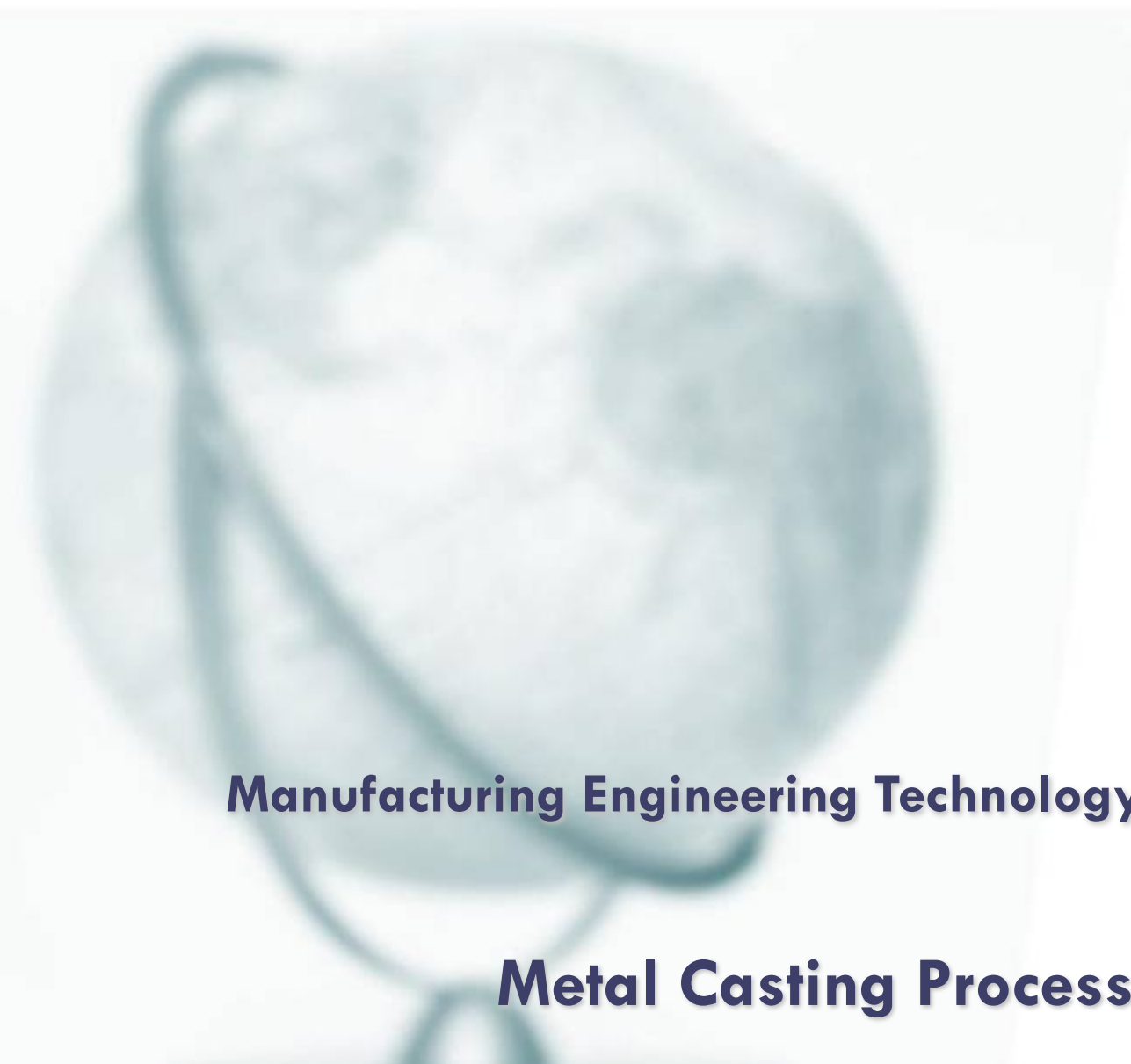


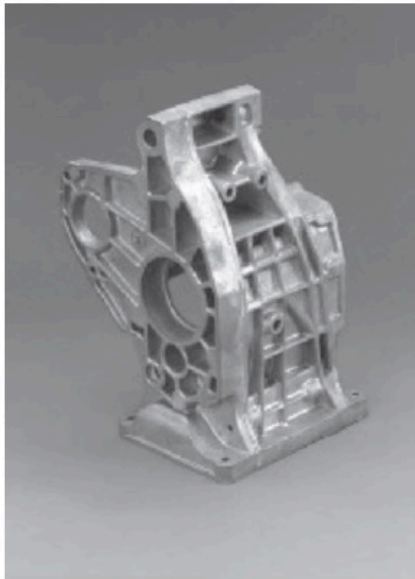


Manufacturing Engineering Technology in SI Units, 6th Edition

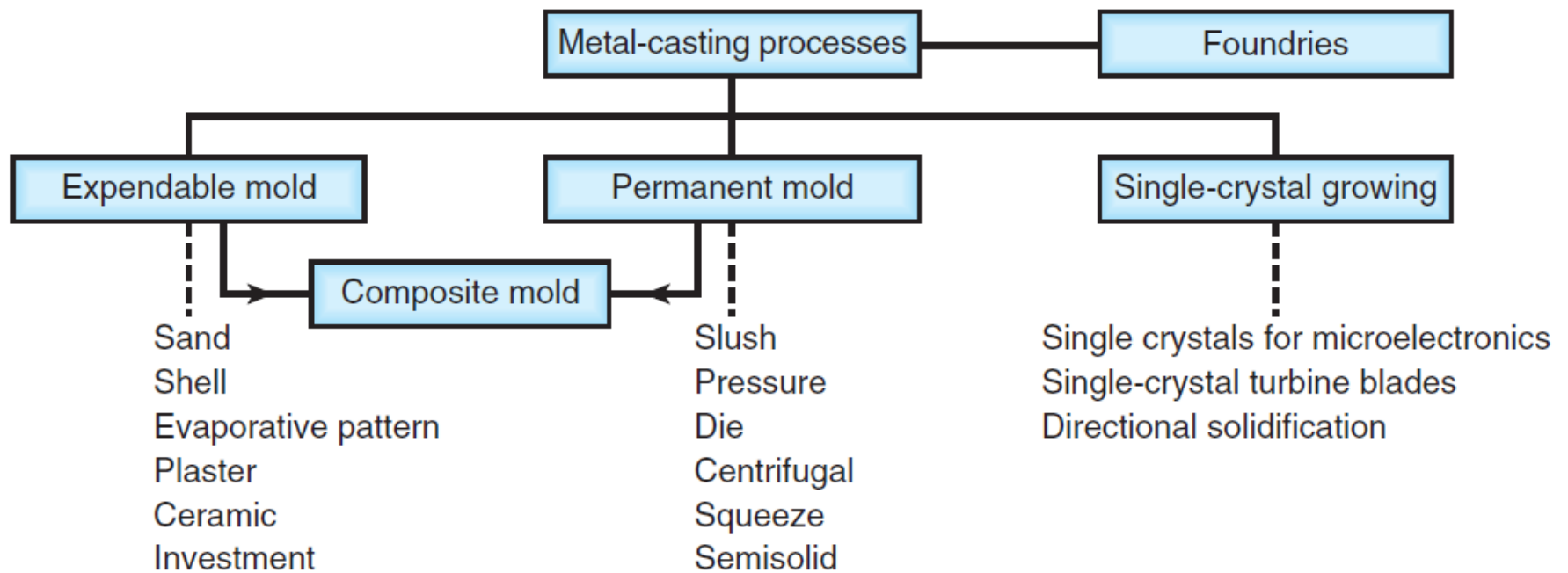
PART II:
Metal Casting Processes and Equipment

Introduction

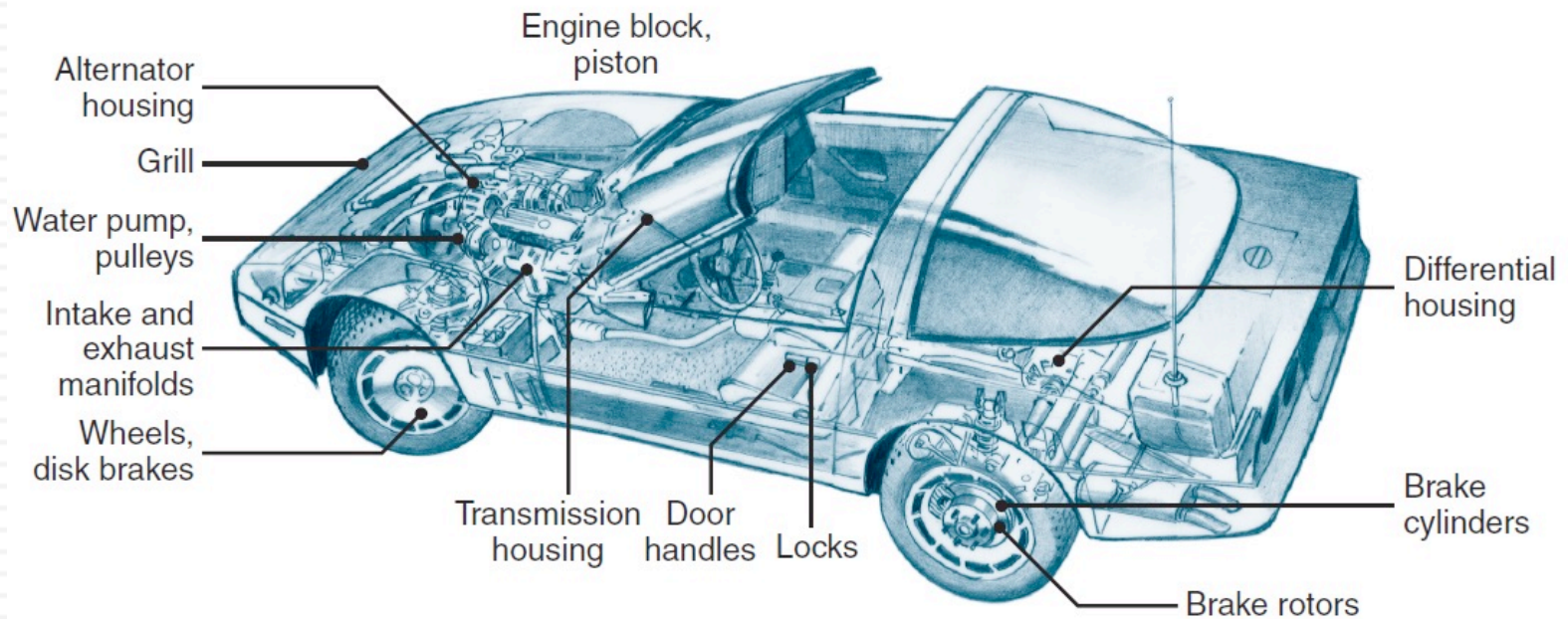
- ❑ **Casting** involves pouring molten metal into a mold cavity
- ❑ Process produce intricate shapes in one piece with internal cavities



Introduction



Introduction



Introduction

- Casting processes advantages are:
 1. Produce complex shapes with internal cavities
 2. Very large parts can be produced
 3. Difficult materials shape can be produced
 4. Economically competitive with other manufacturing processes

Manufacturing Engineering Technology in SI Units, 6th Edition
Chapter 10: Fundamentals of Metal Casting

Chapter Outline

1. Introduction
2. Solidification of Metals
3. Fluid Flow
4. Fluidity of Molten Metal
5. Heat Transfer
6. Defects

Introduction

- **Casting process involves:**
 - a) Pouring molten metal into a mold patterned
 - b) Allowing it to solidify
 - c) Removing the part from the mold

- **Considerations in casting operations:**
 - 1. Flow of the molten metal into the mold cavity
 - 2. Solidification and cooling of the metal
 - 3. Type of mold material



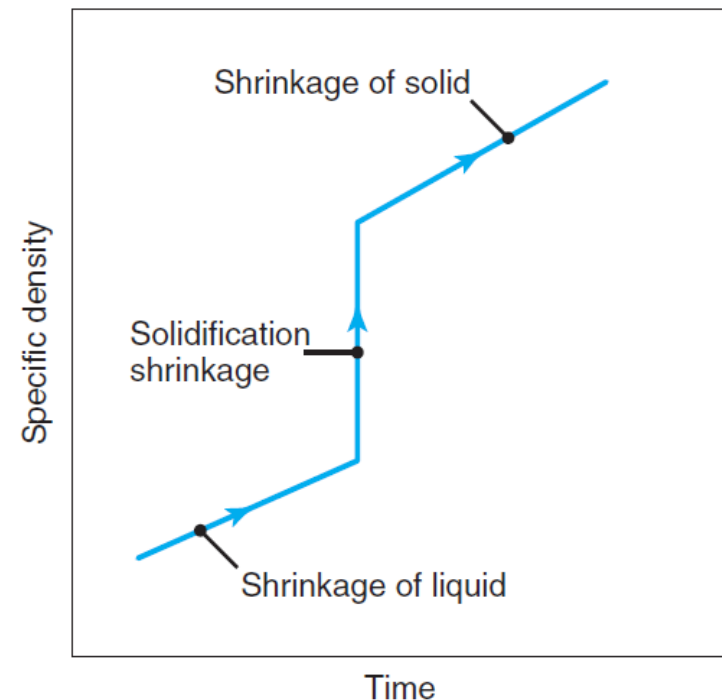
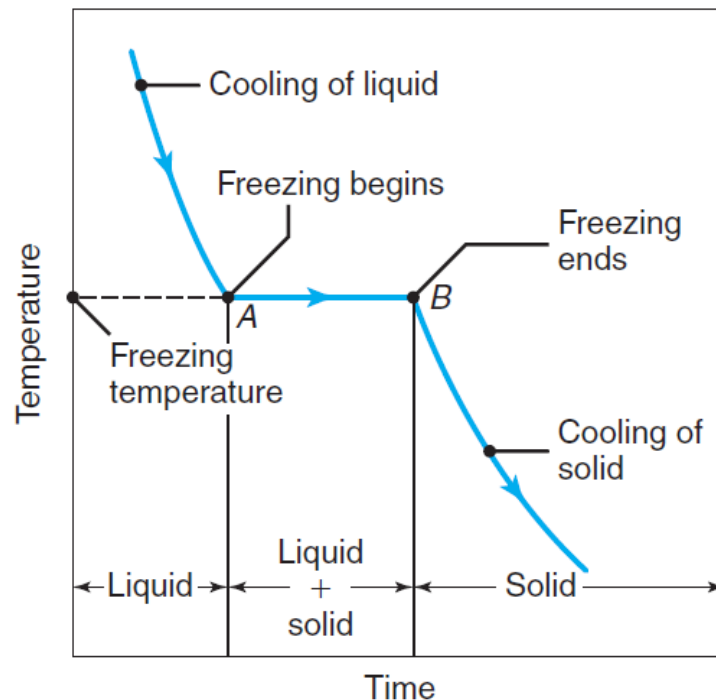
Introduction

- Solidification and cooling of metals are affected by metallurgical and thermal properties of the metal
- Type of mold also affects the rate of cooling

Solidification of Metals:

Pure Metals

- Pure metal has a clearly defined melting point and solidifies at a constant temperature



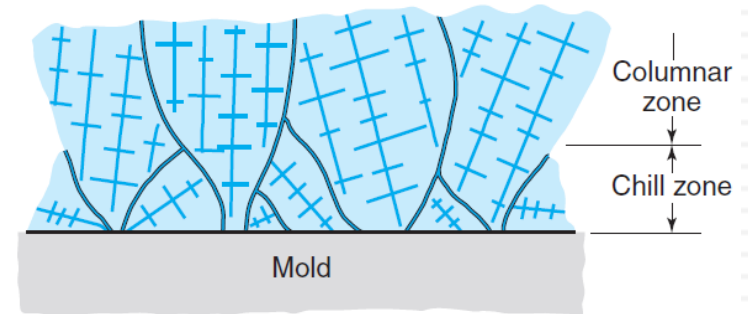
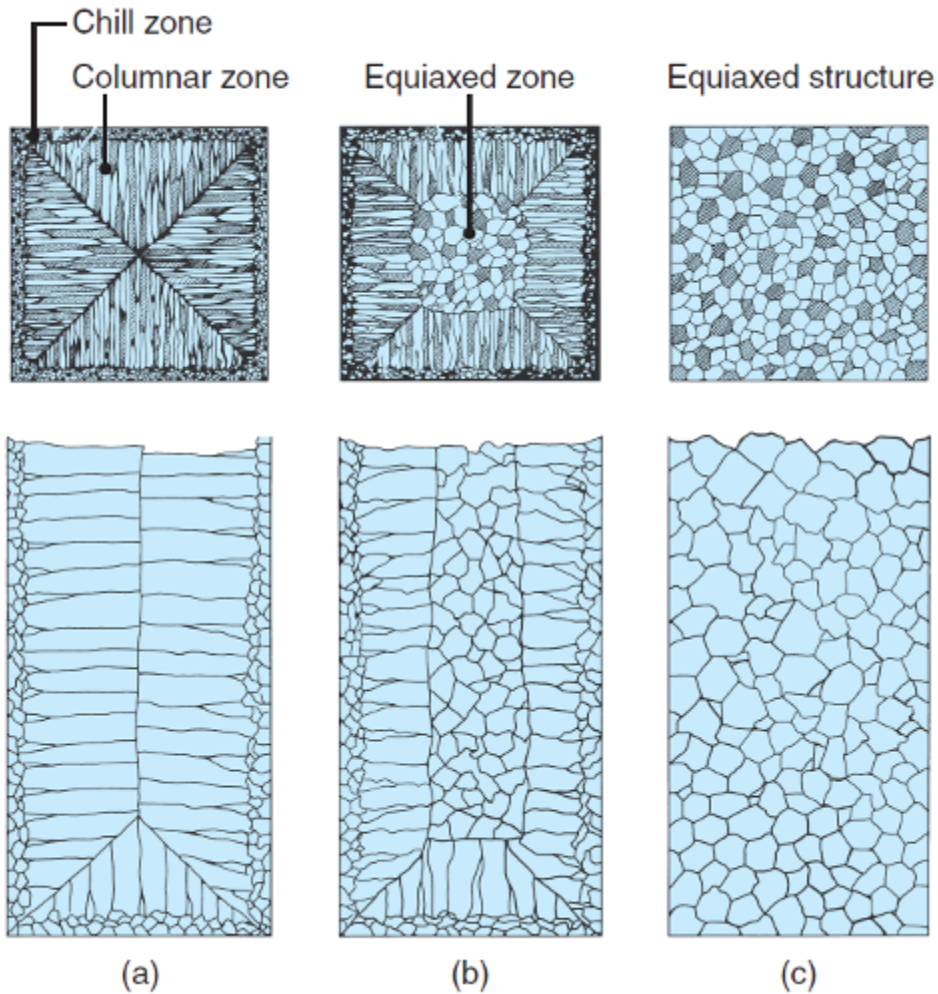
Solidification of Metals:

Pure Metals

- When temperature of the molten metal drops to its freezing point, *latent heat of fusion* is given off
- *Solidification front* moves through the molten metal from the mold walls in toward the center
- Metals shrink during cooling and solidification
- Shrinkage can lead to microcracking and associated porosity
- Grains grow in a direction opposite to heat transfer out through the mold

Solidification of Metals:

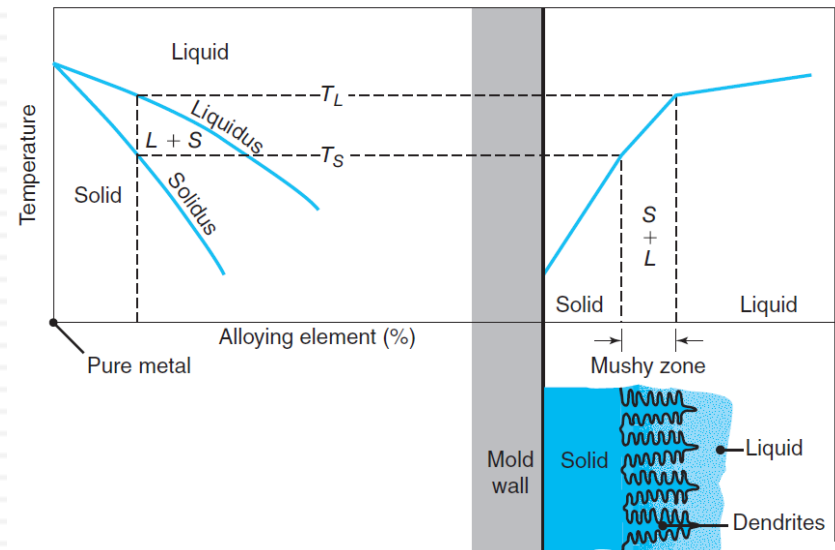
Pure Metals



Solidification of Metals:

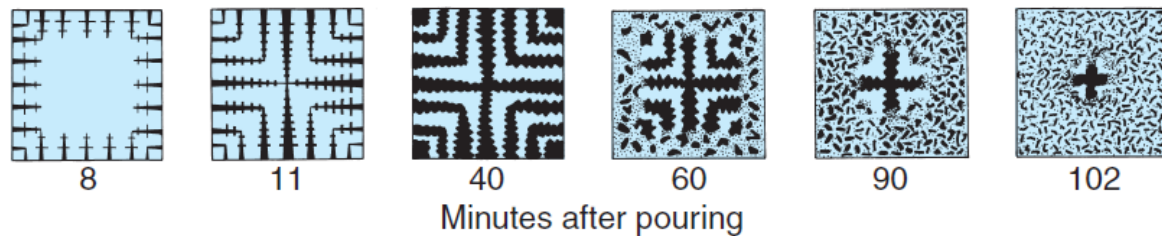
Alloys

- ❑ Solidification in alloys starts when below liquidus and complete when it reaches the solidus
- ❑ Alloy in a *ushy* or *pasty* state consisting of **columnar dendrites**
- ❑ Dendrites have inter-locking 3-D arms and branches
- ❑ Dendritic structures contribute to detrimental factors

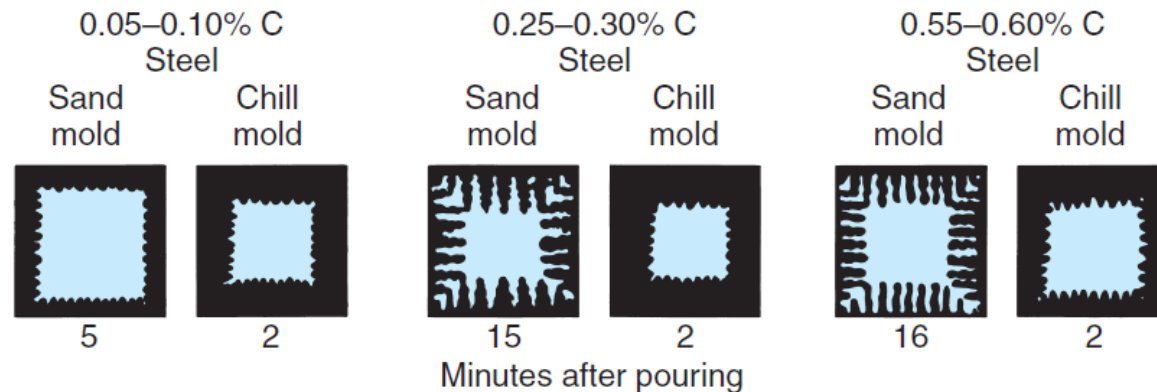


Solidification of Metals: Alloys

- Width of the **mushy zone** is described in terms of **freezing range, $T_L - T_S$**



(a)



(b)

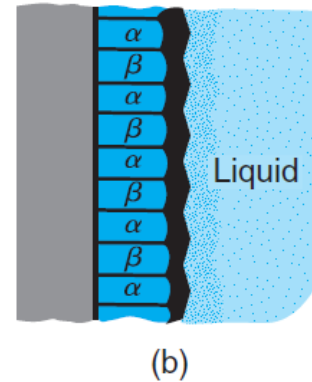
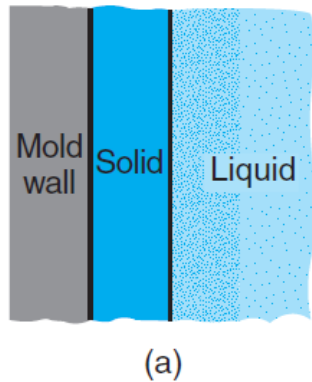
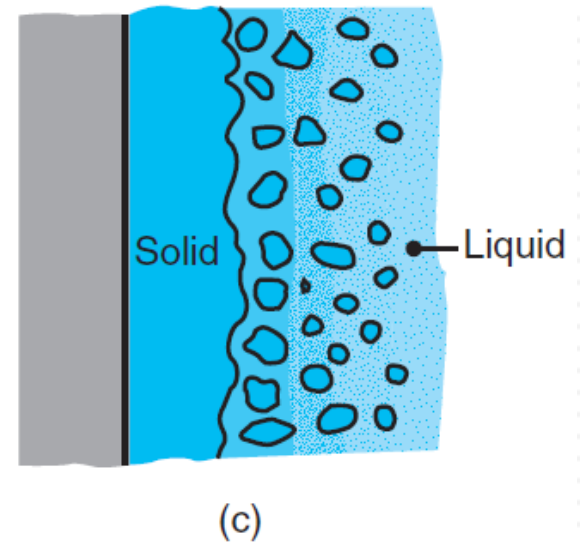
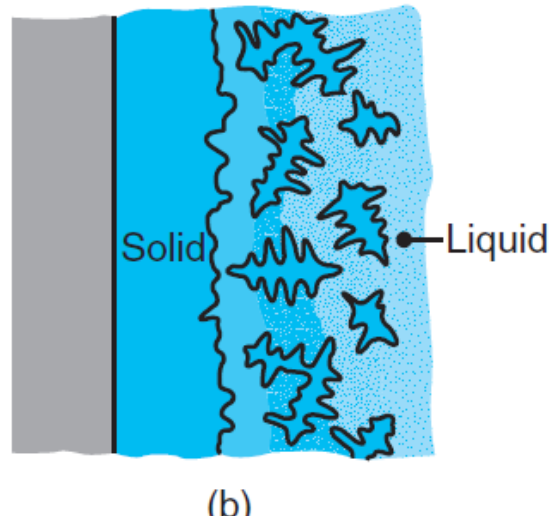
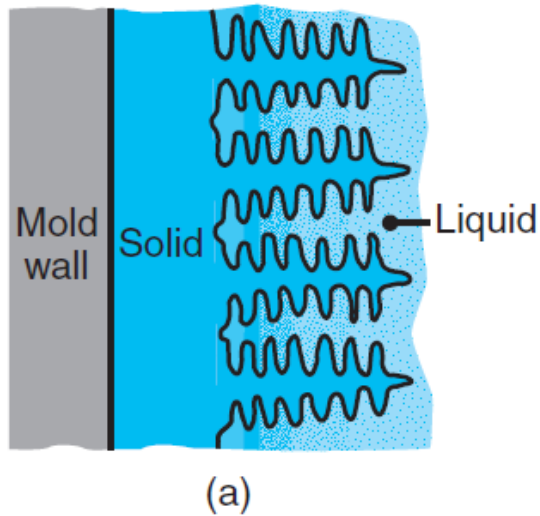
Solidification of Metals: Alloys

Effects of Cooling Rates

- ❑ Slow cooling rates result in *coarse* dendritic structures with large spacing between dendrite arms
- ❑ For higher cooling rates the structure becomes *finer* with smaller dendrite arm spacing
- ❑ Smaller the grain size, the strength and ductility of the cast alloy increase, microporosity in the casting decreases, and tendency for casting to crack

Solidification of Metals:

Alloys



Solidification of Metals:

Structure–property Relationships

- Compositions of dendrites and liquid metal are given by the *phase diagram* of the particular alloy
- Under the faster cooling rates, **cored dendrites** are formed
- Surface of dendrite has a higher concentration of alloying elements, due to solute rejection from the core toward the surface during solidification of the dendrite (**microsegregation**)

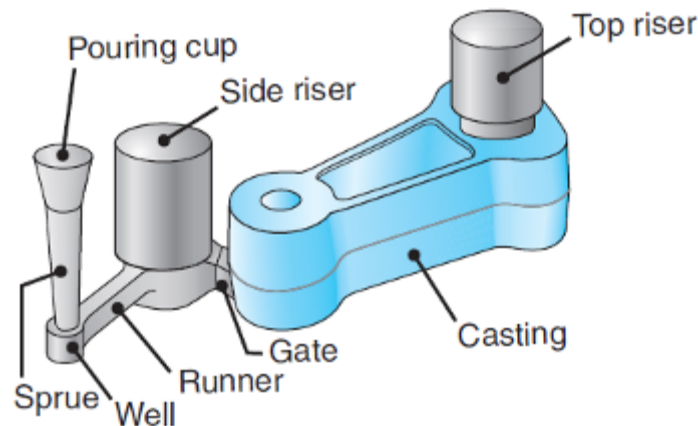
Solidification of Metals:

Structure–property Relationships

- ❑ **Macrosegregation** involves differences in composition throughout the casting itself
- ❑ **Gravity segregation** is the process where higher density inclusions and lighter elements float to the surface
- ❑ Dendrite arms are not strong and can be broken up by agitation during solidification
- ❑ Results in finer grain size, with equiaxed nondendritic grains

Fluid Flow

- Successful casting requires proper design; to ensure adequate fluid flow in the system
- Typical riser-gated casting
- Risers serve as reservoirs, supplying molten metal to the casting as it shrinks during solidification



Fluid Flow

- Two basic principles of fluid flow

1) Bernoulli's Theorem

- Based on the principle of the conservation of energy
- Relates pressure, velocity, elevation of fluid and frictional losses in a system
- At a particular location in the system, the Bernoulli equation is

$$h_1 + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} = h_2 + \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + f$$

1 and 2 represent two different locations in the system

Fluid Flow

2) Mass Continuity

- Law of mass continuity states that

$$Q = A_1 v_1 = A_2 v_2$$

Q = volume rate of flow

A = cross sectional area of the liquid stream

v = average velocity of the liquid in that cross section

- Flow rate will decrease as the liquid moves through the system

Fluid Flow

Sprue Design

- Assuming the pressure at the top of the sprue is equal to the pressure at the bottom and frictionless,

$$\frac{A_1}{A_2} = \sqrt{\frac{h_2}{h_1}}$$

- Moving downward from the top, the cross sectional area of the sprue must decrease

Fluid Flow

Modeling

- Velocity of the molten metal leaving the gate is obtained from

$$v = c\sqrt{2gh}$$

where h = distance from the sprue base to the liquid metal height
 c = friction factor

- For frictionless flow, c equals unity 1
- Flows with friction c is always between 0 and 1

Fluid Flow

Flow Characteristics

- Presence of **turbulence** is as opposed to the *laminar flow* of fluids
- The *Reynolds number*, Re , is used to quantify fluid flow

$$Re = \frac{vD\rho}{\eta}$$

v = velocity of the liquid

D = diameter of the channel

ρ, η = density and viscosity of the liquid

Fluidity of Molten Metal

- *Fluidity* consists of 2 basic factors:
 1. Characteristics of the molten metal
 2. Casting parameters

Viscosity

- Viscosity and *viscosity index* increase, fluidity decreases

Surface Tension

- High surface tension of the liquid metal reduces fluidity



Fluidity of Molten Metal

Inclusions

- Inclusions can have a adverse effect on fluidity

Solidification Pattern of the Alloy

- Fluidity is inversely proportional to the freezing range

Mold Design

- Design and dimensions of the sprue, runners and risers influence fluidity

Fluidity of Molten Metal

Mold Material and its Surface Characteristics

- High thermal conductivity of the mold and the rough surfaces lower the fluidity

Degree of Superheat

- *Superheat* improves fluidity by delaying solidification

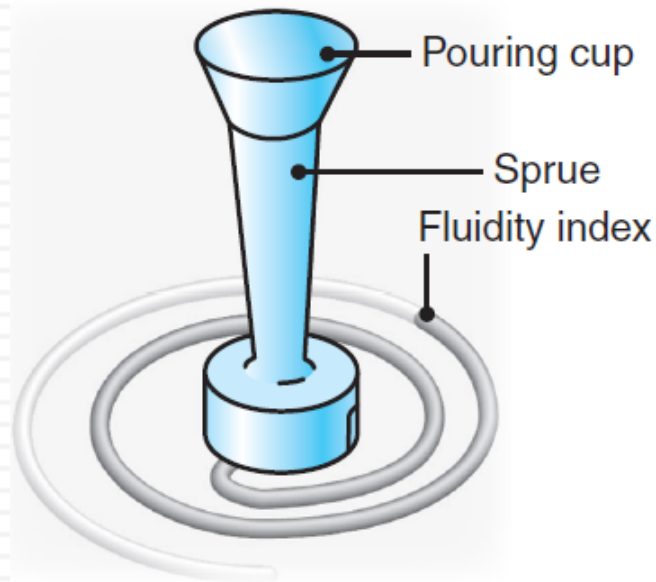
Rate of Pouring

- Slow rate of pouring lower the fluidity

Fluidity of Molten Metal:

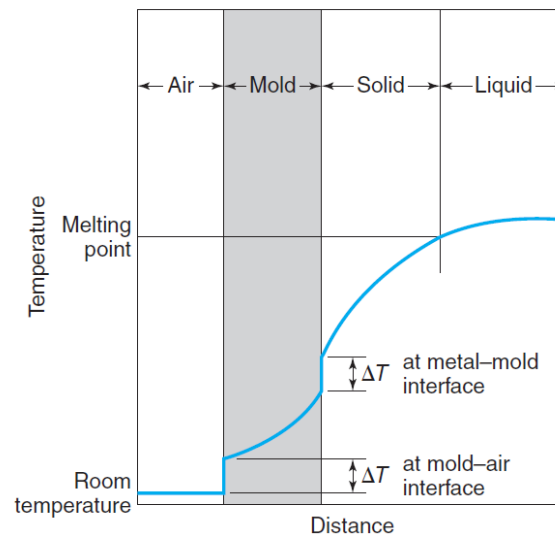
Tests for Fluidity

- One common test is to make molten metal flow along a channel at room temperature
- The distance the metal flows before it solidifies and stops flowing is a measure of its fluidity



Heat Transfer

- Heat transfer complete cycle include pouring, solidification and cooling to room temperature
- Metal flow rates must be high enough to avoid premature chilling and solidification
- But not so high as to cause turbulence



Heat Transfer:

Solidification Time

- A thin skin form at the cool mold walls during solidification
- Thickness of the skin increases with respect to time
- *Chvorinov's rule* states that

$$\text{Solidification time} = C \left(\frac{\text{Volume}}{\text{Surface Area}} \right)^n$$

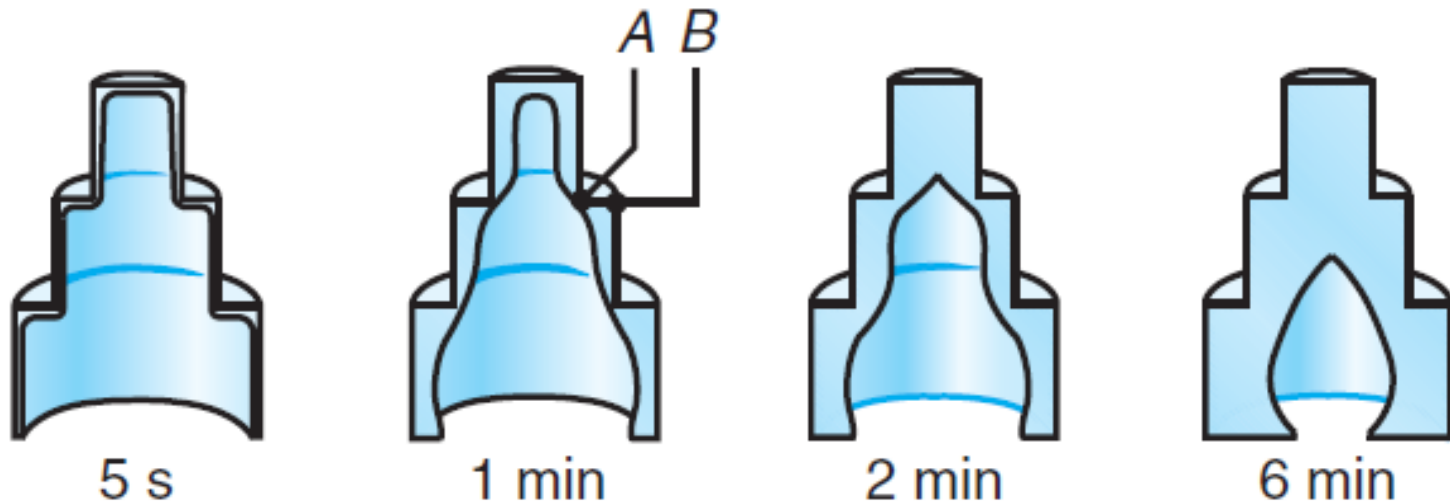
where n is taken as 2

- C is a constant that reflects mold material, metal properties and temperature

Heat Transfer:

Solidification Time

- Hollow ornamental and decorative objects are made by slush casting



Heat Transfer:

Solidification Time

EXAMPLE 10.1

Solidification Times for Various Shapes

3 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 is 2.

Heat Transfer:

Solidification Time

Solution

Solidification Times for Various Shapes

Volume of the piece is taken as unity,

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

For sphere,

$$V = \left(\frac{4}{3}\right)\pi r^3 = \left(\frac{3}{4\pi}\right)^{1/3} \quad \text{and} \quad A = 4\pi r^2 = 4\pi \left(\frac{3}{4\pi}\right)^{2/3} = 4.84$$

Heat Transfer:

Solidification Time

Solution

For cube, $V = a^3$, $a = 1$ and $A = 6a^2 = 6$

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

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

The respective solidification times are

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

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

Heat Transfer:

Shrinkage

- Metals shrink (contract) during solidification and cooling to room temperature
- *Shrinkage* due to 3 sequential events:
 1. Contraction of the molten metal before solidification
 2. Contraction of the metal during phase change
 3. Contraction of the solidified metal when drop to ambient temperature

Heat Transfer:

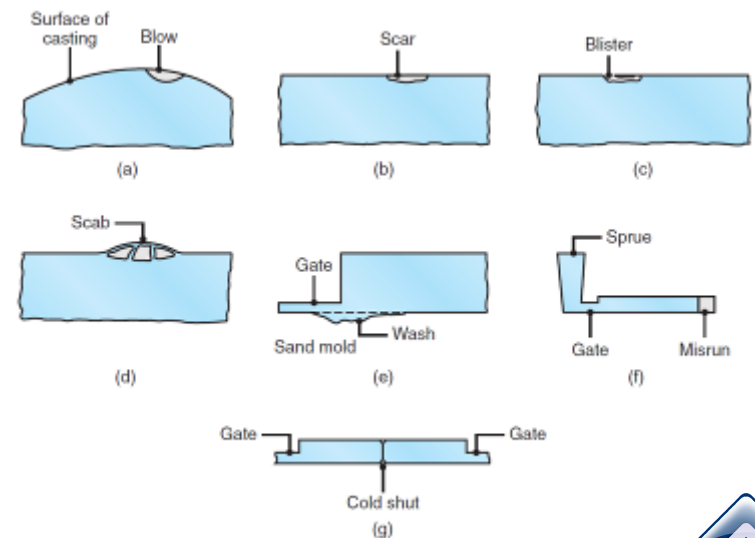
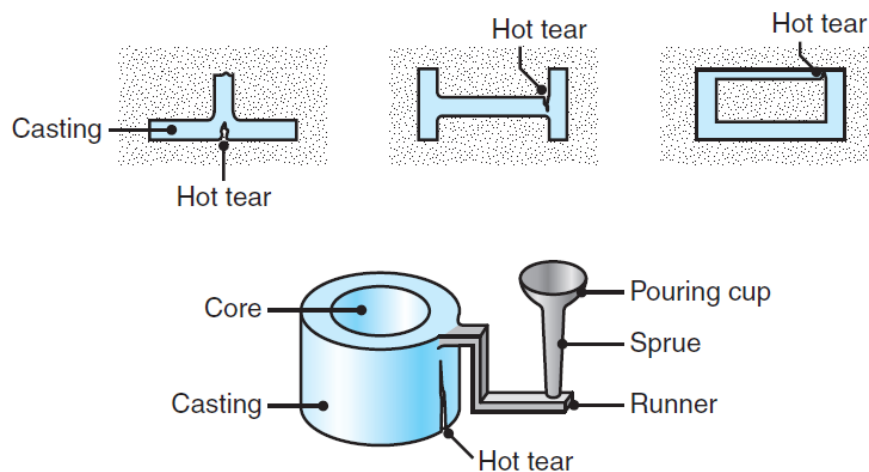
Shrinkage

Volumetric Solidification Contraction or Expansion for Various Cast Metals

Contraction (%)		Expansion (%)	
Aluminum	7.1	Bismuth	3.3
Zinc	6.5	Silicon	2.9
Al-4.5% Cu	6.3	Gray iron	2.5
Gold	5.5		
White iron	4-5.5		
Copper	4.9		
Brass (70-30)	4.5		
Magnesium	4.2		
90% Cu-10% Al	4		
Carbon steels	2.5-4		
Al-12% Si	3.8		
Lead	3.2		

Defects

- Defects are developed depend materials, part design and processing techniques
- Defects can develop in castings



Defects

- International Committee of Foundry Technical Associations has a standardized nomenclature for casting defects

A—Metallic projections

B—Cavities

C—Discontinuities

D—Defective surface

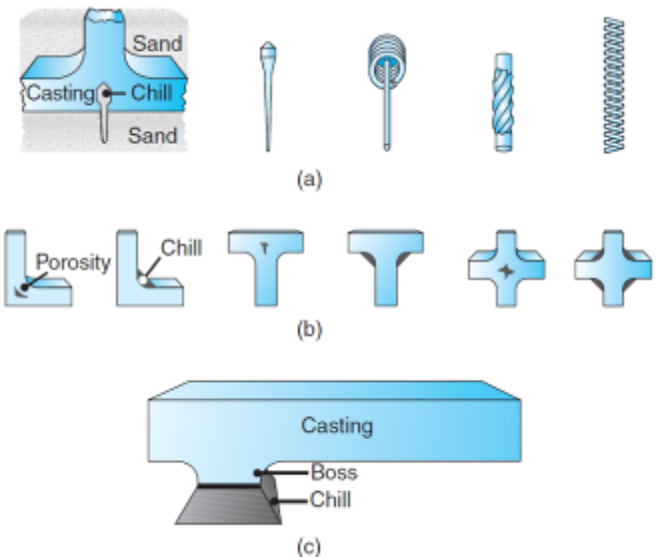
E—Incomplete casting

F—Incorrect dimensions or shape

G—Inclusions

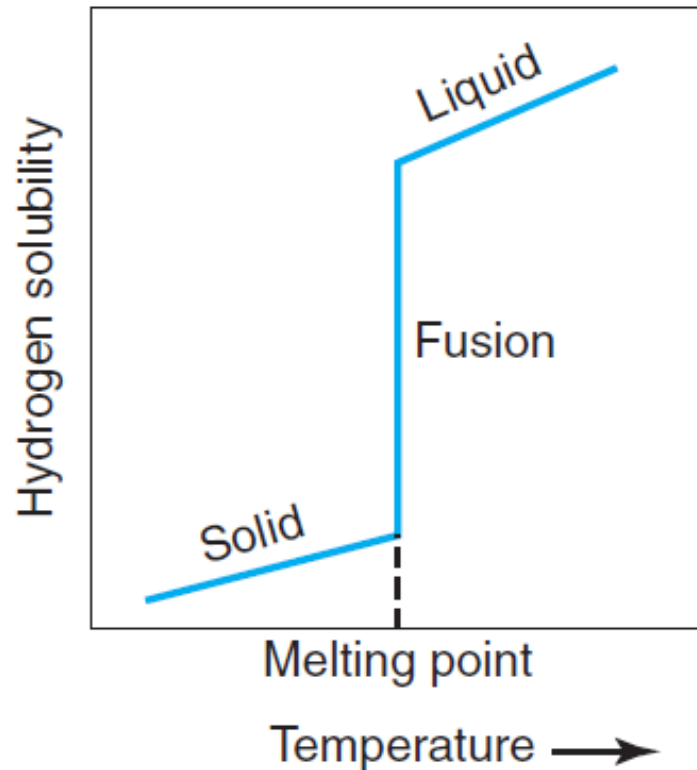
Defects: Porosity

- *Porosity* is caused by *shrinkage*, entrained and/or dissolved *gases*
- Porosity can cause ductility to a casting and surface finish
- Shrinkage can be reduced by:
 1. Adequate liquid metal
 2. Internal or external chills
 3. Cast with alloys
 4. Hot isostatic pressing



Defects: Porosity

- When a metal begins to solidify, the dissolved gases are expelled from the solution



Defects: Porosity

EXAMPLE 10.2

Casting of Aluminum Automotive Pistons

- Aluminum piston for an internal combustion engine: (a) as cast and (b) after machining



Defects: Porosity

EXAMPLE 10.2

- Simulation of mold filling and solidification

