

## CASTING PROCESS - 2

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## Outline

- Casting Molds
  - Gating system – pouring basin, sprue, runner, gate
  - Riser
  - Core
- Heating and melting
  - Melting furnaces
- Pouring
- Solidification
- Additional processes after solidification
- Metals for casting

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## The Mold in Casting

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

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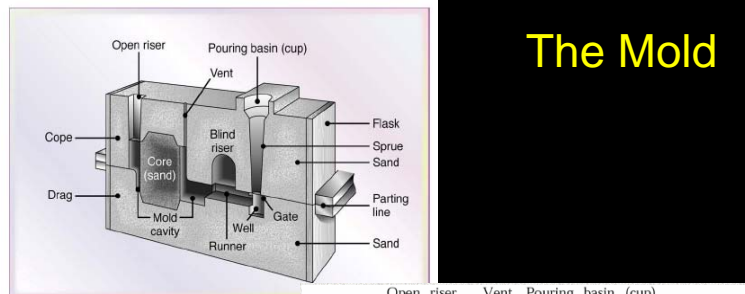
## Sand Casting Mold Terms

- 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*

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# The Mold

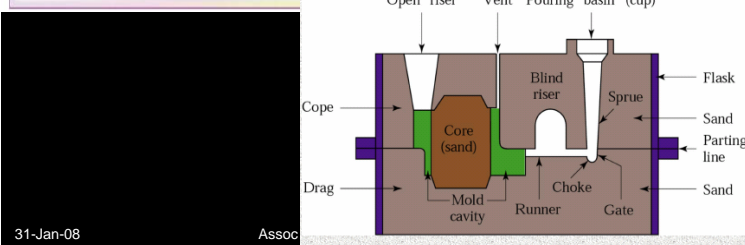
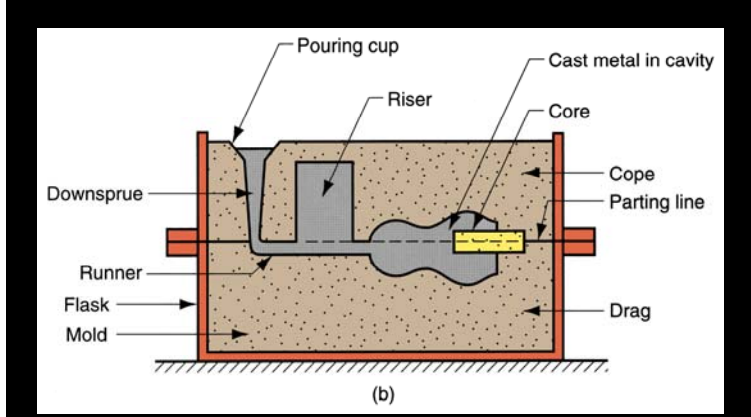


Figure 11.4 Schematic illustration of a sand mold, showing various features.

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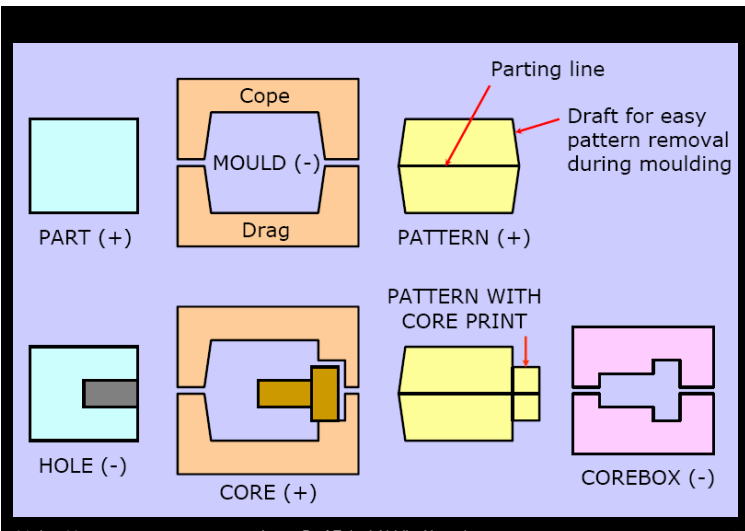


## Sand casting mold

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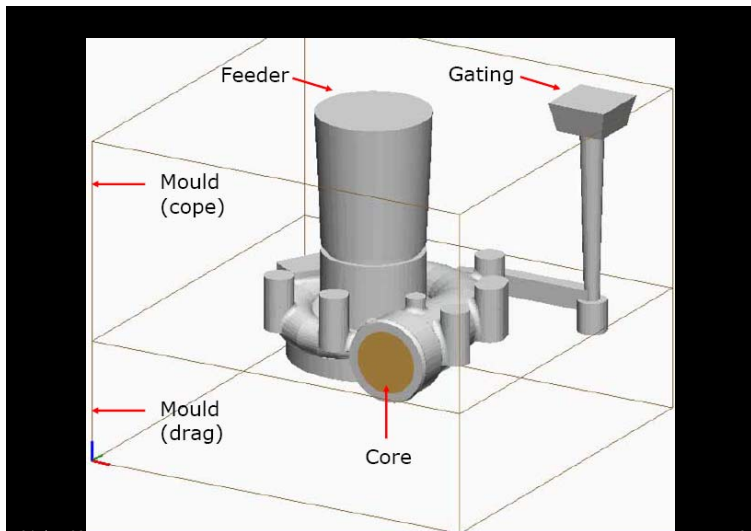
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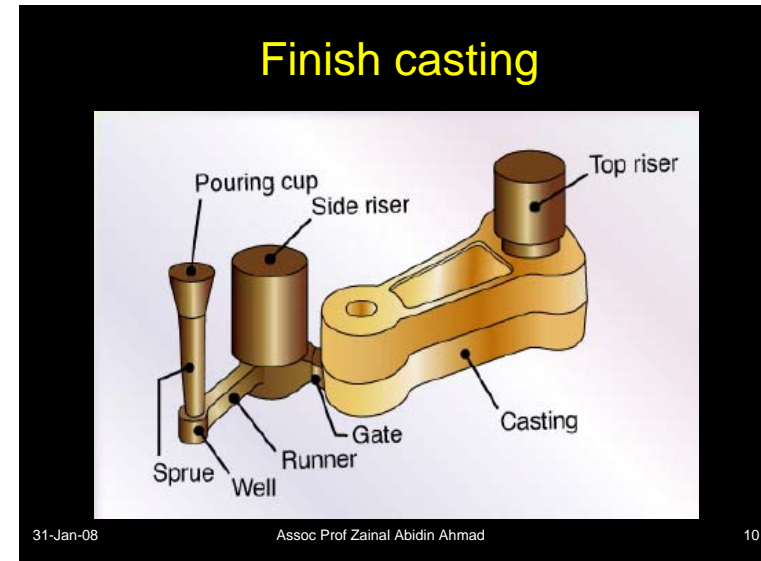
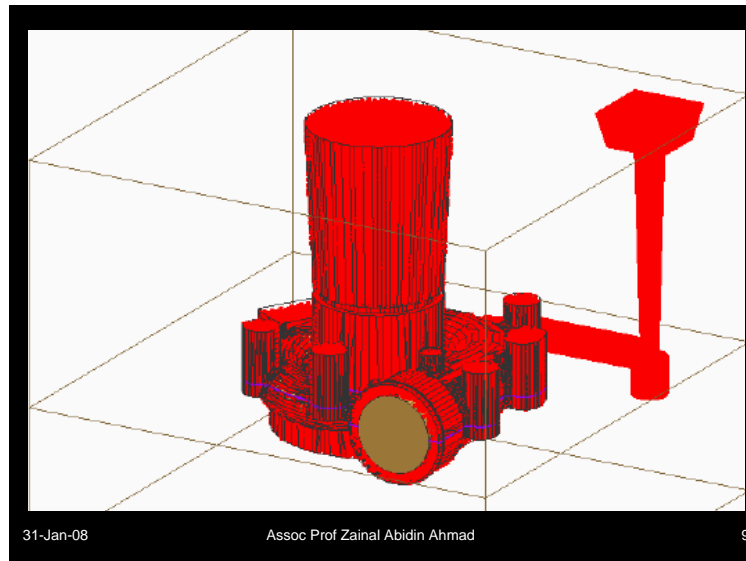
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## Forming the Mold Cavity

- 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 has desired shape of cast part
- The pattern is usually oversized to allow for shrinkage of metal as it solidifies and cools
- Sand for the mold is moist and contains a binder to maintain shape
- [Video clips](#)

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## Gating System

- Channel through which molten metal flows into cavity from outside of mold
- Consists of a *downsprue*, through which metal enters a *runner* leading to the main cavity
- At top of downsprue, a *pouring cup* is often used to minimize splash and turbulence as the metal flows into downsprue

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## Riser

- Reservoir in the mold which is a source of liquid metal to **compensate for shrinkage during solidification**
- The riser must be designed to **freeze after** the main casting in order to satisfy its function

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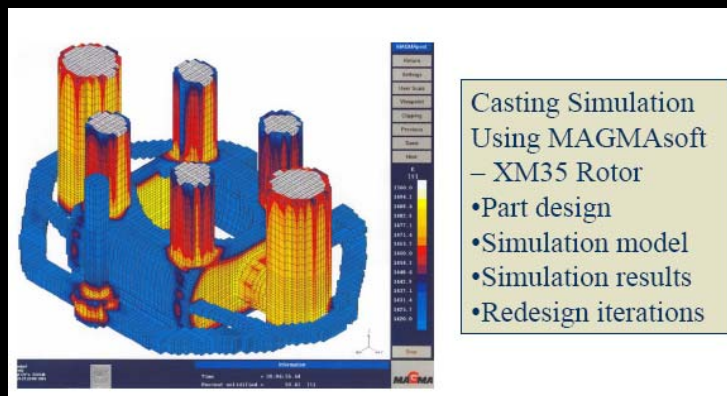
## Riser Design

- Riser is waste metal that is separated from the casting and remelted to make more castings
- To minimize waste in the unit operation, it is desirable for the volume of metal in the riser to be a minimum

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## Cores in the Mold Cavity

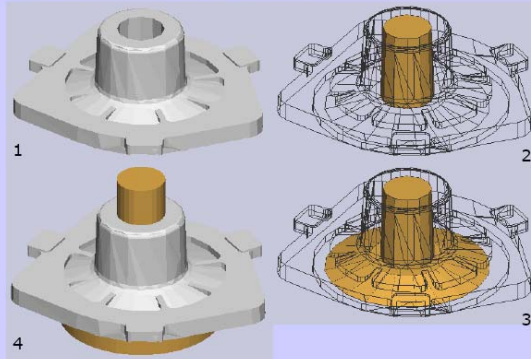
- The mold cavity provides the external surfaces of the cast part
- In addition, a casting may have **internal surfaces**, determined by a **core**, placed inside the mold cavity to define the interior geometry of part
- In sand casting, cores are generally made of sand

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## Cores for Holes



1-Part, 2-One cored feature, 3-Joint core feature, 4-Core with print

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## Heating the Metal

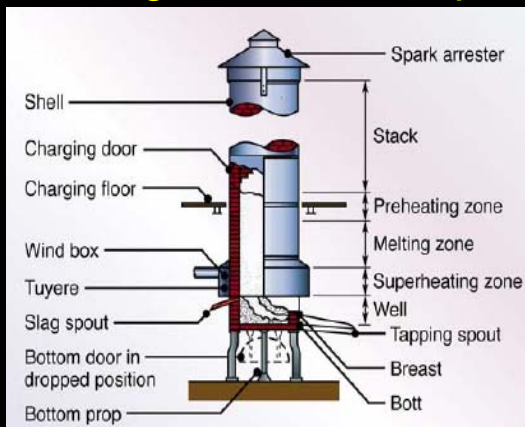
- Heating furnaces are used to heat the metal to molten temperature sufficient for casting
- The heat required is the sum of:
  1. Heat to raise temperature to melting point
  2. Heat of fusion to convert from solid to liquid
  3. Heat to raise molten metal to desired temperature for pouring

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## Melting furnaces - Cupola



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## Melting furnaces - Cupola

- Vertical cylindrical furnace equipped with tapping spout near base
- Used only for cast irons, although other furnaces are also used, largest tonnage of cast iron is melted in cupolas.
- The "CHARGE", consisting of iron, coke, flux, and alloying elements, is loaded through a charging door located less than halfway up height of cupola.

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## Melting furnaces - Crucible

- Metal is melted without direct contact with burning fuel mixture
- Sometimes called indirect fuel-fired furnace
- Container (crucible) is made of refractory material or high-temperature steel alloy
- Used for non-ferrous metals such as bronze, brass, and alloys of zinc and aluminium.
- Three types used in foundries

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## Melting furnaces - Crucible

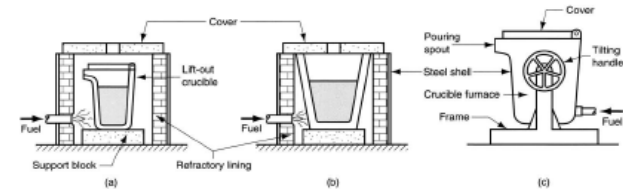


Figure 11.19 - Three types of crucible furnaces:

- (a) lift-out crucible,
- (b) stationary pot, from which molten metal must be ladled, and
- (c) tilting-pot furnace

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## Melting furnaces –Direct fuel fired

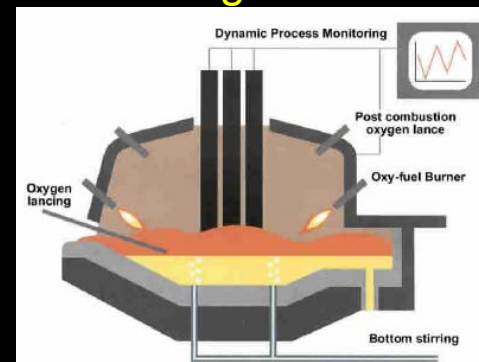
- Small open-hearth in which charge is heated by natural gas fuel burners located on side of furnace.
- Furnace roof assists heating action by reflecting flame down against charge
- At bottom of hearth is a tap hole to release molten metal.
- Generally used for nonferrous metals such as copper based alloys and aluminium.

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## Melting furnaces



Oxygen-Fuel,  
Oxygen Lance Furnace

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## Melting furnaces – electric arc

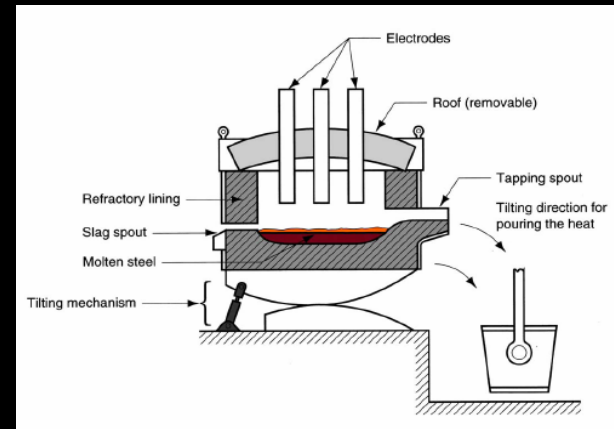
- Charge is melted by heat generated from an electric arc
- High power consumption, but electric arc furnaces can be designed for high melting capacity
- Used primarily for melting steel

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## Melting furnaces – electric arc



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## Melting furnaces - Induction

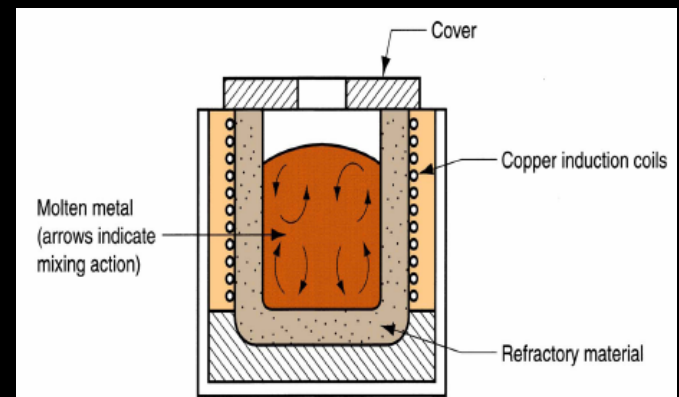
- Uses alternating current passing through a coil to develop magnetic field in metal
- Induced current causes rapid heating and melting
- Electromagnetic force field also causes mixing action in liquid metal
- Since metal does not contact heating elements, the environment can be closely controlled, which result in molten metals of high quality and purity.
- Melting steel, CI, and aluminium alloys are common applications in foundry work

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## Melting furnaces - Induction

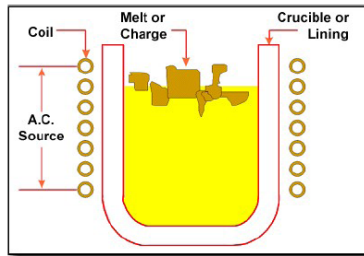


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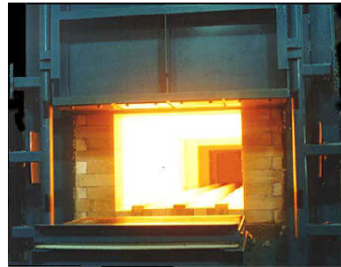
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## Melting furnaces



Induction Furnace



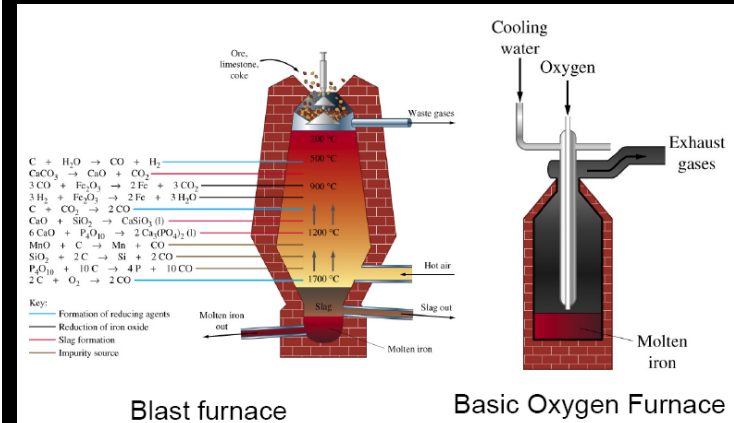
Electric Furnace

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## Melting furnaces



Blast furnace

Basic Oxygen Furnace

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## Pouring the Molten Metal

- For this step to be successful, metal must flow into all regions of the mold, most importantly the main cavity, before solidifying
- Factors that determine success:
  - Pouring temperature
  - Pouring rate
  - Turbulence

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## Ladles

- Used to move molten metal from furnace to mold

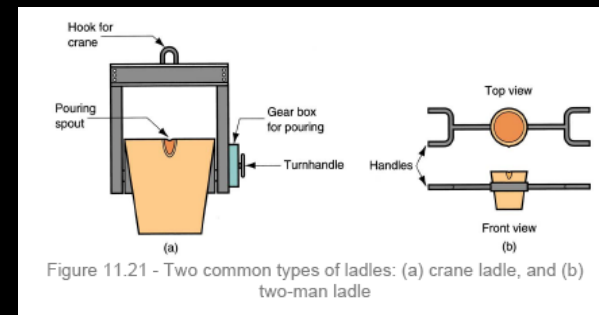


Figure 11.21 - Two common types of ladles: (a) crane ladle, and (b) two-man ladle

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## Solidification of Metals

Transformation of molten metal back into solid state

- Solidification differs depending on whether the metal is a pure element or an alloy

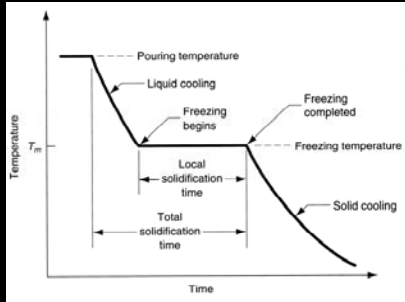


Figure 10.4 - Cooling curve for a pure metal during casting

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## Solidification of Pure Metals

- Due to chilling action of mold wall, a thin skin of solid metal is formed at the interface immediately after pouring
- Skin thickness increases to form a shell around the molten metal as solidification progresses
- Rate of freezing depends on heat transfer into mold, as well as thermal properties of the metal

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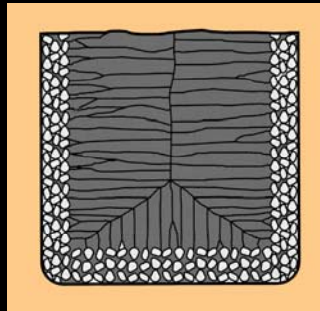


Figure 10.5 - Characteristic grain structure in a casting of a pure metal, showing randomly oriented grains of small size near the mold wall, and large columnar grains oriented toward the center of the casting

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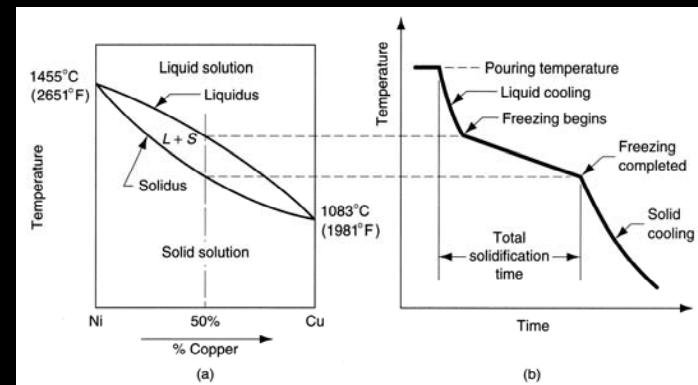


Figure 10.6 - (a) Phase diagram for a copper-nickel alloy system and (b) associated cooling curve for a 50%Ni-50%Cu composition during casting

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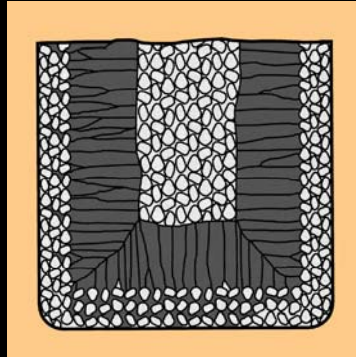


Figure 10.7 - Characteristic grain structure in an alloy casting, showing segregation of alloying components in center of casting

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## Solidification Time

- Solidification takes time
- Total solidification time  $TST$  = time required for casting to solidify after pouring
- $TST$  depends on size and shape of casting by relationship known as *Chvorinov's Rule*

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## Chvorinov's Rule

$$TST = C_m \left( \frac{V}{A} \right)^n$$

where  $TST$  = total solidification time;  $V$  = volume of the casting;  $A$  = surface area of casting;  $n$  = exponent usually taken to have a value = 2; and  $C_m$  is *mold constant*

## Mold Constant in Chvorinov's Rule

- $C_m$  depends on mold material, thermal properties of casting metal, and pouring temperature relative to melting point
- Value of  $C_m$  for a given casting operation can be based on experimental data from previous operations carried out using same mold material, metal, and pouring temperature, even though the shape of the part may be quite different

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## What Chvorinov's Rule Tells Us

- A casting with a higher volume-to-surface area ratio cools and solidifies more slowly than one with a lower ratio
  - To feed molten metal to main cavity,  $TST$  for riser must be greater than  $TST$  for main casting
- Since riser and casting mold constants will be equal, design the riser to have a larger volume-to-area ratio so that the main casting solidifies first
  - This minimizes the effects of shrinkage

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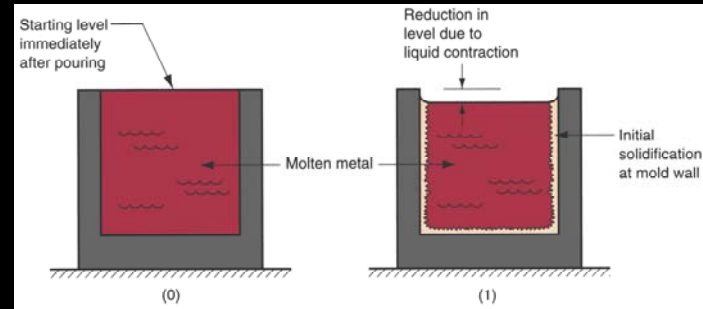


Figure 10.8 - Shrinkage of a cylindrical casting during solidification and cooling: (0) starting level of molten metal immediately after pouring; (1) reduction in level caused by liquid contraction during cooling (dimensional reductions are exaggerated for clarity in sketches)

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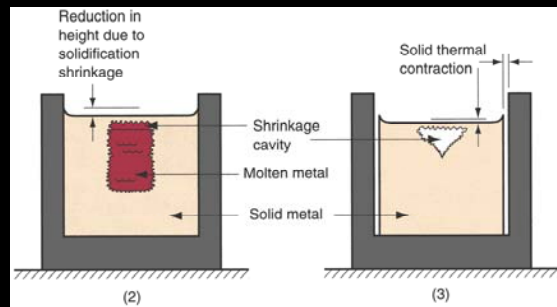


Figure 10.8 - (2) reduction in height and formation of shrinkage cavity caused by solidification shrinkage; (3) further reduction in height and diameter due to thermal contraction during cooling of the solid metal (dimensional reductions are exaggerated for clarity in our sketches)

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## Solidification Shrinkage

- Occurs in nearly all metals because the solid phase has a higher density than the liquid phase
- Thus, solidification causes a reduction in volume per unit weight of metal
- Exception: cast iron with high C content
  - Graphitization during final stages of freezing causes expansion that counteracts volumetric decrease associated with phase change

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## Shrinkage Allowance

- Patternmakers account for solidification shrinkage and thermal contraction by making mold cavity oversized
- Amount by which mold is made larger relative to final casting size is called *pattern shrinkage allowance*
- Casting dimensions are expressed linearly, so allowances are applied accordingly

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## Directional Solidification

- To minimize damaging effects of shrinkage, it is desirable for regions of the casting most distant from the liquid metal supply to freeze first and for solidification to progress from these remote regions toward the riser(s)
  - Thus, molten metal is continually available from risers to prevent shrinkage voids
  - The term *directional solidification* describes this aspect of freezing and methods by which it is controlled

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## Achieving Directional Solidification

- Desired directional solidification is achieved using Chvorinov's Rule to design the casting itself, its orientation in the mold, and the riser system that feeds it
- Locate sections of the casting with lower  $V/A$  ratios away from riser, so freezing occurs first in these regions, and the liquid metal supply for the rest of the casting remains open
- *Chills* - internal or external heat sinks that cause rapid freezing in certain regions of the casting

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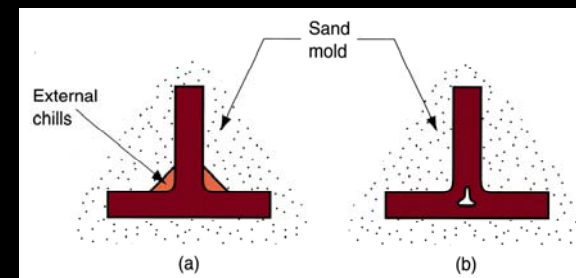


Figure 10.9 - (a) External chill to encourage rapid freezing of the molten metal in a thin section of the casting; and (b) the likely result if the external chill were not used

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## Additional steps after solidification

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

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## Trimming

- Removal of sprues, runners, risers, parting-line flash, fins, chaplets and any other excess metal from the cast part
- Can be done by hammering, shearing, hack-sawing, band-sawing, abrasive wheel cutting or torch cutting methods.

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## Removing cores

- If cores have been used, they must be removed.
- Most cores are bonded, and they often fall out of casting as the binder deteriorates.
- In some cases, they are removed by shaking casting – manually or mechanically.
- Solid cores must be hammered or pressed out.

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## Surface cleaning

- Removal of sand from casting surface and otherwise enhancing appearance of surface.
- Various cleaning methods : tumbling, air-blasting with coarse sand or metal shot, wire brushing, buffing and chemical pickling.
- Surface cleaning is most important for sand casting, this step can be avoided for most permanent molds.

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## Heat treatment

- Castings are often heat treated to enhance properties
- Reasons for heat treating
  - For subsequence processing operations such as machining
  - To bring out the desired properties for application of the part in service.

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## Metals for Casting

- Most commercial castings are made of alloys rather than pure metals
  - Alloys are generally easier to cast, and properties of product are better
- Casting alloys can be classified as:
  - Ferrous
  - Nonferrous

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## Ferrous Casting Alloys: Cast Iron

- Most important of all casting alloys
- Tonnage of cast iron castings is several times that of all other metals combined
- Several types: (1) gray cast iron, (2) nodular iron, (3) white cast iron, (4) malleable iron, and (5) alloy cast irons
- Typical pouring temperatures ~ 1400°C (2500°F), depending on composition

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## Ferrous Casting Alloys: Steel

- The mechanical properties of steel make it an attractive engineering material
- The capability to create complex geometries makes casting an attractive shaping process
- Difficulties faced by the foundry working with steel:
  - Pouring temperature of steel is higher than for most other casting metals ~ 1650°C (3000°F)
  - At these temperatures, steel readily oxidizes, so molten metal must be isolated from air
  - Molten steel has relatively poor fluidity

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## Nonferrous Casting Alloys: Aluminum

- Generally considered to be very castable
- Pouring temperatures low – melting temperature of aluminum  $T_m = 660^\circ\text{C}$  (1220°F)
- Properties:
  - Light weight
  - Range of strength properties by heat treatment
  - Ease of machining

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## Nonferrous Casting Alloys: Copper Alloys

- Includes bronze, brass, and aluminum bronze
- Properties:
  - Corrosion resistance
  - Attractive appearance
  - Good bearing qualities
- Limitation: high cost of copper
- Applications: pipe fittings, marine propeller blades, pump components, ornamental jewelry

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## Nonferrous Casting Alloys: Zinc Alloys

- Highly castable, commonly used in die casting
- Low melting point – melting point of zinc  $T_m = 419^\circ\text{C}$  (786°F)
- Good fluidity for ease of casting
- Properties:
  - Low creep strength, so castings cannot be subjected to prolonged high stresses

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