, railroad brake shoes, crushers, and pulverizers	G	VP	VP
Zinc	Door handles, radiator grills	E	D	E

*E = excellent; G = good; F = fair; VP = very poor; D = difficult.

Editor, by George Kalpakjian and Steven E.

Schmid.

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Economics of Casting

- The cost of the cast part (unit cost) depends on several factors: including materials, tooling, equipment, and labor.
- Preparations for casting a product include the production of molds and dies that require raw materials, time, and effort – all of which also influence product cost.
- Relatively little cost is involved in molds for sand casting. On the other hand, molds for various processes and die-casting dies require expensive materials and a great deal of preparation.

Economics of Casting

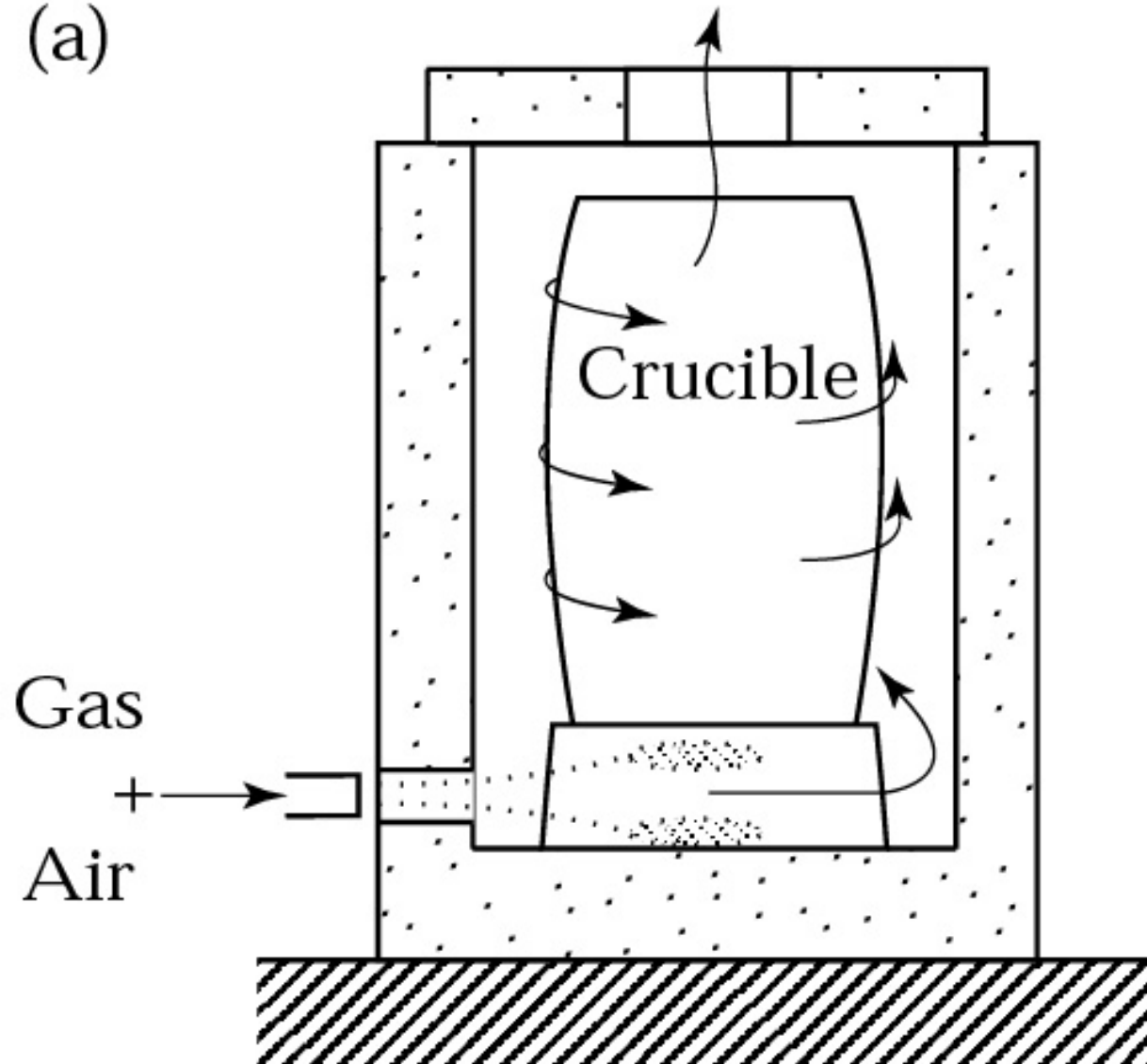
- There are also major costs involved in making patterns for casting.
- Costs also are involved in melting and pouring the molten metal into molds and in heat treating, cleaning, and inspecting the casting.
- Heat treatment is an important part of the production of many alloys groups (especially ferrous castings) and may be necessary to produce improved mechanical properties.
- The equipment cost per casting will decrease as the number of parts cast increase. Sustained high-production rates, therefore, can justify the high cost of dies and machinery.
- However, if the demand is relatively small, the cost-per-casting increases rapidly. It then becomes more economical to manufacture the parts by sand casting.

3.7 melting practice, cupola furnace, defects in casting

- A **cupola** or **cupola furnace** is a melting device used in [foundries](#) that can be used to melt [cast iron](#).
[The](#) cupola can be made almost any practical size.

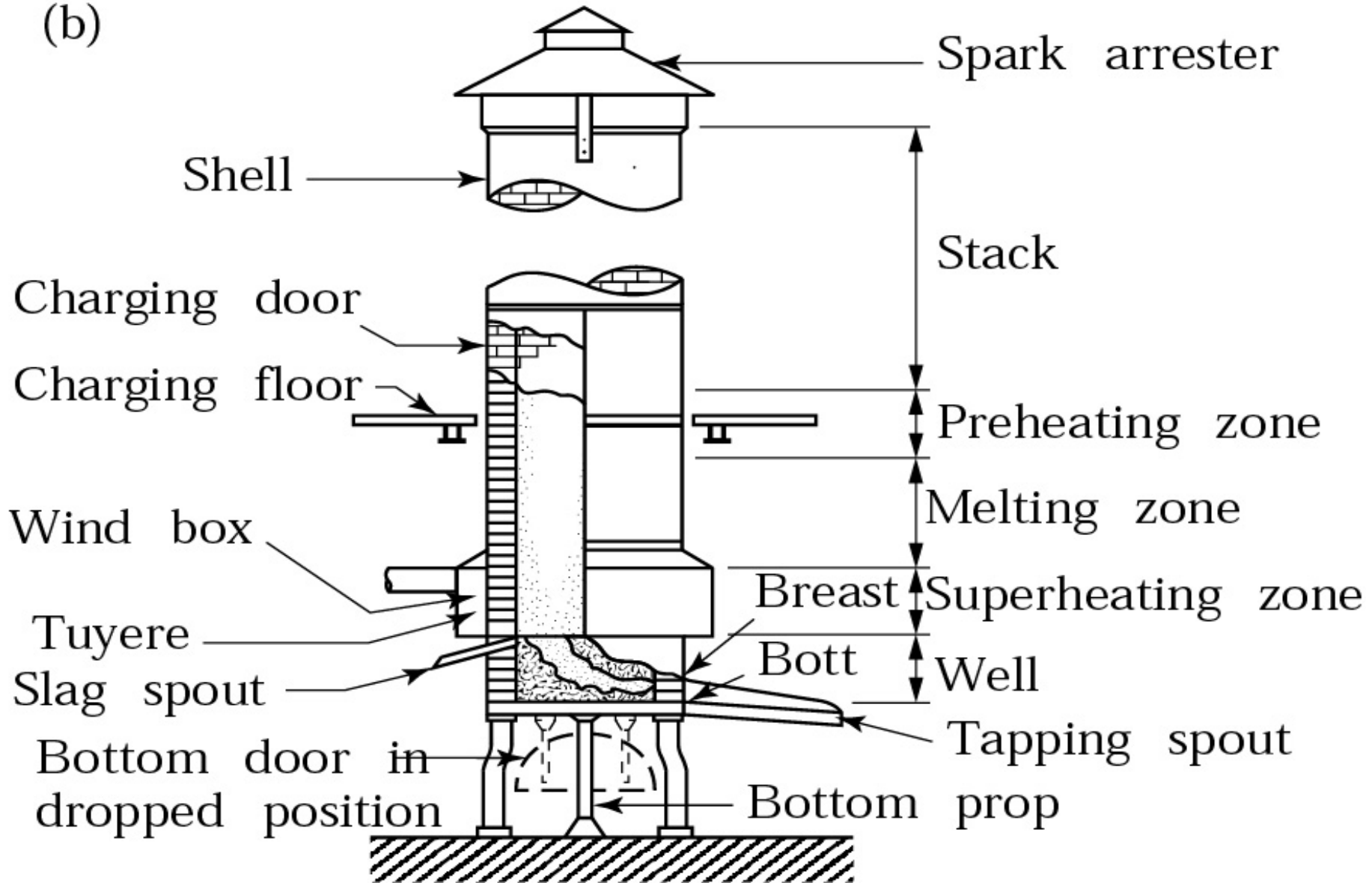
Crucible furnace

(a)

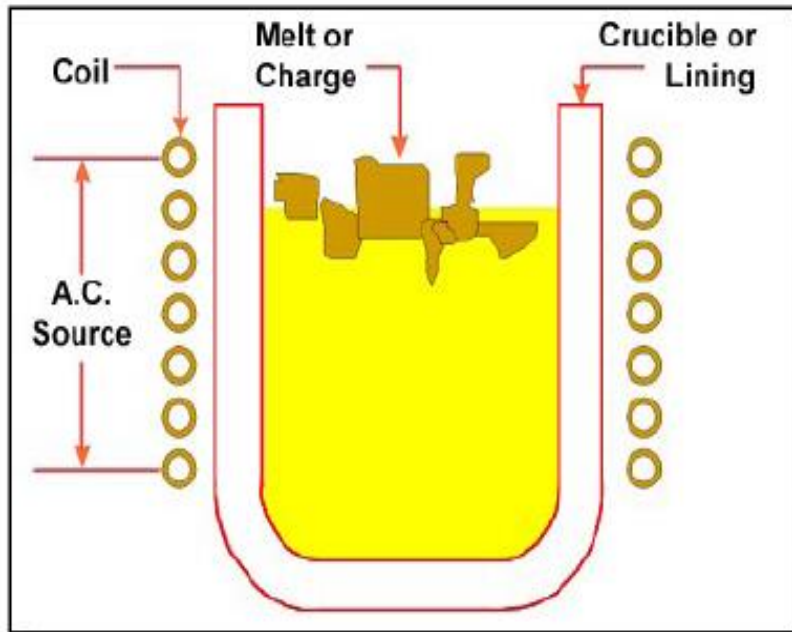


Cupola furnace

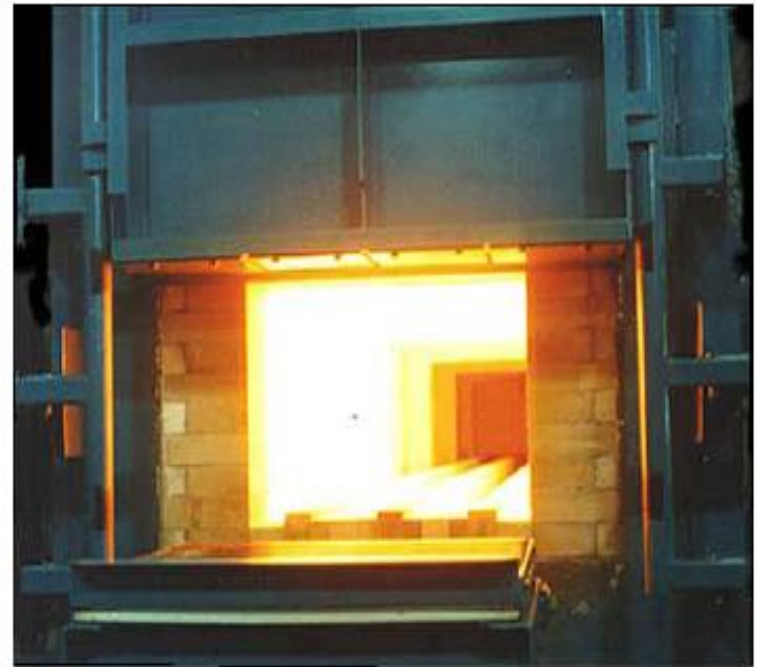
(b)



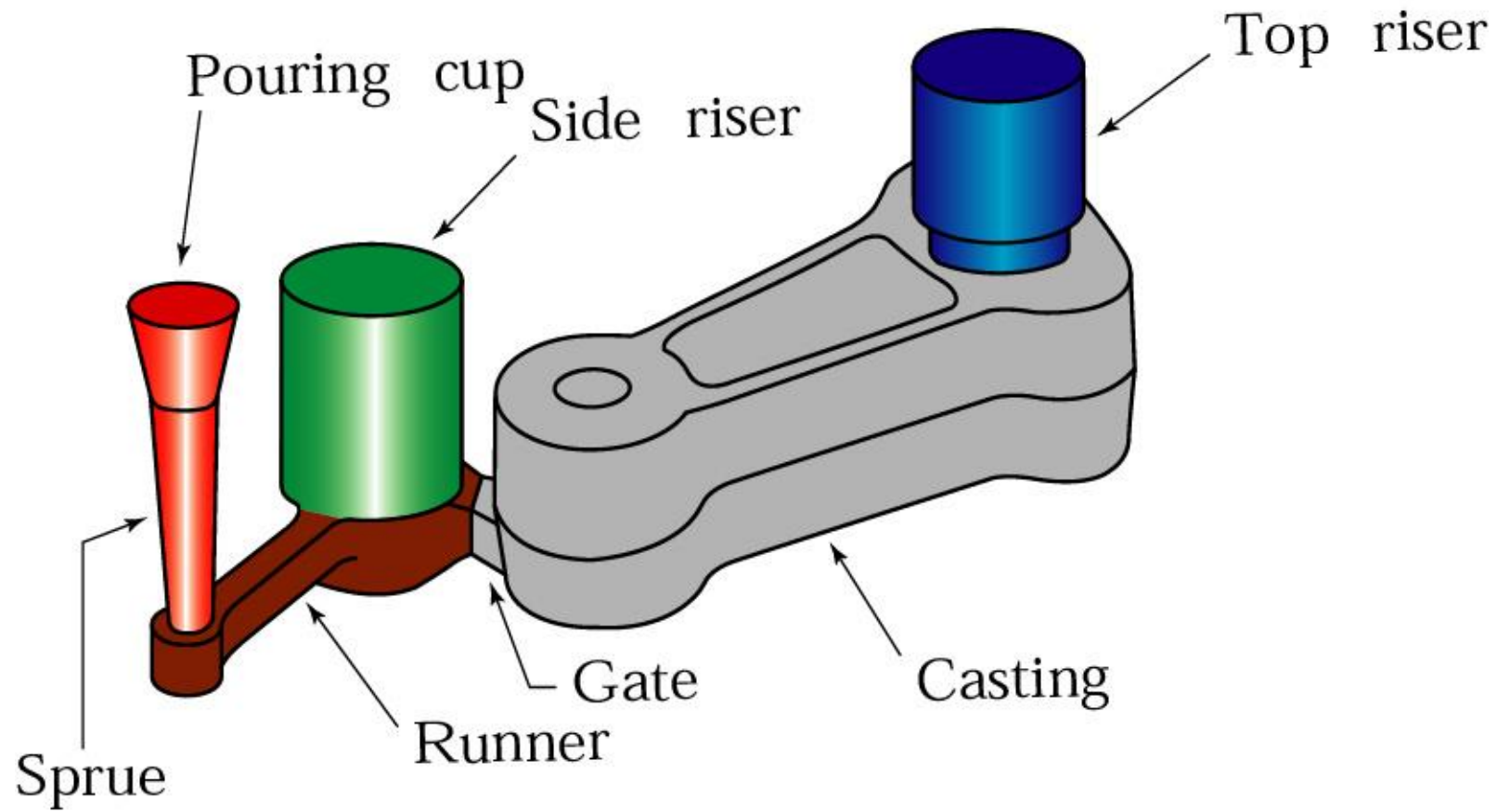
Electric Furnaces



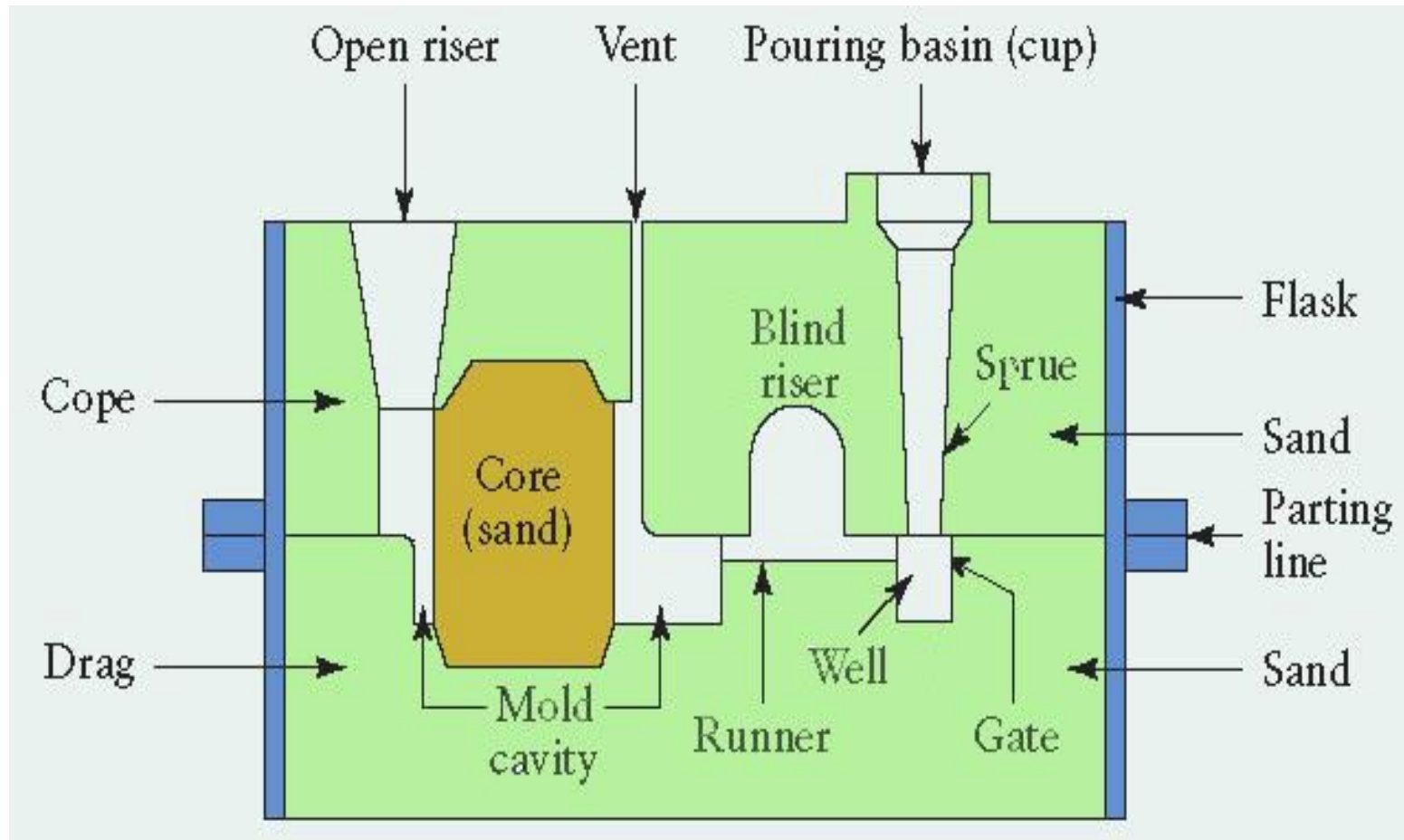
Induction Furnace



Electric Furnace

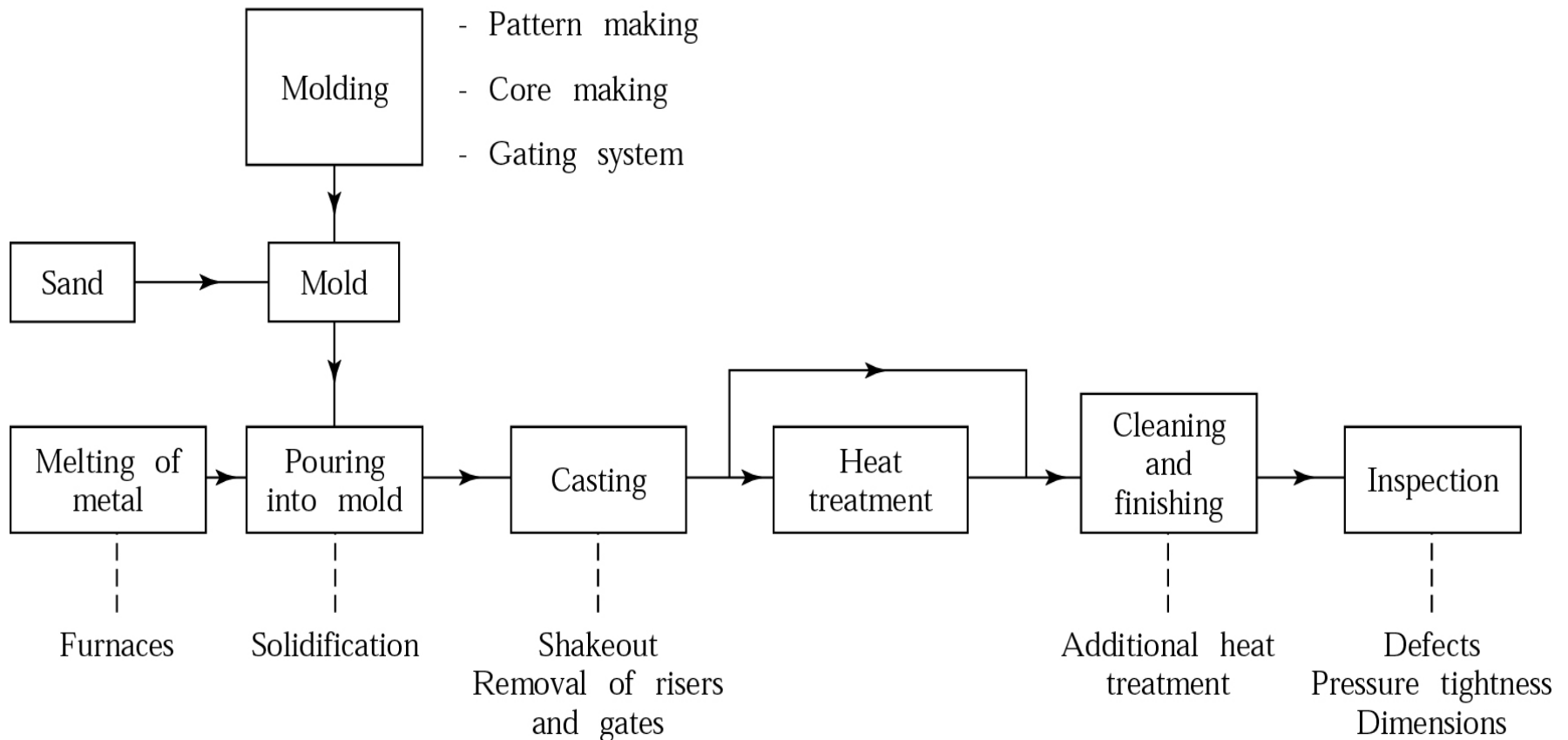


Features of a Sand Mold



The above figure have Schematic illustration of a sand mold, showing various features.

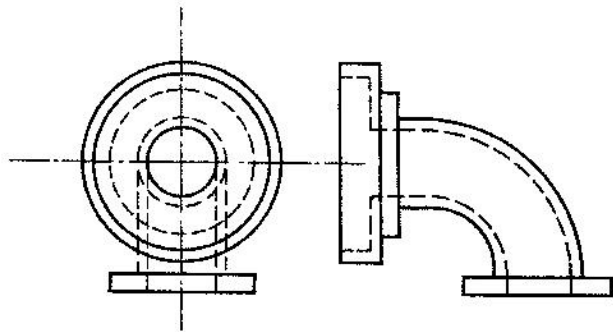
Steps in Sand Casting



Figures show that Outline of production steps in a typical sand-casting operation.

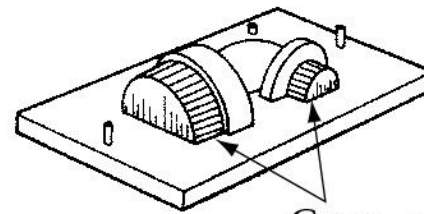
Steps in Sand Casting

(a)



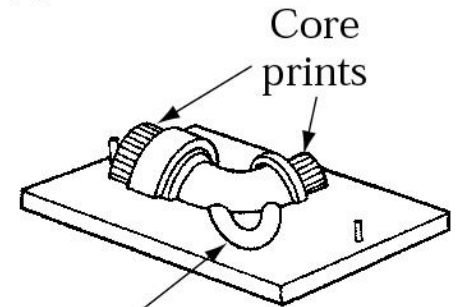
Mechanical drawing of part

(b)



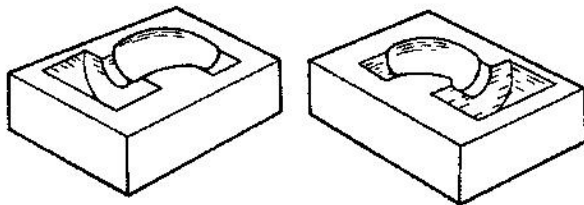
Cope pattern plate

(c)



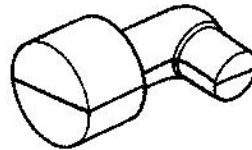
Drag pattern plate

(d)



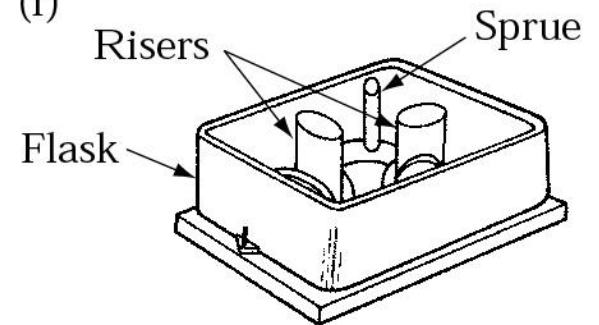
Core boxes

(e)



Core halves
pasted together

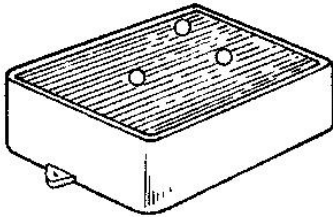
(f)



Cope ready for sand

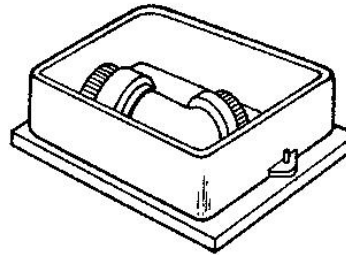
Steps in Sand Casting

(g)



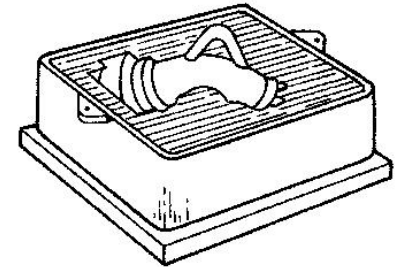
Cope after ramming with sand and removing pattern, sprue, and risers

(h)



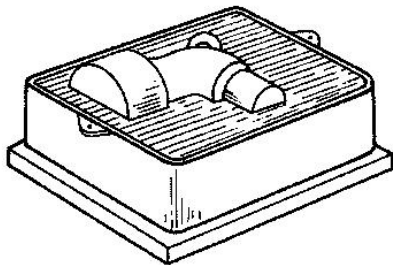
Drag ready for sand

(i)



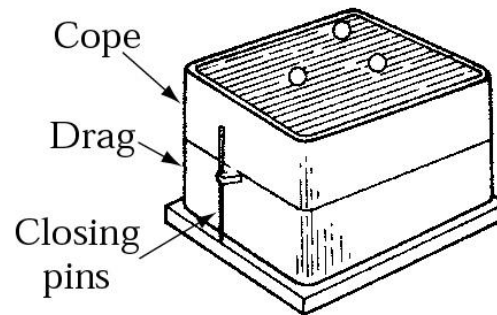
Drag after removing pattern

(j)



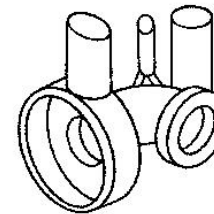
Drag with core set in place

(k)



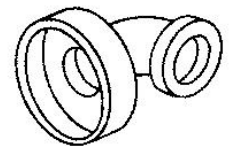
Cope and drag assembled ready for pouring

(l)



Casting as removed from mold; heat treated

(m)



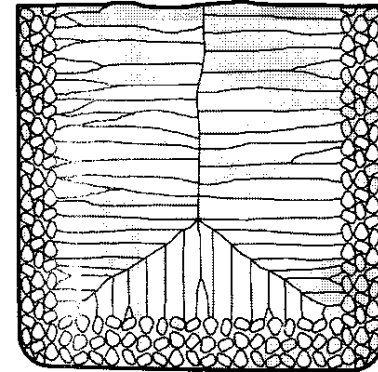
Casting ready for shipment

Sand Casting Process

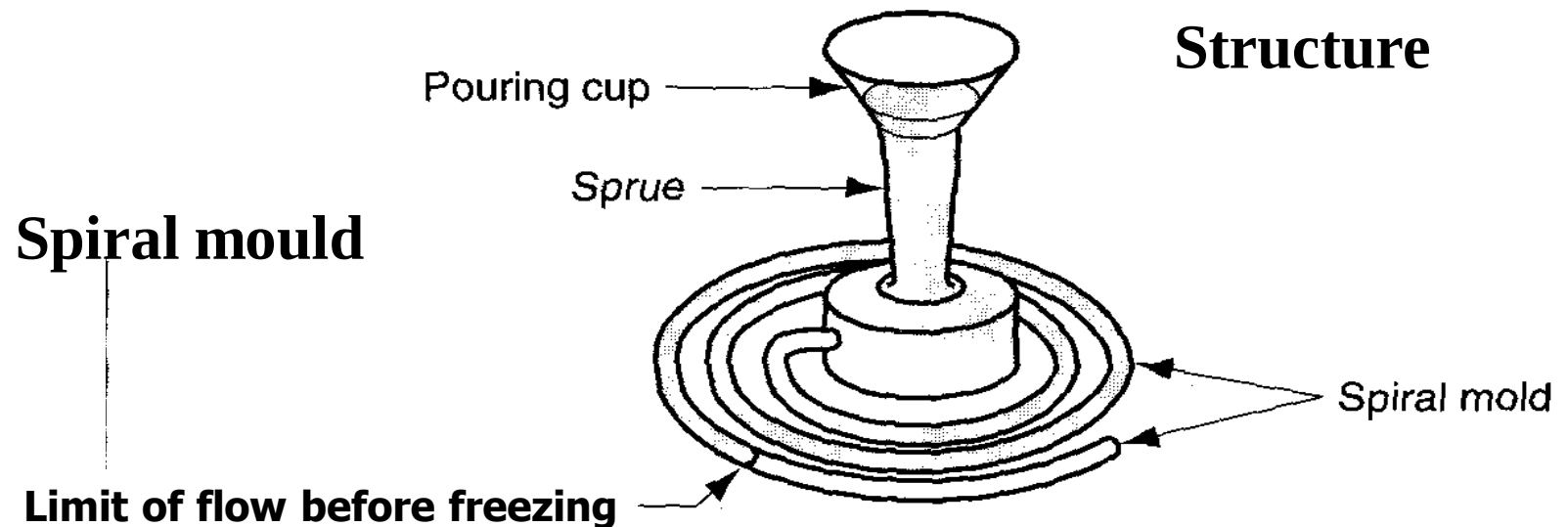
- Pattern (oversized to allow for shrinkage)
- Ramming sand around Pattern in a Flask
- Compacting / jolting sand (green sand, skin dried or, loam molded)
- Withdraw Pattern, add Core
- Reassemble Mould, with Gating, Runner, Riser, and Sprue
- Weight and ready for pouring.

Process Parameters

- Pouring Temperature
- Cooling rate
- Fluidity (viscosity)

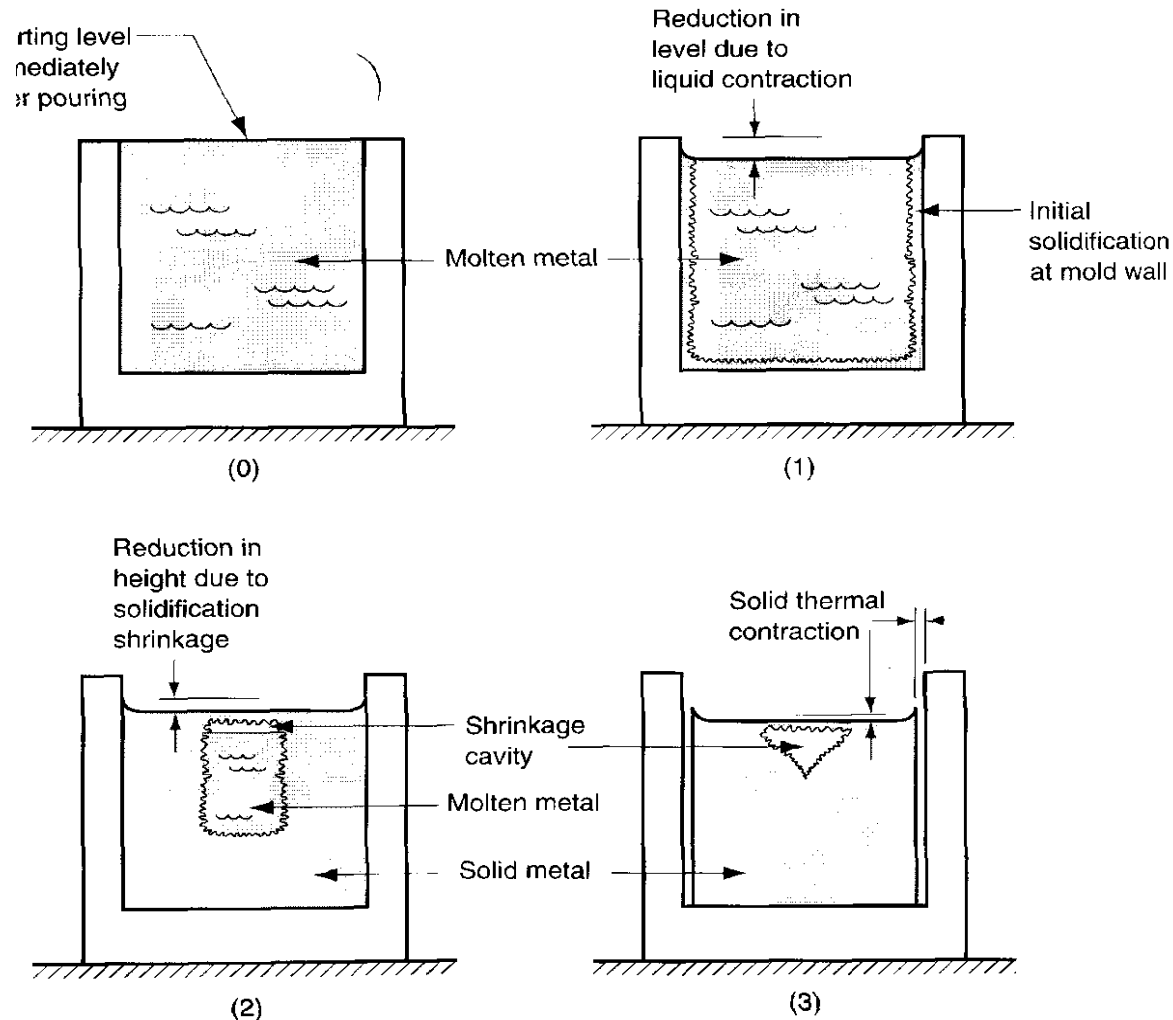


**Grain
Structure**



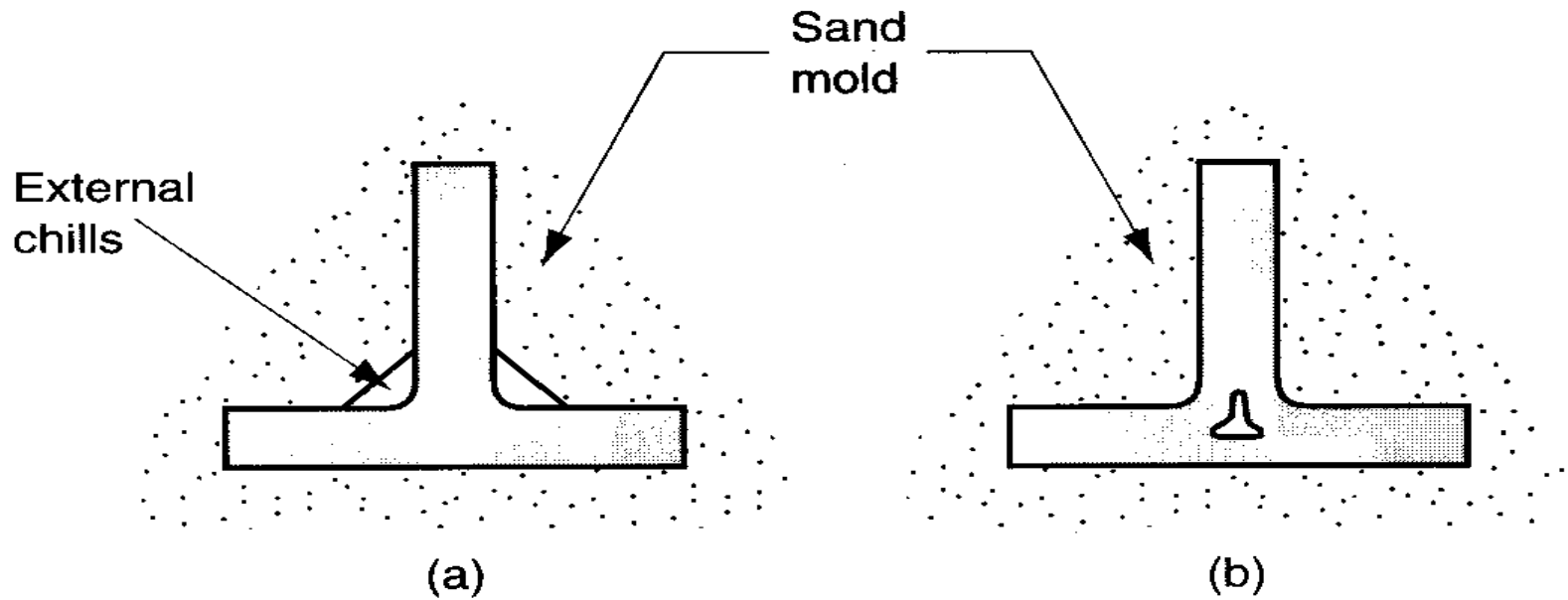
Shrinkage

- Liquid contraction
- Solidification shrinkage
- Solid thermal contraction



Shrinkage

Directional shrinkage



Parting Line

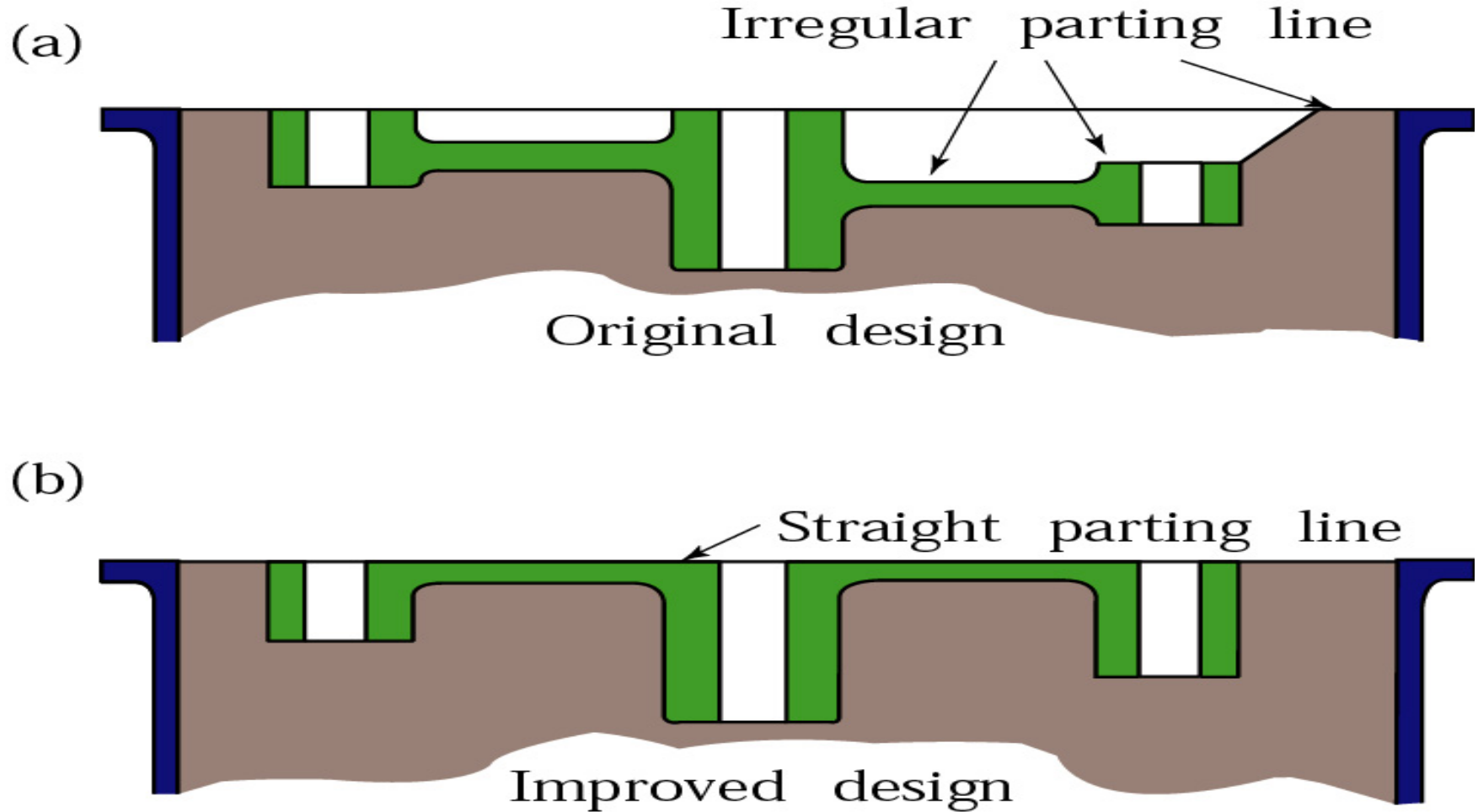
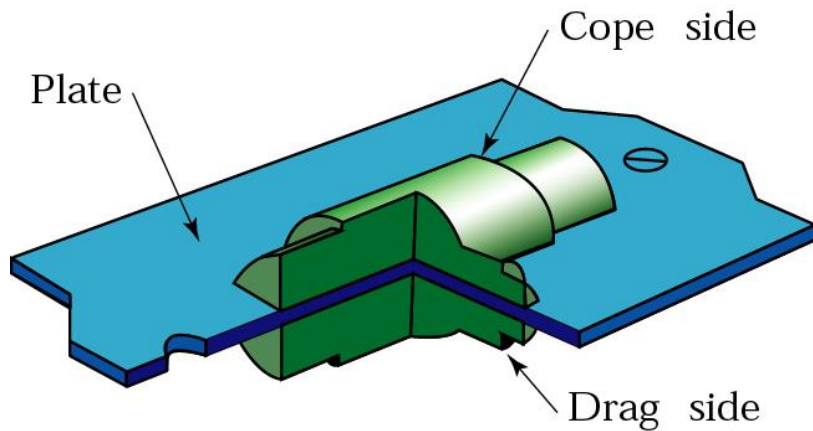


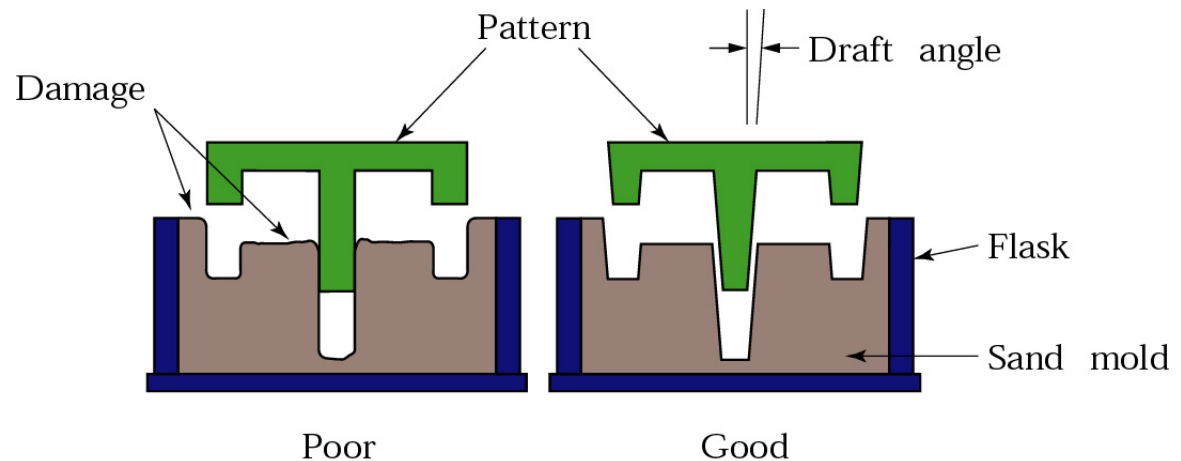
Figure that show Redesign of a casting by making the parting line straight to avoid defects

Patterns for Sand Casting



A typical metal match-plate pattern used in sand casting.

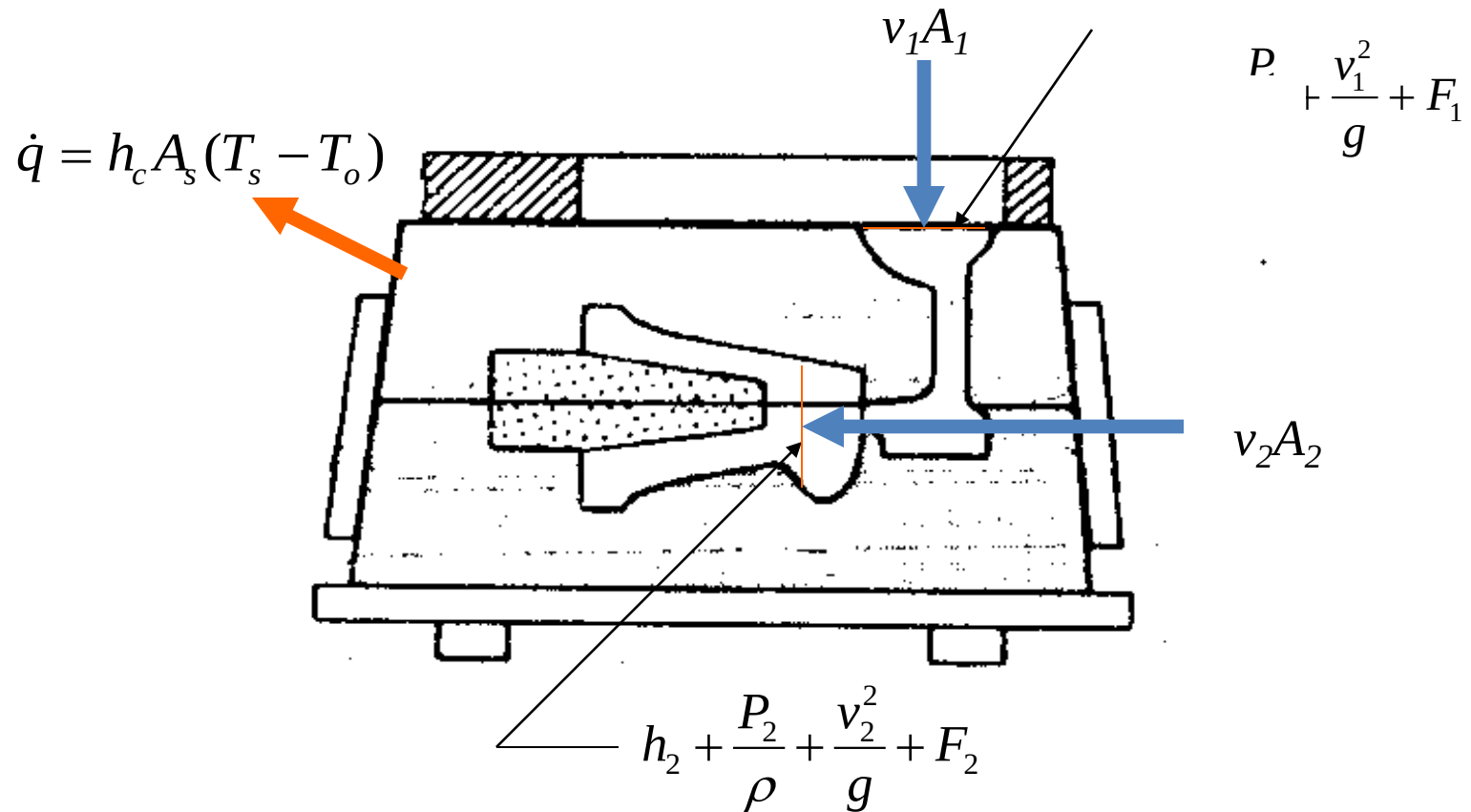
Taper on patterns for ease of removal from the sand mold.



Design of Casting

- Geometry
- Machining allowance
- Finishing
- Shrinkage factor
- Wall thickness, Fillet radius
- Runner, gating, Sprue system
- Grain size
- Mechanical properties

Casting Design



Sand Casting - Process

- Produce parts with complex geometries, both internally and externally.
- Possible to net shape with no further manufacturing required.
- Large parts can be produced.
- Wide choice of metals.
- Suitable for mass production.

Sand Casting

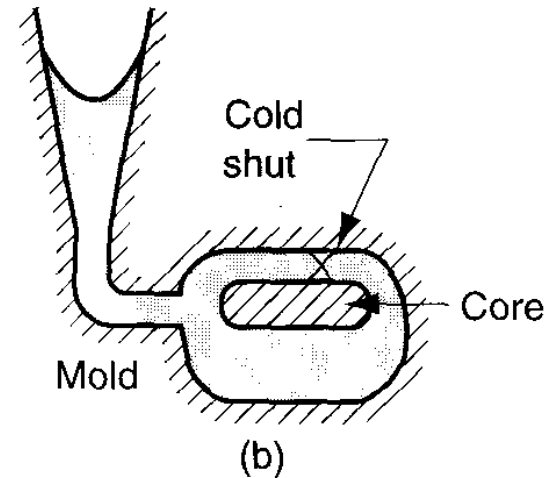
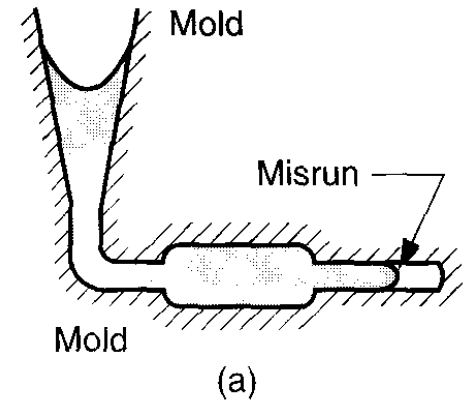
- Porosity
- Poor dimensional control for some processes
- Poor surface finish for some processes
- Limitation on mechanical properties
- Safety hazard
- Environmental hazard

Other Casting Processes

- Casting Quality
- Product Design Considerations

Defect of Casting process

- Misruns - unfilled region exists
 - insufficient fluidity of melt
 - low pouring temperature
 - slow pouring
 - cross-section too thin
- Cold shut - premature freezing at fusion point. Similar reason as misrun

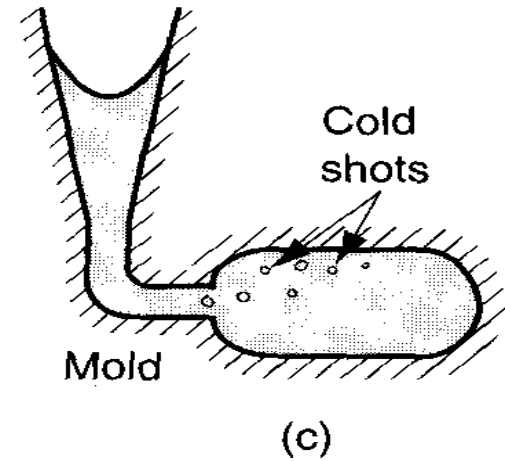


cating

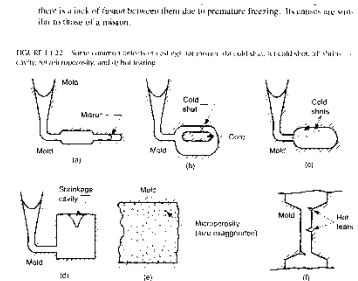
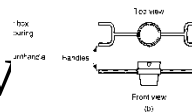
Cold shots - Splattering during pouring forming solid globules

Redesign of pouring procedure or gating system is needed.

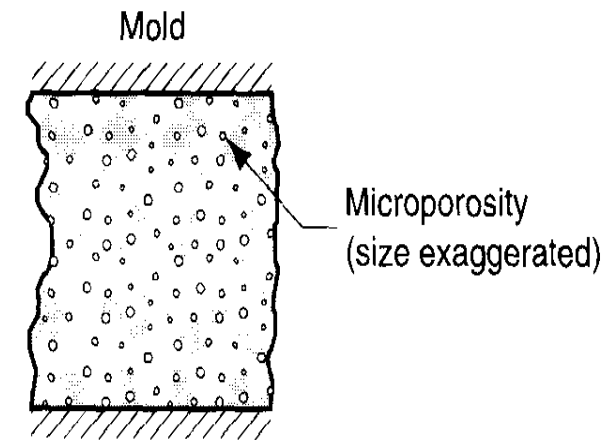
Shrinkage cavity - depression
internal void caused
solidification shrinkage. Solved
by proper riser design.



the other a two-person lead for maintenance. The two-person lead can be introduced at the start of the mold, or the mold can be filled by the two exiles into the mold during the next and other impurities as the metal is poured. The two-person lead can be used to fill the mold from the bottom, since the



- Micro porosity - Network of small voids caused by localized solidification shrinkage. Caused by the freezing manner of the alloy.



the other a two-pronged fork for mounting in

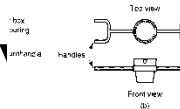
aked molten metal can be introduced into it, perhaps rendering the casting defective. If these voids enter the mold during pouring and when impurities in the metal possess the molten metal to retard oxidation. In so liquid metal from the bottom, since the top

been removed from the mold, a number of operations include (1) riddling, (2) removing, (3) repair, if required, and (4) heat treatment to its final state, as, for example, The required varies with casting processes and cast

entire and costly. as, namely, rising, pouring the flash, fins, of cast part. In the case of brittle casting alloys, all these appendages on the casting can be left, but setting, hand sawing, abrasive wheel cutting, or they must be removed. Most cores are chemically often fall out of the casting as the binder dissolved by dissolving the casting, either manually or removed by chemically dissolving the binder must be hammered or pressed out.

in the case of sand casting. In many of the other mold processes, this step can be avoided and from the surface of the casting and otherwise

that case with and to two pronged forks.

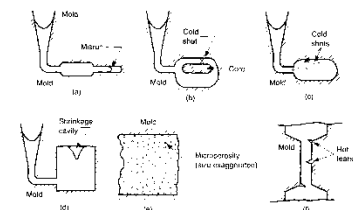


- Hot tearing - Occurs at localities with high stress due to inability to shrink naturally. Resolve mold collapsing or remove from the mold immediately after freezing.

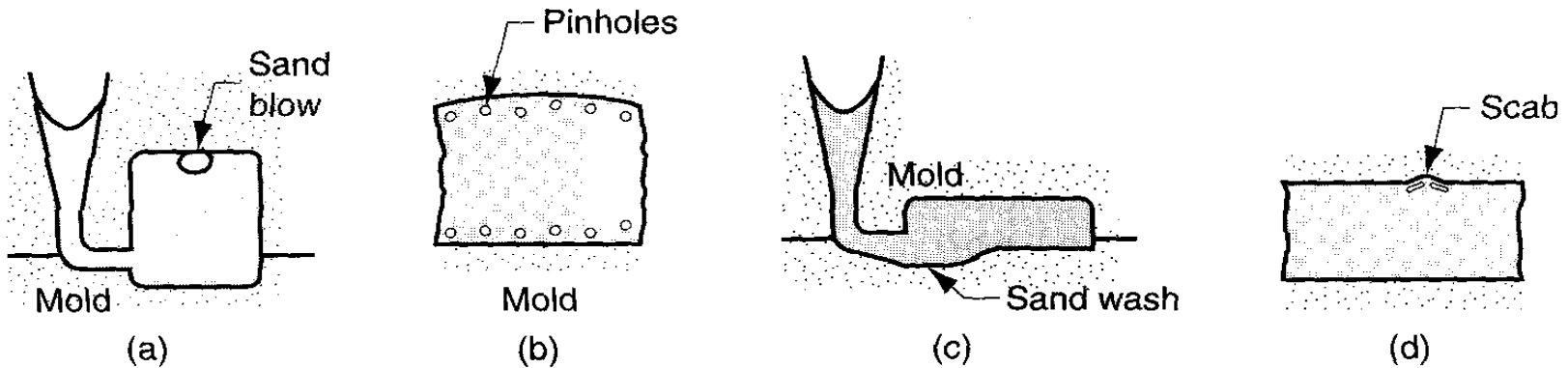
(e)

the Cold shut. A cold shut occurs when two portions of the metal flow together, but there is a lack of fusion between them due to premature freezing. It causes the casting to be of a weak.

FIG. 1.1.22 Some common defects of sand casting. (a) Cold shut, (b) Cold shut, (c) Cold shut, (d) Cold shut, (e) Cold shut, (f) Cold shut, (g) Cold shut, (h) Cold shut, (i) Cold shut, (j) Cold shut, (k) Cold shut, (l) Cold shut, (m) Cold shut, (n) Cold shut, (o) Cold shut, (p) Cold shut, (q) Cold shut, (r) Cold shut, (s) Cold shut, (t) Cold shut, (u) Cold shut, (v) Cold shut, (w) Cold shut, (x) Cold shut, (y) Cold shut, (z) Cold shut.

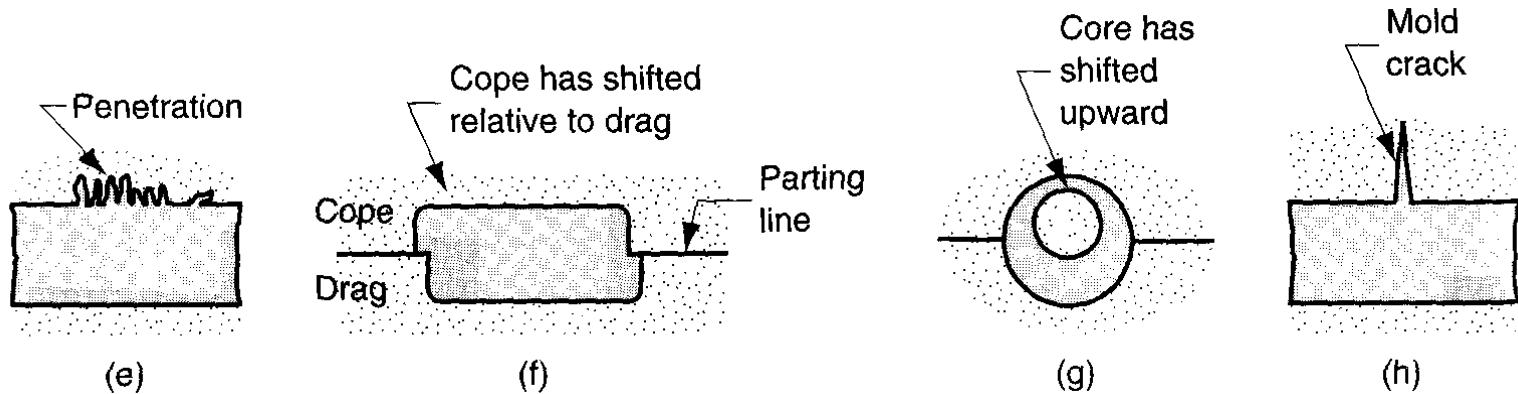


Casting Quality - Defects Casting



- Sand blow - cavity caused by mold gas during pouring. Low permeability, poor venting or high moisture content.
- Pin holes - small gas cavities.
- Sand wash - erosion of sand mold during pouring.
- Scabs - mold surface locally flakes off and embedded in the casting during solidification.

Casting Quality - Defects Casting

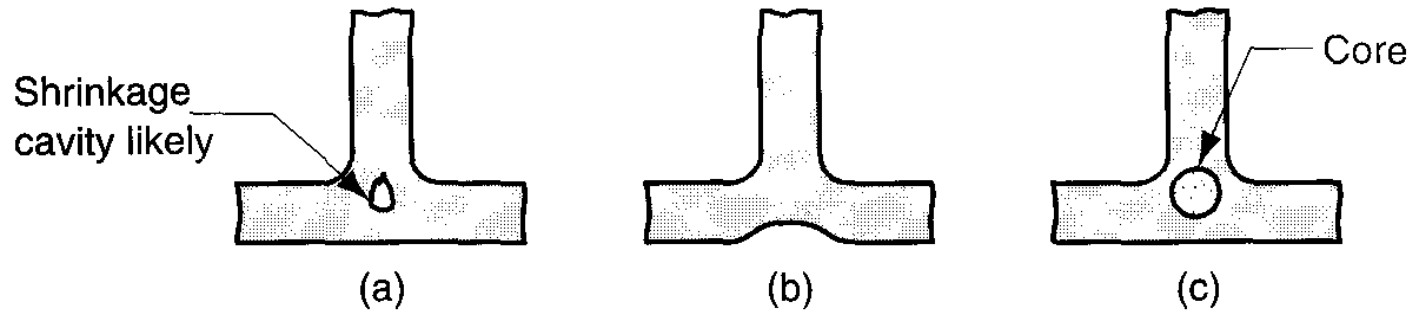


- Penetration - penetration of molten metal into the sand. Harder packing of sand is needed.
- Mold shift - shift of the cope relative to the drag.
- Core shift - shift of the core, usually vertical.
- Mold crack - mold strength insufficient, liquid metal form a fin of the final casting.

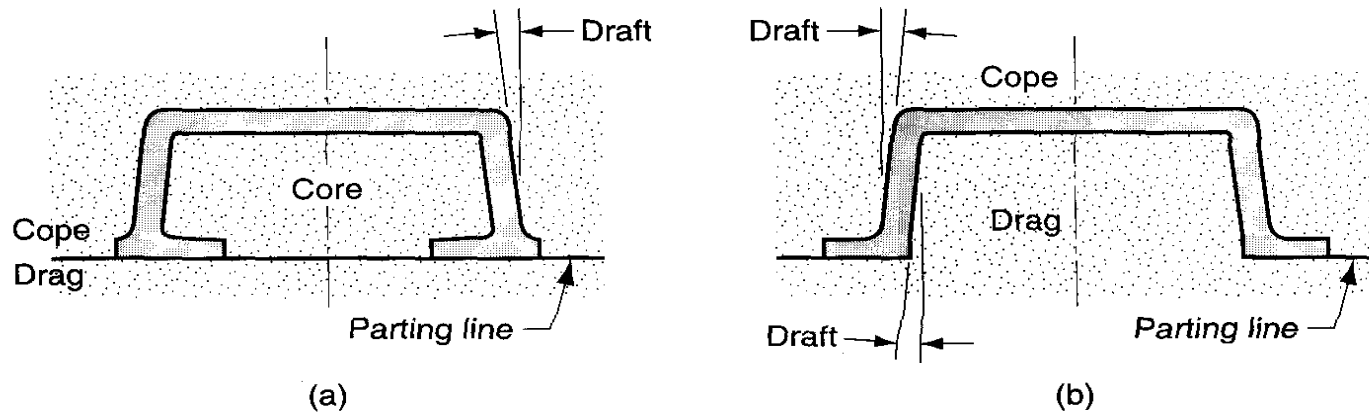
Product Design Considerations

- Geometric simplicity - Avoid unnecessary complexity.
- Corners - Avoid sharp corners, generous fillet radius.
- Section thickness - Uniform section thickness to avoid shrinkage cavities and hot spots.
- Draft - Facilitate removal of parts from mold. (1 deg. For sand and 2/3 deg. for permanent)
- Use of cores - minimize the use of core
- Dimensional tolerance and surface finish - proper choice of casting method.
- Machining allowances - For assembly purposes, typically 1.5 to 6 mm.

Product Design Considerations



Shrinkage, hot spot



Draft and core elimination