

UPPSC-AE

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Uttar Pradesh Public Service Commission

Combined State Engineering Services Examination
Assistant Engineer

Mechanical Engineering

Manufacturing

Well Illustrated **Theory** *with*
Solved Examples and Practice Questions



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Manufacturing

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1.1 Introduction

It generally means pouring molten metal into a refractory mould with a cavity of the shape to be made and allowing it to solidify. When Solidified, the desired metal object is taken out from the refractory mould by taking mould apart.

It is clear from the definition of the process that a successful **casting operation** needs a knowledge in the following areas:

- (i) Preparation of moulds and patterns (used to make the mould).
- (ii) Melting and pouring of the liquefied metal
- (iii) Solidification and further cooling to room temperature
- (iv) Defects and inspection.

Advantages of Casting:

1. It is used to produce intricate shapes.
2. Both hard and soft, ductile and brittle materials can be produced.
3. Large size objects can be produced.

Limitations:

1. Dimensional accuracy and surface finish is poor.
2. It is laborious and time consuming process.
3. Gas defects are common in casting products.
4. There are non-uniform mechanical properties in casting products.

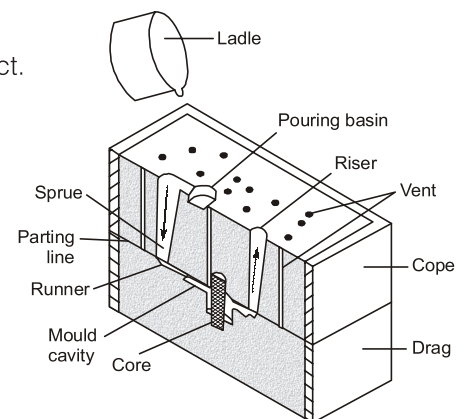
1.2 Casting Terms and Components

Flask

- A **moulding flask** is one which holds the sand mould intact.
- Depending upon the position of the flask in the mould structure it is referred to by various names such as
 - Drag – lower moulding flask
 - Cope – upper moulding flask
 - Cheek – intermediate moulding flask used in three-piece moulding.
- It is made up of wood for temporary applications and more generally of metal for long-term use.

Pattern

- **Pattern** is a replica of the final object to be made with some modification in the form of allowance and core prints.
- The **mould cavity** is made with the help of the pattern.



Cross section of a sand mould ready for pouring

Parting line

- It is the dividing line between the two moulding flasks that makes up the sand mould.
- In **split pattern**, it is also the dividing line between the halves of the pattern.

Bottom board

- This is a board normally made of wood which is used at the start of the mould making.
- The **pattern** is first kept on the bottom board, sand is sprinkled on it and then the ramming is done in the **drag**.

Facing sand: The small amount of carbonaceous material sprinkled on the inner surface of moulding cavity to give a better surface finish to the casting.

Moulding sand

- It is the freshly prepared **refractory material** used for making the mould cavity.
- It is a mixture of silica, clay and moisture in appropriate proportion to get the desired results and it surrounds the pattern while making the mould.

Core

- It is used for making hollow cavities in **castings**.
- Core are placed in the mould to form hollow regions or otherwise define the interior surface of the castings.

Pouring basin

- A small funnel shaped cavity at the top of the mould into which the **molten metal** is poured.
- It reduces turbulence at the sprue entrance.

Sprue

- The passage through which the molten metal from the **pouring basin** reaches the mould cavity.
- In many cases it controls the flow of the metal into the mould.

Runner

- The passage ways in the parting plane through which molten metal flow.
- It regulate the flow before it reaches the **mould cavity**.

Gate: The actual entry point through which molten metal enters **mould cavity**.

Chaplet

- **Chaplets** are used to support core inside the **mould cavity** to take care of buoyancy force due to molten metal.
- Chaplets are made of same material as that of casting.

Chill: Chills are metallic objects which are placed in the mould to increase the cooling rate of castings to provide uniform or desired cooling rate.

Riser: It is a **reservoir** of molten metal provided 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 **solidification**.

1.2.1 Pattern Allowances

The main modification in pattern is addition of **pattern allowances**. There are five categories of pattern allowance i.e.

- | | | |
|-------------------------|--------------------------|---------------------------|
| (i) Shrinkage allowance | (ii) Draft allowances | (iii) Machining allowance |
| (iv) Shake allowance | (v) Distortion allowance | |

(i) Shrinkage Allowance

- The **shrinkage allowance** is provided to take care of the contractions of a casting. The total contraction of a casting takes place in three stages, and it consists of:
 - **Liquid shrinkage:** The contraction of the liquid from the **pouring temperature** to the **freezing temperature**.
 - **Solidification shrinkage:** The contraction associated with the change of phase from liquid to solid and it is phase transformation process.
 - **Solid shrinkage:** The contraction of the solid casting from the freezing temperature to the room temperature.
- It must be noted, solid shrinkage is the last stage of the contraction which is taken care of by **shrinkage allowance**. Obviously, the amount of shrinkage allowance depends on the linear coefficient of thermal expansion (α_l) of the material. The higher the value of this coefficient, the more the value of **shrinkage allowance**.
- First and second stage of shrinkage is compensated by providing riser. (as % of shrinkage volume of casting)
- Table gives some quantitative idea about the shrinkage allowance for casting different materials.

Machining allowance for various metals

Material	Machining allowance 30 - 60 cm	Shrinkage allowance mm/m
Cast iron	4.5 mm	10.5
low carbon steel	4.5 mm	21
Aluminium	3 mm	13
Bronze	3 mm	15.5-22.0
Brass	3 mm	15.5

- Zinc requires maximum shrinkage allowance.
- Aluminium requires high volume of riser because liquid and solidification shrinkage (first and second stage) are maximum for aluminium.
- Invar and bismuth have negligible shrinkage.
- It is positive allowance i.e., extra material is used in pattern compared to required final product.

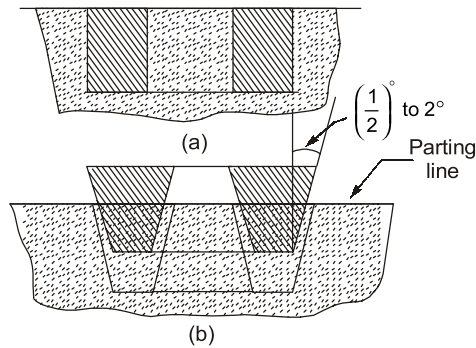
**NOTE**

- The shrinkage allowance is always to be added to the linear dimension. Even in case of internal dimensions (e.g internal diameters of a cylinders), the material has tendency to contract towards the center and thus are to be increased.
- For grey cast iron, there is no need to provide riser because graphite (carbon) is present in H.C.P. lattice which has more volume i.e., expansion of material occurs in liquid and solidification. But there is need to provide shrinkage allowance.

(ii) Draft Allowance

- At the time of withdrawing the pattern from the sand mould, the vertical faces of the pattern are in continual contact with the sand, which may damage the **mould cavity**, as shown in fig. To reduce the chances of this happening, the vertical faces of the pattern are always tapered from the **parting lines**. This provision is called **draft allowance**.
- It is also positive allowance.

- This value depends on the vertical height of the pattern.



(iii) Machining Allowance

- The finish or accuracy achieved in **sand casting** are generally poor and therefore when the casting is functionally required to be good **surface finish**, it is generally achieved by **machining**. Also, ferrous material could have scales on the skin which are to be removed by **cleaning**.
- The **machining allowance** depends on dimension the type of casting material such as silica grain size and the finish required. This may range from 2 to 20 mm.
- It is positive allowance.

(iv) Shake Allowance/Rapping Allowance:

- Before withdrawal from the sand mould, the pattern is rapped all around the vertical forces to enlarge the mould cavity slightly which facilitates its removal.
- It is a negative allowance.
- It is required in each pattern.

(v) Distortion Allowance/Camber Allowance:

- A metal when it has just solidified is very weak and therefore is likely to be distortion prone. The foundry practice should be to make extra material provision for reducing the distortion.
- Distortion allowance can be overcome by providing the pattern opposite to the direction of distortion.
- It depends on length to thickness ratio.
- It is a neutral allowance.

1.2.2 Pattern Materials

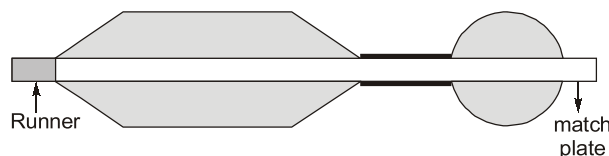
- The usual pattern materials are wood, metals and plastics. The most common used pattern material is wood but the most common disadvantages of wood is its absorption of moisture as a result of which distortion and dimensional changes occur.
- The choice of pattern materials depends:
 - (i) On size of casting.
 - (ii) Complexity of the casting
 - (iii) Number of casting to be made from the pattern.
 - (iv) Cost of the pattern.
 - (v) Dimensional accuracy and surface finish required.
- For very large castings, **wood** is preferred as pattern material, because of their durability and smooth surface finish.

- **Metal patterns** are extensively used for large scale casting production and for closer dimensional tolerances. Though many material such as cast iron, brass, etc can be used as pattern materials, aluminum and white metal are most commonly used. These are light, can be easily work, and are **corrosion resistance**. Since white metal has very small shrinkage the white metal pattern can be used for making additional patterns without worrying about the **double shrinkage allowance**. Most metal pattern are cast in sand moulds from a master wood pattern provided with the double **shrinkage allowance**.
- **Plastics** are also used as pattern materials because of their low weight, easier formability, smooth surface and durability. They do not absorb moisture and are therefore, dimensionally stable and can be cleaned easily. The making of a plastic pattern can be done in sand clay moulds or moulds made of plaster of paris. With a proper combination it is possible to obtain a no shrink plastic material and as such double **shrinkage allowance** may not be required.
- Wax patterns are commonly used in investment casting.
- Sand slingers fill the flask uniformly with sand under high pressure stream, throwing the sand with high speed by impeller.
- Impact moulding produces mould with uniform strength and good permeability.
- For casting of reactive metals as titanium, zirconium, rammed graphite is used to make moulds.

Type of Pattern

The commonly used patterns are classified as follows:

- Single piece pattern :** It is used when the job is very simple. In this method there is no withdrawal problem. It is less expensive.
- Loose piece pattern:** This type of pattern used when the contour of the part is such that withdrawing the pattern from the mould is not possible. Hence during moulding the obstructing part of the contour is held as a loose piece by a wire.
- Gated pattern:** This is simply one or more than one loose pattern with attached gates and runners and provides a channel through which the molten metal can flow from the pouring sprue to the mould cavity. Gated pattern are used for mass production of small shaped products.
- Match plate pattern:** The pattern is made in two halves mounted on both sides of a 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. Generally used mass production of complex shaped object and small casting with higher dimensional accuracy.



- Cope and drag pattern:** Here, the cope and drag halves of a split pattern are separately mounted on two match plates. It is used when pattern are very large and difficult to handle on both sides of single match plate and non-symmetrical objects.
- Sweep pattern:** Normally made of wood. "Sweep" refers to the section that rotates about the an edge to yield circular section. To produce complex shape of 3-D mould cavities, 2-D patterns can be rotated on the surface of the mould. It is used to produce axisymmetric object only.
- Skeleton pattern:** It is used to guide the modular for hand-shaping the mould and for large casting having simple geometrical shapes. A 3-D skeleton is produced using wooden workpiece covered with wire mesh and loam sand.

(viii) **Follow board pattern:** If the patterns are structurally weak then due to ramming force, there is a possibility of bending and breaking of the pattern. To overcome this, patterns are supported by providing follow boards.

1.2.3 Fundamental of Metal Casting

- The factors which affect solidification are the type of metal, thermal properties of both the metal and the mould, the geometric relationship between volume and surface area of casting and shape of the mould.
- Rapid cooling produces a **solidified skin or shell of fine equiaxed grains**.
- Those grains that have favorable orientation will grow preferentially and are called **columnar grains**.
- Solidification in alloys begins when the temperature drops below the liquidus T_L , & is completed when it reaches the solidus temperature T_S . Within this temperature zone, the alloy is in mushy zone or pasty state with **columnar dendrites**. Freezing range = $(T_L - T_S)$.
- **Cast iron** casting generally have **narrow mushy zones**, whereas **Al & Mg alloy** have **wide mushy zones**.
- Lack of uniformity in grain size and grain distribution results in casting with **anisotropic properties**.
- Cored dendrites have a surface composition different from that at their centers and this difference is referred as **concentration gradient**.
- The **inoculant (nucleating agent)** induces nucleation of the grains throughout the liquid metal.
- Techniques for minimizing turbulence generally involve avoidance of sudden changes in flow direction. It causes drops.
- Drops and slag can be almost completely eliminated only by vacuum casting. **Filters** are also used to eliminate drops made of ceramics, mica or fiberglass.

1.3 Fluidity Properties

The capability of the molten metal to fill mould cavities is called **fluidity**. The following characteristics of molten metal influence fluidity:

- Mushy zone (alloy content)
- Viscosity
- Surface Tension
- Inclusions

Fluidity is measured by **spiral test** i.e., distance covered by the liquid metal before solidification in a standard spiral will give the value of fluidity.

Property effect on fluidity

1. Pouring temp.	(↑) ⇒ ↓ increases
2. Viscosity	(↑) ⇒ ↓ decreases
3. Density	(↑) ⇒ ↓ decreases
4. %age of water in metal	(↑) ⇒ ↓ decreases
5. Surface finish	(↑) ⇒ ↑ increases

Fluidity $\propto \frac{1}{\text{Freezing range}}$ ⇒ shorter the freezing range higher will be the fluidity. (As in pure metals and eutectic composition). Conversely, alloys with long freezing ranges have lower fluidity.

The following casting parameters influence fluidity and also influence the fluid flow and thermal characteristic of the system:

- (i) Mould design
- (ii) Mould material and its surface characteristic
- (iii) Degree of superheat
- (iv) Rate of pouring

With flat mould walls skin thickness is proportional to the square root of time. Doubling the time will make skin $\sqrt{2} = 1.41$ or 41% thicker.

$$\text{Thickness} \propto \sqrt{\text{Time}}$$

The solidification time is a function of the volume of a casting and its surface Area.

(Chvorinov's rule)

$$\text{Solidification time} = C \left(\frac{V}{A} \right)^2$$



Example - 1.1 Three metal pieces being cast have the same volume, but different shapes. One is a sphere, one a cube and the other a cylinder with its height equal to its diameter. Which piece will solidify the fastest, and which one the slowest? Assume that $n = 2$.

Solution:

$$\text{Solidification time} \propto \left(\frac{V}{A} \right)^2 \Rightarrow t = C \left(\frac{V}{A} \right)^2$$

Take volume of the piece is taken as unity.

Sphere:

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

$$A = 4\pi r^2 = 4\pi \left(\frac{3}{4\pi} \right)^{\frac{2}{3}} = 4.84$$

Cube:

$$V = a^3$$

$$a = 1$$

and

$$A = 6a^2 = 6$$

Cylinder:

$$V = \pi r^2 h = 2\pi r^3$$

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

$$A = 2\pi r^2 + 2\pi r h = 6\pi r^2 = 6\pi \left(\frac{1}{2\pi} \right)^{\frac{2}{3}} = 5.54$$

The respective solidification times are therefore,

$$t_{\text{sphere}} = 0.043 \text{ C}$$

$$t_{\text{cube}} = 0.028 \text{ C}$$

$$t_{\text{cylinder}} = 0.033 \text{ C}$$

Hence, the cube-shaped piece will solidify the fastest and the spherical piece will solidify the slowest.



DO YOU KNOW?

1. Solidification time:

$$t \propto \left(\frac{V}{A}\right)^2$$

V = volume of riser, A = surface area of riser.

2. Caine's method provides a simple procedure to size the risers in sand casting, while the modulus method is more elaborate and provides a better design.

3. Caine curve :

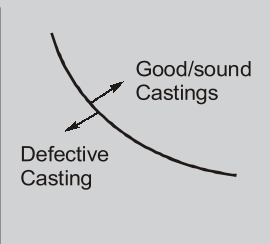
$$X = \frac{a}{y-b} + c \text{ (caine curve)}$$

x -axis is freezing ratio = $\left(\frac{V}{A}\right)_{\text{riser}} / \left(\frac{V}{A}\right)_{\text{casting}}$

y -axis is volume ratio of riser to casting

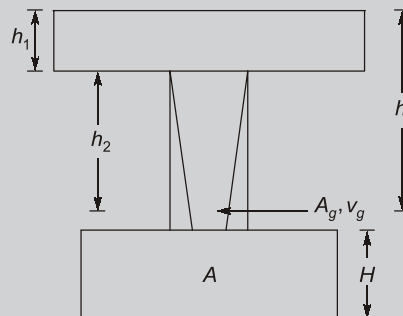
Volume ratio

$$\left(\frac{V_r}{V_c}\right) = y$$



Freezing ratio $\frac{(V/A)_r}{(V/A)_c} = x$

4. Top Gate

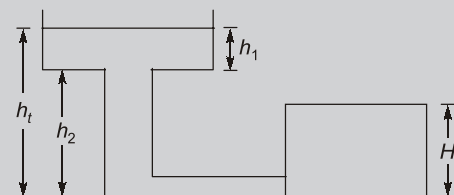


(i) $t_f = \frac{AH}{A_g \sqrt{2gh_t}}$ (time to fill the casting)

(ii) $R = \sqrt{\frac{h_1}{h_t}}$ (aspiration effect) $\left(R = \frac{A_3}{A_2}\right)$

5. Bottom Gate

$t_f = \frac{2A}{A_g \sqrt{2g}} [\sqrt{h_t} - \sqrt{h_t - H}]$ (time to fill the casting)



6. Moulding Machines used mostly are

- (i) Jolting
- (ii) Squeezing
- (iii) Sand Sliding

7. Types of Riser

- (i) Top riser
- (ii) Side riser
- (iii) Blind riser
- (iv) Internal riser

8. **Cores** are materials use for making cavities and hollow projections which cannot be normally produced by the pattern alone.

9. **Chaplets** are metallic support often kept inside the mould cavity to support the cores. These are of the same compulsion as that of the pouring metal so that the mould metal would provide enough heat to completely melt them and thus fuse with it during solidification.

10. Gating Ratio for non-pressurised casting

Sprue Area	:	Runner Area	:	In-gate Area
1	:	4	:	4

11. Gating Ratio for pressurised casting

Sprue Area	:	Runner Area	:	In-gate Area
1	:	2	:	1

12. A pattern is different from the final casting because of the pattern allowances to be added.

13. Cupola is used for melting cast iron. Charge in the cupola consists of Iron, limestone (flux) and coke.

14. Hot blast cupola reduces the heat required for melting by extracting the heat from the hot stack gases.

15. Cleaning of casting

Fettling: Vibrating mechanism is used.
Shot/sand blasting is used.



Student's Assignment

- Q.1** An expendable pattern is used in
 (a) Investment casting
 (b) Flush casting
 (c) Centrifugal casting
 (d) Shell moulding
- Q.2** Which of the following are most suitable material for die casting
 (a) Copper alloys
 (b) Steel
 (c) Lead and its alloys
 (d) None of these
- Q.3** Which of the following process produce a casting when pressure forces a molten metal into a mould cavity
 (a) Investment casting
 (b) Shell moulding
 (c) Centrifugal casting
 (d) Die casting
- Q.4** Automobile piston are casted by the method
 (a) Sand casting
 (b) Pressure die casting
 (c) Investment casting
 (d) Gravity die casting
- Q.5** In centrifugal casting the impurities are collected at
 (a) Periphery of casting
 (b) Centre of casting
 (c) In between the casting
 (d) None
- Q.6** Advantages of shell moulding process are
 1. Close dimensional tolerance.
 2. Good surface finish.
 3. Low cost.
 4. Easier.
 (a) 1, 2, 3 is correct
 (b) 2, 3, 4 is correct
 (c) 1, 2, 4 is correct
 (d) All is correct
- Q.7** Considering the ingredients use in moulding
 1. Dry silica sand
 2. Clay
 3. Phenol formaldehyde
 4. Sodium silicate
 (a) 1 and 2 is correct
 (b) 1 and 3 is correct
 (c) 2 and 3 is correct
 (d) All is correct

Q.8 Which of the following material is added to base sand to impart bonding strength

- (a) Sea coal (b) Silica
- (c) Bentonite (d) Wood flour

Q.9 Fluidity is greatly influenced by

- (a) carbon content of molten metal
- (b) melting temperature of molten metal
- (c) inoculant addition
- (d) pouring temperature of molten metal

Q.10 The casting defect which is not caused by the high pouring temperature of melt is

- (a) Cuts (b) Metal penetration
- (c) Fusion (d) Rat tails

Q.11 Slush casting process is used to produce

- (a) hollow castings
- (b) intricate castings
- (c) Large size castings
- (d) Thin walled castings

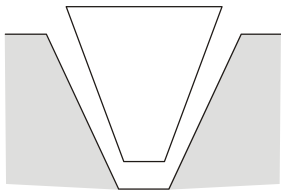
Q.12 Riddle is

- (a) a round sieve
- (b) a long, flat metal plate fitted with an offset handle
- (c) used to make or repair corners in a mould
- (d) None

Q.13 Alloys of which of the following metal is not used for hot chamber die casting?

- (a) Tin (b) Lead
- (c) Zinc (d) Iron

Q.14 The following figure depicts which allowance?



- (a) Machining Allowance
- (b) Distortion Allowance
- (c) Draft Allowance
- (d) Shake Allowance

Q.15 Why are core prints added to the patterns when cores are used?

- (a) They provide different cooling rates to the core
- (b) They provide support to the cores

- (c) They are used to ease the removal of a core
- (d) They are used to manufacture cores

Q.16 Which of the following pattern allowance is known as negative allowance?

- (a) Shrinkage allowance
- (b) Draft allowance
- (c) Rapping allowance
- (d) Machine allowance

Q.17 Casting defect developing due to inadequate venting is

- (a) Inclusions (b) Blow holes
- (c) Cold shuts (d) Hot crack

Q.18 The cupola furnace is used to make

- (a) Pig iron (b) Cast iron
- (c) Wrought iron (d) Steel

Q.19 Which of the following types of centrifugal casting process is used for the casting, whose shape of casting is not axi-symmetric?

- (a) True centrifugal casting
- (b) Semi centrifugal casting
- (c) Centrifuging casting
- (d) None of these

Q.20 Which of the following methods of casting is also known as the liquid metal forging?

- (a) CO₂ casting
- (b) Investment casting
- (c) Permanent mould casting
- (d) Squeeze casting

Q.21 Which of the following methods of casting is employed for the casting of open and hollow objects like toys, dolls, statues etc.?

- (a) Die casting
- (b) Investment casting
- (c) Shell casting
- (d) Slush casting

Q.22 Which of the following moulds or moulding is also known as sodium silicate process.

- (a) Shell moulding (b) Permanent moulding
- (c) Slush moulding (d) CO₂ moulding

Q.23 Which of the following inspections is used for detecting invisible surface defects in a nonmagnetic casting?

- (a) Visual inspection
- (b) Dye penetrant inspection
- (c) Radiographic inspection
- (d) Ultrasonic inspection

Q.24 The main purpose of chaplet is:

- (a) to support core
- (b) to ensure directional solidification
- (c) to provide efficient venting
- (d) to align the mould box parts

Q.25 What is the general shape of an open riser?

- (a) Cubical (b) Trapezoidal
- (c) Cylindrical (d) Spherical

Q.26 Consider the following statements for an induction furnace:

1. High-frequency current is generally used for the furnace working.
2. There is less loss of alloying elements due to oxidation.
3. Pronounced stirring action of molten metal occurs inside the furnace.
4. Slag cover is essential for the efficient working of the furnace.

Which of the above statements are correct?

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

ANSWER KEY**STUDENT'S
ASSIGNMENT**

- | | | | | |
|---------|---------|---------|---------|---------|
| 1. (a) | 2. (c) | 3. (d) | 4. (d) | 5. (b) |
| 6. (c) | 7. (b) | 8. (c) | 9. (d) | 10. (a) |
| 11. (a) | 12. (a) | 13. (d) | 14. (c) | 15. (b) |
| 16. (c) | 17. (b) | 18. (b) | 19. (c) | 20. (d) |
| 21. (d) | 22. (d) | 23. (b) | 24. (a) | 25. (c) |
| 26. (c) | | | | |

HINTS & SOLUTIONS**STUDENT'S
ASSIGNMENT**

1. (a)

Wax pattern is known as expandable pattern and expendable mould which is used in investment casting.

2. (c)

Die casting process is preferred to relatively low melting metal & its alloys like zinc, lead, tin etc.

3. (d)

- Lead and its alloy is most suitable method for die casting.
- Copper alloy can be used only for cold chamber die casting.

4. (d)

Gravity die casting is employed for automobile piston made of aluminium and its alloys.

5. (b)

In centrifugal casting because of density difference, lighter elements such as dross, impurities, and pieces of the refractory lining tend to collect at the inner surface of the casting.

6. (c)

Shell moulding process is a costlier process.

7. (b)

Moulding materials for shell moulding:

- Fine dry silica sand
- Phenol formaldehyde
- Alcohol.

8. (c)

- Bentonite = Impart bonding strength
- Wood flour = → permeability and collapsibility

9. (d)

Fluidity is influenced by: pouring temperature, viscosity, density, o/o of water in sand, surface finish of cavity and permeability.

10. (a)

Cuts occur due to erosion of moulding sand.

11. (a)

Hollow casting with thin wall is produced by slush casting.

12. (a)

Riddle is a round sieve used for cleaning the moulding sand in order to remove unwanted material like metal scrap, pebbles etc.