Metal Casting I

Manufacturing Processes

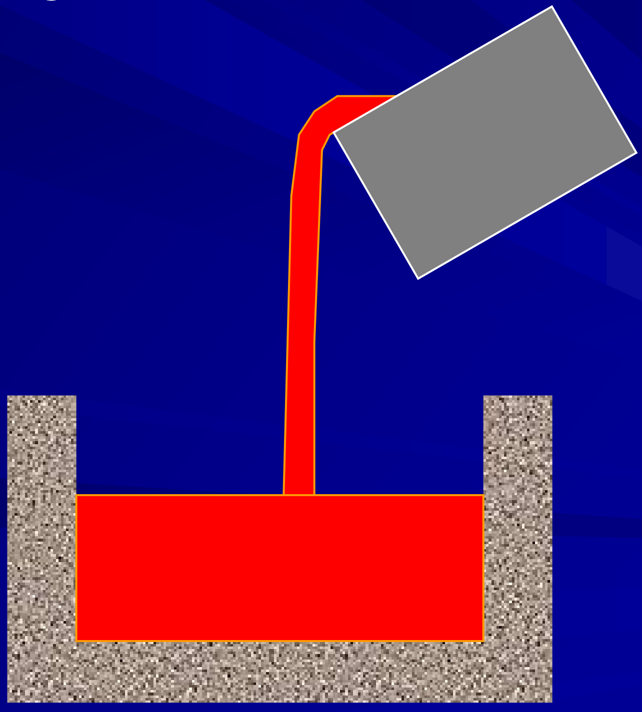
Outline

- Introduction
- Metal Solidification
- Fluid Flow
- Fluidity of Molten Metal
- Heat Transfer
- Casting Defects

Introduction

Casting

Pouring molten metal into a mold shaped after the part to be produced, allowing it to harden, and removing it from the mold



Introduction

Introduction

- Can be used to create complex internal and external part geometries

- Some casting processes can produce parts to net shape (no further manufacturing operations are required)

- Can produce very large parts (cast parts weighing over 100 tons have been made)

- Can be used with any metal that can be heated to its liquid phase

- Some types of casting are suited to mass production

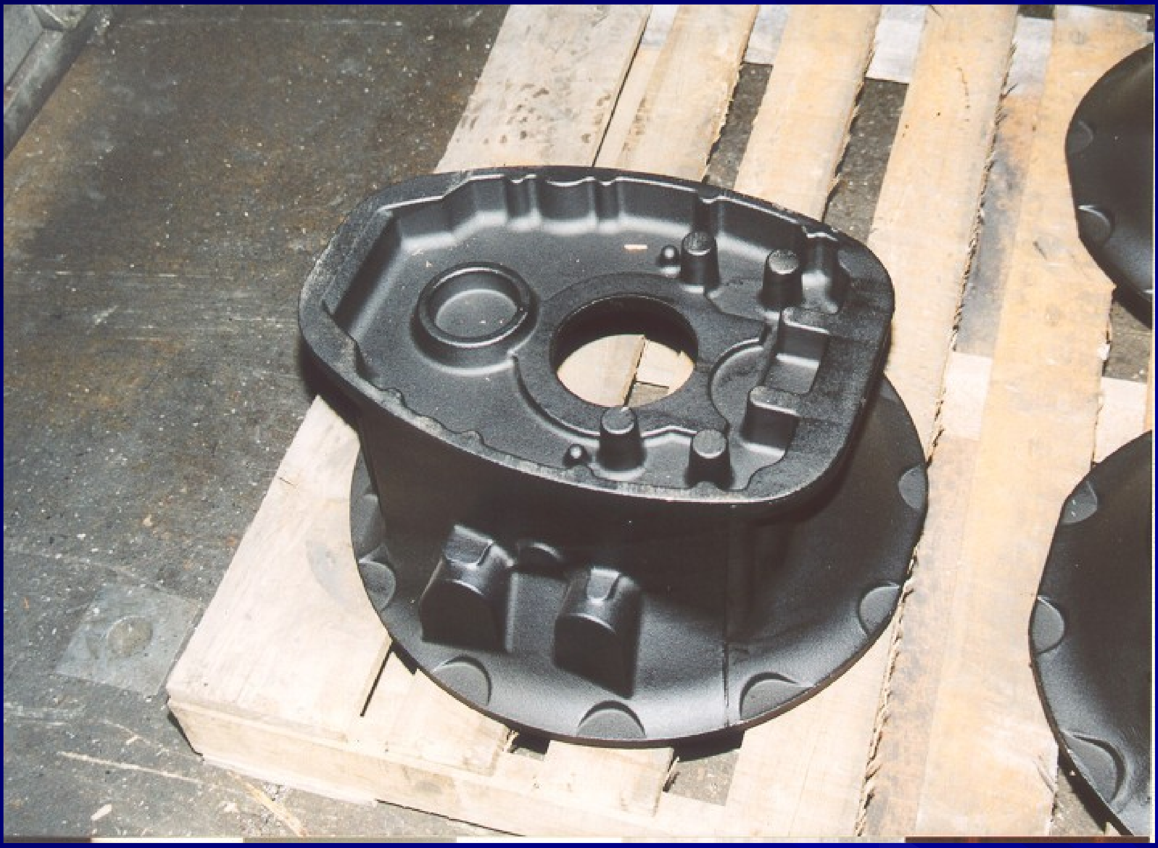
Examples of Cast Parts

Crank handle formed by casting; some areas were machined and assembled after casting

Examples of Cast Parts

C-clamps formed by casting (left) and machining (right)

Examples of Cast Parts



Complex part formed by casting

Courtesy of Toth Industries

Forms of Casting and Terminology

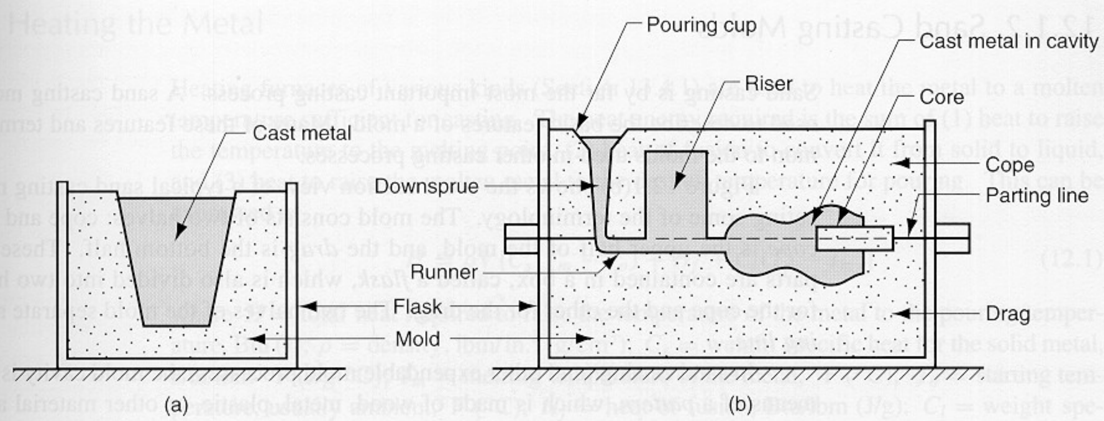


FIGURE 12.1 Two forms of mold: (a) open mold, simply a container in the shape of the desired part; and (b) closed mold, in which the mold geometry is more complex and requires a gating system (passageway) leading into the cavity.

Introduction

Requirements:

- Mold cavity with desired shape and size
- Melting process to provide molten metal
- Pouring process to introduce the metal into the mold
- Solidification process controlled to prevent defects
- Ability to remove the casting from the mold
- Cleaning, finishing and inspection operations

Casting Terminology

- Flask
  - The box containing the mold
- Cope
  - The top half of any part of a 2-part mold
- Drag
  - The bottom half of any part of a 2-part mold
- Core
  - A shape inserted into the mold to form internal cavities
- Core Print
  - A region used to support the core

Casting Terminology

- Mold Cavity
  - The hollow mold area in which metal solidifies into the part
- Riser
  - An extra cavity to store additional metal to prevent shrinkage
- Gating System
  - Channels used to deliver metal into the mold cavity
- Pouring Cup
  - The part of the gating system that receives poured metal
- Sprue
  - Vertical channel
- Runners
  - Horizontal channels

Casting Terminology

Parting Line / Parting Surface

Interface that separates the cope and drag of a 2-part mold

Draft

Taper on a pattern or casting that allows removal from the mold

Core Box

Mold or die used to produce cores

Casting

The process and product of solidifying metal in a mold

Metal Solidification

Pure Metals / Alloys

Cooling Rate

Pure Metals / Alloys

Pure metals solidify at a constant temperature; alloys solidify within a temperature range

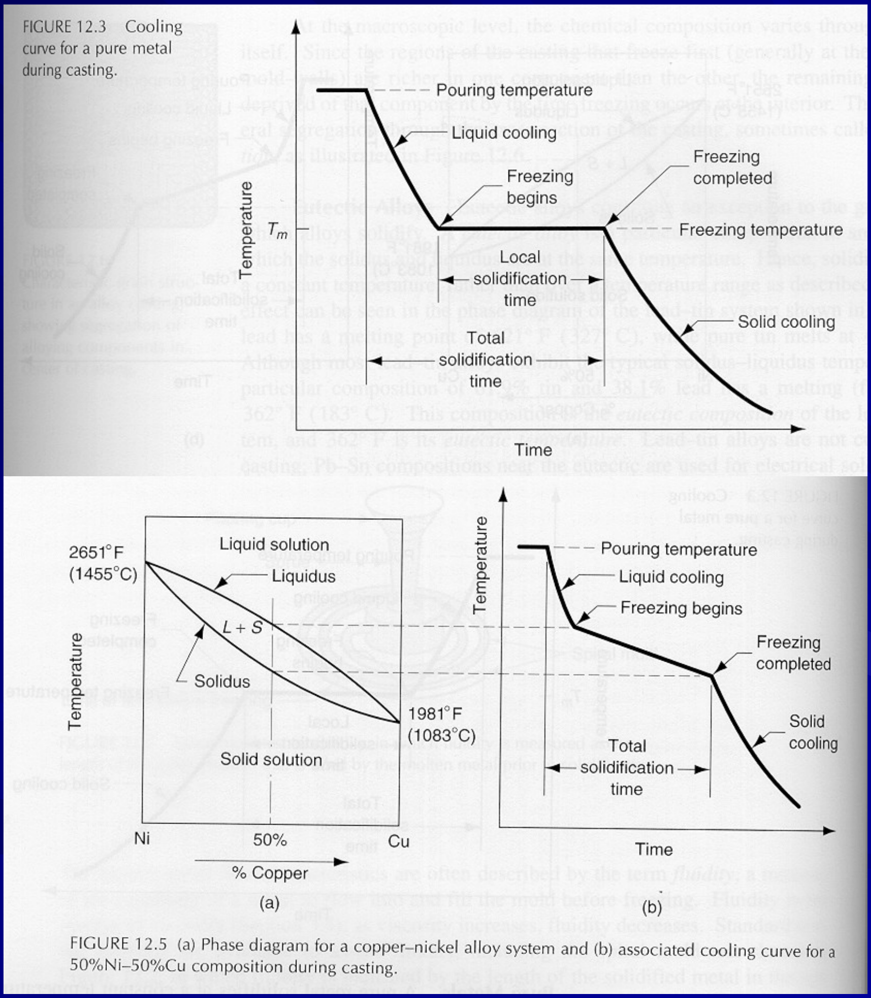
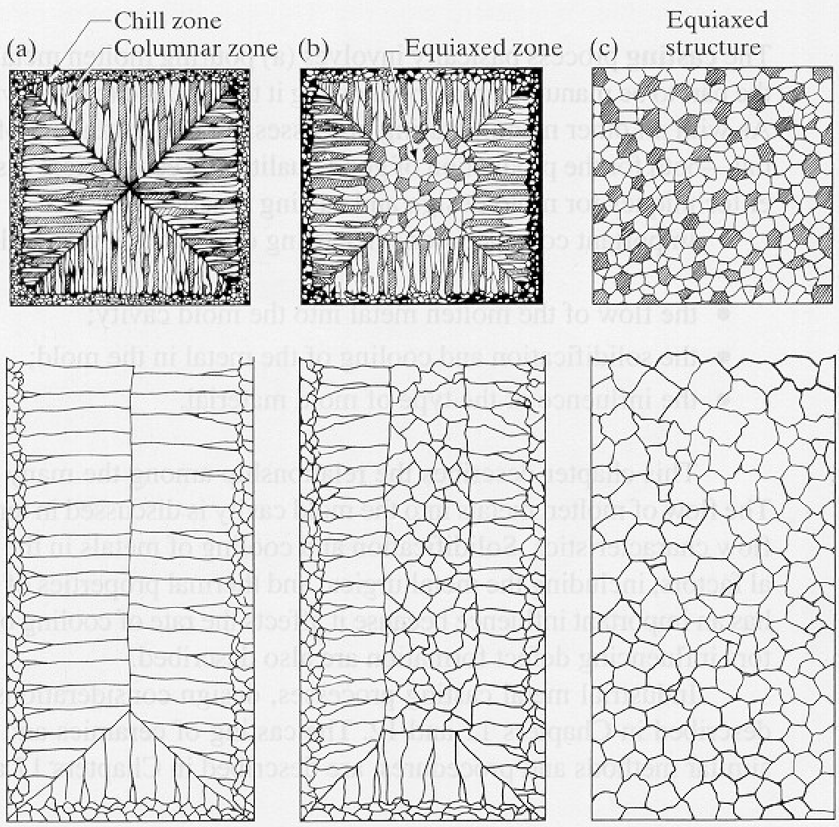


FIGURE 12.3 Cooling curve for a pure metal during casting.

FIGURE 12.5 (a) Phase diagram for a copper–nickel alloy system and (b) associated cooling curve for a 50%Ni–50%Cu composition during casting.

Metal Solidification

FIGURE 10.1 Schematic illustration of three cast structures of metals solidified in a square mold: (a) pure metals; (b) solid-solution alloys; and (c) structure obtained by using nucleating agents. *Source*: G. W. Form, J. F. Wallace, J. L. Walker, and A. Cibula.



A nucleating agent (inoculant) is a substance that induces grains to nucleate and form at the same time throughout the structure.

Cooling Rate

Rapid cooling produces equiaxed (roughly round) grains

Slow cooling towards the interior forms long columnar grains that grow towards the center

Metal Solidification

Dendrites

Tree-like structures that form during the solidification of alloys

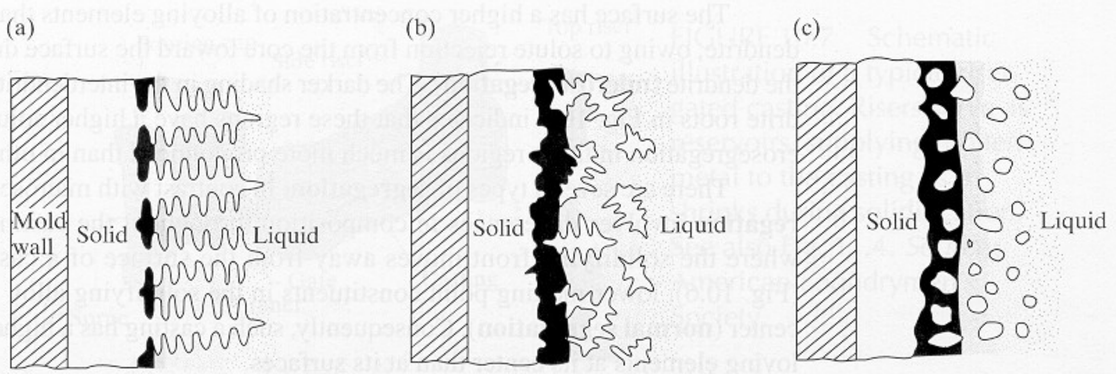


FIGURE 10.5 Schematic illustration of three basic types of cast structures:(a) columnar dendritic; (b) equiaxed dendritic; and (c) equiaxed nondendritic. *Source*: D. Apelian.

Slow cooling rates produce dendrites with larger branch spacing; faster cooling rates produce finer spacing; very fast cooling rates produce no dendrites or grains

Metal Solidification

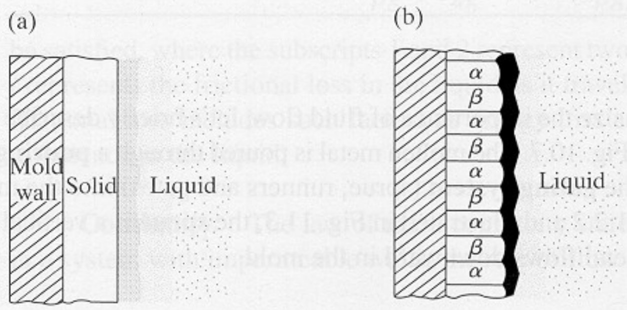


FIGURE 10.6 Schematic illustration of cast structures in (a) plane front, single phase, and (b) plane front, two phase. *Source*: D. Apelian.

Metal Solidification

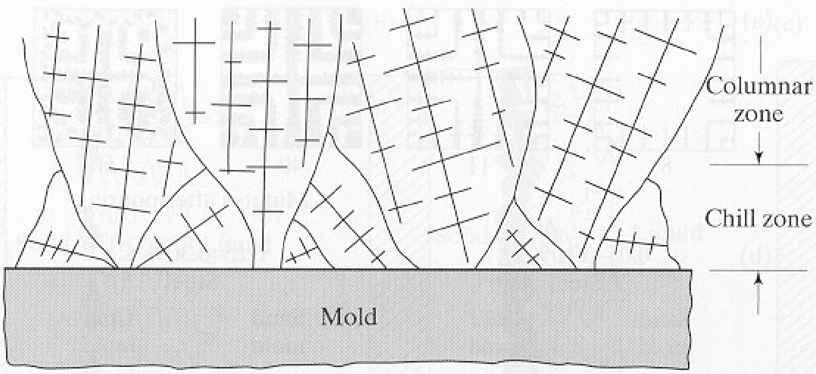


FIGURE 10.2 Development of a preferred texture at a cool mold wall. Note that only favorably oriented grains grow away from the surface of the mold.

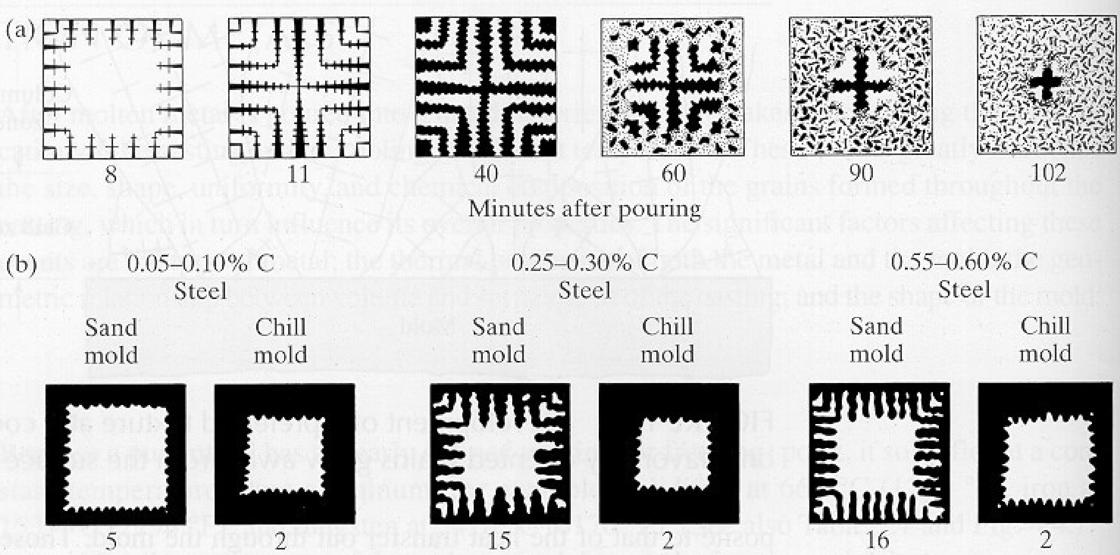
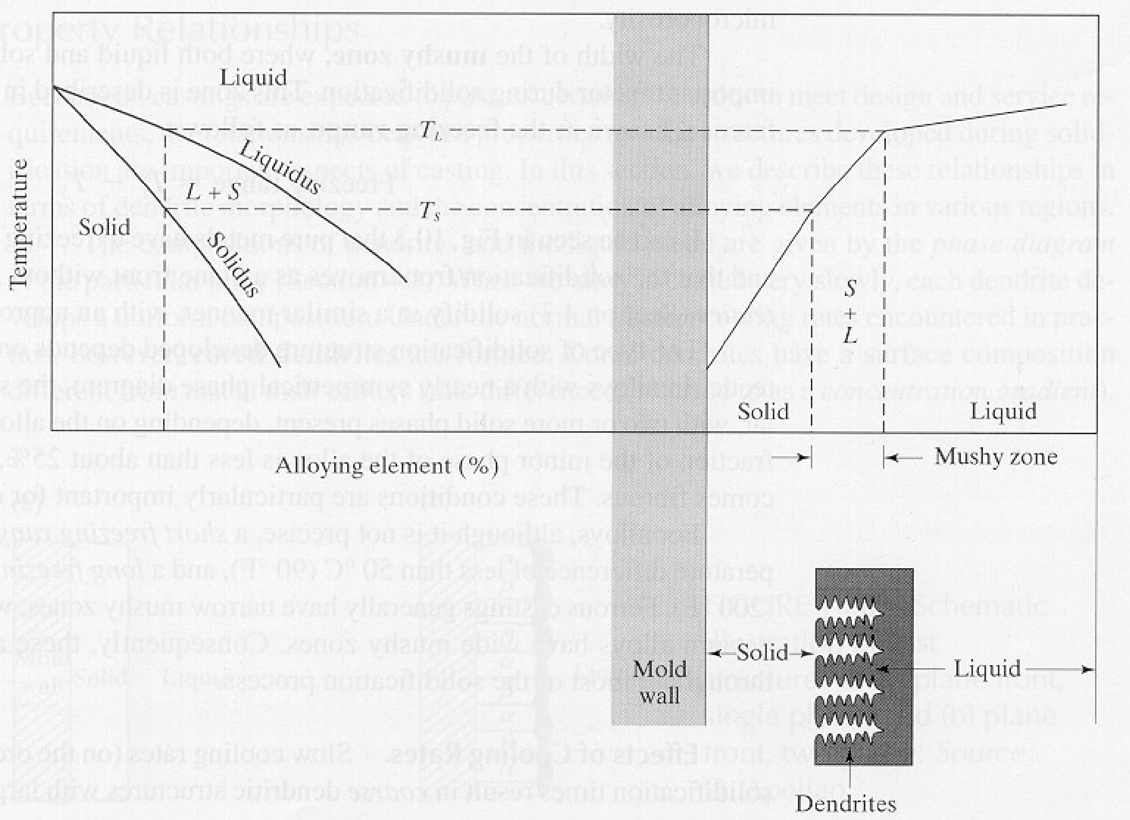


FIGURE 10.4 (a) Solidification patterns for gray cast iron in a 180-mm (7-in.) square casting. Note that after 11 min. of cooling, dendrites reach each other, but the casting is still mushy throughout. It takes about two hours for this casting to solidify completely. (b) Solidification of carbon steels in sand and chill (metal) molds. Note the difference in solidification patterns as the carbon content increases. *Source*: H. F. Bishop and W. S. Pellini.

Metal Solidification

FIGURE 10.3 Schematic illustration of alloy solidification and temperature distribution in the solidifying metal. Note the formation of dendrites in the mushy zone.



Fluid Flow

Metal is poured through a pouring cup

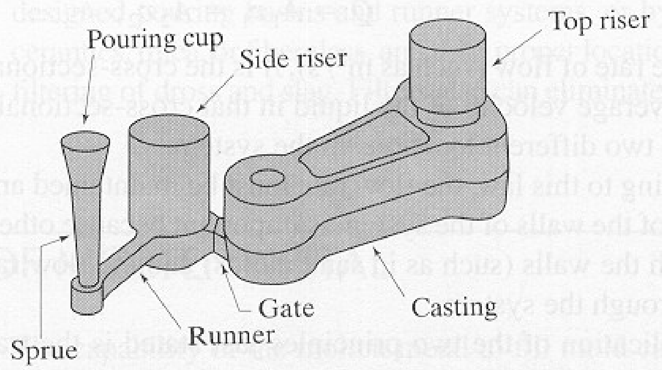


FIGURE 10.7 Schematic illustration of a typical riser-gated casting. Risers serve as reservoirs, supplying molten metal to the casting as it shrinks during solidification. See also Fig. 11.4. *Source*: American Foundrymen's Society.

Risers hold and supply metal to prevent shrinking during solidification

Gates are designed to prevent contaminants from reaching the mold cavity

Fluidity of Molten Metal

- Fluidity
  - The capability of a molten metal to fill mold cavities
- Viscosity
  - Higher viscosity decreases fluidity
- Surface tension
  - Decreases fluidity; often caused by oxide film
- Inclusions
  - Insoluble particles can increase viscosity, reducing fluidity
- Solidification pattern
  - Fluidity is inversely proportional to the freezing temperature range

Fluidity of Molten Metal

- Mold design
  - The design and size of the sprue, runners, and risers affect fluidity
- Mold material and surface
  - Thermal conductivity and roughness decrease fluidity
- Superheating
  - The temperature increment above the melting point increases fluidity
- Pouring
  - Lower pouring rates decrease fluidity because of faster cooling
- Heat transfer
  - Affects the viscosity of the metal

Fluidity of Molten Metal

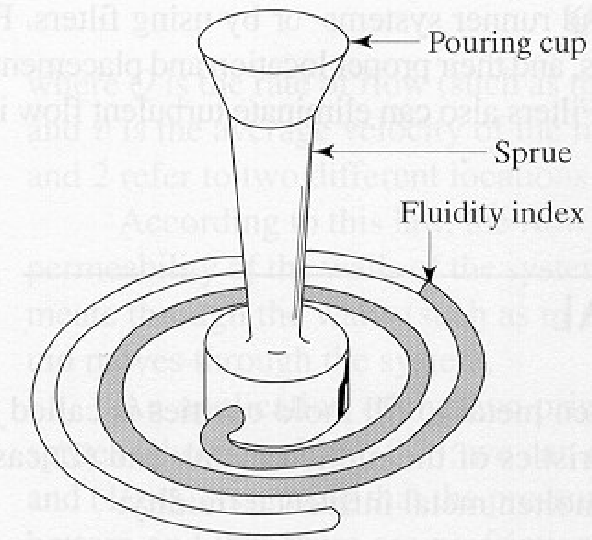


FIGURE 10.8 A test method for fluidity using a spiral mold. The *fluidity index* is the length of the solidified metal in the spiral passage. The greater the length of the solidified metal, the greater is its fluidity.

Heat Transfer

The metal that solidifies first is at the wall of the mold; this solid layer thickens as time passes

Shrinkage during cooling can change the part dimensions and sometimes cause cracking; it is caused by the metal’s thermal expansion properties and the phase change between liquid and solid.

Heat Transfer

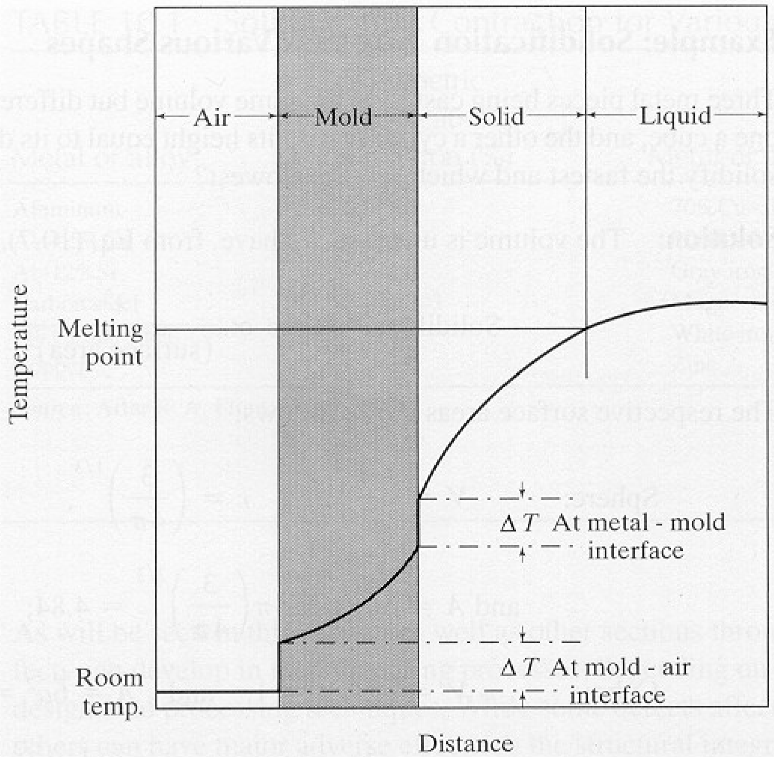
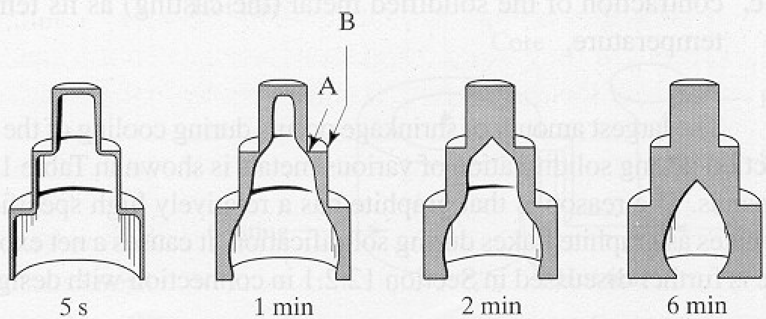


FIGURE 10.9 Temperature distribution at the interface of the mold wall and the liquid metal during solidification of metals in casting.

Heat Transfer

FIGURE 10.10 Solidified skin on 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. *Source*: H. F. Taylor, J. Wulff, and M. C. Flemings.

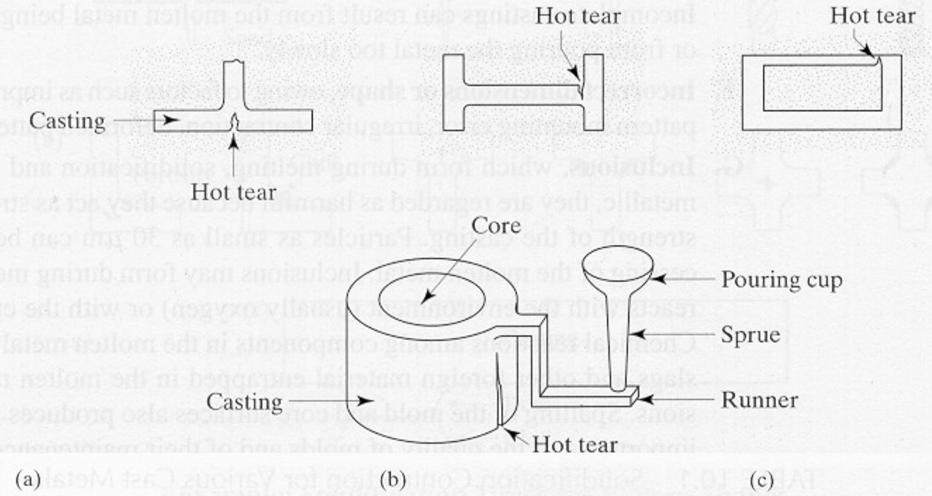


Casting Defects

A. Metallic Projections
B. Cavities
C. Discontinuities
D. Defective surface
E. Incomplete Casting
F. Incorrect dimensions or shape
G. Inclusions

Casting Defects

FIGURE 10.11 Examples of hot tears in castings. These defects occur because the casting cannot shrink freely during cooling, owing to constraints in various portions of the molds and cores. Exothermic (heat-producing) compounds may be used (as exothermic padding) to control cooling at critical sections to avoid hot tearing.



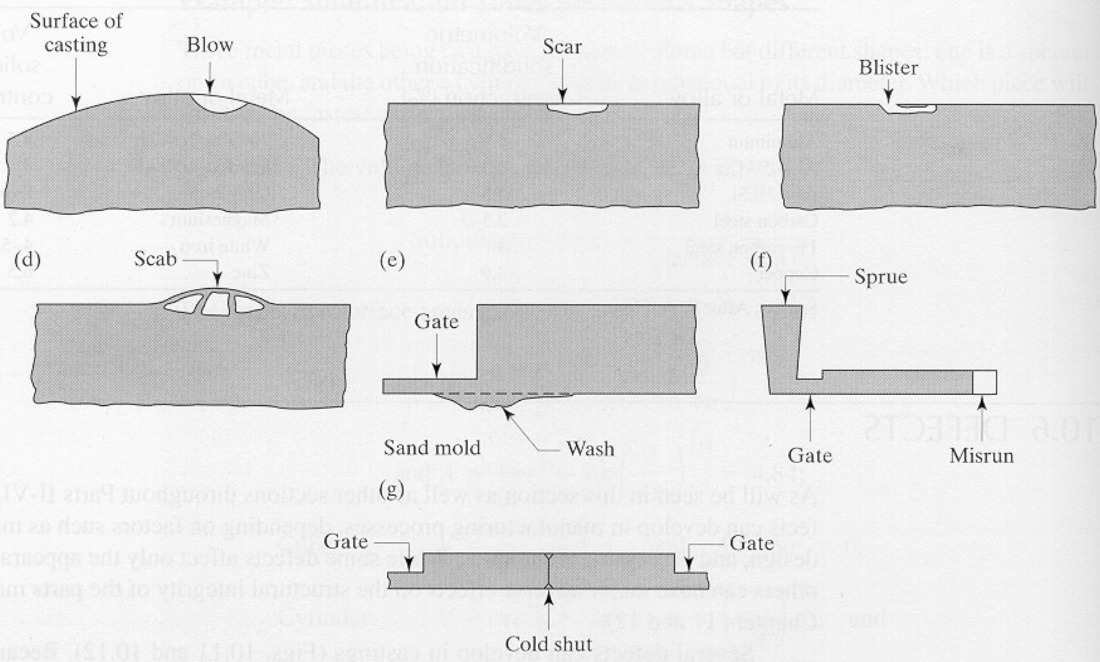


FIGURE 10.12 Examples of common defects in castings. These defects can be minimized or eliminated by proper design and preparation of molds and control of pouring procedures. *Source*: J. Datsko.

Casting Defects

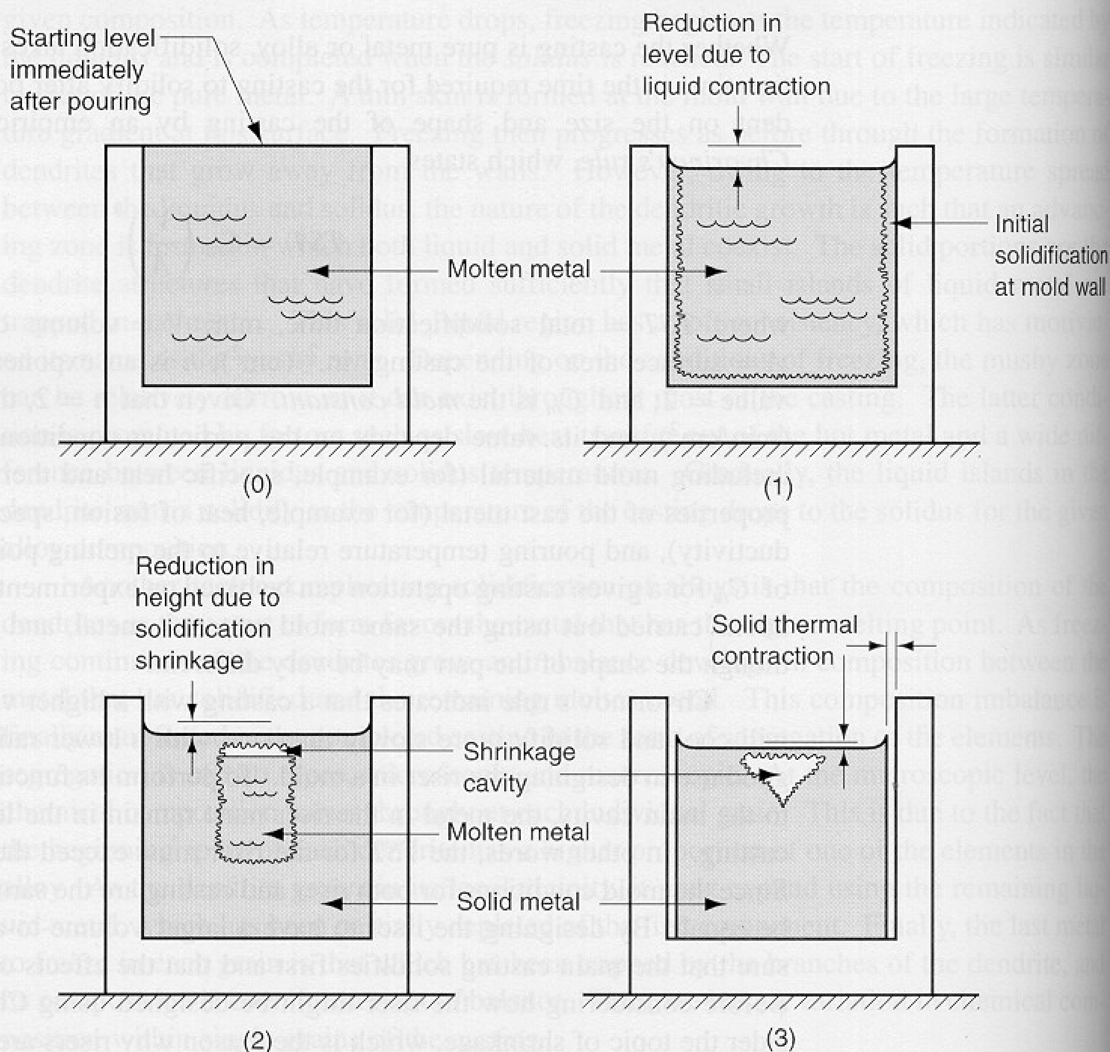
Porosity may be caused by shrinkage and/or gases

Thin sections solidify faster than thick sections; therefore the molten metal cannot be supplied to thick regions that are solidifying

Gases become less soluble in a metal as it cools and solidifies, causing it to be expelled and sometimes form or expand porosity

Casting Defects

FIGURE 12.7 Shrinkage of a cylindrical casting during solidification and cooling: (0) starting level of molten metal immediately after pouring; (1) reduction in level caused by liquid contraction during cooling; (2) reduction in height and formation of shrinkage cavity caused by solidification shrinkage; and (3) further reduction in height and diameter due to thermal contraction during cooling of the solid metal. Dimensional reductions are exaggerated for clarity in our sketches.



Casting Defects

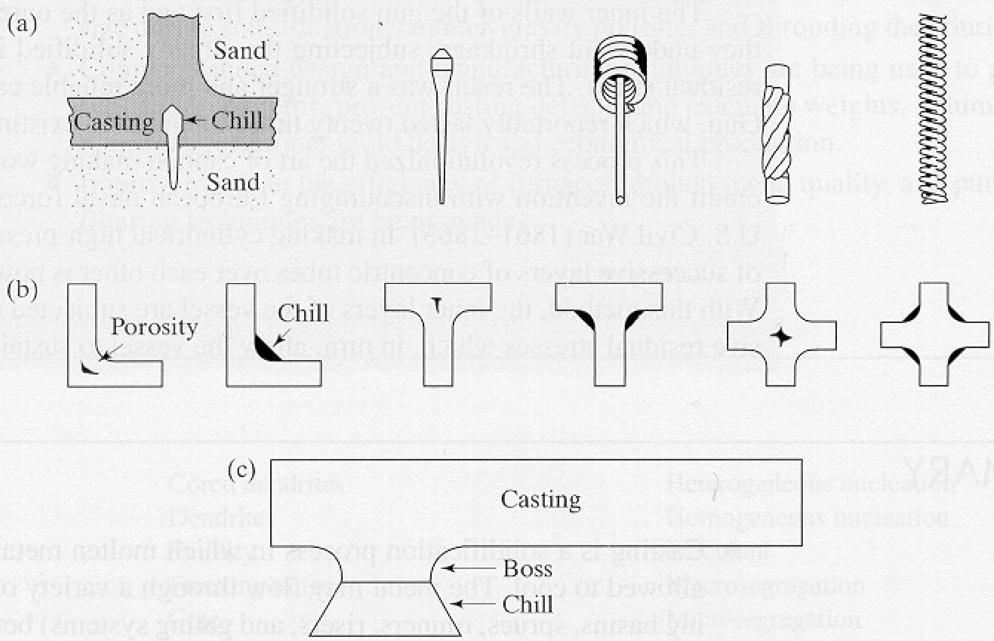
Chills

Pieces of material placed in the mold to speed up heat transfer in thicker areas of the part to prevent shrinkage porosity

Internal chills are left within the cast part; external chills are removed

Chills

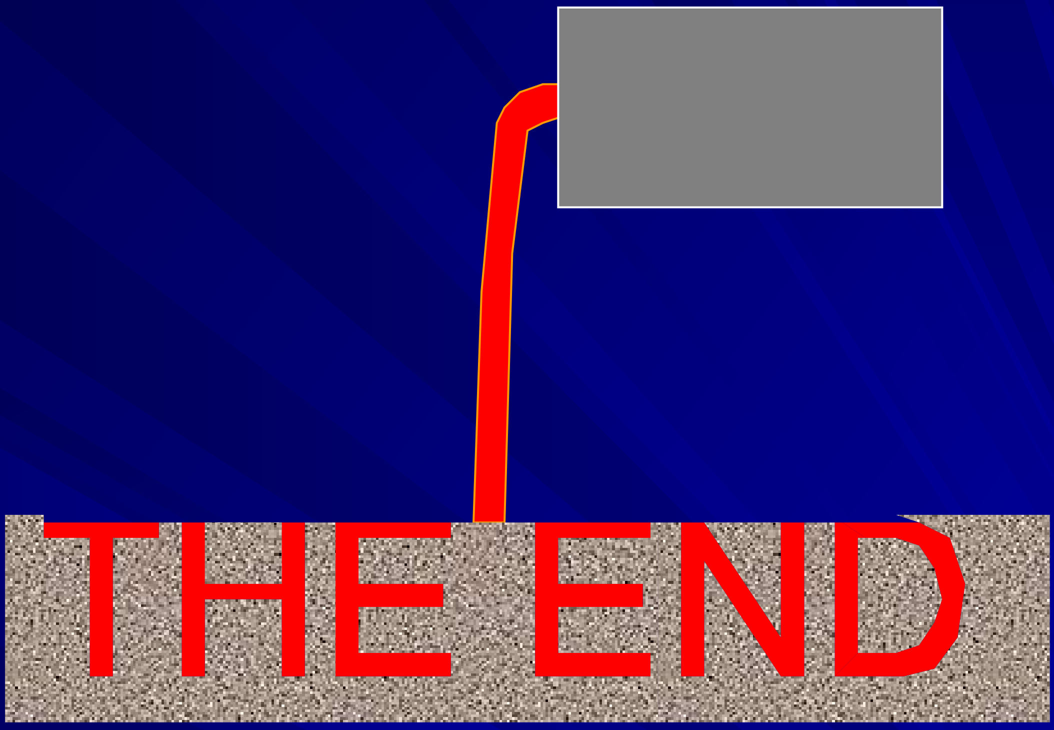
FIGURE 10.13 Various types of (a) internal and (b) external chills (dark areas at corners), used in castings to eliminate porosity caused by shrinkage. Chills are placed in regions where there is a larger volume of metal, as shown in (c).



Summary

Casting involves melting metal and allowing it to solidify in the desired shape

Casting allows the creation of parts that would be difficult or uneconomical to make by machining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