EDPT 601
MATERIALS MANUFACTURING TECHNOLOGY

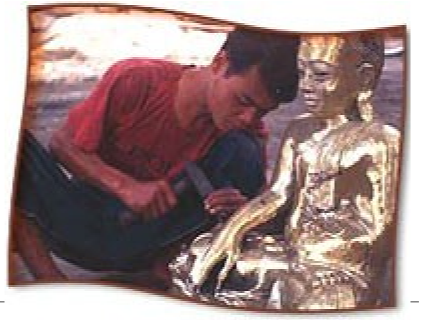
LECTURE 2

METAL CASTING PROCESSES: FUNDAMENTALS OF CASTING

REF. 13 DEGARMO

CH 10 KALPAKJIAN

Metal Casting



Casting is a very old process (4000-3000 BC) using stone and metal moulds to cast copper

It gives a finished or semi finished products independent of the number and shape complexity

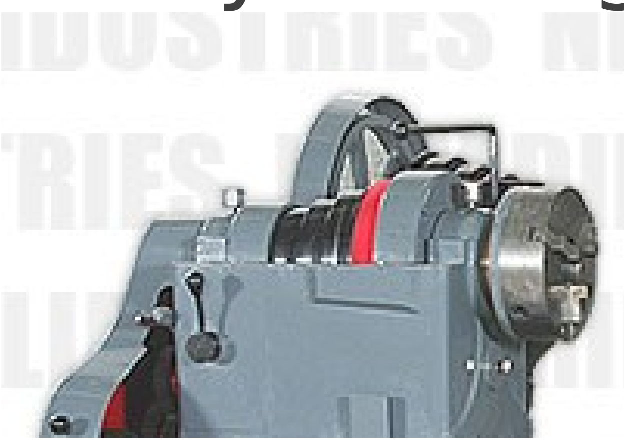
Two trends are having nowadays impact on casting industry:

- mechanization and automation
- the demand for high – quality castings with close tolerances


LIFETIME

Metal Castings

Machine parts made by casting



Go to the workshop and find 5 different cast parts

Fundamentals of Casting Process

Casting is a solidification process

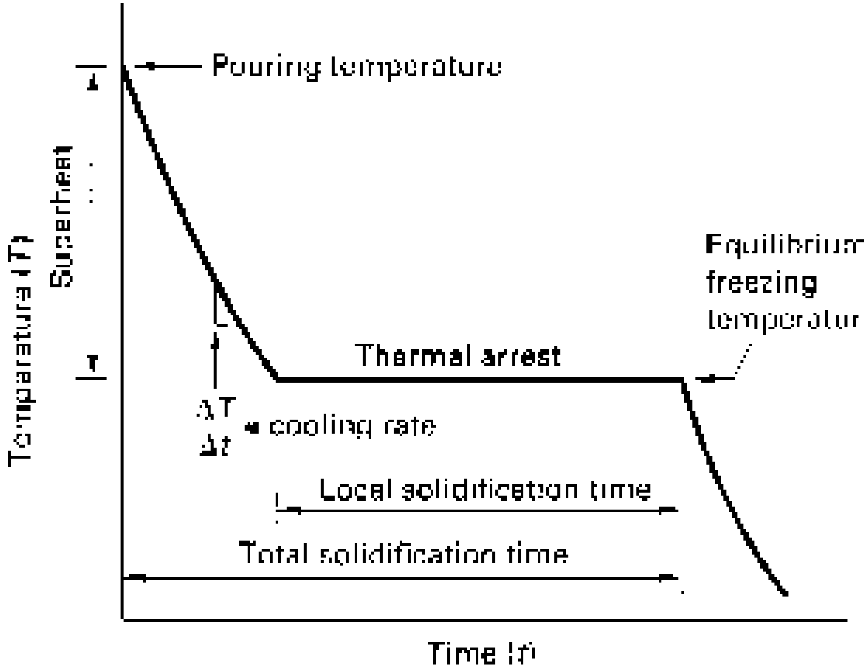
What metals can be cast?

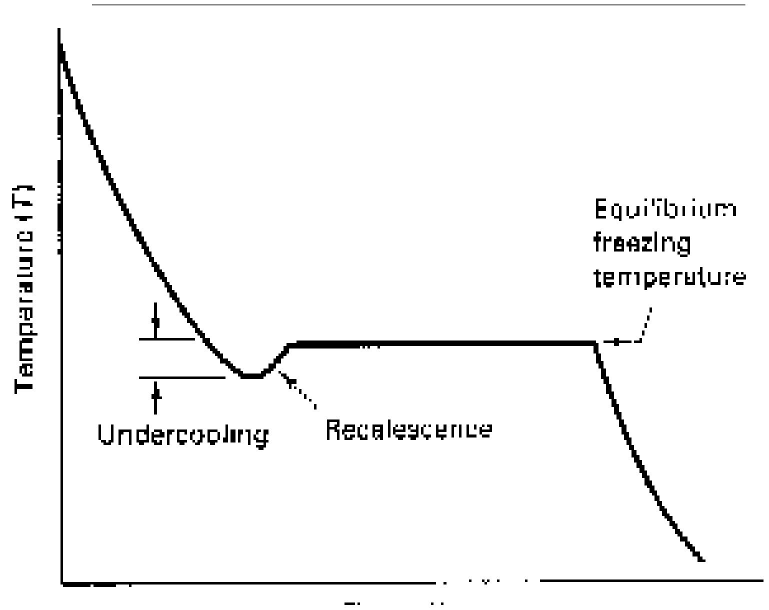
Alloys are divided into:

- Cast Alloys
- Wrought Alloys

Solidification occurs in two stages: nucleation and growth

Cooling curve for a pure metal or eutectic-composition alloy

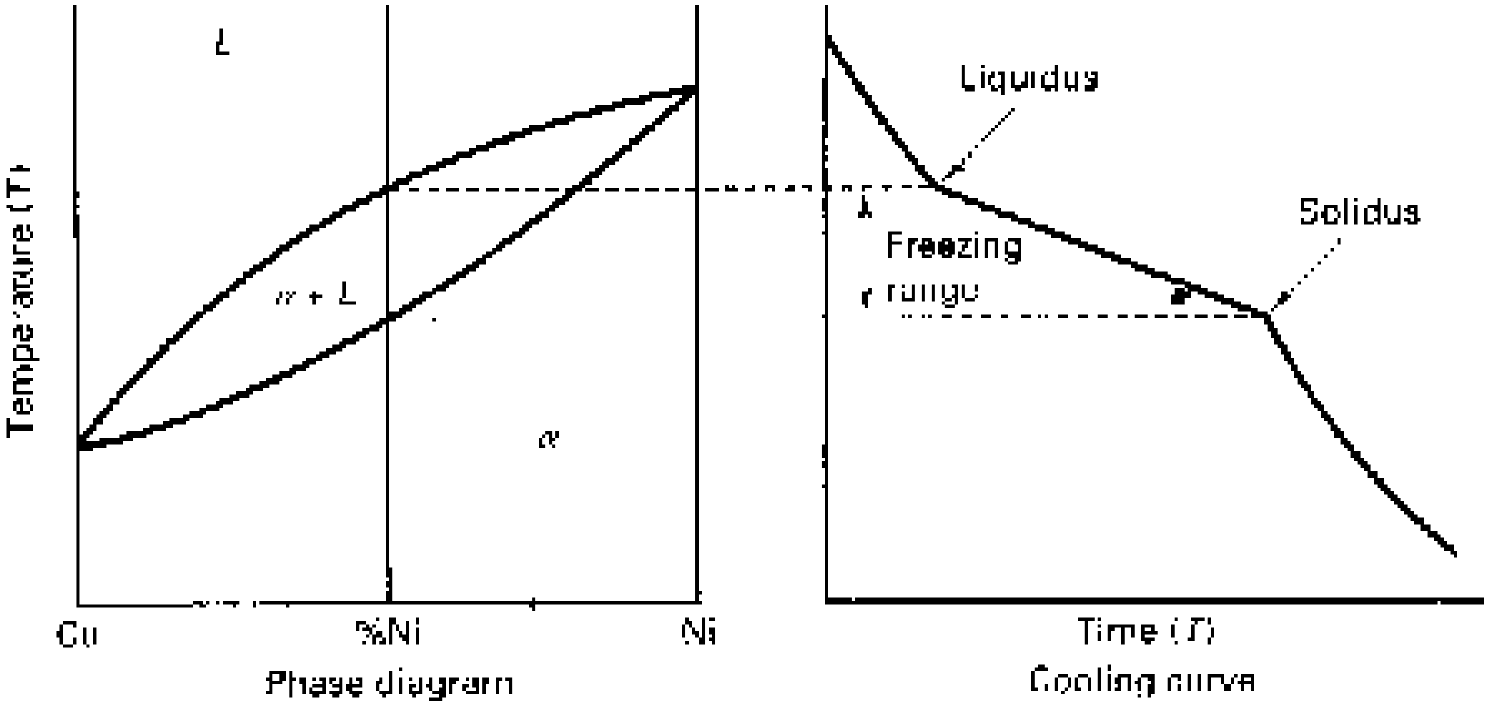




Cooling curve for a pure metal or eutectic-composition alloy (metals with a distinct freezing point), indicating major features related to solidification.

Cooling curve depicting undercooling and subsequent recalescence

Phase diagram and companion cooling curve for an alloy with a freezing range



The slope changes indicate the onset and termination of solidification

Ingot Structure

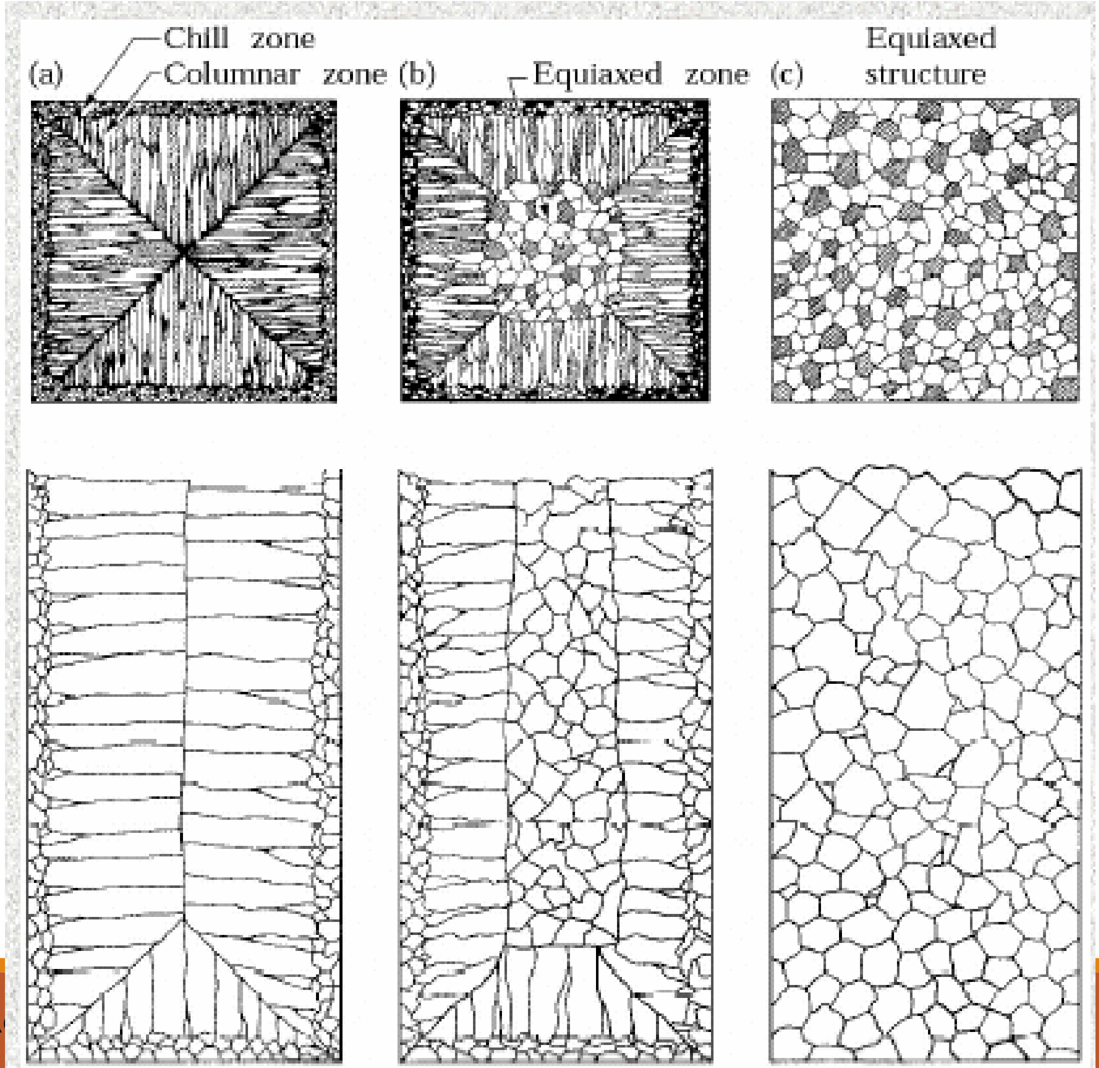
Schematic illustration of three cast structures of metals solidified in a square mold:

illustrating the typical ingot structure with **columnar and equiaxed grains for:**

a) **Pure Metal**

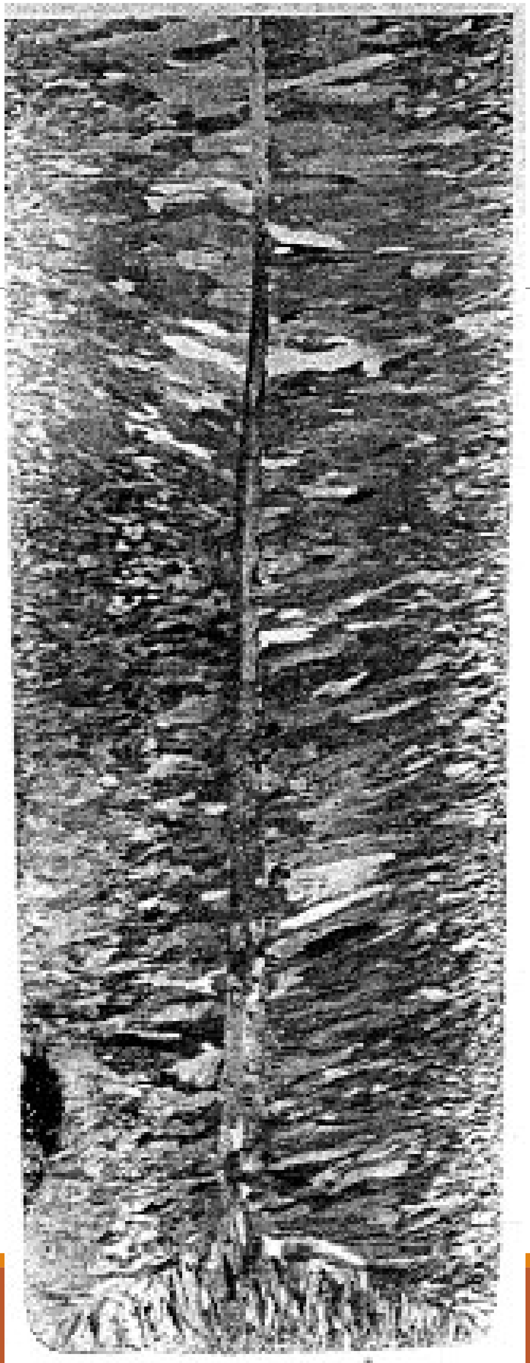
b) **Solid Solution Alloy**

a) **Using Nucleating Agents**



Ingot Structure

Longitudinal section in a cast metal bar showing the chill zone at the periphery and columnar grains growing towards the center



Typical features of cast products:

-Dendritic structure

-Macro and microsegration

Grain Structure

To improve the mechanical properties of a cast product:

- Fine grains have improved strength and mechanical properties

- reduce or eliminate defects such as porosity

In order to obtain fine grains:

- the rate of nucleation should be high. This is intentionally obtained by increasing cooling rate
- adding inoculants or grain refiner to the liquid metal

What is needed for a casting process??

Basic requirements of Casting Processes

1. A Mold cavity:
   - pattern making
   - Core making
   - Gating system
2. A melting process :
   - melting
3. A pouring technique
4. The solidification process (by cooling)
5. Removal of casting-
   - shakeout – removal of risers and gates
6. Cleaning and finishing

Sand mold features

***Pattern*: approximately duplicate of final casting**

***Flask*: the box that contains the moulding aggregate**

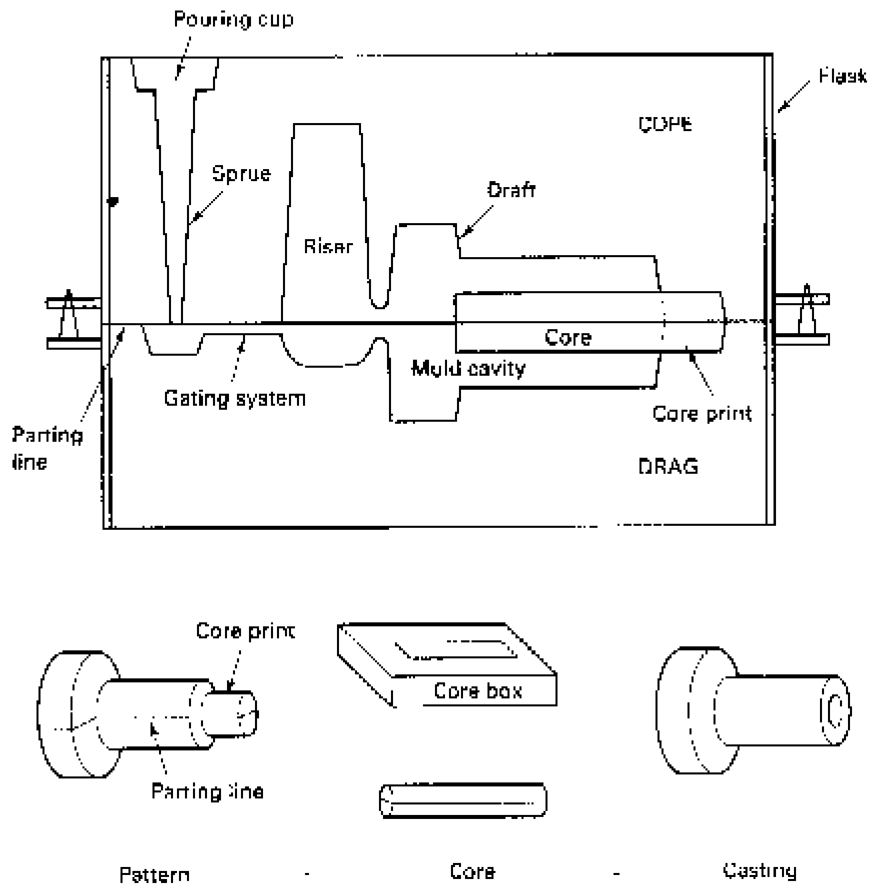
***Cope*: is the top half of the flask**

***Drag* is the bottom half**

***Core*: sand shape that is inserted into mould to produce internal features (holes..)**

***Core print* : region added to pattern, core or mould that is used to locate and support the core within the mould**

***Parting line*: separates cope and drag**



Sand mold cont'd

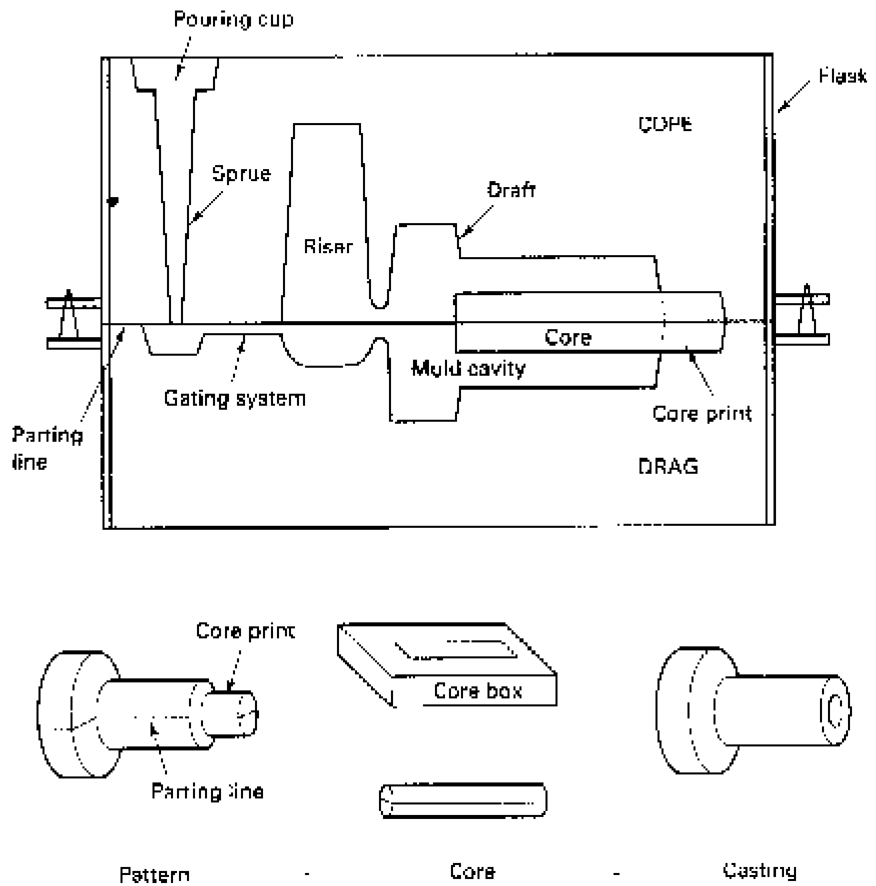
***Mould cavity*:** void to be filled with molten metal to produce the casting

***Riser*:** extra void in the mould- will be filled with molten metal – will act as reservoir of molten metal to compensate for solidification shrinkage

***Gating system*:** channels used to deliver molten metal from outside the mould into the mould cavity

***Pouring cup*:** the portion of gating system that receives the molten metal

Sprue: vertical portion of gating system- metal flows from sprue to horizontal channels (runners) and finally through controlled entrances (gates) into mould cavity.



Casting terminology- sand mold features

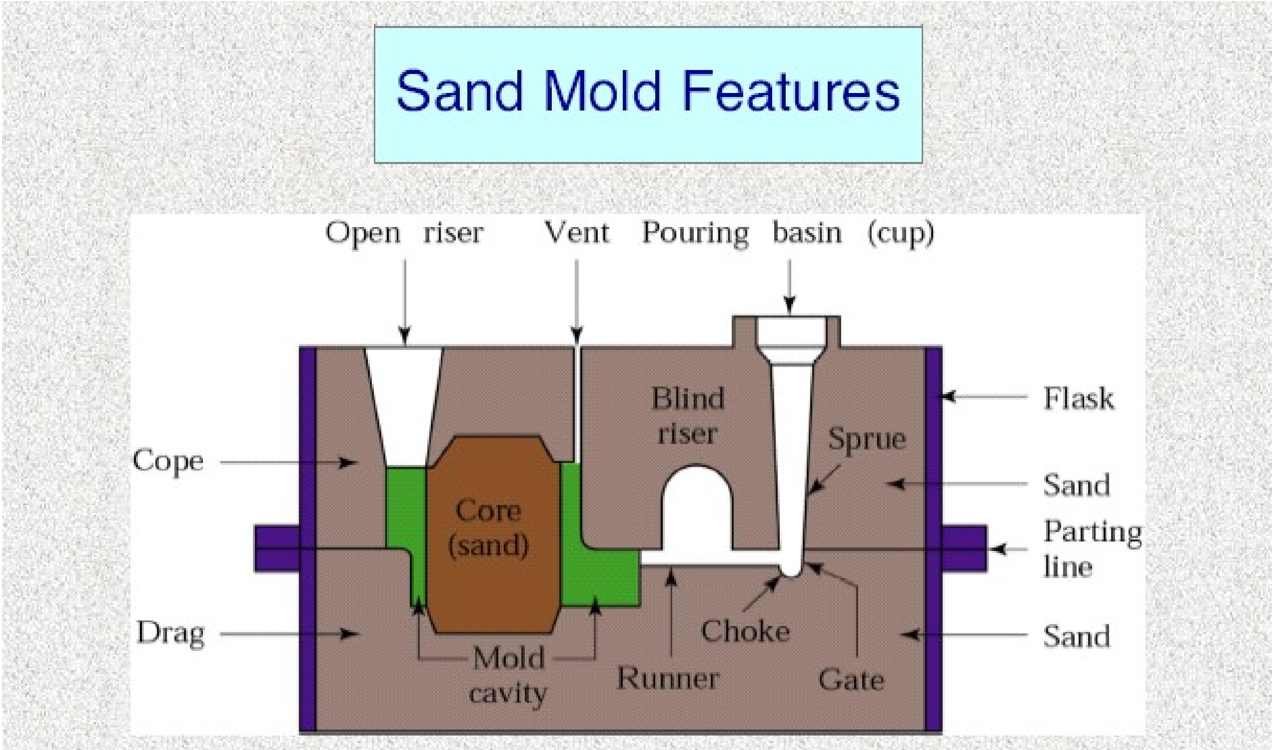


Figure 11.4 Schematic illustration of a sand mold, showing various features.


ABERCROMBIE

Gating System

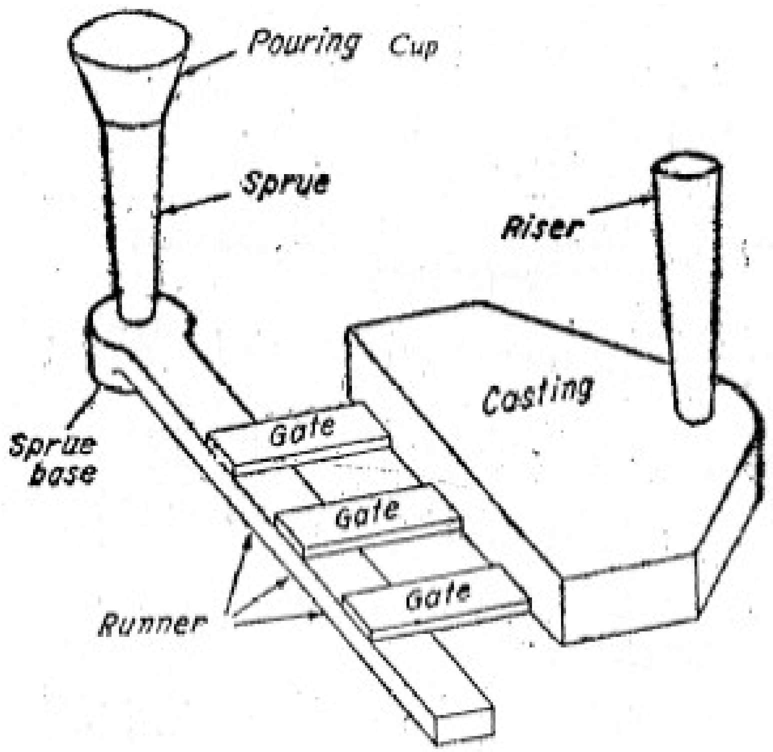
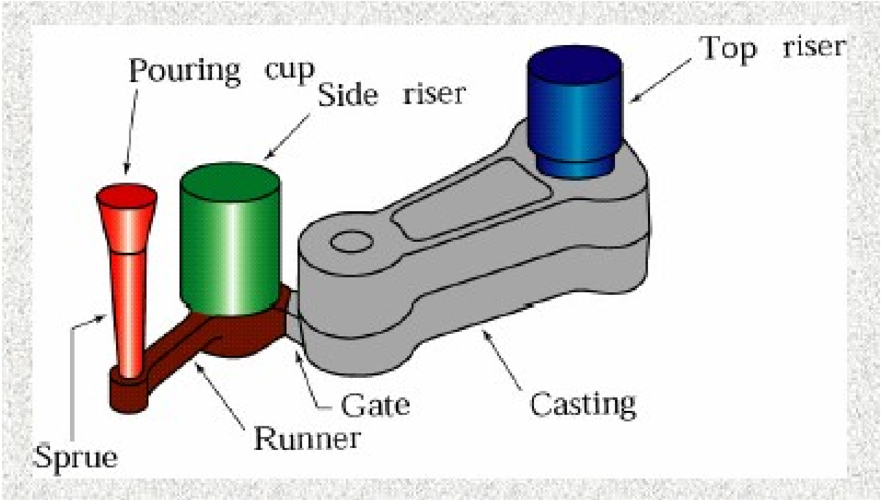


Fig. 8·1 Components of Gating System.



Schematic illustration of a typical
Riser-gated system casting
Risers serve as a reservoir supplying
Molten metal to the casting as it shrinks
During solidification

Calculating Solidification Time

The amount of heat that must be removed from a casting to cause it to solidify is proportional to :

- The amount of superheat (ΔT)

- The amount of metal in the casting or casting volume (V)

i.e. to the ability to remove heat from a casting is directly related to the surface area (A) through which heat can be extracted and the insulating value of the mould

accordingly, the solidification time ts is given by:

$$ts = B\left(\frac{V}{A}\right)^n$$

where n=1.5 to 2.0

B= mould constant depending on mould material, thickness, amount of superheat, melt characteristics

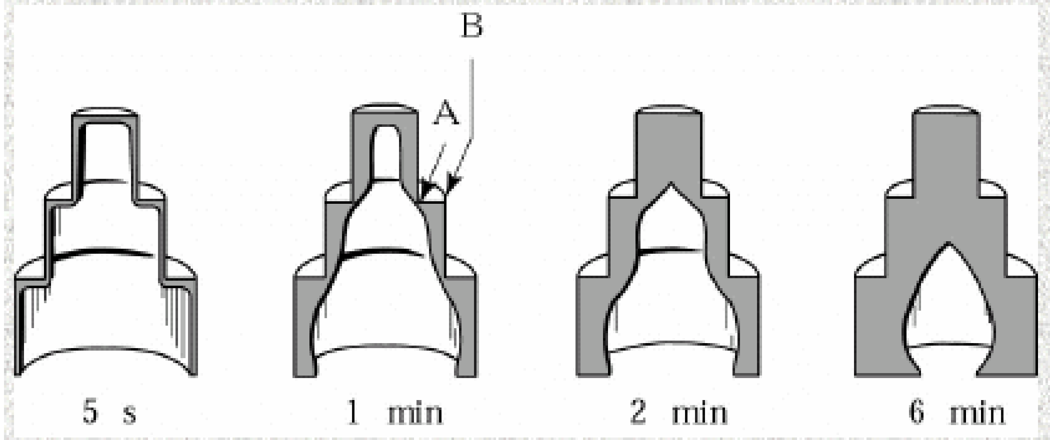
Test specimens can be cast to determine B for a given mould material, metal and condition for casting. This value can then be used to calculate ts for other casings and for the riser

Progress of Solidification with time

Solidified skin for a steel casting.

The remaining molten metal is poured out at the times indicated in the figure.

Hollow ornamental and decorative objects are made by a process called slush casting, which is based on this principle



Casting Design:

Includes:

1. pattern design
2. Riser design
3. Gating design
4. Core design

1. pattern design

Draw the casting shape and dimensions with :

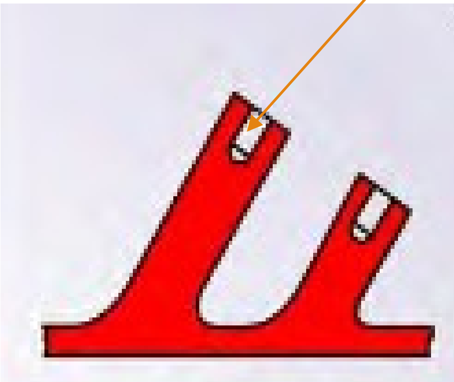
1.Simplification of details,

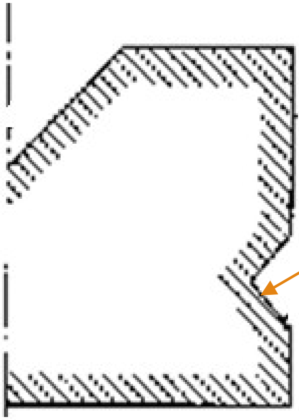
2. Consideration of shrinkage, due to:
   - contraction of liquid prior to solidification
   - contraction due to change in phase
   - contraction of solidified metal

3. Draft

4. Machining allowances

1.Simplified Details





Small holes or deep

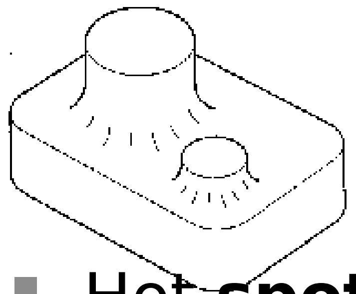
2. Shrinkage

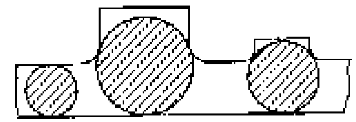
- contraction of liquid prior to solidification
- contraction due to change in phase
- contraction of solidified metal

Table for solidification contraction of various cast metals upon solidification (due to change in phase)

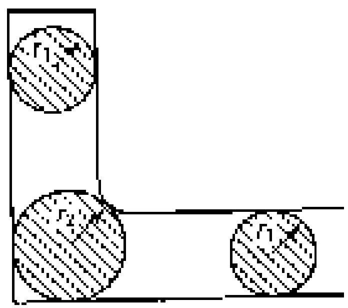
Metal	**% Shrinkage (by volume)**
Aluminium	6.6
Copper	4.9
Magnesium	4.0
Zinc	3.7
Low-C Steel	2.5 – 3
High-C Steel	4.0
White Cast Iron	4.0 – 5.5
Grey Cast Iron	-1.9

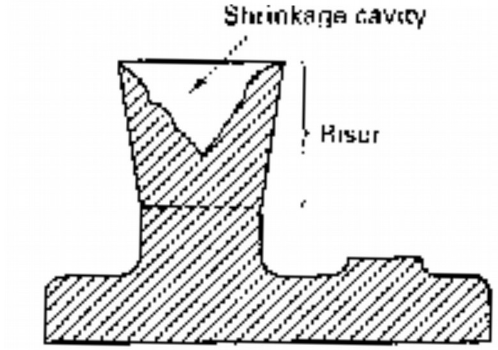
Shrinkage - Hot spots





- Hot **spots often result from intersecting** sections of various thickness.





- The “hot spot” at section is caused by intersecting sections.

- Use of a riser to keep the shrinkage cavity external to the casting.

Shrinkage in the solid state:

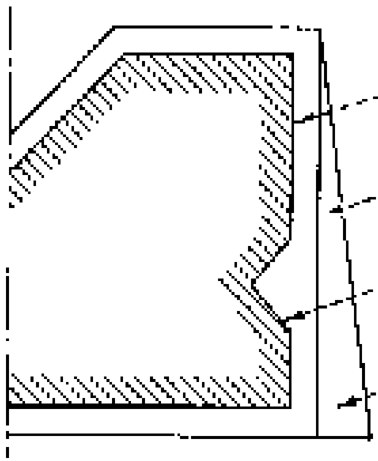
- Solid contraction should be considered in the pattern dimensions using shrink rule

Some typical shrinkage :

Cast iron	0.8- 1.0 %
Steel	1.5-2.0%
Aluminium	1.0 – 1.3%
Magnesium	1.0- 1.3 %
Brass	1.5%

Example: a shrink rule for brass would designate 100mm at a length which is actually 101.5mm

Pattern design : allowances, draft and machining allowances

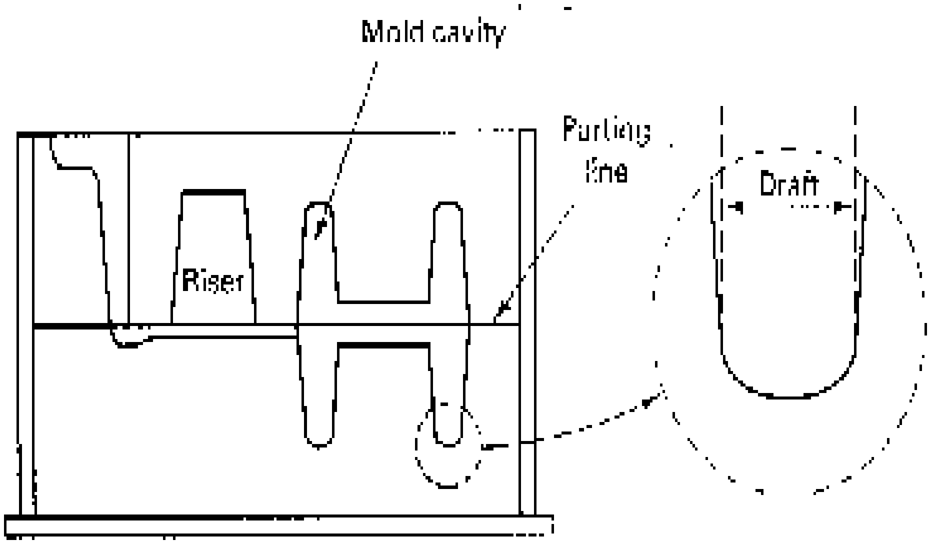


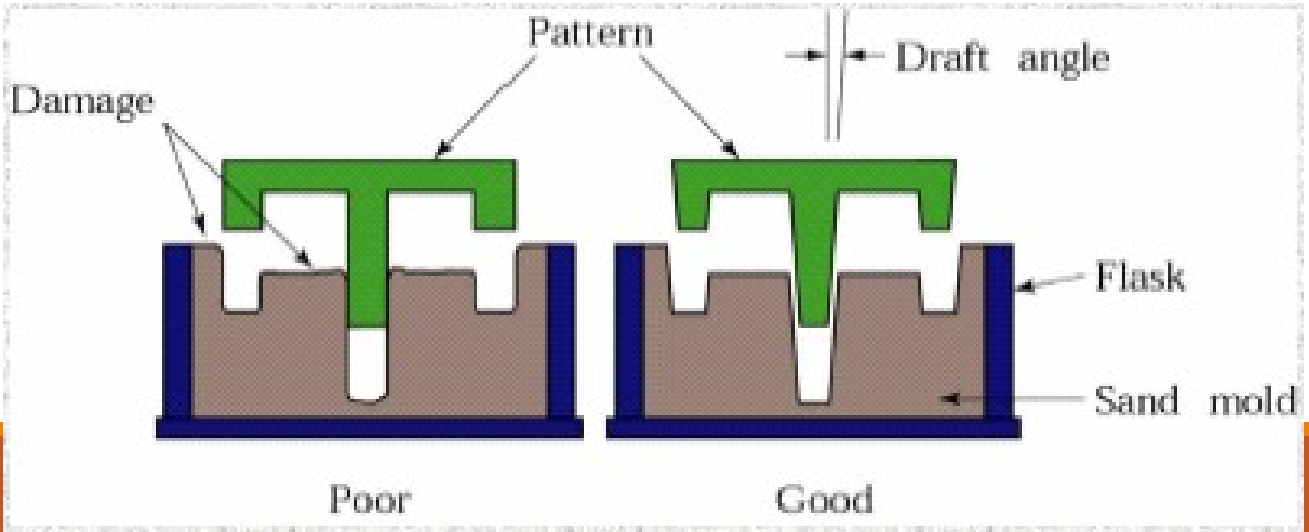
Various allowances incorporated into a casting pattern

How to put the draft?

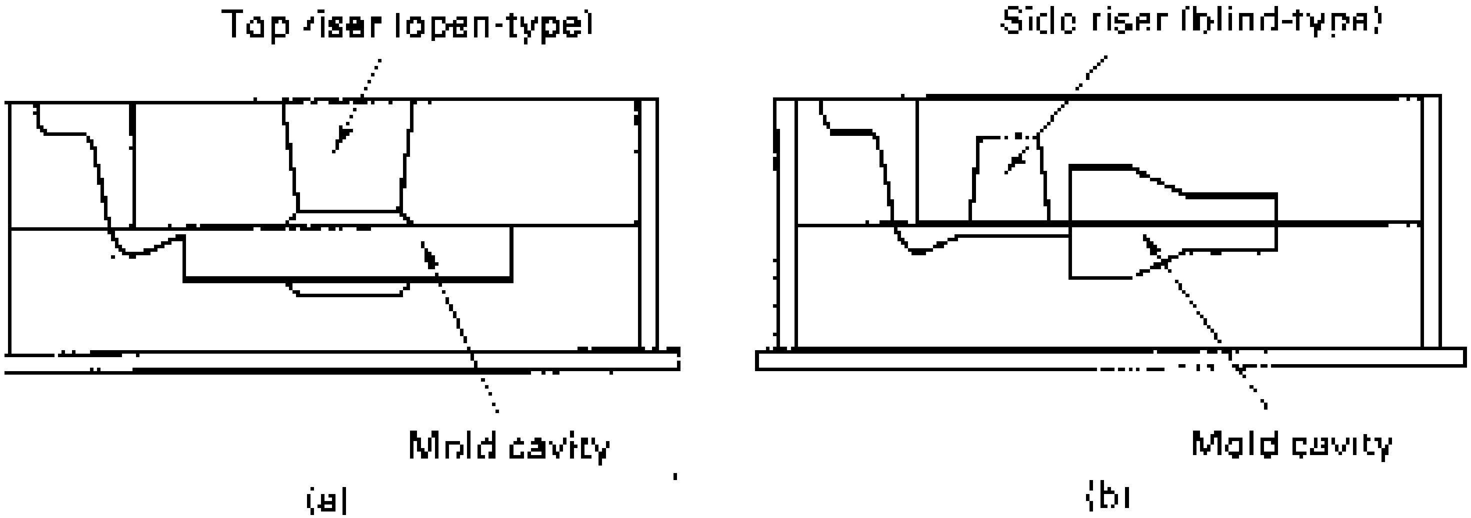
Based on Parting line

Two-part mold showing the parting line and the incorporation of a draft allowance on vertical surfaces.





2. Riser design



Schematic of a sand casting mold, showing an open-type top riser (left) and a blind-type side riser (right). The side riser is a live riser, receiving the last hot metal to enter the mold. The top riser is a dead riser, receiving metal that has flowed through the mold cavity.

2. Riser Calculations

Calculation of riser solidification time

$$t_{riser} = 1.25 t_{casting}$$

$$\left(V/A\right)^2_{Riser} = 1.25 \left(V/A\right)^2_{Casting}$$

For a cylinder with D and H

$$V = \frac{\pi D^2}{4} H$$

$$A = \pi D H + 2\left(\frac{\pi D^2}{4}\right)$$

Castings should be designed to promote directional solidification from far extremities towards the riser

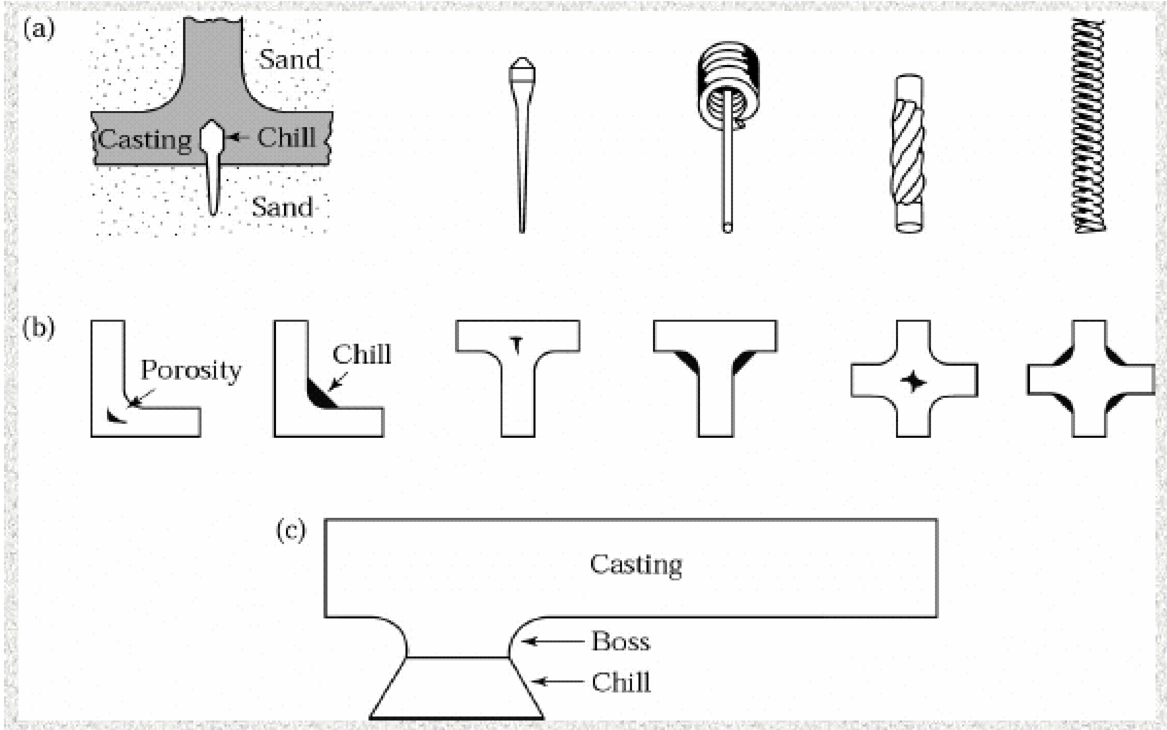
Multiple risers may be used

Riser shape is mostly cylindrical

2. Risering Aids

There are some aids for improving casting quality and reducing defects:

- Various types of a) internal and b) external chills used in castings to eliminate porosity caused by shrinkage
- Chills are placed in regions where there is larger volume of metal (c)

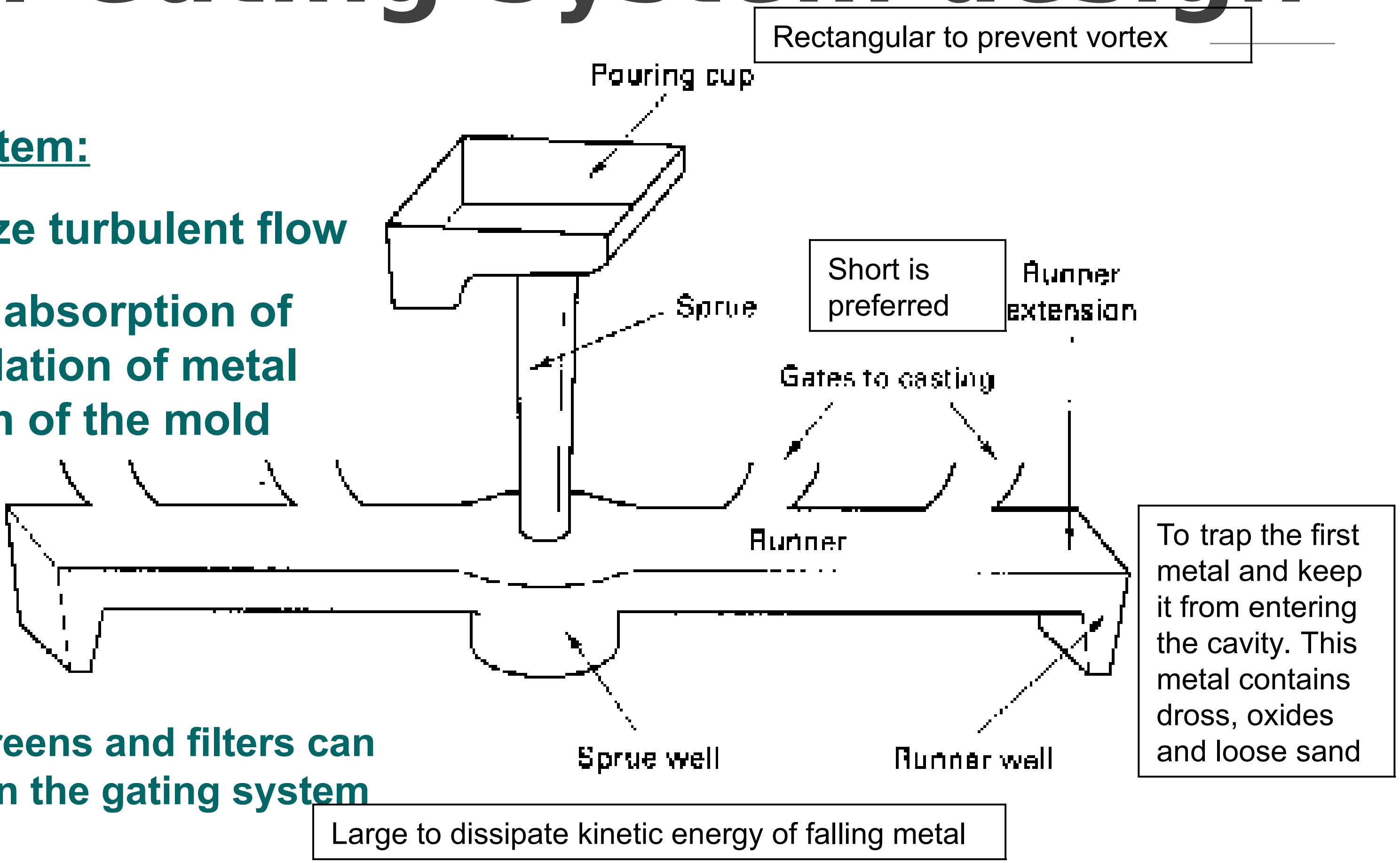


Insulating sleeves and exothermic materials can be used for directional solidification and improving casting yield

3. Gating System design

Gating System:

- **To minimize turbulent flow**
- **To reduce absorption of gases, oxidation of metal and erosion of the mold**



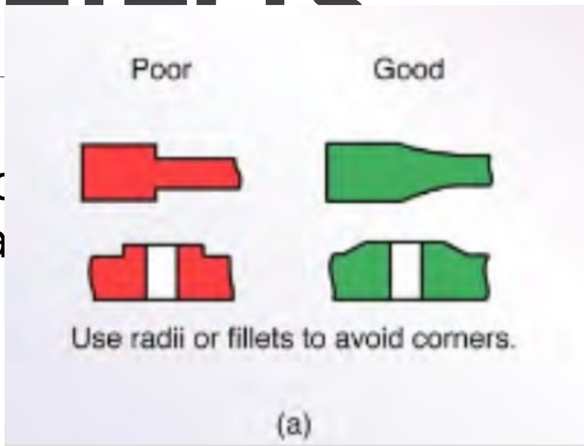
- **Ceramic screens and filters can be inserted in the gating system**

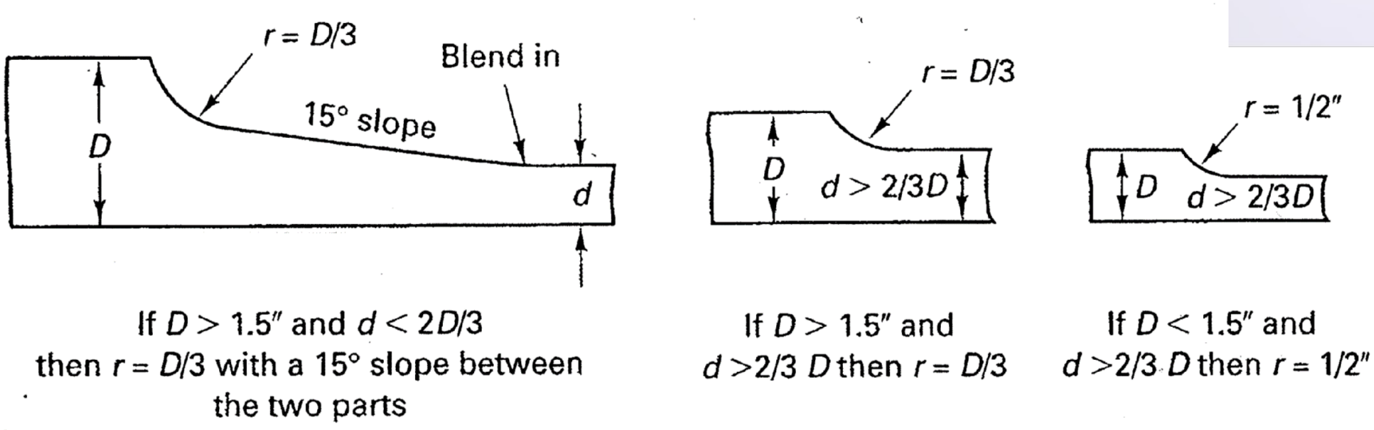
Typical gating system for a horizontal parting plane mold, showing key components involved in controlling the flow of metal into the mold cavity.

4.Design Considerations to avoid casting defects

avoid sharp corners

- use fillets to blend section changes smoo
- avoid rapid changes in cross-section area





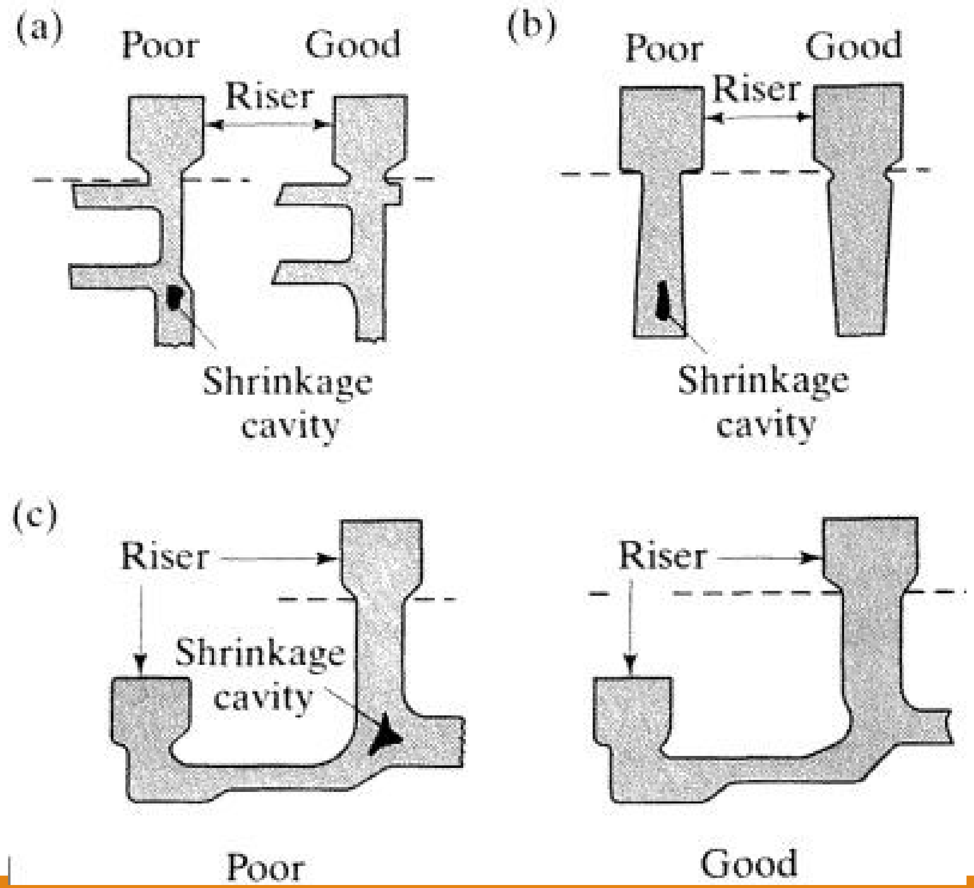
Typical guidelines for section change transitions in castings.

Design Considerations

account for shrinkage

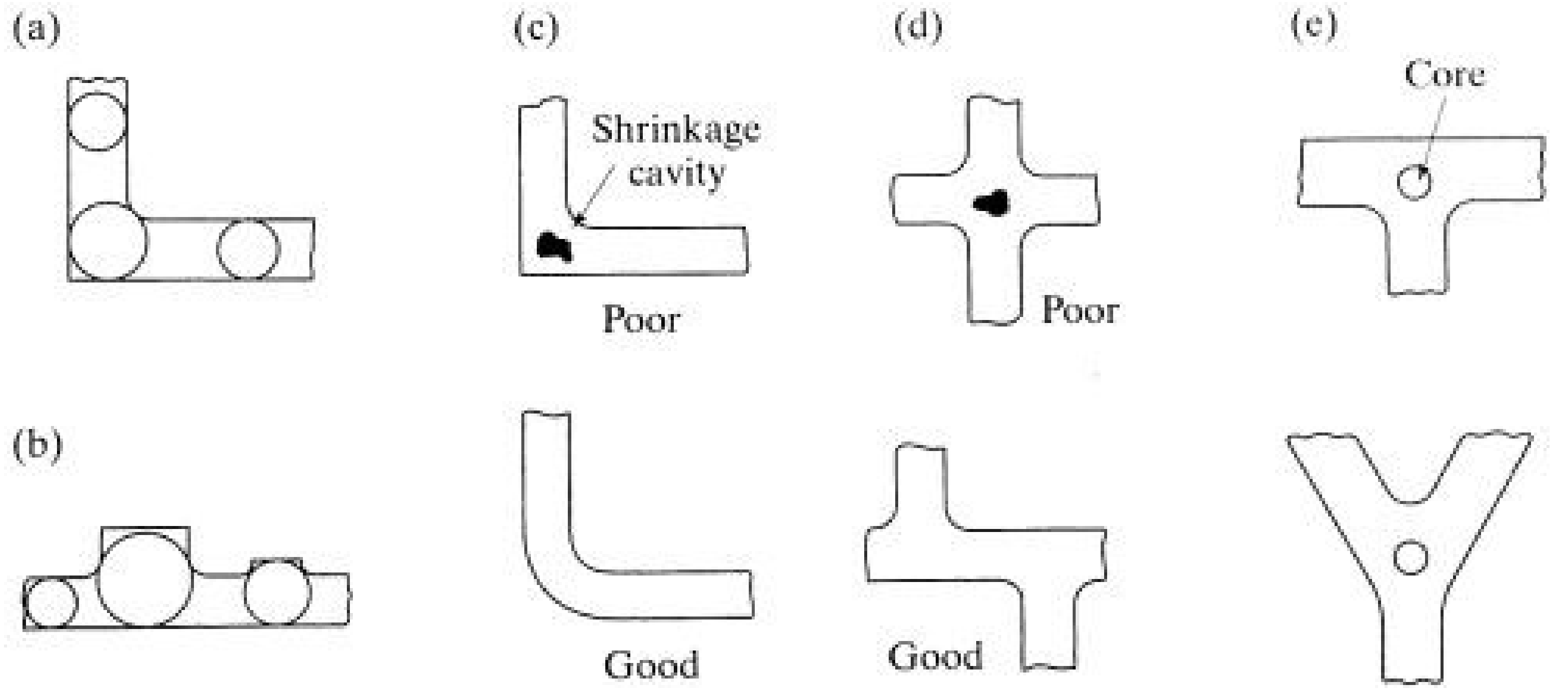
- geometry

- shrinkage cavities



Design Considerations

Avoid shrinkage cavities



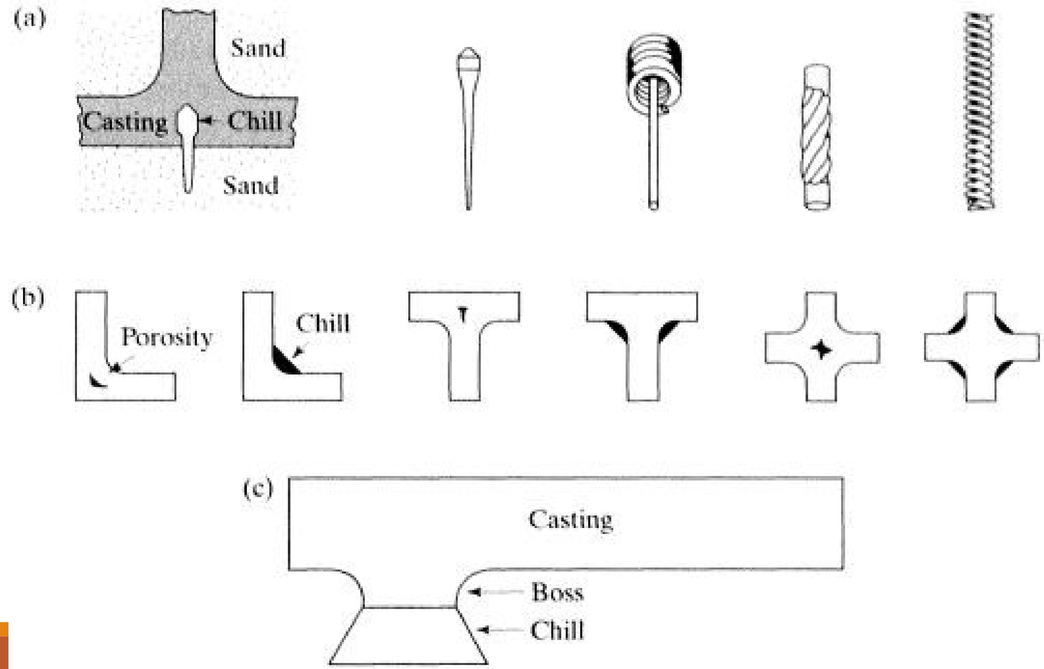
Design Considerations

avoid rapid changes in cross-section areas

if unavoidable, design mold to ensure

- easy metal flow

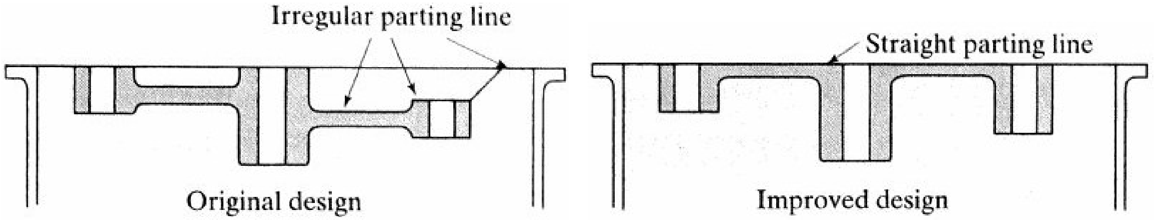
- uniform, rapid cooling (use chills, fluid-cooled tubes)

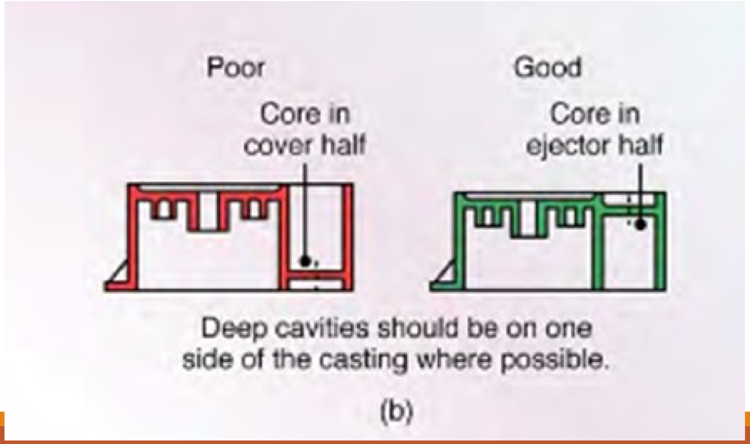


Design Considerations

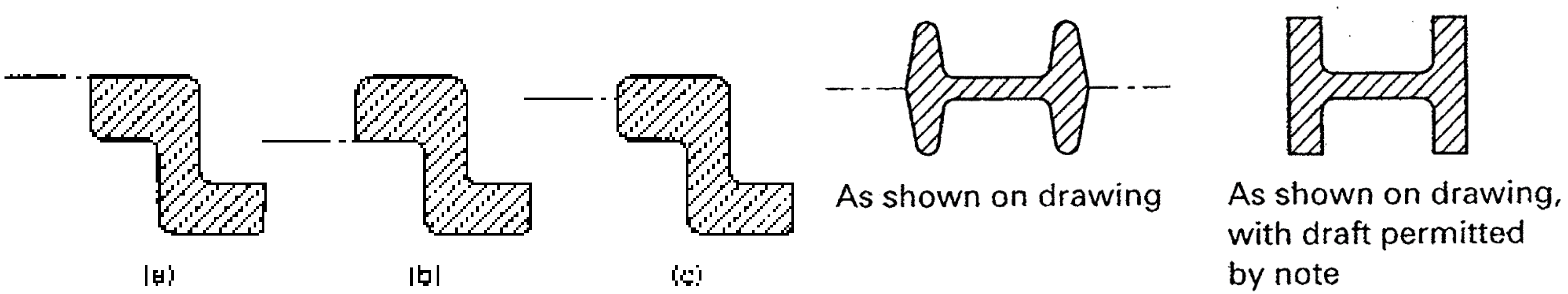
proper design of parting line

- "flattest" parting line is best





Design Considerations

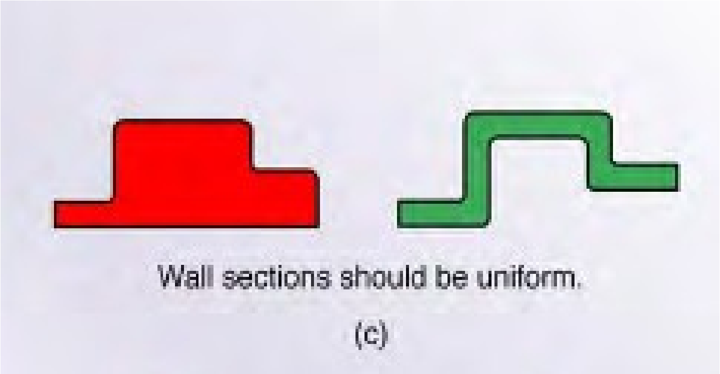


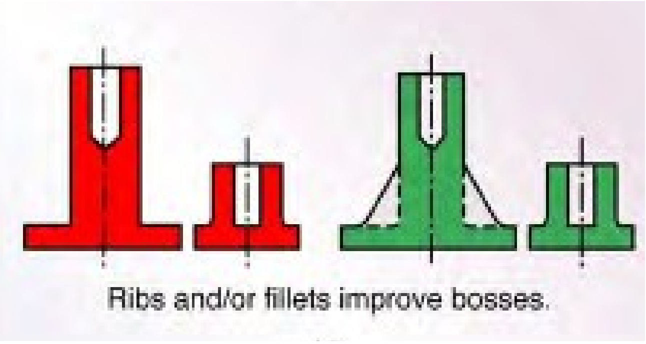
Optional results, with and without draft (exaggerated)

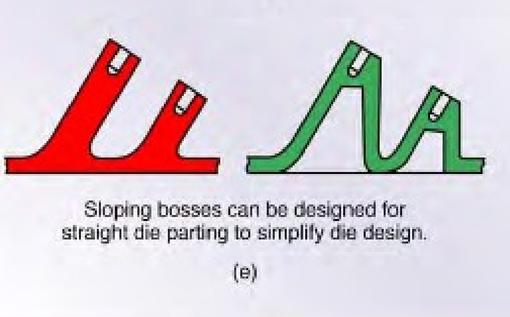
- Parting planes should not intersect rounded edges. Three alternative designs are presented.

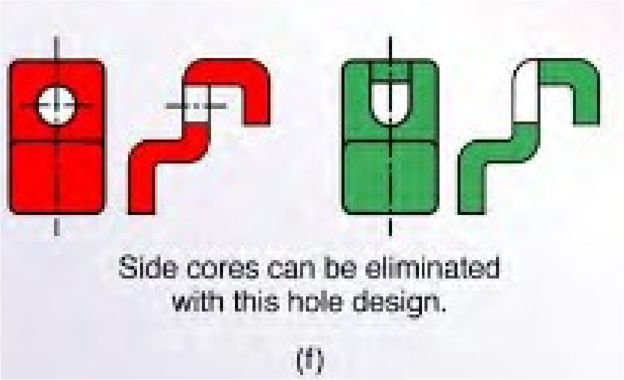
(top left) Design where the location of the parting plane is specified by the draft (top right) part with draft unspecified. (bottom) various options to produce the top right part, including a no-draft design.

Design consideration





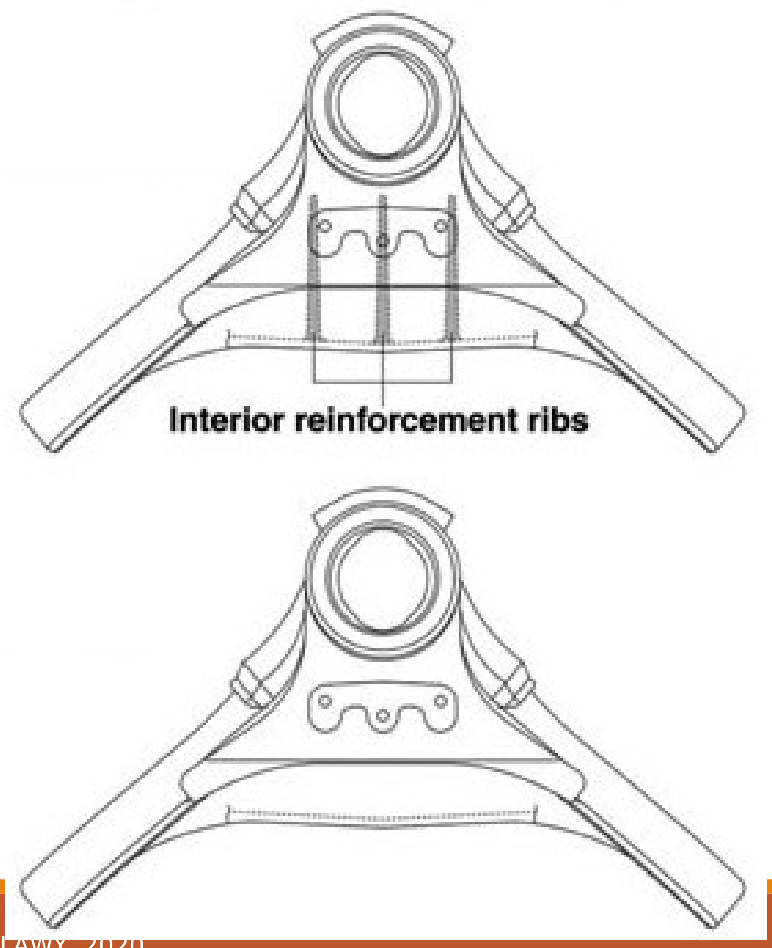




Design Considerations

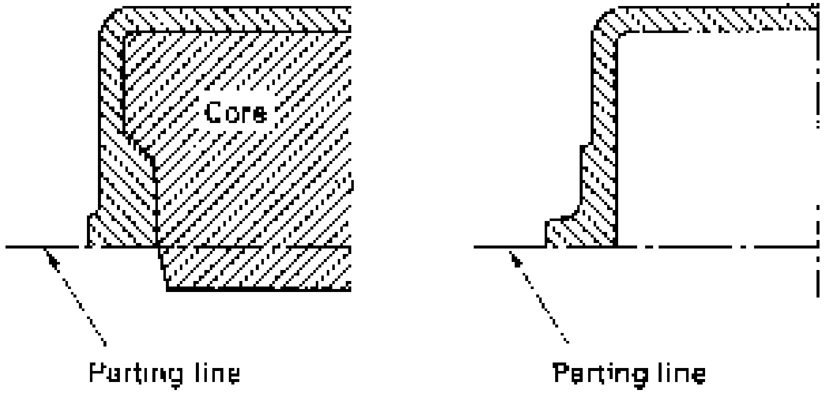
avoid large, flat areas

- warpage due to residual stresses

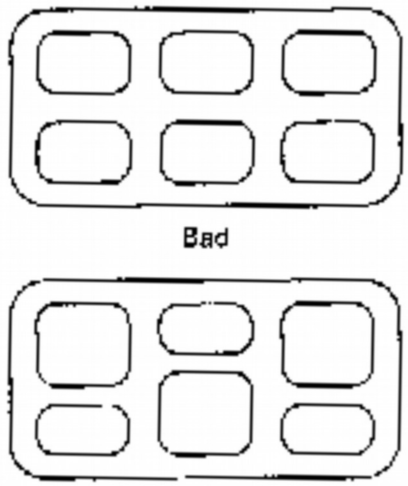


Design Considerations

- Use part design modification to eliminate problems



Elimination of a dry-sand core by a change in part design.



- Method of using staggered ribs to prevent cracking during cooling.

4. Core Design Considerations

Hollow castings

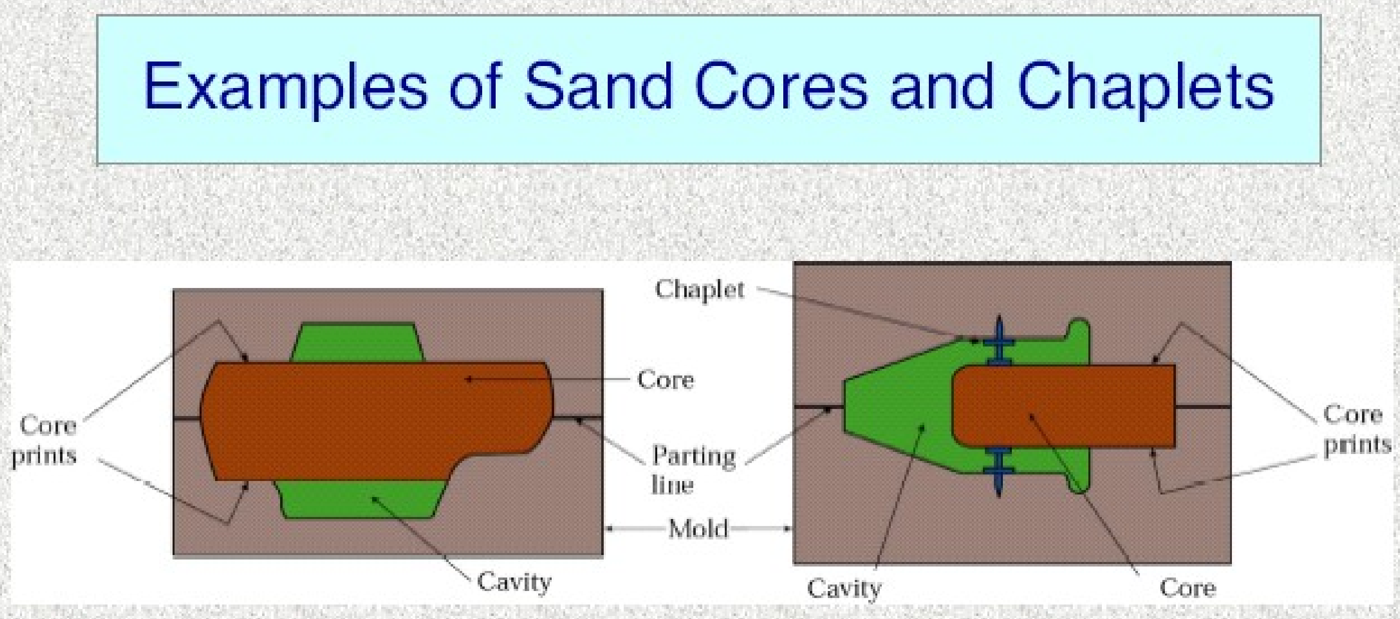
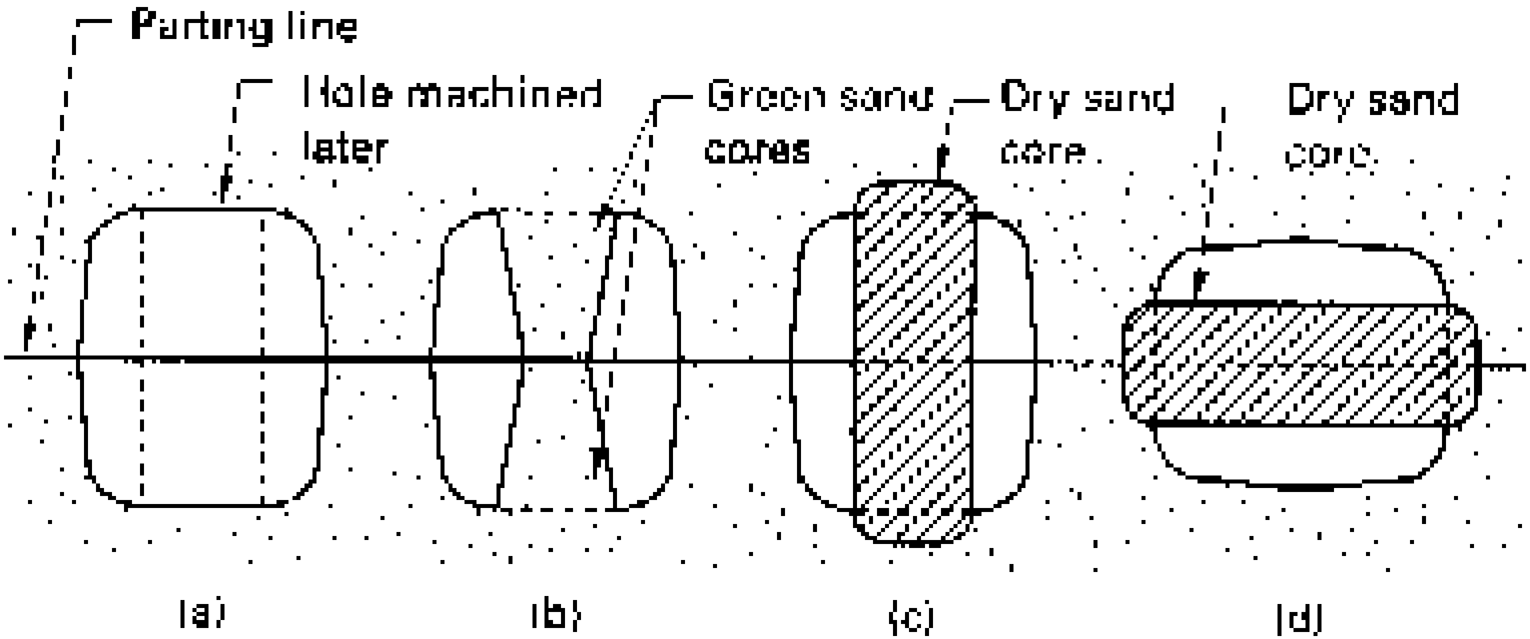


Figure 11.8 Examples of sand cores showing core prints and chaplets to support cores.

The core size or diameter has to be larger than the produced cavity to compensate for shrinkage

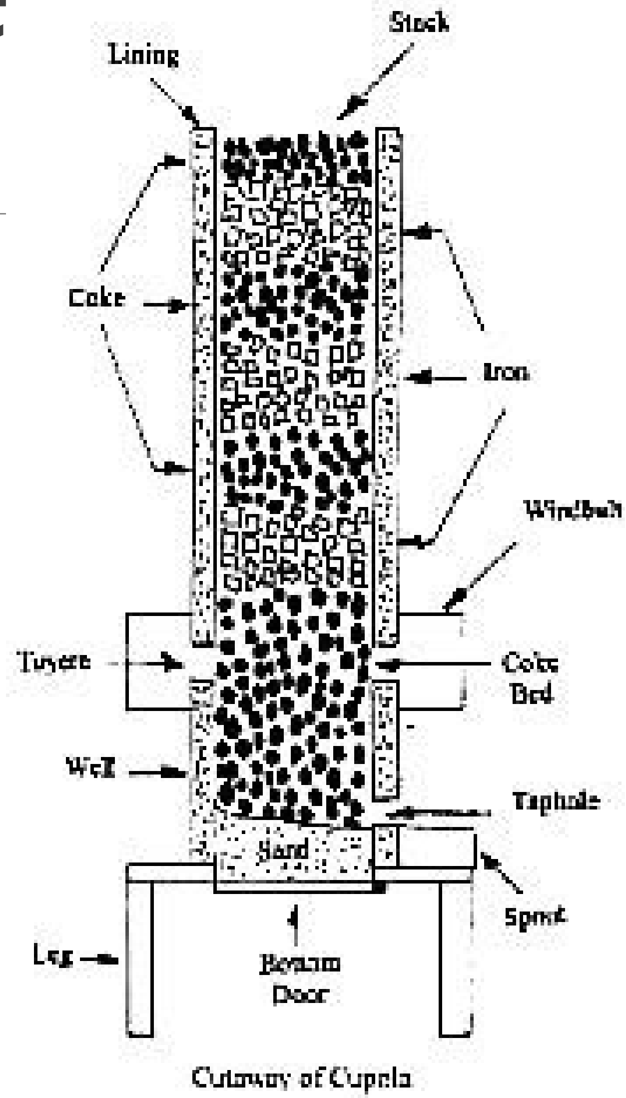
Four methods of making a hole in a cast pulley. Threy show the use of a core.



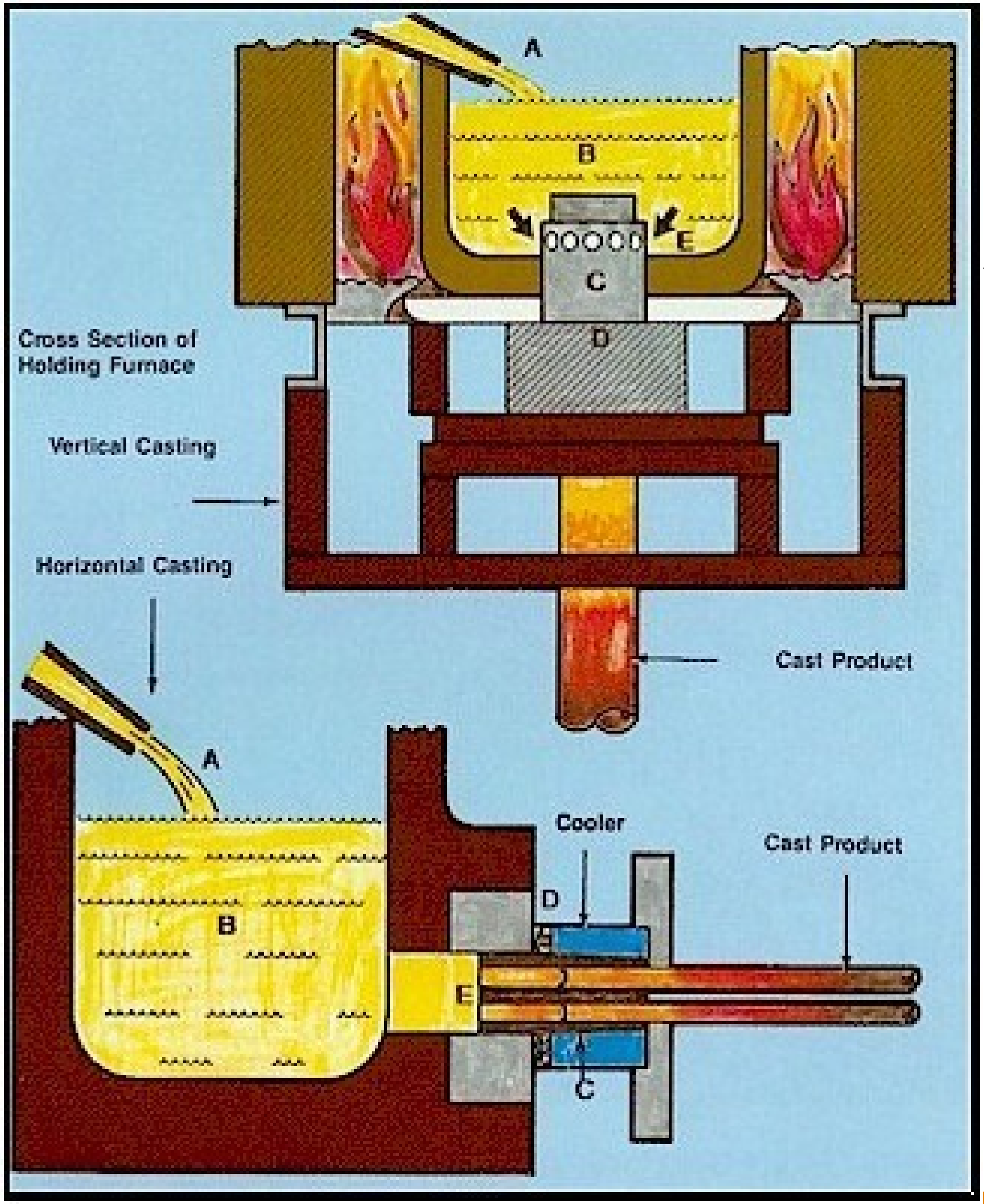
Melting furnaces

Crucible furnace

Channel induction furnace



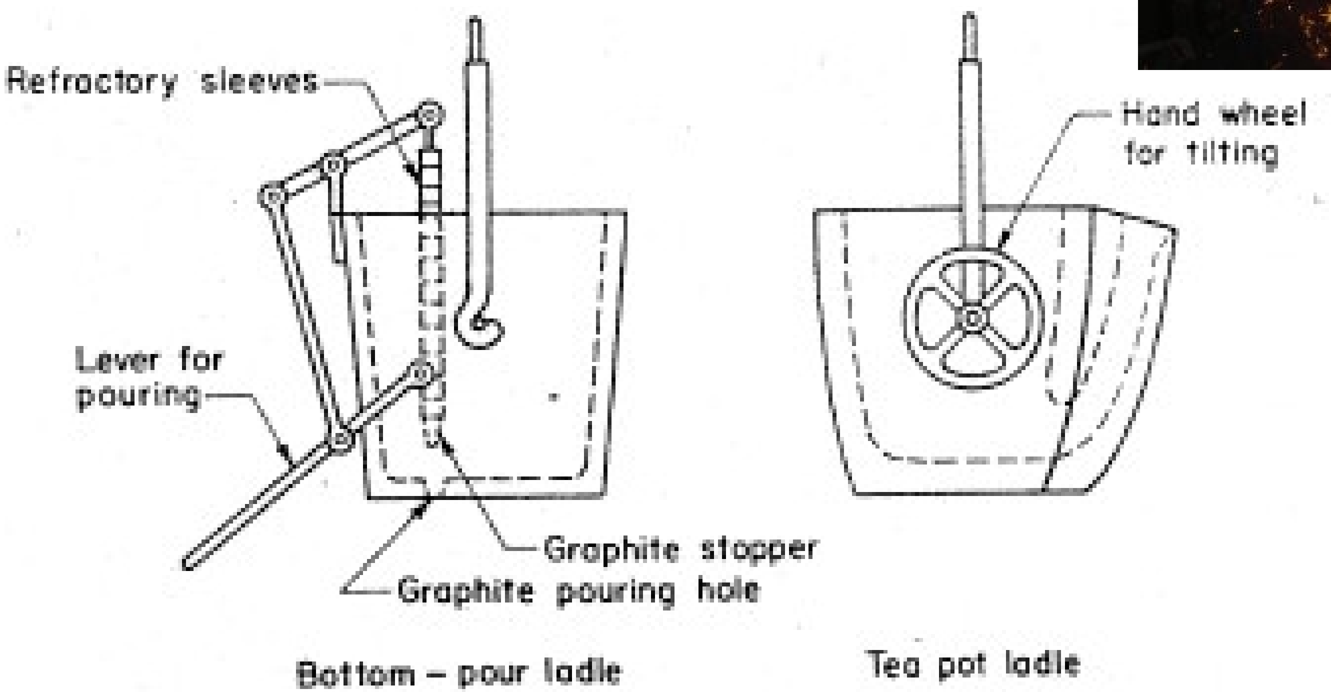
Cupola furnace for cast iron



Holding furnaces

Resistance furnace

Pouring of Castings



2 types of ladles used in the pouring of castings

- Note how each avoids pouring the impure material from the top of the molten pool

Review questions

Find 10 different cast products and explain why they are cast

Describe the main operations or steps in performing a casting process and the equipment needed for each step.

Explain the reasons why heat transfer and fluid flow are important in metal casting

Draw the cooling curve of pure metal and of an alloy. Describe the related cooling and solidification parameters.

Sketch a typical cast structure of pure metal, alloy, alloy with nucleating agent

What is the columnar and equiaxed structures? What is their effect on the mechanical properties of the cast product?

What are the different parts of a casting mold? What is the function of risers and gating system?

What are the chills? Where should they be located? How they can reduce the shrinkage cavities in a casting?

Write the equation for the solidification time

A round casting is 0.2m in diam. And 0.5m in length. Another casting of the same metal is elliptical in cross section with a major to minor axis ratio of 2 and has the same length and cross sectional area as the round casting. Both pieces are cast under the same conditions. What is the difference in the solidification times of the two castings?