Casting

- Casting processes exploit the fluidity of a liquid as it flows, assuming the shape of a prepared container, and solidifies upon cooling.
Casting Process and Properties

- Solid material is melted.
- Molten material is poured into cavity containing desired shape (subsequent to cooling and solidification).
- Objects can have virtually any configuration (complex shapes).
- Resistance to working stresses can be optimized.
- Directional properties can be controlled.
- Pleasing appearance can be produced.

Size of Cast Parts

- Cast parts range in size from a fraction of an inch to over 40 feet and many tons.
- Advantages of shape production with casting processes:
  - Complex shapes
  - Hollow sections or internal cavities
  - Irregular or curved surfaces
  - Very large parts
  - Parts made from difficult to machine materials

Generally Speaking

- It is almost impossible to design a part that cannot be cast by one or more of the commercial casting processes.
- This is different than any of the other categories or families of processes that we will talk about.
Casting Process Requirements

1. Mold cavity.
2. Melting process.
3. Pouring technique.
4. Solidification process.
5. Mold removal.
6. Cleaning, finishing and inspection.

Mold Cavity

- Has the desired shape of the casting including allowances for shrinkage and solidification.
- Must have refractory characteristics to handle extreme temperatures of molten metal.
- Can be single-use or multiple-use type.

Melting Process

- Means of providing molten metal to the mold.
- Must be able to provide proper temperature and quantities of metal at a reasonable cost.
Pouring Technique

- Means of introducing the molten metal into the mold cavity.
- Provision should be made for the escape of all air or gases present in the cavity before pouring and those introduced by the hot metal.

Solidification Process

- Castings must be designed so that solidification occurs without producing internal porosity or voids.
- Mold should also not provide too much restraint to the shrinkage or casting may crack (hot tear) while metal is hot and strength is low.

Mold Removal

- Process of removing the casting from the mold.
- Different for multiple use and single use processes.
Cleaning, Finishing & Inspection

- Extraneous material is removed:
  - Gating, risering systems
  - Flash
- Finish machining is performed to obtain final dimensions.
- Inspection of parts to ensure proper dimensions and quality.

Definitions

- Pattern – approximate duplicate of final casting. Must compensate for shrinkage.
- Molding material – media used to create mold cavity.
- Flask – rigid container that holds molding material (in most cases).
- Cope and drag – top and bottom halves of horizontally parted two-part flask.

Figure 11-2 Cross section of a typical two-part sand-mold, indicating various mold components and terminology.
Definitions

- **Core** – shape that is inserted into a mold to produce a hollow portion of a casting.
- **Core print** – areas of the mold cavity used to support the core within the mold.
- **Mold cavity** – combination of mold material and cores that will produce final shape of casting.
- **Riser** – extra reservoir of molten metal that can flow into the casting to compensate for solidification shrinkage.

![Diagram](image1)

Figure 11-2 Cross section of a typical two-part sand-mold, indicating various mold components and terminology.

Definitions

- **Gating system** – network of connected channels that feeds molten metal to the mold cavity.
- **Pouring cup** – portion of gating system that initially receives molten metal from pouring vessel and controls delivery to the rest of the mold.
- **Sprue** – downward portion of gating system.
- **Runners** – horizontal channels in the gating system.
- **Gates** – controlled entrances to the mold cavity.
Definitions

Figure 11-9 Typical gating system for a horizontal parting plane mold, showing key components involved in controlling the flow of metal into the mold cavity.

Vents – provide escape for gases in the mold cavity.

Parting line – interface that separates the cope and drag halves of the flask.

Draft – taper on the pattern that permits it to be withdrawn from the mold.

Core box – mold or die used to create cores.

Figure 11-2 Cross section of a typical two-part sand-mold, indicating various mold components and terminology.
Solidification Process

- Solidification is a freezing process.
- Many product properties are set during solidification.
- Many defects are solidification related.
- Solidification occurs in two stages:
  - Nucleation
  - Growth

Solidification Process

- Nucleation – stable particles of solid (grains) begin to form within the molten metal.
- Usually begin where heat is being removed at the highest rate (i.e. mold walls).
- Nucleation occurs at a temperature actually below the equilibrium melting point.
  - Difference in temperature is known as under-cooling.

Solidification Process

1. Nuclei form at certain points in the molten metal.
2. Nuclei begin to grow.
3. Nuclei continue to grow.
4. As the nucleation grows, it develops into a dendritic structure.
5. Solidification is complete; the structure of the dendrite structure remains.
Intentionally introducing impurities into molten metal for the purpose of controlling grain structure is called **inoculation** or **grain refinement**.

Inoculates may include:
- Grey cast iron castings – graphite, ferrosilicon or calcium silicide.
- Aluminum and titanium castings – Aluminum Silicate or aluminum-titanium metal alloy.
Solidification Process

Inoculation or grain refinement

Solidification Process

- Second step is growth – as heat continues to be removed from the mold.
- Directional solidification – solidification interface sweeps through the material continuously.

Solidification Process
Cooling Curves

- Provide insight into the melting/freezing behavior of metals. Used to develop phase diagrams (MET 34800).
- **Pouring temperature** is the temperature of the metal as it enters the mold cavity. This is higher than the melting/freezing point of the material.
- **Superheat** is the difference between the melting point of the material and the pouring temperature.
- Some materials freeze at one temperature (pure metals and compounds) while others freeze over a range of temperatures and therefore have a freezing range.

Figure 11-3 Cooling curve for a pure metal or eutectic-composition alloy (metals with a distinct freezing point), indicating major features related to solidification.

Figure 11-4 Phase diagram and companion cooling curve for an alloy with a freezing range. The slope changes indicate the onset and termination of solidification.
Solidification Time

- Total solidification time – time from the start of pouring to the end of solidification.
- Local solidification time – the time from start to finish of solidification.
- Equation was developed to predict the time for solidification of a casting.
- Chvorinov’s Rule (see page 273)
  - Solidification is related to the ratio of the casting’s volume to surface area.

Cast Structure

Castings that are permitted to solidify (no additional features in the mold) have three different zones:

- Chill zone – narrow band of randomly oriented crystals that form on the surface of the casting.
- Columnar zone – long thin crystals showing fast heat removal and directionality.
- Equiaxed zone – spherical, randomly oriented, crystals usually the result of slower cooling or inoculation.

Figure 11-5 Internal structure of cast metal bar showing the chill zone at the periphery, columnar grains growing toward the center, and a central shrinkage cavity.
Molten Metal Problems

- Most molten metals will absorb oxygen.
- These produce oxides that are carried into the casting (this is bad).
- This dross or slag gets trapped in the casting and affects the final quality of the part.

Cast Structure

- Columnar Grains
- Grain structure of ingot
- Interrupted grains
- Heat treated grains

Columnar Grains
Molten Metal Problems

- Dross and slag can be controlled during the pouring and melting processes:
  - Flux covering molten metal during melting.
  - Pouring in a vacuum or protective atmosphere.
  - Lower pouring temperatures.
  - Skimmed off prior to pouring.
  - Ladle design.
  - Ceramic filters.

Vacuum Pouring Methods

Porosity

- Molten metal can also dissolve gases.
- As the metal solidifies, the gases must be rejected.
- If they are not rejected, they freeze in the casting causing porosity.

Radiograph showing porosity.
Porosity

Several methods exist to help eliminate this problem:
- Perform in vacuum
- Use low solubility gas environment
- Keep superheat low
- Gas flushing
- Control pouring speed

Fluidity

- Ability of a metal to flow as a liquid.
- Some metals flow better than others.
- Misruns and cold shuts occurs due to the freezing/flowing of molten metal in the casting.
  - Misrun – area of a casting where two streams of material were flowing and freezing together simultaneously.
  - Cold shut – area of casting shut off because freezing occurred before molten metal could flow to remainder of mold cavity.
Pouring Temperature

- Excessive superheat can cause problems such as
  - Penetration – metal too runny causing breakdown of sand mold.
  - Porosity – gas entrapment.

Gating System

- Gating system controls flow of molten metal.
  - Design is based on casting shape and material being poured.
  - Turbulence must be minimized.
  - Sprue wells, runner extensions and runner wells should be used to reduce the effects of kinetic energy within cavity.
  - Runner wells can be used to trap dross.
Solidification Shrinkage

- Principle stages of shrinkage:
  - Shrinkage of liquid.
  - Solidification shrinkage.
  - Solid metal contraction.
- Last two are of primary concern.
- Contraction depends on the properties of the metal being cast.
- Freezing range is another material factor that affects structure of castings.

Shrinkage during solidification can result in voids within the casting.
Shrinkage after solidification can result in hot tears or cracking.
Shrinkage must be accounted for in pattern design so final casting will meet the desired dimensional requirements.
Gating system and riser design critical to preventing voids.
Solidification Shrinkage

- Reservoirs designed to feed molten metal into the solidifying casting to compensate for solidification shrinkage.
- Designed to produce directional solidification.
- Designed to conserve metal.
- Need to have a long freezing time.
- Base on Chvorinov’s rule – what would be the best shape?!

Small surface area per unit volume. Height = Diameter considered ideal.

Riser Definitions

- Top riser – sits on top of the casting.
- Side riser – located adjacent to the mold cavity.
- Blind riser – contained entirely within the mold cavity.
- Open riser – exposed to atmosphere.
- Live (hot) riser – receive the last hot metal that enters the mold.
- Dead (cold) riser – fill with metal that has already flowed through the mold cavity.
Riser Definitions

Figure 11-12 A three-step-step block aluminum casting made with (top) and without (bottom) a riser.

Figure 11-13 Schematic of a sand casting mold, showing (a) an open-type top riser and (b) a blind-type riser. 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.

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Size of Risers

- The size of risers can also be calculated using Chvorinov’s rule. For riser design we need:
  - how much metal needs to be supplied,
  - the optimal shape/configuration, and
  - the total time needed for the casting to solidify (riser solidification time must be greater).

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Risering Aids

- Assist risers in their job.
- Some promote directional solidification.
- Some reduce the number and size of risers.
- Aid include:
  - External chills – placed in mold adjacent to the casting to absorb heat.
  - Internal chills – placed inside the mold cavity.
  - Insulating sleeves around the riser.
  - Exothermic material around the riser that supplies heat.
Patterns

- Casting is divided into two different categories:
  - Expendable Mold
  - Reusable Mold
- Most expendable mold processes begin with a reusable pattern.
- However, patterns can also be expendable.

- The approximate nature of patterns is due to several factors (allowances):
  - Shrinkage – during solidification and cooling.
  - Draft – allows pattern extraction from mold.
  - Finish machining – allowance or ‘stock’ required for machined surfaces.
  - Distortion – occurs in complex shapes.
- Pattern making is an art requiring skill.
Patterns

Casting Design Guidelines

- Casting design directly affects the ease of molding.
- Parting plane of casting is very important and affects the following areas:
  - Number of cores
  - Method of supporting cores
  - Use of effective gating
  - Weight of final casting
  - Final dimensional accuracy

Casting Design Guidelines

- Minimize use of cores.
- Want to control solidification process:
  - Chvorinov’s rule – small thin sections cool rapidly with stronger, harder material.
  - Heavier thicker sections cool more slowly and have weaker larger grained sections.
  - Must be careful when designing – can’t have large section between two small thin sections.
Casting Design Guidelines

- Intersections can cause problems:
  - Stress concentrations
  - Hot spots
  - However, if too large, can cause hot spots.
- Radii/fillets can be used to eliminate stress concentrations.
  - However, if too large, can cause hot spots.
- Use risers to feed large sections.

The End – See Oncourse for Videos