Lecture 6

Chapter 10

Fundamentals of Metal Casting

• Casting of Metals
  – Pouring of molten metal into a patterned mold
    • Flow of molten metal through cavities
  – Solidification
    • Shrinkage
    • Expansion
  – Removal of part from mold
Structures of Cast Metals

- Casting zones
  - Chill zone
  - Columnar zone
  - Equiaxed zone

- Control of microstructure
  - Cooling rate
  - Nucleating agents

Effects of Cooling on Microstructure

- Slow cooling rates
  - Coarse dendritic structures

- High cooling rates
  - Finer dendrites
  - Larger equiaxed zone
  - Smaller grains
    - Increased
      - Strength
      - Ductility
    - Decreased
      - Porosity
      - Chance of hot tear
Controlling the Microstructure of Cast Metals

- Increased convection
  - Smaller dendrites
- Decreasing grain size
  - Mechanical vibration
  - Nucleating agents

Temperature Profile in a Casting
Solidification in a Casting

Shrinkage and Expansion in Castings

### TABLE 10.1

<table>
<thead>
<tr>
<th>Metal or alloy</th>
<th>Volumetric solidification contraction (%)</th>
<th>Metal or alloy</th>
<th>Volumetric solidification contraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>6.6</td>
<td>70%Cu–30%Zn</td>
<td>4.5</td>
</tr>
<tr>
<td>Al–4.5%Cu</td>
<td>6.3</td>
<td>90%Cu–10%Al</td>
<td>4</td>
</tr>
<tr>
<td>Al–12%Si</td>
<td>3.8</td>
<td>Gray iron</td>
<td>Expansion to 2.5</td>
</tr>
<tr>
<td>Carbon steel</td>
<td>2.5–3</td>
<td>Magnesium</td>
<td>4.2</td>
</tr>
<tr>
<td>1% carbon steel</td>
<td>4</td>
<td>White iron</td>
<td>4–5.5</td>
</tr>
<tr>
<td>Copper</td>
<td>4.9</td>
<td>Zinc</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Source: After R. A. Flinn.

- **Shrinkage**
  - Contraction of molten metal prior to solidification
    - Dependent on superheat
  - Contraction of metal during solidification
  - Contraction of solidified metal as temperature drops to room temp
    - Dependent on solidification temperature (or range)
Hot Tearing

- Hot tearing
  - Occurs due when casting is not allowed to shrink freely

Defects of Castings
Chapter 11

Metal Casting Processes

### TABLE 11.1

<table>
<thead>
<tr>
<th>Process</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>Almost any metal cast; no limit on size, shape or weight; low tooling cost.</td>
<td>Some finishing required; somewhat coarse finish; wide tolerances.</td>
</tr>
<tr>
<td>Shell mold</td>
<td>Good dimensional accuracy and surface finish; high production rate.</td>
<td>Part size limited; expensive patterns and equipment required.</td>
</tr>
<tr>
<td>Expendable pattern</td>
<td>Most metal cast with no limit on size; complex shapes</td>
<td>Patterns have low strength and can be costly for low quantities.</td>
</tr>
<tr>
<td>Plaster mold</td>
<td>Intricate shapes; good dimensional accuracy and finish; low porosity.</td>
<td>Limited to nonferrous metals; limited size and volume of production; mold making time relatively long.</td>
</tr>
<tr>
<td>Ceramic mold</td>
<td>Intricate shapes; close tolerance parts; good surface finish.</td>
<td>Limited size.</td>
</tr>
<tr>
<td>Investment</td>
<td>Intricate shapes; excellent surface finish and accuracy; almost any metal cast.</td>
<td>Part size limited; expensive patterns, mold, and labor.</td>
</tr>
<tr>
<td>Permanent mold</td>
<td>Good surface finish and accuracy; low porosity; high production rate.</td>
<td>High mold cost; limited shape and tolerances; not suitable for high-melting-point metals.</td>
</tr>
<tr>
<td>Die</td>
<td>Excellent dimensional accuracy and surface finish; high production rate.</td>
<td>Die cost in high part size limited; usually limited to nonferrous metals; long lead time.</td>
</tr>
<tr>
<td>Centrifugal</td>
<td>Large cylindrical parts with good quality; high production rate.</td>
<td>Equipment is expensive; part shape limited.</td>
</tr>
</tbody>
</table>
Typical Elements of a Sand Casting

- Metal match plate
- Taper for ease of removal
Using Cores in Sand Molds

- Sand casting core
  - Definition of hollow regions
    - External lettering
    - Deep external pockets

Sequence of Operations in Sand Casting
Sequence of Operations in Sand Casting

(f) Cope after ramming with sand and removing pattern, sprue, and risers

(g) Drag ready for sand

(h) Drag after removing pattern

(i) Drag with core set in place

(j) Cope and drag assembled ready for pouring

(k) Cope

(l) Casting as removed from mold; heat treated

(m) Casting ready for shipment

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Investment Casting

(a) Mold to make pattern

(b) Injection wax or plastic pattern

(c) Ejecting pattern

(d) Wax pattern

(e) Pattern assembly (tree)

(f) Stucco coating

(g) Completed mold

(h) Stucco wax or plastic

(i) Melted metal

(j) Pattern

(k) Pattern meltout

(l) Pouring

(m) Shrinkout

(n) Casting
Comparison of Conventional Casting and Investment Casting

Chapter 12

Metal Casting: Design, Materials, and Economics
Using Fillets

(a) Poor

(b) Good

Avoid Hot Spots and Porosity

(a) Poor

(c) Shrinkage cavity

(b) Good

(d) Good

(e) Core
Avoid Shrinkage Cavities

(a) Poor (b) Good

Riser

Shrinkage cavity

(c)

Riser

Shrinkage cavity

**Comparison of Manufacturing Properties**

<table>
<thead>
<tr>
<th>Type of alloy</th>
<th>Application</th>
<th>Castability*</th>
<th>Weldability*</th>
<th>Machinability*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>Pistons, clutch housings, intake manifolds</td>
<td>E</td>
<td>F</td>
<td>G-E</td>
</tr>
<tr>
<td>Copper</td>
<td>Pumps, valves, gear blanks, marine propellers</td>
<td>F-G</td>
<td>F</td>
<td>F-G</td>
</tr>
<tr>
<td>Ductile iron</td>
<td>Crankshafts, heavy-duty gears</td>
<td>G</td>
<td>D</td>
<td>G</td>
</tr>
<tr>
<td>Gray iron</td>
<td>Engine blocks, gears, brake disks and drums, machine bases</td>
<td>E</td>
<td>D</td>
<td>G</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Crankcase, transmission housings</td>
<td>G-E</td>
<td>G</td>
<td>E</td>
</tr>
<tr>
<td>Malleable iron</td>
<td>Farm and construction machinery, heavy-duty bearings, railroad rolling stock</td>
<td>G</td>
<td>D</td>
<td>G</td>
</tr>
<tr>
<td>Nickel</td>
<td>Gas turbine blades, pump and valve components for chemical plants</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Steel (carbon and low alloy)</td>
<td>Die blocks, heavy-duty gear blanks, aircraft undercarriage members, rail-road wheels</td>
<td>F</td>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>Steel (high alloy)</td>
<td>Gas turbine housings, pump and valve components, rock crusher jaws</td>
<td>F</td>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>White iron</td>
<td>Mill liners, shot blasting nozzles, railroad brake shoes, crushers and pulverizers</td>
<td>G</td>
<td>VP</td>
<td>VP</td>
</tr>
<tr>
<td>Zinc</td>
<td>Door handles, radiator grills</td>
<td>E</td>
<td>D</td>
<td>E</td>
</tr>
</tbody>
</table>

*E, excellent; G, good; F, fair; VP, very poor; D, difficult.
Cost Comparison of Different Casting Techniques

TABLE 12.6

<table>
<thead>
<tr>
<th>Process</th>
<th>Die</th>
<th>Equipment</th>
<th>Labor</th>
<th>Production rate (Pc/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>L</td>
<td>L</td>
<td>L–M</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Shell-mold</td>
<td>L–M</td>
<td>M–H</td>
<td>L–M</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Plaster</td>
<td>L–M</td>
<td>M</td>
<td>M–H</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Investment</td>
<td>M–H</td>
<td>L–M</td>
<td>H</td>
<td>&lt;1000</td>
</tr>
<tr>
<td>Permanent mold</td>
<td>M</td>
<td>M</td>
<td>L–M</td>
<td>&lt;60</td>
</tr>
<tr>
<td>Die</td>
<td>H</td>
<td>H</td>
<td>L–M</td>
<td>&lt;200</td>
</tr>
<tr>
<td>Centrifugal</td>
<td>M</td>
<td>H</td>
<td>L–M</td>
<td>&lt;50</td>
</tr>
</tbody>
</table>

* L, low; M, medium; H, high.