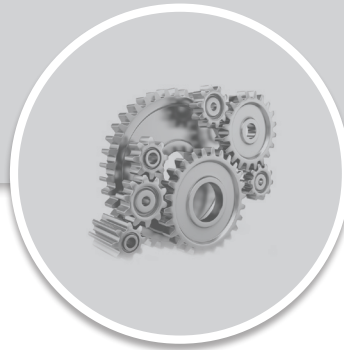


MECHANICAL ENGINEERING

Production Engineering



Comprehensive Theory
with Solved Examples and Practice Questions





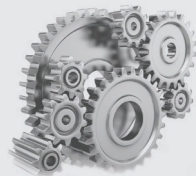
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Production Engineering

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CONTENTS

Production Engineering

CHAPTER 1

Metal Casting..... 1-43

1.1	Introduction.....	1
1.2	Terms associated with casting	2
1.3	Pattern	2
1.4	Types of Patterns.....	5
1.5	Properties of Moulding Sand.....	8
1.6	Moulding Sand	10
1.7	Core.....	12
1.8	Gating System.....	13
1.9	Sprue Design	15
1.10	Top Gate	16
1.11	Bottom Gate.....	17
1.12	Parting Line Gate.....	19
1.13	Step Gate.....	19
1.14	Solidification Time	19
1.15	Types of Solidification	21
1.16	Riser	22
1.17	Special casting processes.....	25
1.18	Expandable - Pattern Casting (Lost Foam)/Full molding	26
1.19	Shell moulding.....	26
1.20	Investment Casting	27
1.21	CO ₂ Moulding	28
1.22	Die Casting	28
1.23	Slush Casting	30
1.24	Centrifugal Casting.....	30
1.25	Casting Defects.....	32
	Objective Brain Teasers	34
	Conventional Brain Teasers	39

CHAPTER 2

Welding 44-88

2.1	Introduction.....	44
2.2	Metallurgy in Welding.....	44
2.3	Bead Geometry.....	46
2.4	Types of Welding.....	46
2.5	Arc Welding.....	47
2.6	Types of Arc Welding Machines.....	49
2.7	Shielded Metal Arc Welding (SMAW).....	53
2.8	Electrodes	54
2.9	Welding efficiency	55
2.10	GAS Tungsten Arc Welding (GTAW) or Tungsten Inert Gas Welding (TIG)	57
2.11	Metal Inert Gas Welding (MIG) or Gas Metal Arc Welding (GMAW).....	58
2.12	Plasma Arc Welding.....	60
2.13	Submerged Arc Welding (SAW)	60
2.14	Chemical Welding.....	61
2.15	Thermit welding.....	64
2.16	Resistance Welding	65
2.17	Electro Slag Welding or Electro Gas Welding.....	72
2.18	Solid State Welding Process	73
2.19	Radiant Energy Welding Techniques	75
2.20	Soldering and Brazing.....	76
2.21	Defects in Welding.....	77
2.22	Weldability.....	80
	Objective Brain Teasers	80
	Conventional Brain Teasers	84

CHAPTER 3**Metal Cutting.....89-167**

3.1	Introduction.....	89
3.2	Machine tool.....	90
3.3	Classification of cutting tools.....	93
3.4	Tool Geometry.....	93
3.5	Nose Radius.....	97
3.6	Tool Signature.....	97
3.7	Orthogonal and oblique cutting.....	98
3.8	Distribution of Heat in Deformation Zone.....	100
3.9	Types of Chips.....	101
3.10	Analysis of metal cutting velocities, forces and power.....	102
3.11	Mechanism of chip formation.....	106
3.12	Theoretical determination of shear plane angle (ϕ)....	108
3.13	Mechanisms of Tool Wear.....	110
3.14	Types of Tool Wear.....	112
3.15	Taylor's Tool Life Equation.....	113
3.16	Effect of Parameters on Tool Life.....	115
3.17	Machinability.....	116
3.18	Measurement of Cutting Forces.....	118
3.19	Shaping and Planning.....	118
3.20	Grinding.....	120
3.21	Finishing Operations.....	125
3.22	Drilling.....	127
3.23	Drill Geometry.....	128
3.24	Turning, Boring and Taper Turning.....	130
3.25	Reaming and Reamers.....	131
3.26	Trepanning.....	131
3.27	Counter Boring.....	131
3.28	Counter Sinking.....	132
3.29	Milling.....	132
3.30	Indexing in milling.....	138
3.31	Broaching.....	141
3.32	Jigs and Fixtures.....	141
3.33	Principle of Location.....	142

3.34	Lathes and Lathe Operations.....	143
	<i>Objective Brain Teasers</i>	162
	<i>Conventional Brain Teasers</i>	164

CHAPTER 4**Metal Forming..... 168-218**

4.1	Introduction.....	168
4.2	Terminology Related to Metal Forming.....	169
4.3	Cold Working.....	169
4.4	Hot Working.....	170
4.5	Warm Forming.....	170
4.6	Annealing.....	171
4.7	Malleability.....	171
4.8	Rolling.....	172
4.9	Forging.....	184
4.10	Extrusion.....	188
4.11	Wire Drawing.....	192
4.12	Sheet Metal Operations.....	195
4.13	Punching and Blanking.....	195
4.14	Deep Drawing.....	197
4.15	Bending.....	200
4.16	High Energy Rate Forming (HERF).....	202
4.17	Tube Bending and Forming.....	203
4.18	Powder Metallurgy.....	205
	<i>Objective Brain Teasers</i>	215
	<i>Conventional Brain Teasers</i>	218

CHAPTER 5**Engineering Metrology and Instrumentation..219-278**

5.1	Introduction.....	219
5.2	Accuracy and Precision.....	219
5.3	Limits, Fits and Tolerances.....	220
5.4	Angular Measurements.....	231
5.5	Linear Measurement.....	233
5.6	Geometric Features : Measuring Straightness, Flatness, Roundness and Profile.....	236

5.7	Comparator	240
5.8	Surface Finish	247
5.9	Acceptance Tests	250
5.10	Screw Thread Metrology	253
5.11	Precision ball measurement.....	259
5.12	Coordinate Measuring Machines	262
	<i>Objective Brain Teasers</i>	272
	<i>Conventional Brain Teasers</i>	274

CHAPTER 6

Computer Integrated Manufacturing ...279-301

6.1	Introduction.....	279
6.2	Numerical Control	279
6.3	Types of Control Circuits.....	281
6.4	Stepper motor.....	282
6.5	Computer Numerical Control.....	284
6.6	Machining Centre	285
6.7	Flexible Manufacturing System (FMS).....	286
6.8	Part Programming	286
6.9	Fixed Zero v/s Floating Zero.....	286
6.10	Structure of an NC part program	287
6.11	List of G codes	288
6.12	List of M codes	288
6.13	Description of some important codes	289
6.14	APT Language	293
	<i>Objective Brain Teasers</i>	297
	<i>Conventional Brain Teasers</i>	300

CHAPTER 7

Non Traditional Machining Methods 302-323

7.1	Introduction.....	302
7.2	Ultrasonic Machining (USM)	303
7.3	Abrasive Jet Machining.....	305

7.4	Electric Discharge Machining (EDM).....	306
7.5	Chemical Machining (CM).....	311
7.6	Electro Chemical Machining.....	312
7.7	Laser Beam Machining.....	317
7.8	Electron Beam Machining.....	318
7.9	Plasma Arc Machining.....	319
7.10	Water Jet Machining	319
7.11	Abrasive water jet machining.....	320
	<i>Objective Brain Teasers</i>	321

CHAPTER 8

Additive Manufacturing324-333

8.1	Introduction.....	324
8.2	Generic AM Processes	324
8.3	Data path for AM.....	325
8.4	CAD Model into .stl Format	325
8.5	Effects of building using different layer thicknesses.....	325
8.6	Generation of Geometrical Layer Information on Single Layers.....	326
8.7	.stl Format	326
8.8	Layer Manufacturing Processes	327
8.9	Additive Manufacturing Technologies	328
8.10	Electron Beam Melting (EBM).....	331
8.11	Selective Laser Melting (SLM) or Direct Metal Laser Melting (DMLM) or Laser Powder Bed Fusion (LPBF).....	331
8.12	Different Additive Manufacturing Processes	331
8.13	Additive Manufacturing Materials	332
8.14	Benefits of AM technology	332
8.15	Limits of AM Technology	333
8.16	AM Technology Applications	333



Metal Casting

CHAPTER

1

1.1 INTRODUCTION

Casting is the oldest and still most widely used process. Casting is a manufacturing process in which a **mould cavity** is created out of sand or some permanent material and **liquid metal** is poured and allowed to solidify into this cavity. The product is taken out after solidification either by breaking the mould or taking the mould apart. If the mould is broken after each cast then it is called **expendable mould**. If the same mould is used for a number of castings, it is called **permanent mould**.

1.1.1 Sand Casting process

- Sand casting uses ordinary silica sand as the primary mould material.
- The sand grains are mixed with small amounts of other materials, such as clay and water, to improve mouldability and cohesive strength, and are then packed around a pattern that has the shape of the desired casting.
- The pattern is removed before pouring of molten metal. To facilitate this, the mould is usually made in two or more pieces.
- An opening called as sprue hole is cut from the top of the mould through the sand and connected to a system of channels called runners.
- The molten metal is poured into the sprue hole, flows through the runners, and entering the mould cavity through an opening called as gate.
- Gravity flow is the most common means of introducing of metal into the mould.
- After solidification, the mould is broken and the finished casting is removed.
- The casting is then fettled by cutting off the ingate and the feeder head.

Advantages of casting

1. It can be used to produce intricate shapes because molten metal can easily flow into small sections in the mould cavity.
2. Both hard and soft, ductile and brittle materials can be casted easily.
3. Large size castings can be produced weighing upto 200 tonnes.
4. Sand casting is a cheap process.

Limitations

1. Dimensional accuracy and surface finish of sand casted products is very poor.
2. Sand casting is labourious and time consuming process.
3. Sand casting are prone to gas defects.
4. Casting do not have uniform mechanical properties due to non-uniform cooling.

1.2 TERMS ASSOCIATED WITH CASTING

- **Flask:**
 - (i) A moulding flask is one which holds the sand mould intact.
 - (ii) It is made up of **wood** for temporary applications or more generally of **metal** for long term use.
 - (iii) The top moulding flask is known as cope and the bottom one is known as drag. Sometimes, a third flask is placed in between cope and drag which is known as cheek.

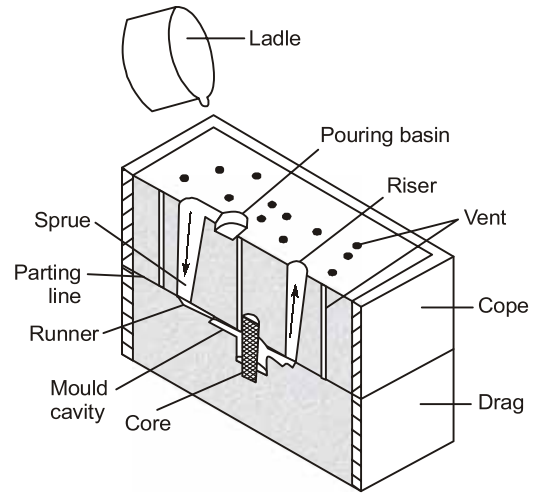


Figure: Cross section of a sand mould

- **Pattern:** It is the replica of final product to be made with some **allowances**. It is used to make mould cavity.
- **Core:** It is used for making **hollow cavities** in casting.
- **Pouring Basin:** A small funnel shaped cavity at top of the mould into which the molten metal is poured.
- **Sprue:** The passage through which the molten metal from the pouring basin reaches the mould cavity.
- **Runner:** The passage way in the parting plane through which molten metal flow before it reaches the mould cavity.
- **Gate:** The actual entry point through which molten metal enters the mould cavity.
- **Chaplet:** Chaplets are used to support cores inside the mould cavity to take care of its own weight and overcome the metallostatic forces.
- **Chills:** Chills are metallic objects, which are placed in the mould to increase the **cooling rate** of casting to provide uniform or desired cooling rate.
- **Riser:** It is a reservoir of molten metal in the casting so that hot metal can flow back into the mould cavity when there is **a reduction in volume** of metal due to contraction.
- **Parting line :** It is the dividing line between two moulding flasks.
- **Vent :** Small openings created in the mould to facilitate the escape of air and gases.

1.3 PATTERN

Patterns are objects which are similar in shape to that of final casting required. Some modifications in the form of allowances and core prints are done while deciding the size and features of a pattern. Also, some intricate details of final product may be omitted on pattern, specifically for those which are to be used with sand casting.

1.3.1 Pattern Allowances

1. Shrinkage or contraction allowance
2. Draft or taper allowance
3. Machining or finish allowance
4. Shake or rapping allowance
5. Distortion or Camber allowance.

1.3.2 Shrinkage Allowance

When the liquid metal is cooled from pouring to ambient temperature during solidification, it experiences a shrinkage or contraction due to its inherent nature.

The figure on the right shows the cooling curve for a pure metal. It describes the variation of temperature with time upon cooling.

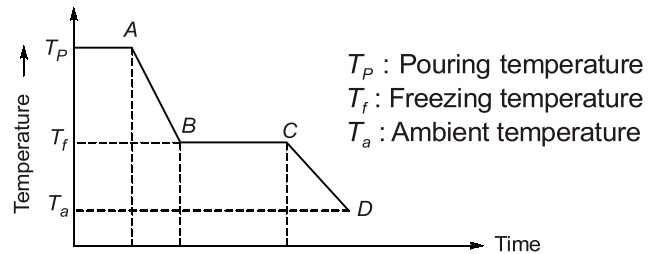


Figure: Cooling curve

It can be observed from the cooling curve that cooling occurs in 3 stages i.e. from A to B, from B to C and then from C to D. On this basis, the shrinkage in liquid metal can be classified as:

- 1. Liquid shrinkage:** Shrinkage in liquid metal when it is cooled from pouring to freezing temperature.
- 2. Solidification shrinkage:** Shrinkage in the liquid metal when it undergoes phase transformation at freezing temperature.
- 3. Solid shrinkage:** Shrinkage in metal when it cools from freezing to ambient temperature.

Liquid and solidification shrinkage can be compensated with the help of riser since the metal is still in liquid state. But the solid shrinkage can only be compensated by changing the pattern dimensions in the form of pattern shrinkage allowance.

The shrinkage allowance is generally positive in nature i.e. it is provided as an extra length along dimensions of the pattern. For e.g. if the shrinkage allowance for a particular metal is mentioned as 'x' mm/m length then it means 1 m length of casting will require a corresponding dimension of $(1 + x \times 10^{-3})$ m length.

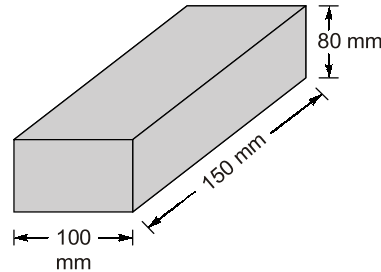


- There are some metals like Bismuth, Antimony, germanium and silicon which expand upon cooling. For such metals, we provide negative shrinkage allowance.
- Shrinkage allowances for some important materials:

Material	Allowance
Bismuth	Negligible
Cast iron	10 mm/metre length
Aluminium	12-15 mm/metre length
Steel	20 mm / metre length
Brass	23 mm / metre length
Zinc, Lead	25 mm / metre length

EXAMPLE : 1.1

Design a pattern for the casting shown below if it is to be produced by steel material by considering shrinkage of 20 mm/m.

**Solution:**

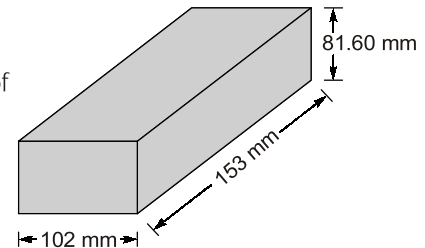
For 1 mm steel shrinkage allowance should be of 0.02 mm

$$\therefore \text{Allowance on length} = 150 \times 0.02 = 3.00 \text{ mm}$$

$$\text{Allowance on breadth} = 100 \times 0.02 = 2 \text{ mm}$$

$$\text{Allowance on width} = 80 \times 0.02 = 1.60 \text{ mm}$$

\therefore Length, breadth and width of pattern will be 153 mm 102 mm and 81.60 mm respectively.

**1.3.3 Machining Allowance**

Casting produces poor surface finish and tolerance. To get smooth surface finish in casting machining is required. Due to machining casting size is reduced and to overcome this, machining or finish allowance is provided on the pattern. It is expressed in terms of each surface of casting (mm/surface). It is positive in nature.

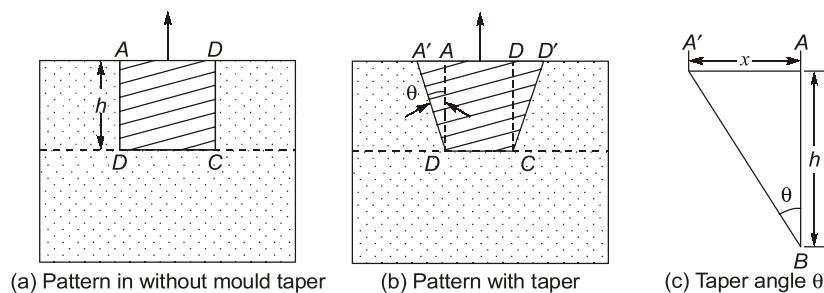
1.3.4 Draft or Taper Allowance

Figure: Draft allowance

Around $1/2$ to 2° taper is provided over the vertical surfaces of pattern for easy removal from the sand mould as shown in figure. The value of taper angle can be calculated by geometry as

$$x = h \tan \theta$$

The draft allowance is added as extra material i.e. it is a positive allowance. The internal sections always require more draft allowance as compared to external sections as shown in figure. This is so because the amount and strength of sand mould material surrounded by internal sections of pattern is less. Small patterns may not require taper allowance at all.

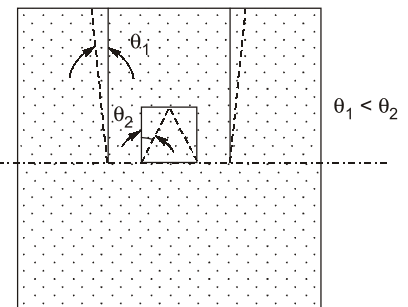


Figure: External surfaces require less taper

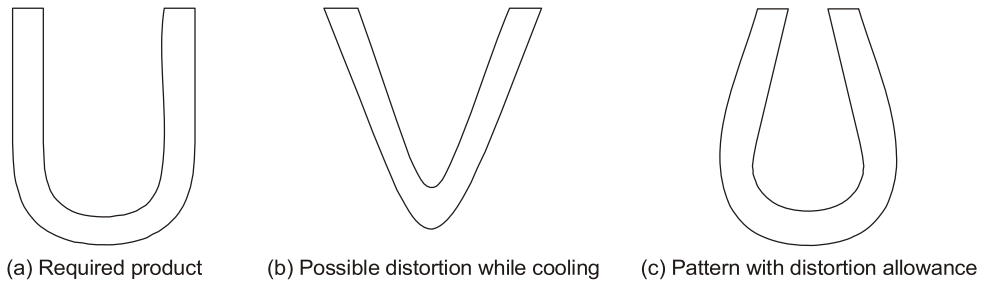
1.3.5 Rapping or Shake Allowance

For easy removal of the pattern from the mould, clearance is required between pattern and mould. This can be produced by shaking the pattern. Due to shaking size of cavity is increased. To overcome this, size of the pattern can be reduced in the form of shake allowance. It is a negative allowance.

NOTE: Ramming is a process of packing sand around the pattern and in flask by application of a little pressure with the help a wooden hammer.

1.3.6 Distortion or Camber allowance

Some typical shaped casted products like V-shape, U-shape and flat objects with very less thickness can distort, while cooling and solidification. In order to take care of this distortion, a distortion allowance is provided in the opposite direction on the pattern.



1.4 TYPES OF PATTERNS

1.4.1 Solid or Single Piece Pattern

For simple shaped castings, this pattern can be used. One of such a surface of such a pattern is flat.

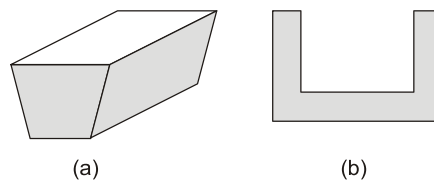


Figure: Examples of single piece pattern

1.4.2 Split Piece Pattern

This is used to produce complex shapes, pattern can be split into number of pieces. Pattern is split along the parting surface, the position of which is determined by shape of casting.

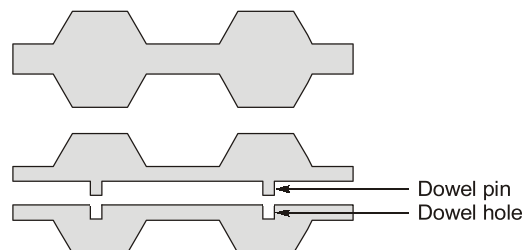


Figure: Split piece pattern

1.4.3 Loose Piece Pattern

- This pattern is used when the contour of the part is such that withdrawing the pattern made as a single piece is not possible.
- It is used when parts with internal webs, projections, undercuts, etc. are to be manufactured.

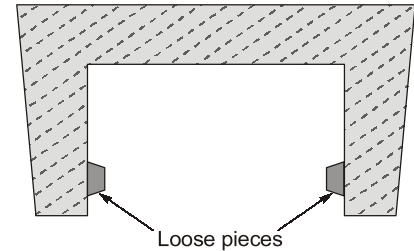


Figure: Loose piece pattern

1.4.4 Gated Pattern

The gate and runner is the integral part of the pattern. This would eliminate the hand cutting of the runner and gates and hence productivity is improved. It is used to produce small size objects in mass production.

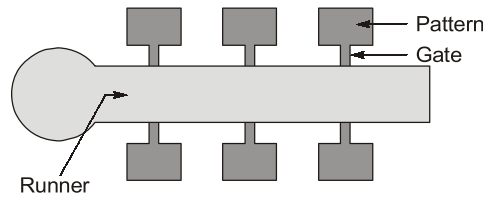


Figure: Gated Pattern

1.4.5 Match Plate Pattern

This pattern is made in two halves which are mounted on both sides of a single match plate (of wood or metal) conforming to the contour of the parting surface. The match plate is accurately placed between the cope and the drag flasks by means of locating pins. For small castings, several patterns can be mounted on the same match plate to increase the production rate.

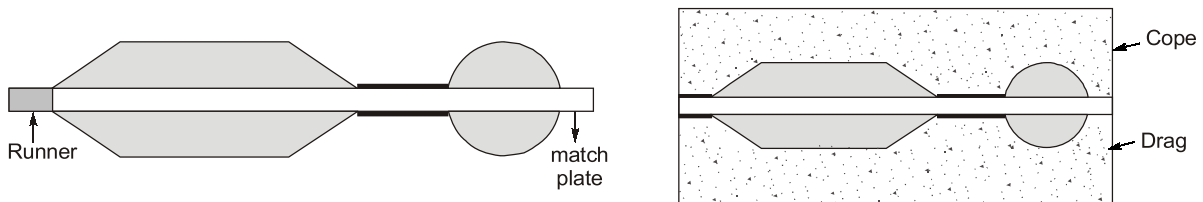


Figure: Match plate pattern

1.4.6 Cope and Drag Pattern

- It is similar to split pattern.
- In addition to splitting the pattern, the cope and drag halves of the pattern along with the gating and riser systems are attached separately to the metal or wooden plates along with the alignment pins.
- This type of pattern is used for castings which are heavy and inconvenient for handling and also for continuous production.
- It is used to produce big size casting.

1.4.7 Sweep Pattern

- It is used to generate surfaces of revolution in large castings, and to prepare moulds out of a paste-like material. Here "sweep" refers to the section that rotates about an edge to yield circular sections. It is generally made of wood.
- To produce 3 dimensional complex cavity using two dimensional plane pattern we can use sweep pattern.

- Two dimension plane pattern will be swept inside the mould cavity by 360° by fixing one of its end. Due to this, the cost of producing pattern will be reduced.
e.g.: Cone, cylinder, large size bells etc..

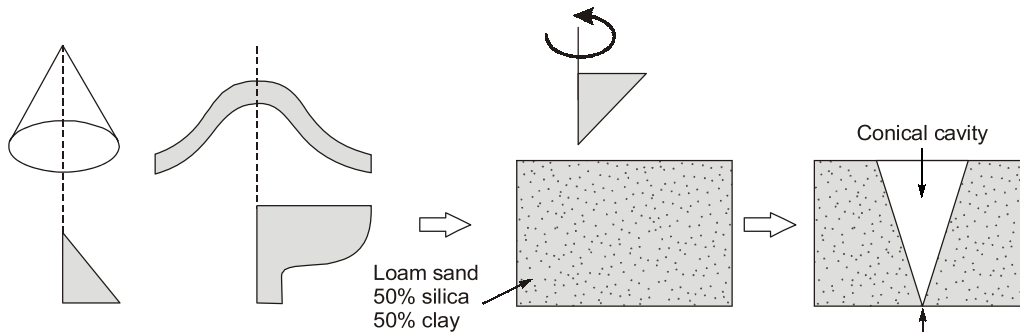


Figure: Use of sweep pattern for producing a conical cavity

1.4.8 Follow board Pattern

This type of pattern is adopted for those castings where there are some portions which are structurally weak and if not supported properly are likely to break under the force of ramming.

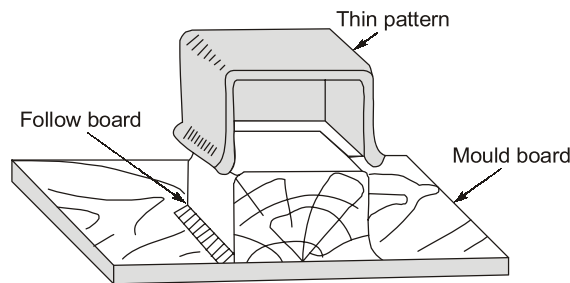


Figure: Follow-board pattern

1.4.9 Skeleton Pattern

- This type of pattern will be used to produce large size shells and cylinders. To produce such objects very large size pattern is required.
- To minimize the material consumption on preparing the pattern skeleton pattern is used.
- 3-dimensional skeleton is produced using small wooden pieces to get the required casting shape on skeleton wire mesh will be added.

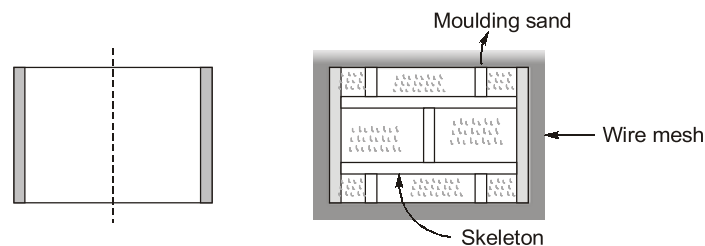


Figure: Skeleton Pattern

NOTE: The selection of pattern material and type depends on the size and shape of casting, dimensional accuracy, quantity to be produced and the moulding process.

1.5 PROPERTIES OF MOULDING SAND

1.5.1 Refractoriness

It is the ability of moulding sand to withstand high temperature of molten metal without fusion.

1.5.2 Green Strength

- The moulding sand that contains moisture is termed as **green sand**.
- Green sand should have enough strength so that the mould can retain its shape during pattern removal, conveying, etc.

1.5.3 Dry Strength

- When molten metal poured into the mould, the sand around the mould cavity is quickly converted to **dry sand** as the moisture in the sand immediately evaporates due to heat in the molten metal.
- At this stage, it should retain the mould cavity and at the same time withstand the metallostatic forces applied by the liquid metal.

1.5.4 Hot Strength

It is the strength of the sand that is required to hold the shape of the mould cavity after all the moisture is eliminated and sand reaches a higher temperature.

1.5.5 Permeability or Porosity

Permeability or porosity of the moulding sand is the measure of its ability to permit gases to flow through it. The moulding sand should allow gases (absorbed by metal during melting and pouring) and steam generated to escape to prevent defects. Permeability number is a measure which quantifies this property and is given by,

$$P_n = \frac{VH}{PAT}$$

where, V = Volume of air passing through the mould specimen (cm^3)

H = Height of mould specimen (cm)

P = Pressure of the air passing through the specimen (gm/cm^2)

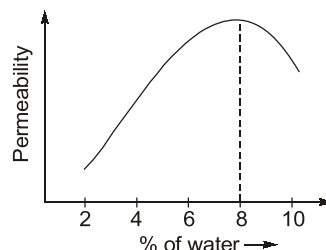
A = Area of cross section of cylindrical specimen (cm^2).

T = Time required to pass through specimen (minutes).

The standard permeability test is to measure time taken by 2000 cm^3 of air at a pressure of 980 Pa ($= 10 \text{ g}/\text{cm}^2$), to pass through a standard sand specimen confined in a specimen tube. The standard specimen size is 50.8 mm in diameter and height.

Thus, for standard specimen,
$$P_n = \frac{501.28}{PT}$$

By adding water upto 8% the permeability value will increase, beyond 8% permeability will start decreasing as shown in curve below:



1.5.6 Grain size

- Grain fineness number indicates the average grain size distribution of a given moulding sand sample.
- Greater the grain fineness number; finer the grain size.
- Grain fineness number can be determined by conducting **sieve shaker test**.
- ASTM has defined grain size number as,

$$N = 2^{n-1}$$

where, N is the number of grains per square inch visible in a prepared specimen of 100 X and n is the ASTM grain size number.

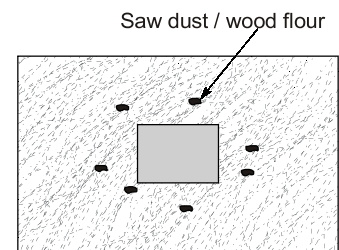
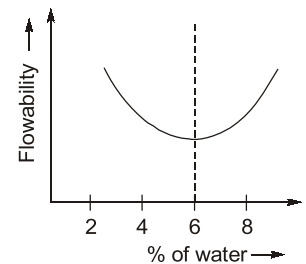
- Low ASTM number implies a few large sized grains while high ASTM number implies large number of small sized grains.

1.5.7 Flowability

- The ability of sand to flow due to ramming force to fill the mould flask and occupy each and every corner of cavity is known as flowability.

1.5.8 Collapsibility

- Ability of the moulding sand due to which it will not offer any resistance against the shrinkage/contraction of molten metal while solidification is called collapsibility.
- During the solid contraction of the casting, if the mould creates resistances, cracks will appear over the casting.
- Saw dust or wood powder can be added to sand to improve collapsibility. Since when molten metal poured, wood powder burns to ash due to this mould near casting is easily collapses and provides less resistance due to shrinkage.



1.5.9 Adhesiveness

This is the property of sand mixture to adhere to another body. The moulding sand should cling to the sides of the moulding boxes so that it does not fall out when the flasks are lifted and turned over. This property depends on the type and amount of binder used in the sand mix.

1.5.10 Cohesiveness

It is the property by which sand particles stick among themselves so that a mould with adequate strength can be obtained.

1.5.11 Toughness

- Ability to resist impact and shock loads by the moulding sand.
- **Shatter index test** is done for toughness measurement.

1.5.12 Hardness

- Moulds must have sufficient hardness to minimise erosion caused due to flow of liquid metal. It is a surface property and is expressed by mould hardness number which ranges from 0 to 100.
- If Hardness > 80 : Permeability will be less
Hardness < 80 : Size of cavity may increase

8. Inclusions

It form during melting, solidification and molding. Generally nonmetallic, they are regarded as harmful because they act as stress raisers and reduce the strength of casting. Inclusion may form during melting when molten metal reacts with the environment or with the crucible or mold material. Chemical reaction among components in the molten metal may produce inclusion slag and other foreign material entrapped in the molten metal also become inclusion.

EXAMPLE : 1.16

The casting defect in which rough spots of excess metal appears because of erosion of moulding sand is known as

- (a) Drop (b) Swell
(c) Metal penetration (d) Cuts

Solution: (d)

Cuts and washes : If velocity of molten metal is high or strength of mould is less then it results in erosion of moulding sand and results in appearance of rough spots.

EXAMPLE : 1.17

Which of the following pairs of casting process & applications are correctly matched?

- (a) Sand casting - Turbine blades (b) Centrifugal casting - Cast iron pipes
(c) Investment casting - Large bells (d) Die casting - IC engines

[MSQ]

Solution: (b, d)

Sand casting is used for producing large bells, centrifugal casting are used for making symmetrical items i.e. pulley, ring, wire rod etc. Investment casting is used for producing complex shapes, very close tolerances and high surface finish, it can produce engine parts, turbine blades, denture medical in surgical instruments, gold ornaments etc.

OBJECTIVE
BRAIN TEASERS

Q.1 Match List-I (Moulding process) with List-II (Binding agent) and select the correct answer.

List-I

- A. Green sand
B. Cores sand
C. Shell moulding
D. Carbon dioxide process

List-II

1. Silicate
2. Organic
3. Clay
4. Plaster of Paris
5. Plastic

Codes:

	A	B	C	D
(a)	3	2	5	1
(b)	3	2	4	1
(c)	2	3	5	4
(d)	2	3	4	5

Q.2 Which of the following are characteristics of lost-foam process?

- (a) It has design flexibility.
(b) It cannot be easily automated.
(c) The casting requires minimal finishing and cleaning.
(d) The flow velocity of molten metal in mould depends upon degradation of the polymer.

[MSQ]

Q.3 Match **List-I** (Produce) with **List-II** (Process of manufacture) and select the correct answer.

List-I

- A. Automobile piston in aluminium alloy.
- B. Engine crankshaft in spheroidal graphite iron
- C. Carburettor housing in aluminium alloy.
- D. Cast titanium blades

List-II

1. Pressure die casting
2. Gravity die casting
3. Sand casting
4. Precision investment casting.
5. Shell moulding

Codes:

	A	B	C	D
(a)	3	2	1	5
(b)	3	2	5	1
(c)	2	1	3	4
(d)	4	1	2	3

Q.4 Match **List-I** with **List-II** and select the correct answer.

List-I

- A. Die casting
- B. Centrifugal casting
- C. Centrifuging
- D. Continues casting

List-II

1. Molten metal is forced into the die under pressure
2. Axis of rotation does not coincide with axis of mould
3. Metal solidifies when mould is rotating
4. Continuously pouring molten metal into mould
5. Plastic

Codes:

	A	B	C	D
(a)	1	3	2	4
(b)	4	3	2	1
(c)	1	2	3	4
(d)	4	2	3	1

Q.5 An expendable pattern is used in

- (a) Slush casting
- (b) Squeeze casting
- (c) Centrifugal casting
- (d) investment casting

Q.6 Which one of the following processes consist of central sprue to feed metal into cavities through a number of radial gates?

- (a) Centrifuging
- (b) Semi-centrifugal casting
- (c) True centrifugal casting
- (d) Precision casting

Q.7 Which of the following materials are used for making patterns in investment casting method?

- | | |
|---------|------------|
| 1. Wax | 2. Rubber |
| 3. wood | 4. Plastic |

Select the correct answer.

- (a) only 1 and 3
- (b) only 2 and 3
- (c) only 1, 2 and 4
- (d) only 2, 3 and 4

Q.8 Which one of the following would produce strongest components?

- (a) Die casting
- (b) Hot rolling
- (c) Cold rolling
- (d) Forging

Q.9 In hot chamber method a die casting

- (a) only low melting point metals can be used.
- (b) high melting point metals can be cast.
- (c) Die is kept hot by electrical heating
- (d) Die is kept cold by circulating water.

Q.10 Ornamental objects, statues, toys etc are cast by

- (a) Die casting
- (b) Pressed casting
- (c) Centrifugal casting
- (d) Slush casting

Q.11 Consider the following statements about casting process:

1. Casting is labour intensive process.
2. Forging products are inferior to casting in respect of strength.
3. Pattern and part to be made are exact in shape and size.
4. Cores are used for making runner and gate.

Which of the above statement/s is/are correct?

- (a) 1, 2 and 3
- (b) 1 and 3 only
- (c) 3 and 4 only
- (d) 1 only

Q.20 Which of the following properties not influence the fluidity of molten metal?

- (a) Surface tension
- (b) Melting point of metal
- (c) Inclusions
- (d) Degree of superheat

Q.21 Consider the following statements about solidification of molten metal:

1. Pure metal solidifies at a range of temperature.
2. The solidification front moves from wall towards centre.
3. Metals which shrinks while cooling are generally don't shrink during solidification.
4. In pure metals the solidification front moves as a plane without forming a mushy zone.

Which of the above statements are correct?

- (a) 1, 3 and 4
- (b) 1 and 2 only
- (c) 2 and 4 only
- (d) 1, 2 and 4

Q.22 Match **List-I** (Cooling rates) with **List-II** (Resultant structure of alloys) and select the correct answer.

List-I

- P.** Slow cooling rates
- Q.** High cooling rates
- R.** Very high cooling rates

List-II

1. Fine dendritic structure
2. Amorphous structure
3. Coarse dendritic structure

Codes:

	P	Q	R
(a)	3	1	2
(b)	2	1	3
(c)	3	2	1
(d)	1	2	3

Q.23 Which of the following supports the core and avoid and avoid them from shifting?

- (a) Core prints
- (b) Chaplets
- (c) Cope
- (d) Both (a) and (b)



ANSWER KEY

- 1. (a) 2. (a, c, d) 3. (a) 4. (a)
- 5. (d) 6. (a) 7. (c) 8. (d) 9. (a)
- 10. (d) 11. (d) 12. (a, d) 13. (a) 14. (d)
- 15. (8750.78) 16. (4.44) 17. (4.976)
- 18. (50.74) 19. (b) 20. (b) 21. (c)
- 22. (a) 23. (d)

HINTS & EXPLANATIONS

- 2. (c)
It can be easily automated.
- 11. (d)
 - Forging products are superior.
 - Pattern is made little larger than part after adding allowances.
 - Cores are used for making hollow cavities inside the casting.
- 12. (d)
 - Solid shrinkage is compensated by pattern.
 - Chaplets are used to support core.
- 13. (a)
Urea formaldehyde binders burn out faster and collapse at lower temperature as compared to phenol formaldehyde binders. Thus urea formaldehyde binders are suitable for use at lower temperature metals like Al, Mg, thin sections of brass, bronze.
Phenol formaldehyde binders are employed for thick sections of CI, steel castings,
- 15. (8750.78)
Mass of disk,

$$\rho V = 2.7 \times \left(\frac{\pi}{4} \times 30^2 \times 4 \right)$$

$$= 7634 \text{ gm}$$

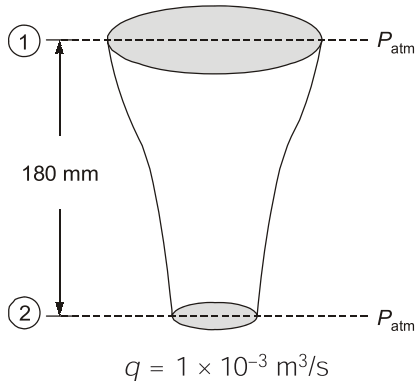
Amount of aluminium heated = 7634×1.07
= 8168.38 gm

$$\text{Heat required} = m[C \times (T_m - T_\infty) + L + C \times (T_p - T_m)]$$

$$q = 8168.38 \times [0.88 \times (660 - 25) + 389.3 + 0.88 \times (800 - 600)]$$

$$q = 8750785.5 \text{ J or } 8750.78 \text{ kJ}$$

16. (4.44)



The pressure at bottom should be atleast greater than or equal to P_{atm} .

Using Bernoulli's equation

$$P_{atm} + \frac{V_1^2}{2g} + h_1 = P_{atm} + \frac{V_2^2}{2g} + h_2$$

$$V_1 = \frac{q}{A_1} = \frac{10^{-3}}{810 \times 10^{-6}} = 1.234 \text{ m/s}$$

$$\therefore V_2^2 = V_1^2 + 2gh_1$$

$$= (1.234)^2 + 2g \times 0.18$$

$$V_2 = 2.248 \text{ m/s}$$

Area at bottom,

$$A_2 = \frac{10^{-3}}{2.248} = 444 \text{ mm}^2$$

17. (4.976)

$$\left(\frac{V}{A}\right)_{\text{casting}} = \frac{7.5 \times 12.5 \times 2}{2(7.5 \times 12.5 + 12.5 \times 2 + 2 \times 7.5)}$$

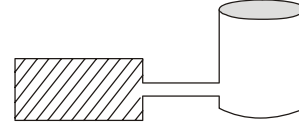
$$\left(\frac{V}{A}\right)_{\text{casting}} = 0.701$$

Using Chvorinov's rule,

$$t_f = K \left(\frac{V}{A}\right)^2$$

$$\Rightarrow K = \frac{2}{(0.701)^2} = 4.07 \text{ min/cm}^2$$

For side riser,



$$\left(\frac{V}{A}\right)_R = \frac{\frac{\pi}{4} d^2 \times d}{2 \times \frac{\pi}{4} d^2 + \pi d^2} = \frac{d}{6}$$

$$t_f = K \left(\frac{V}{A}\right)_R^2$$

$$\Rightarrow \frac{V}{A} = \sqrt{\frac{t_f}{K}} = \sqrt{\frac{2.8}{4.07}}$$

$$d = 4.976 \text{ cm}$$

$$h = d = 4.976 \text{ cm}$$

18. (50.74)

The minimum speed required to hold molten metal at upper wall is

$$\frac{mv^2}{R} = mg$$

$$v = \sqrt{gR} = \sqrt{9.81 \times 0.5} = 2.214 \text{ m/s}$$

We know, $v = \frac{\pi DN}{60}$

$$\therefore N = \frac{V \times 60}{\pi \times D} = \frac{2.214 \times 60}{\pi \times 1}$$

$$N = 42.284 \text{ rpm}$$

Required rotational speed (20% excess) = $1.2 \times 42.284 = 50.74 \text{ rpm}$

■■■■



CONVENTIONAL BRAIN TEASERS

Q.1 Three metal pieces being cast have the same volume but different shapes, one is sphere, one is a cube and other a cylinder with its height equal to its diameter. Which piece will solidify the fastest and which one the slowest?

Solution:

Let volume of each casting be 1 unit.

We know,
$$t_s = K \left(\frac{V}{SA} \right)^2 \quad [k : \text{Constant}]$$

For sphere,
$$V_{\text{sphere}} = \frac{4}{3} \pi r^3$$

$$1 = \frac{4}{3} \pi r^3$$

$$r^3 = \frac{3}{4\pi}; \quad r = \left(\frac{3}{4\pi} \right)^{1/3}$$

$$\text{Surface Area} = 4\pi r^2 = 4 \times \pi \times \left(\frac{3}{4\pi} \right)^{2/3} = 4.83$$

Cube,
$$\text{Volume} = a^3$$

$$1 = a^3 \Rightarrow a = 1$$

$$\text{Surface Area} = 6a^2 = 6 \times 1 = 6$$

Cylinder,
$$\text{Volume} = \pi r^2 h$$

$$r^3 = \frac{1}{2\pi}$$

$$r = \left(\frac{1}{2\pi} \right)^{1/3}$$

Surface area = $2\pi r h + 2\pi r^2 = 2\pi r^2 + 2\pi r^2 = 4\pi r^2 = 4 \times \pi \times \left(\frac{1}{2\pi} \right)^{2/3} = 5.85$
Solidification times,

$$t_s \propto \frac{1}{(\text{Surface area})^2}$$

$$t_{\text{sphere}} = \frac{1}{(4.83)^2} = 0.0428$$

$$t_{\text{cube}} = \frac{1}{6^2} = 0.0277$$

$$t_{\text{cylinder}} = \frac{1}{5.85^2} = 0.0291$$

Hence, cube casting will solidify fastest and sphere slowest.