

روشهاي توليد و کارگاه
PRODUCTION TECHNIQUES

FUNDAMENTALS OF METAL CASTING



DEPARTMENT OF MECHANICAL ENGINEERING
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Casting process

The casting process involves:

- ✓ Pouring molten metal into a mold patterned after the part to be manufactured
- ✓ Allowing it to solidify
- ✓ Removing the part from the mold

Important considerations in casting operations:

- ✓ Flow of the molten metal into the mold cavity
- ✓ Solidification and cooling of the metal in the mold
- ✓ Influence of the type of mold material



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Solidification of metals

Pouring molten metal into a mold:

- ✓ Accompanied by taking place of a series of events (heat and mass transfer, solidification,...)
- ✓ The events influence the size, shape, uniformity, and chemical composition of the grains formed throughout casting
- ✓ Grains influence overall properties of casting
- ✓ The events are affected by
 - ✓ Type of material
 - ✓ Thermal properties of the metal and the mold
 - ✓ Geometric relationship between volume and surface area of casting
 - ✓ Shape of mold



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Solidification of metals

□ Pure metals:

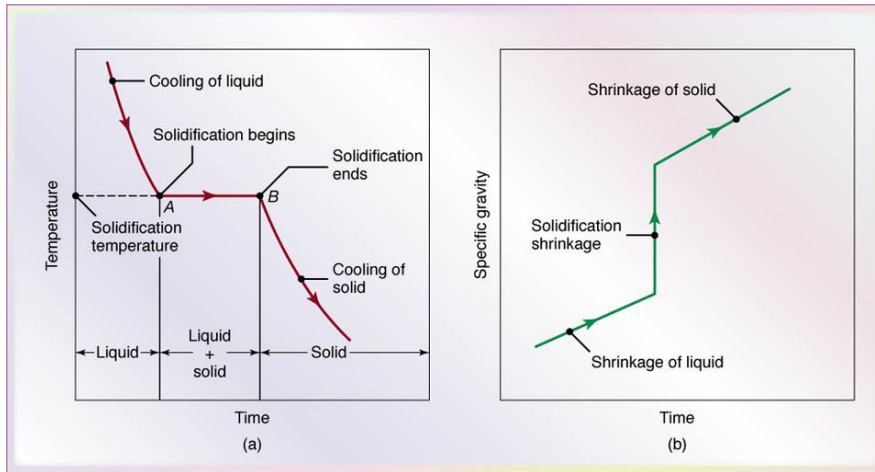
- ✓ Solidify at constant temperature
- ✓ The solidification front (solid-liquid interface) moves through the molten metal from the mold walls in toward the center
- ✓ Grains structures:
 - ✓ Fine equiaxed at the mold walls
 - ✓ Grains grow in a direction opposite to the heat transfer direction
 - ✓ Columnar grains
 - ✓ Equiaxed and coarse grains away from the mold walls



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Solidification of Pure Metals



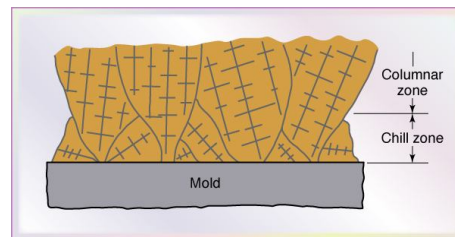
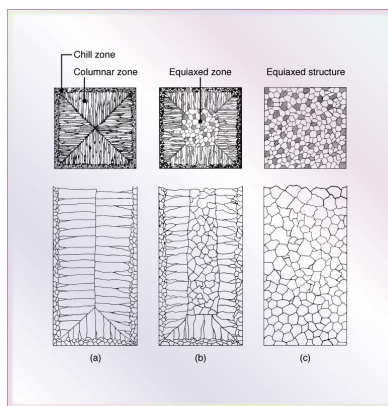
(a) Temperature as a function of time for the solidification of pure metals. Note that the freezing takes place at a constant temperature. (b) Density as a function of time



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Cast Structures of Solidified Metals



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

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.



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Solidification of metals

□ Alloys:

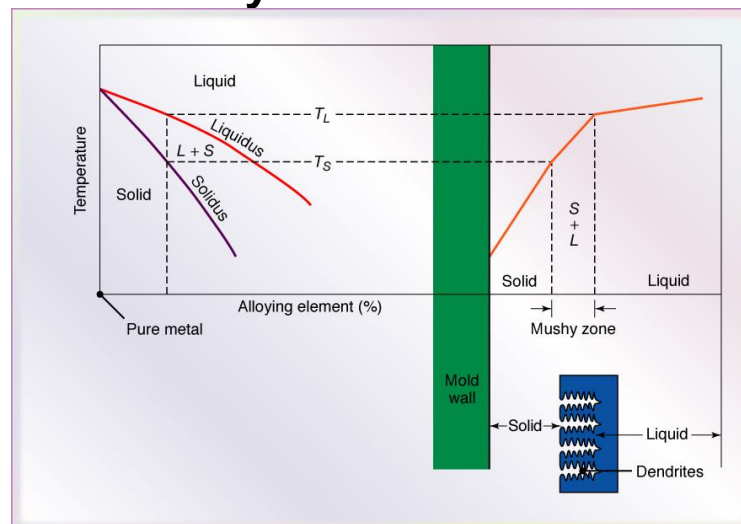
- ✓ Begins at liquidus temperature and is complete when it reaches the solidus temperature
- ✓ Mushy state within the temperature range ($T_L - T_S$), consisting columnar dendrites
- ✓ Dendrites have 3D arms and branches
- ✓ The width of mushy zone: Freezing range = $T_L - T_S$
 - ✓ Short freezing range $\Delta T < 50^\circ\text{C}$ like ferrous casting
 - ✓ long freezing range $\Delta T > 110^\circ\text{C}$ like aluminum alloys
- ✓ Lamellar or fibrous structure



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Alloy Solidification



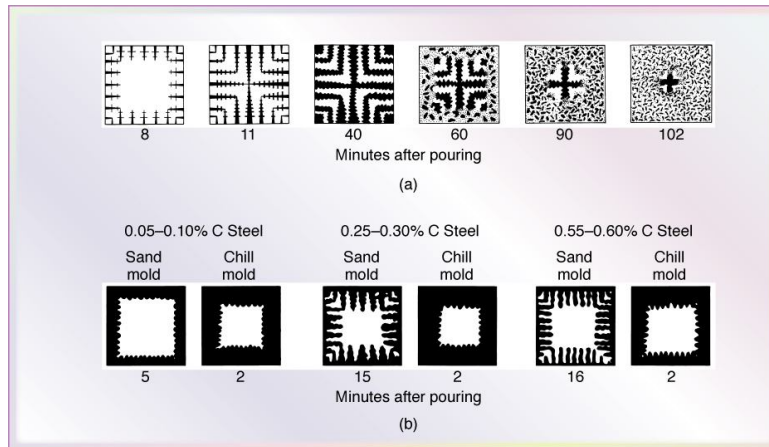
Schematic illustration of alloy solidification and temperature distribution in the solidifying metal. Note the formation of dendrites in the mushy zone.



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Solidification of Iron and Carbon Steels



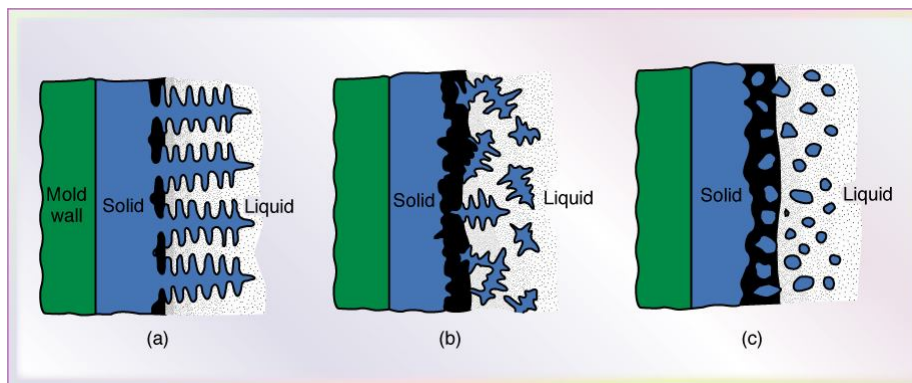
(a) Solidification patterns for gray cast iron in a 180-mm square casting. Note that after 11 minutes of cooling, dendrites reach each other, but the casting is still mushy throughout. It takes about two hours for this casting to solidify completely. (b) Solidification of carbon steels in sand and chill (metal) molds. Note the difference in solidification patterns as the carbon content increases.



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Basic Types of Cast Structures



Schematic illustration of three basic types of cast structures: (a) columnar dendritic; (b) equiaxed dendritic; and (c) equiaxed nondendritic.



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Solidification of metals

□ Alloys:

□ Effects of cooling rates:

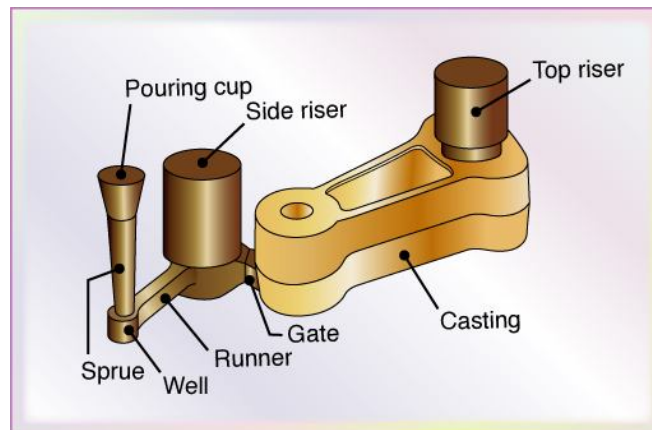
- ✓ Slow cooling rate (order of 10^2 K/s): coarse dendritic structure with large spacing between dendrite arms
- ✓ High cooling rate (order of 10^4 K/s): finer structure with smaller dendrite arm spacing
- ✓ Higher cooling rates (order of 10^6 to 10^8 K/s): amorphous structure
- ✓ Decreasing grain size:
 - ✓ Increase strength and ductility
 - ✓ Decreases microprosoity
 - ✓ Decreases tendency for the casting to crack (hot tearing)



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Fluid flow: a basic gravity casting system



Schematic illustration of a typical riser-gated casting. Risers serve as reservoirs, supplying molten metal to the casting as it shrinks during solidification.



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Fluid flow

❑ **A basic gravity casting system consists of:**

- ✓ Pouring basin (cup) for pouring the molten metal into mold
- ✓ Gating system (sprue, runners and gates)
- ✓ Sprue: a tapered vertical channel for downward molten flow
- ✓ Runners: the channels that carry the molten metal from the sprue into the mold cavity or connect the sprue to the gate
- ✓ Gate: the portion of the runner through which the molten metal enters the mold cavity
- ✓ Riser (feeder): serves as reservoirs of molten metal to supply any molten metal necessary to prevent porosity due to shrinkage during solidification



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Fluid flow

❑ **Successful casting requires:**

- ✓ Proper design and control of the solidification process to ensure adequate fluid flow in the system
- ✓ Well designed gating system
 - ✓ Duty of gating system:
 - ✓ To flow the molten metal into mold cavity
 - ✓ To trap contaminants such as oxides and other inclusions
 - ✓ To avoid or minimize problems such as premature cooling and turbulence
- ✓ Two basic principles of fluid flow relevant to gating design:
 - ✓ Bernoullies theorem (conservation of energy)
 - ✓ Mass continuity



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Fluid Flow and Solidification Time

Bernoulli's theorem $h + \frac{p}{\rho g} + \frac{v^2}{2g} = \text{constant}$

Mass continuity $Q = A_1 v_1 = A_2 v_2$

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

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

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



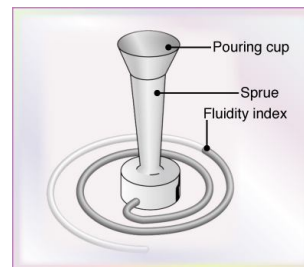
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Fluidity of molten metal

❑ The capability of the molten metal to fill mold cavities, and is affected by:

- ✓ Viscosity
- ✓ Surface tension
- ✓ Inclusions
- ✓ Solidification pattern of alloy
- ✓ Mold design
- ✓ Mold material and its surface characteristics
- ✓ Rate of pouring
- ✓ Heat transfer



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.

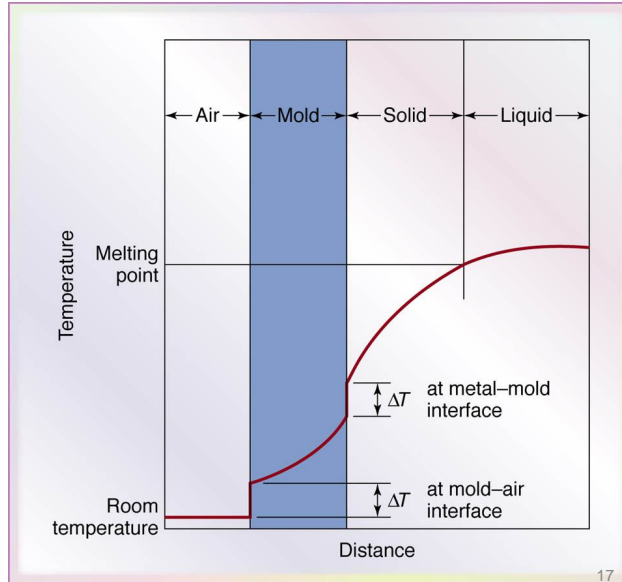


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Temperature Distribution during Metal Solidification

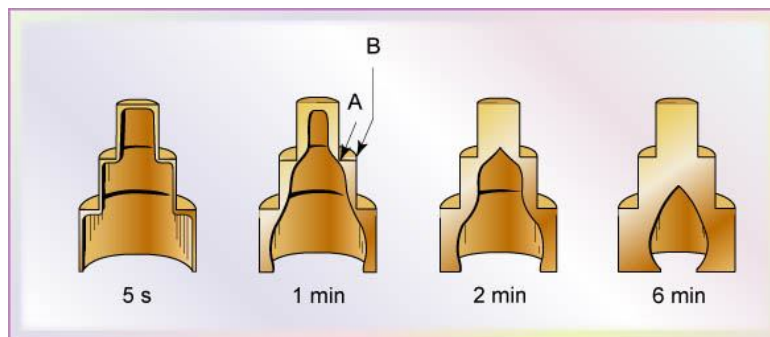
Temperature distribution at the interface of the mold wall and the liquid metal during the solidification of metals in casting



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Solidified Skin on a Steel Casting



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.



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Shrinkage

- ❑ **Contraction of metals during solidification and while cooling to room temperature as a result of their thermal expansion**
- ✓ Causes dimensional changes and sometimes cracking
- ✓ Three sequential events in shrinkage:
 - ✓ Contraction of the molten metal as it cools prior to its solidification
 - ✓ Contraction of the metal during phase change from liquid to solid (latent heat of fusion)
 - ✓ Contraction of the solidified metal (the casting) as its temperature drops to ambient temperature (largest part)



Solidification Contraction or Expansion

TABLE 10.1

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 | | |



Shrinkage Allowance for Casting in Sand Molds

TABLE 12.1

Normal Shrinkage Allowance for Some Metals Cast in Sand Molds

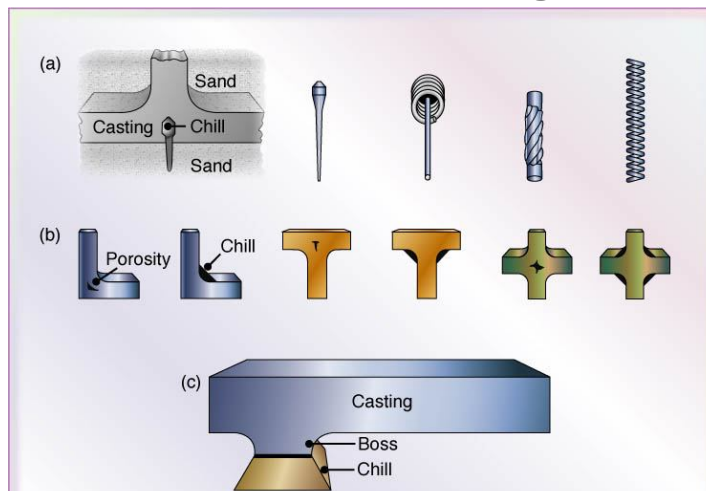
| Metal | % |
|----------------------|----------|
| Gray cast iron | 0.83–1.3 |
| White cast iron | 2.1 |
| Malleable cast iron | 0.78–1.0 |
| Aluminum alloys | 1.3 |
| Magnesium alloys | 1.3 |
| Yellow brass | 1.3–1.6 |
| Phosphor bronze | 1.0–1.6 |
| Aluminum bronze | 2.1 |
| High-manganese steel | 2.6 |



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Types of Internal and External Chills used in Casting



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).

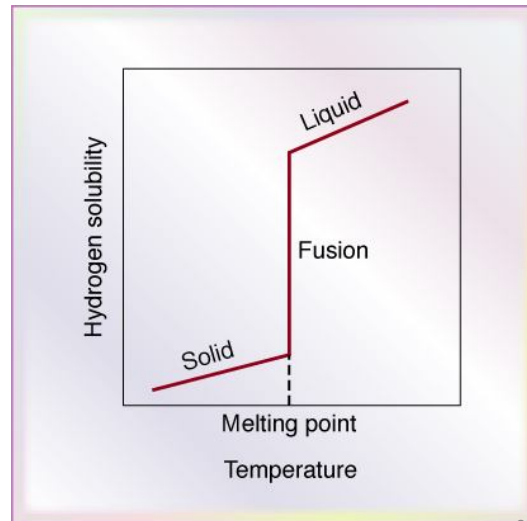


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Solubility of Hydrogen in Aluminum

Solubility of hydrogen in aluminum. Note the sharp decrease in solubility as the molten metal begins to solidify.



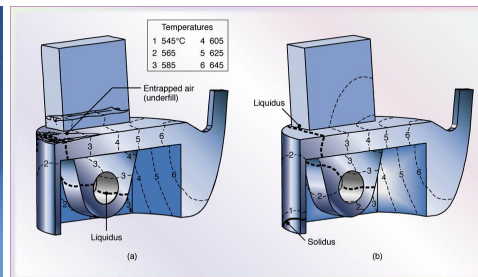
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Casting of an Aluminum Piston



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



Simulation of mold filling and solidification. (a) 3.7 seconds after start of pour. Note that the mushy zone has been established before the mold is filled completely. (b) Using a vent in the mold for removal of entrapped air, 5 seconds after pour.



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