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METAL CASTING

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CASTING PROCESS

- Fundamentals of casting process
- Principles of casting process
- Typical examples of the product produced by casting process
  Engine Block, Machine tool parts, etc.

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When casting becomes inevitable??

- For example when you want to machine very large size holes
- For producing parts of complicated shapes
CASTING PROCESS

- Steps involved in casting process
  - Pattern making.
  - Mould making.
  - Core making.
  - Melting of metal and pouring.
  - Cooling and solidification.
  - Cleaning of castings and inspection.

Casting

Refractory mold → pour liquid metal → solidify, remove → finish.

- VERSATILE: complex geometry, internal cavities, hollow sections.
- VERSATILE: small (~1 gram) → very large parts (~1000 Kg).
- ECONOMICAL: little wastage (extra metal is re-used).
- ISOTROPIC: cast parts have same properties along all directions.

Sand Casting

- Cope: Top half
- Dag: Bottom half
- Core: for internal cavities
- Pattern: positive
- Funnel → sprue → runners → gate → cavity → {risers, vents}
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Sand Casting Considerations

(a) How do we make the pattern?
   - cut, carve, machine

(b) Why is the pattern not exactly identical to the part shape?
   - pattern → outer surfaces; (inner surfaces: core)
   - shrinkage, post-processing

(c) Parting line
   - how to determine?

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CASTING PROCESS

- Required casting
- Core box
- Pattern
- Core
- Cavity
- Gating system
- Sand mould in two-piece flask

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Sand Casting Considerations...

(d) Taper
   - do we need it?

(e) Core prints, chaplets
   - hold the core in position
   - chaplet is metal (why?)

(f) Cut-off, finishing
PROPERTIES OF PATTERN MATERIAL...

- It should be easily shaped, worked, machined and joined.
- It should be resistant to wear and corrosion.
- It should be resistant to chemical action.
- It should be dimensionally stable and must remain unaffected by variations in temperature and humidity.
- It should be easily available and economical.

WOOD

- Easily available
- Low weight
- Low cost
- It absorbs moisture and hence dimensions will change
- Lower life
- Suitable for small quantity production and very large size castings.

METAL

- Used for mass production
- For maintaining closer dimensional tolerances on casting.
- More life when compared to wooden patterns
- Few of the material used include CI, Al, Fe, Brass etc. Al is widely used.
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PLASTIC
- Low weight
- Easier formability
- Do not absorb moisture
- Good corrosion resistance

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POLYSTYRENE
- Used for prototype (single piece) castings
- Also known as Disposable patterns.

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TYPES OF PATTERNS
(a) Solid pattern  (b) Split pattern  (c) Loose piece pattern
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TYPES OF PATTERNS

- SOLID PATTERN
  Simple shape castings are produced by
  this type of patterns

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TYPES OF PATTERNS

- SPLIT PATTERN
  Used when patterns cannot be made
  as a single piece

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TYPES OF PATTERN

- LOOSE PIECE PATTERN Used when
  1. Withdrawal of pattern from mould is not possible
  2. Castings is having projections, undercuts, etc
     After ramming first main pattern is removed and then
     the loose pieces
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GATED PATTERN

- Runner
- Pattern
- Gate

(a) Gated pattern for 8 castings

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GATED PATTERN

- Used for producing small sized cavities in one mould

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MATCH PLATE PATTERN

- Pattern
- Match plate

(b) Match plate pattern
MATCH PLATE PATTERN

- Split patterns attached on either side is known as Match plate pattern.
- It increases production and helps in maintaining uniformity in the size and shape of the castings.

DISPOSABLE PATTERN

(a) Disposable pattern in sand mould
(b) Hot metal replacing disposable pattern

PATTERN ALLOWANCE

- WHY ARE ALLOWANCES NECESSARY?
TYPES OF ALLOWANCE

- SHRINKAGE ALLOWANCE
- MACHINING ALLOWANCE
- DRAFT OR TAPER ALLOWANCE
- DISTORTION ALLOWANCE
- RAPPING OR SHAKE ALLOWANCE

SHRINKAGE ALLOWANCE

- Provided to compensate for shrinkage of material
- Pattern is made slightly bigger
- Amount of allowance depends upon type of material, its composition, pouring temperature etc.

MACHINING ALLOWANCE

- Provided to compensate for machining on casting.
- Pattern is made slightly bigger is size.
- Amount of allowance depends upon size and shape of casting, type of material, machining process to be used, degree of accuracy and surface finish required etc.
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**DRAFT OR TAPER ALLOWANCE**

(a) Pattern with zero or no draft
(b) Pattern with draft

(Not to scale)

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**DRAFT OR TAPER ALLOWANCE**

- Provided to facilitate easy withdrawal of the pattern.
- Typically it ranges from 1 degree to 3 degree for wooden patterns.

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**DISTORTION ALLOWANCE**

- Provided on patterns whose castings tend to distort on cooling.

(a) Required shape of casting
(b) Casting produced when no distortion allowance is provided
(c) Pattern with distortion allowance
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MOULDING PROCESS

- Bench Moulding
- Floor Moulding
- Pit Moulding

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TYPES OF MOULDING OPERATIONS

- Hand Moulding
- Machine Moulding

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CORES

- Why Cores are used?

Diagram showing the components of sand moulding in a two-piece flask.
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**CORE PROPERTIES**
- It must be strong to retain the shape while handling,
- It must resist erosion by molten metal,
- It must be permeable to gases,
- It must have high refractoriness, and
- It must have good surface finish to replicate it on to the casting.

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**STEPS IN CORE MAKING**
- Core sand preparation.
- Core making.
- Core baking.

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**GATING SYSTEM**
- It refers to the passageway through which molten metal passes to enter mould cavity.

![Gating System Diagram]

- Pouring cup
- Sprue
- Sprue base
- Runner
- Riser
- Gate
- Casting
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**RISER**

- Pouring cup
- Sprue
- Sprue base
- Runner
- Casting
- Riser
- Gate

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**SPRUE**

- Metal pouring cup
- Corners
- Metal pulling down
- Low pressure zone
- Gate
- Sprue
- Liquid metal

(a) Straight sprue
(b) Tapered sprue

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**SOLIDIFICATION TIME**

*[Chvorinov's Rule]*

- **Total Solidification Time**\(TST\)

\[
TST = c \left(\frac{volume}{surface\ area}\right)^n
\]

Where \(c\) = mould constant depends upon the mould material, metal properties & temperature
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.

CASTING YIELD

- What is casting yield?

$$C_y = \frac{W_c}{W_c + W_g} \times 100\%$$

DEFECTS IN CASTING
Basic categories of casting defects

1. Metallic projections:
   - Fins, flash or projections

2. Cavities
   - Blow holes, pin holes, shrinkage cavities

3. Discontinuities
   - Cracks, cold or hot tears
   - Cold shuts - improper fusion of different streams of metals
   - Improper solidification can cause tears

4. Defective surface
   - Surface folds, laps, scars, adhering sand layers and oxide scales

5. Incomplete casting
   - Misruns (due to premature solidifications)
   - Insufficient metal poured
   - Leaks in the mold

6. Incorrect dimensions
   - Incorrect allowances
   - Deformed pattern
   - Pattern mounting error

7. Inclusions
   - Nonmetallic particles usually
   - Bad for casting - acts as stress raiser
   - Materials from alloys, crucible, mold etc
   - Sand particles, ceramic particles
   - Can be avoided using filters, good strong molds etc
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**BLOW HOLES**

- Appears as small round voids opened to the casting surface.
- Caused by hard ramming and low permeability sands.

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**SHRINKAGE DEFECTS**

- Caused by inadequate feeding of molten metal.

![Diagram of casting with risers](image)

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**HOT TEARS**

- Appears as external cracks or discontinuities on casting surface.
- Caused by hard ramming, too much of shrinkage of molten metal and poor design of casting.
MISRUNS

- Mould cavity remaining unfilled (casting is too thin or temperature is too cold)

COLD SHUT
- Imperfect fusion of molten metal in the mould cavity.

POUR SHORT
- Mould cavity is not completely filled for the want of molten material.

INCLUSIONS
- Foreign material present within the metal of a casting.

Common Casting defects

- Blow
- Scar
- Blister
- Gas holes
- Pin holes
- Porosity
- Drop
- Dirt
- Buckle
- Scab
- Rat tail
- Penetration
- Swell
- Misrun
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Common Casting defects

- Nonmetallic inclusion
- Gate
- Cold shot
- Shrinkage cavity
- Hot tear
- Mold shift
- Core shift

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Casting defects

- Inclusions in spheroidal graphite cast iron.
- Part of the surface has been machined away to show the inclusions more clearly.
- A crossjoint in a large gray iron valve body casting produced by mismatch of top and bottom parts of the mould.

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- Flash
- Mold Shift
- Porosity
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Inclusions
Gas pockets
Short Casting

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Summary of casting defects

<table>
<thead>
<tr>
<th>Defect</th>
<th>Cause</th>
<th>Foundry remedy</th>
<th>Design remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flash</td>
<td>Flow into mold join</td>
<td>Lower pouring temperature,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase mold box clamping</td>
<td></td>
</tr>
<tr>
<td>Oxide and dross</td>
<td>Entrapment of foreign material</td>
<td>Increase care and cleanliness during pouring</td>
<td></td>
</tr>
<tr>
<td>Shrinkage cavities</td>
<td>Lack of sufficient feed metal</td>
<td>Promote directional solidification by controlling heat flow</td>
<td>Relocate risers and ingates</td>
</tr>
<tr>
<td>Misruns</td>
<td>Low metal fluidity</td>
<td>Raise pouring temperature</td>
<td>Reconsider position, size and number of ingates and vents</td>
</tr>
</tbody>
</table>

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Inspection of casting

1. Visual Inspection
   - Most surface defects can be seen
2. Pressure test
   - The casting is filled with pressurized air after closing all the openings
   - E.g. gear boxes, pressure vessels, look for leaks by submerging in special liquids
   - Pressurized oil can also be used in some cases
3. Radiographic Examination
   - Usually x-rays or g rays
   - X-ray method is used for voids, non-metallic inclusions, porosity, cracks
   - Defects appear darker than surrounding
4. Ultrasound examination

- Ultrasound across the casting
- Sound transmitted across homogenous metals
- However discontinuities reflect sound back.
- Not good for cast iron

5. Dye Penetration Inspection

- To detect invisible surface defects in non-magnetic castings
- A dye of fluorescent material is sprayed or applied near the surface. The surface is then wiped and viewed in darkness
- Cracks will be visible

6. Magnetic Particle inspection

- Induce magnetic field through section under inspection
- Powdered Ferro-magnetic magnetic material is spread onto the surface
- Voids or cracks result in abrupt changes in permeability of material – leads to leakage in magnetic field
- Particles concentrate on the disrupted field or on the crack.

ADVANTAGES OF CASTING PROCESS

- No restriction on type of metal or alloy.
- No restriction on size of the component that can be casted.
- Economically suitable for batch and mass production.
**DISADVANTAGES OF CASTING PROCESS**

- High energy consuming process.
- Highly labor intensive.
- Raw material requirement is quite high.
- For producing 1 ton of steel casting about 2.2 tons of metal, 0.3 tons of facing sand and 4 tons of baking sand are needed apart from many other materials.
- More time is involved.
- High environmental pollution.

**SELECTION OF CASTING PROCESS**

- Quantity to be produced.
- Requirement of the product in terms of surface finish, accuracy, complexity etc.
- Physical properties of the material.
- Process capability to meet the requirement of point 2 and 3.
- Initial investment required and operational costs.
- Other factors such as environmental pollution, availability of skilled operator (if required), possibility of automation.

**Crank Shaft**
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Impellers

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V6 engine block

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AUDI engine block
EXAMPLE 1

- A job shown in the Figure is to be made of steel by casting process. The mould for this job is made from a wooden pattern. Determine the dimensions of the wooden pattern. Assume machining allowance of 2 mm on each side, shrinkage allowance of 2% and a taper allowance of 1 degree.

EXAMPLE -1

Solution

Step-1: Machining Allowance

- It is given that machining allowance of 2 mm on each side is to be given. Thus, each side is increased by 2 mm resulting in the basic dimension of the pattern as shown in Figure (a). The required casting is shown with dotted lines.
Step-2 : Taper Allowance

We decide to cast the job horizontally and use a solid pattern for this casting. For this design, the draft allowance is to be provided on the vertical sides (24 mm long). Considering the given taper allowance of 1 degree, the side view of the pattern would be as shown in Figure (b).

The taper allowance value $x$ is calculated from the geometry of the Figure (b) as

$$x = 24 \tan 1 = 0.419 \text{ mm}.$$  

Thus, the top surface dimension is increased to provide for draft allowance from

$$54 \times 84 \text{ mm to } 54.838 \times 84.838 \text{ mm}.$$
**Step-3 Shrinkage Allowance:**

Given shrinkage allowance is 2%. Now, the dimensions of pattern are increased by 2% on all sides.

That is, dimension 54 mm will become

\[ 54 + \frac{(54 \times 2)}{100} = 55.08 \text{mm or 55.1mm} \]

The dimension 54.838 will become

\[ 54.838 + \frac{(54.838 \times 2)}{100} = 55.9 \text{mm} \]

Similarly, all other dimensions are calculated and the final dimensions of the pattern are shown in Figure 2.

**Example 2**

A job shown in Figure 2 is to be made from steel by casting process. The mold for this job is made from wooden pattern. Determine the dimensions of the wooden pattern assuming machining allowance of 3 mm on each side, shaking allowance of 1 mm on length and width, shrinkage allowance of 3%
Solution

Step-1 : Machining Allowance

Since given machining allowance is 3 mm on each side, add 3 mm on each side of the part shown in Figure. The dimensions of the pattern after machining allowance will be:

- \( L = 80 + 2 \times 3 = 86 \text{ mm} \)
- \( W = 40 + 2 \times 3 = 46 \text{ mm} \)
- \( H = 30 + 2 \times 3 = 36 \text{ mm} \)

The dimensions of the pattern after adding machining allowance are shown in the following figure...
Step-2: Shrinkage Allowance

The shrinkage allowance of 3% is added to all the dimensions of the pattern shown in Figure. Dimension of the pattern after providing shrinkage allowance of 3% will be:

- \[ L = 86 + 86 \times \frac{3}{100} = 88.58 \text{ mm,} \]
- \[ W = 46 + 46 \times \frac{3}{100} = 47.38 \text{ mm} \]
- \[ H = 36 + 36 \times \frac{3}{100} = 37.08 \text{ mm} \]

EXAMPLE #2

Step -3: Shaking Allowance

- Given shaking allowance is 1 mm on length and width.
- Recall that, shaking allowance is a negative allowance.
- Hence, 1 mm has to be reduced from the calculated values of length and width side.
- Students are advised to note that the height of the pattern doesn’t require any shaking allowance.
EXAMPLE #2

Therefore, final dimension of the pattern will be:

- L = 88.58 – 1 = 87.58 mm
- W = 47.38 – 1 = 46.38 mm
- H = 37.08 mm

Example 3

The downsprue leading into the runner of a certain mold has a length = 175 mm. The cross-sectional area at the base of the sprue is 400 mm². The mold cavity has a volume = 0.001 m³. Determine: (a) the velocity of the molten metal flowing through the base of the downsprue, (b) the volumetric flow rate, and (c) the time required to fill the mold cavity.
Example 3: Solution

- (a) Velocity \( v = (2gh)^{0.5} \)
  \[= (2 \times 9810 \times 175)^{0.5}\]
  \[= 1853 \text{ mm/s}\]

- (b) Volume flow rate \( Q = vA \)
  \[= 1853 \times 400\]
  \[= 741,200 \text{ mm}^3/\text{s}\]

- (c) Time to fill cavity \( MFT = V/Q \)

Example 4

In casting experiments performed using a titanium alloy and a zircon sand mold, it took 155 s for a cube-shaped casting to solidify. The cube was 50 mm on a side. If the same alloy and mold type were used, find the total solidification time for a cylindrical casting in which the diameter = 30 mm and length = 50 mm.

Example 4: Solution

- Cube Volume \( V = (50)^3 \)
  \[= 125,000 \text{ mm}^3\]

- Cube Area \( A = 6 \times (50)^2 \)
  \[= 15,000 \text{ mm}^2\]

- Cube \( (V/A) = 125,000/15,000 \)
  \[= 8.33 \text{ mm}\]

- \( C_m = TST/(V/A)^2 \)
  \[= 155/(8.33)^2\]
  \[= 2.23 \text{ s/mm}^2\]
Example 5

A mold cavity has the shape of a cube, 100 mm on a side. Determine the volume and dimensions of the final cube after cooling to room temperature if the cast metal is copper. Assume that the mold is full at the start of solidification and that shrinkage occurs uniformly in all directions. For copper, solidification shrinkage is 4.9%, solid contraction during cooling is 7.5%.

Example 5: Solution

- Volume of cavity $V = (100)^3 = 10^6 \text{ mm}^3$
- Volume of casting $V = 10^6(1-0.049)(1-0.075) = 879,675 \text{ mm}^3$
- Dimension on each side of cube $= (879,675)^{0.333} = 95.82 \text{ mm}$