Metal Casting Processes

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Session Objectives

• At the end of the session students should have understood
  – Fundamentals of metal casting
  – Metal casting processes
    • Sand casting
    • Die casting
    • Investment casting
    • Continuous casting
  – Case studies
    • Cylinder block
    • Piston
Manufacturing Processes

Casting:
- Expendable mold
- Permanent mold

Forming & Shaping:
- Rolling
- Forging
- Extrusion
- Drawing
- Sheet forming
- PM

Machining:
- Turning
- Milling
- Drilling
- Boring
- Grinding
- Shaping
- Broaching

Joining:
- Welding
- Brazing
- Soldering
- Bonding
- Assembly

Finishing:
- Lapping
- Polishing
- Deburring
- Surface treating
- Coating
What is casting?

- Processing methods affect material properties differentially
  (and therefore the final component)
- Casting
  - Mostly Metals
- Casting involves pouring/injecting molten material into a prepared cavity. On solidification the metal takes the form of the cavity.
- Cavity is formed within a Mould.
- Choice of manufacturing technique dependant upon
  - required properties of component
  - Suitability
  - cost
Advantages of Casting

• Excellent for large and complex shapes, particularly with internal features
• Can produce net shape or near net shape components
• Used where mechanical properties are not of paramount importance
• Used where solid state processing is difficult or uneconomic
Applicability of Casting

- Excellent for large and complex shapes, particularly with internal features
- Can produce net shape or near net shape components
- Used where mechanical properties are not of paramount importance
- Used where solid state processing is difficult or uneconomical
ALUMINUM ALLOY CASTINGS

Large, complex sand casting by rigid mould technology meeting stringent radiographic and penetrant NDT stds.

Aeroengine gear case casting in Al-Si-Mg alloy A 356
MAGNESIUM ALLOY CASTINGS

Main Gear Box Housing of the Advanced Light Helicopter

Large surface area with wall thickness of 5 mm. As-cast internal oil passages, 5-12 mm dia, running to a total length of 500 mm. Casting weight: 50 kgs, Process: Rigid mould
MAGNESIUM ALLOY CASTINGS

Large diameter, large surface area, thin walled casting for missile applications

Reduction gear cover casting for a helicopter engine with as-cast internal oil passages
# Casting processes

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Metal Casting Processes

Expendable mold
- Sand
  - Shell
  - Expandable pattern
  - Plaster
  - Ceramic
  - Investment

Permanent mold
- Slush
  - Pressure
  - Die
  - Centrifugal
  - Squeeze
  - Semisolid

Single-crystal growing
- Single-crystal for Microelectronics
- Single-crystal Turbine blades
  - Directional solidification
CASTING PROCESSES OPERATIONS - FLOW CHART

COMPONENT DRAWING

CASTING DRG
- DRAFT; M/C ALLOWANCE;
- CORNER & FILLET RADII;
- PARTING LINE.

TOOL DRG.
- PATTERN & CORE BOX
- /DIE DESIGN;
- CONTRACTION ALLOWANCE;
- AUXILLIARY TOOLS
- LIKE CHILLS, TEMPLATES,
- MOULD BOXES Etc.

METHODS DRG.
- POURING & FEEDING
- SYSTEM MFG. PROCESS
- DETAILS MOULD MEDIA
- METAL TEMP. Etc.

TEST SHEET
- DETAILED TEST
- REQTS. AND
- ACCEPTANCE
- STANDARDS

ESTIMATES & QUOTATION

COMPONENT DRAWING

TOOL MFG. INCLUDING
- AUXILLIARY TOOLS

MOULD AND CORE PREPERATION
OR DIE PREPERATION

SAND MIXING AND
- TESTING

ASSEMBLY

CASTING

FURNACES MELT AND REFINE

KNOCK OUT

RECLAIMED SAND

FETTLING AND CLEANING

HEAT TREATMENT

NDT AND INSPECTION

SHIPPING

REJECTION

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Sand Casting with a core in place

(a) Mechanical drawing of part
(b) Cope pattern plate
(c) Drag pattern plate
(d) Core boxes
(e) Core halves pasted together
(f) Cope ready for sand
(g) Cope after ramming with sand and removing pattern, sprue, and risers
(h) Drag ready for sand
(i) Drag after removing pattern
(j) Drag with core set in place
(k) Cope and drag assembled and ready for pouring
(l) Casting as removed from mold; heat treated
(m) Casting ready for shipment

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A Review of Casting Processes

- Shell mold casting
- Investment casting
- Permanent mold casting
- Pressure die casting
- Centrifugal casting
Shell Mold Casting

- Metallic 2-piece pattern, 175°C-370°C
- coated with a lubricant (silicone)
- mixture of sand, thermoset resin/epoxy-urea formaldehyde
- cure (baking)
- remove patterns,
  join half-shells → mold
- pour metal
- solidify (cooling)
- break shell → part

Applications: small mechanical parts requiring high precision such as gear housings, cylinder heads and connecting rods etc
Expendable Pattern Casting

- Styrofoam pattern (PS) dipped in refractory slurry → dried
- sand (support)
- pour liquid metal
- foam evaporates, metal fills the shell
- cool, solidify
- break shell → part

Applications: cylinder heads, crankshafts, brake components and manifolds, machine bases

Al engine blocks and other components of the GM saturn automobiles are made by this process
Plaster-mold, Ceramic-mold casting

Plaster-mold slurry: plaster of paris (CaSO₄), talc, silica flour
Ceramic-mold slurry: silica, powdered Zircon (ZrSiO₄)

- The slurry forms a shell over the pattern
- Dried in a low temperature oven
- Remove pattern
- Backed by clay (strength), baked (burn-off volatiles)
- cast the metal
- break mold \(\rightarrow\) part

Plaster-mold: \textit{good finish (Why ?)}
\begin{itemize}
  \item plaster: low conductivity => low warpage, residual stress
  \item low mp metal (Zn, Al, Cu, Mg), gears, valves, fittings,
  \item tooling and ornaments
\end{itemize}

Ceramic-mold: \textit{good finish}
\begin{itemize}
  \item high mp metals (steel, …) => impeller blades, turbines, cutters for machining operations, dies for metal working and molds for making plastics or rubber components
\end{itemize}
Investment casting (lost wax process)

(a) Wax pattern (injection molding)

(b) Multiple patterns assembled to wax sprue

(c) Shell built → immerse into ceramic slurry → immerse into fine sand (few layers)

(d) dry ceramic melt out the wax fire ceramic (burn wax)

(e) Pour molten metal (gravity) → cool, solidify
[Hollow casting: pouring excess metal before solidification

(f) Break ceramic shell (vibration or water blasting)

(g) Cut off parts (high-speed friction saw) → finishing (polish)
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Precision / Investment Castings
Precision / Investment Castings

- Precision torque converter castings for aeroengine
- Thin walled investment casting—“rope pulley”—for a commuter aircraft
- Investment casting for instrument frame

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Permanent mold casting

MOLD: made of metal (cast iron, steel, refractory alloys)

CORE: (hollow parts)
- metal: core can be extracted from the part
- sand-bonded: core must be destroyed to remove

Mold-surface: coated with refractory material

- Spray with lubricant (graphite, silica)
  - improve flow, increase life
- good tolerance, good surface finish
- low mp metals (Cu, Bronze, Al, Mg)
GDC or Permanent Mould Casting

- Non expendable metal moulds 2% Ni. Cast iron, steel
- Pour by gravity at die temp 150 to 200°C
- Life 1000 to 2000 pieces
- Better strength
- Better dimensions
- Better Grains
- Low Incidence of Gas Porosity
- Faster rate of production
- Restriction of Alloys / Shape / Geometry
- Require good venting
- Incorporate cooling ribs in die (thick sections)
Metal Mould Casting – Gravity Die

Two part permanent mould mounted on moulding machine, with centre core designed to pull down for casting removal

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Application: Brake System
Weight: approx. 2.5 Kgf

Application: Brake System
Weight: approx. 0.750 Kgf (set)
Application:
Transmission3 (gear box)
Weight: approx. 3.25 Kgf

Application:
Transmission3 (gear box)
Weight: approx. 1.5 Kgf
PDC (Pressure Die Casting)

- Liquid metal injected into steel die at high velocity – solidifies under pressure
- Injection Pressure : 7 MPa to 140 MPa
- Locking force - 2000 ton
- Casting rate: 5 – 10 pieces / minute
- Die material: 0.3 C; 5.0 Si; 1.3 Mo; 1.0V. hardened to 420 – 460 BHN
- Die life: 50,000 to 2 lakh pieces
- Excellent surface finish / reproducibility
- Excellent dimensional accuracy: 0.05mm
- Castability 1mm (Al alloy)
- Alloy restriction / shape & size restriction
- Prone to gas porosity (finely dispersed N)-can be avoided by O₂ purging producing Al₂O₃ surface
Hot Chamber Die Casting

- Used for lower melting point alloys (zinc and magnesium)
- Mold pressures usually 7 MPa to 14 MPa but can be up to 35 MPa.
Cold Chamber Die Casting

- Used for higher melting point alloys – aluminum and copper based
- Die pressures from 35 to 140 MPa
Pressure die cast components for automotive applications
Centrifugal casting

- permanent mold
- rotated about its axis at 300 ~ 3000 rpm
- molten metal is poured

- Surface finish: better along outer diameter than inner,
- Impurities, inclusions, closer to the inner diameter
Centrifugal casting

Eg. Cylinder Liners, Piston rings etc.
Ladle

Tundish

Submerged nozzle

Mould - may oscillate

Rollers plus water spray

Flame cut to billet length

Further rolling and heat treatment
# Summary of Process Capabilities

<table>
<thead>
<tr>
<th>Process</th>
<th>Alloy Range</th>
<th>Weight Range Kg</th>
<th>Economic Quantity</th>
<th>Thin Section mm</th>
<th>Surface Finish μm</th>
<th>Dimensional Accuracy mm per 100mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>Most</td>
<td>0.1 to 100,000</td>
<td>1 to 100,000</td>
<td>&gt; 5</td>
<td>6.3 to 25</td>
<td></td>
</tr>
<tr>
<td>Evaporative</td>
<td>Most</td>
<td>0.5 to 5000</td>
<td>1000 +</td>
<td>&gt; 2</td>
<td>3.2 to 12.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Investment</td>
<td>Most</td>
<td>0.05 to 250</td>
<td>1000 +</td>
<td>&gt; 1.5</td>
<td>0.8 to 3.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Gravity Die</td>
<td>Non-ferrous</td>
<td>0.1 to 70</td>
<td>1000 +</td>
<td>&gt; 5</td>
<td>3.2 to 6.3</td>
<td>0.25</td>
</tr>
<tr>
<td>LPDC</td>
<td>Non-ferrous</td>
<td>5 to 25</td>
<td>1000 +</td>
<td>&gt; 4</td>
<td>1.6 to 6.3</td>
<td>0.55</td>
</tr>
<tr>
<td>HPDC</td>
<td>Non-ferrous</td>
<td>0.05 to 25</td>
<td>5000 +</td>
<td>&gt; 0.5</td>
<td>0.4 to 3.2</td>
<td>0.15</td>
</tr>
<tr>
<td>Process</td>
<td>Advantages</td>
<td>Disadvantages</td>
<td>Examples</td>
<td></td>
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<td>------------------------------------------------</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>many metals, sizes, shapes, cheap</td>
<td>poor finish &amp; tolerance</td>
<td>engine blocks, cylinder heads</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shell mold</td>
<td>better accuracy, finish, higher production rate</td>
<td>limited part size</td>
<td>connecting rods, gear housings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expendable pattern</td>
<td>Wide range of metals, sizes, shapes</td>
<td>patterns have low strength</td>
<td>cylinder heads, brake components</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plaster mold</td>
<td>complex shapes, good surface finish</td>
<td>non-ferrous metals, low production rate</td>
<td>prototypes of mechanical parts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ceramic mold</td>
<td>complex shapes, high accuracy, good finish</td>
<td>small sizes</td>
<td>impellers, injection mold tooling</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Investment</td>
<td>complex shapes, excellent finish</td>
<td>small parts, expensive</td>
<td>jewellery</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Permanent mold</td>
<td>good finish, low porosity, high production rate</td>
<td>Costly mold, simpler shapes only</td>
<td>gears, gear housings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Die</td>
<td>Excellent dimensional accuracy, high production rate</td>
<td>costly dies, small parts, non-ferrous metals</td>
<td>gears, camera bodies, car wheels</td>
<td></td>
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<tr>
<td>Centrifugal</td>
<td>Large cylindrical parts, good quality</td>
<td>Expensive, few shapes</td>
<td>pipes, boilers, flywheels</td>
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</table>
Casting Defects

- Discontinuities in castings that exhibit a size, shape, orientation, or location that makes them detrimental to the useful service life of the casting.

- Some casting defects are remedied by minor repair or refurbishing techniques, such as welding.

- Other casting defects are cause for rejection of the casting.
Summary

• Fundamentals of metal casting its applicability
• Different methods of casting
• Process characteristics and comparisons of different casting techniques
• Casting defects have been studied