Production & Industrial Engineering

Manufacturing Process - I

Comprehensive Theory
with Solved Examples *and* Practice Questions

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Manufacturing Process-I

CHAPTER 01

Metal Casting

INTRODUCTION

Metal Casting is one of the oldest materials shaping methods known. Casting means pouring molten metal into a mold 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 mold either by breaking the mold or taking the mold apart. The solidified object is called the casting. By this process, intricate parts can be given strength and rigidity frequently not obtainable by any other manufacturing process. The mold, into which the metal is poured, is made of some heat resisting material. Sand is most often used as it resists the high temperature of the molten metal. Permanent molds of metal can also be used to cast products.

Virtually nothing moves, turns, rolls, or flies without the benefit of cast metal products. The metal casting industry plays a key role in all the major sectors of our economy. There are castings in locomotives, cars trucks, aircraft, office buildings, factories, schools, and homes.

Advantages

The metal casting process is extensively used in manufacturing because of its many advantages.

1. Molten material can flow into very small sections so that intricate shapes can be made by this process. As a result, many other operations, such as machining, forging, and welding, can be minimized or eliminated.
2. It is possible to cast practically any material that is ferrous or non-ferrous.
3. As the metal can be placed exactly where it is required, large saving in weight can be achieved.
4. The necessary tools required for casting molds are very simple and inexpensive. As a result, for production of a small lot, it is the ideal process.
5. There are certain parts made from metals and alloys that can only be processed this way.
6. Size and weight of the product is not a limitation for the casting process.

Limitations

1. Dimensional accuracy and surface finish of the castings made by sand casting processes are a limitation to this technique. Many new casting processes have been developed which can take into consideration the aspects of dimensional accuracy and surface finish. Some of these processes are die casting process, investment casting process, vacuum-sealed molding process, and shell molding process.
2. The metal casting process is a labor intensive process.

1.1 Casting Terminology

1. **Flask:** A metal or wood frame, without fixed top or bottom, in which the mold is formed. Depending upon the position of the flask in the molding structure, it is referred to by various names such as drag – lower molding flask, cope – upper molding flask, cheek – intermediate molding flask used in three piece molding.
2. **Pattern:** It is the replica of the final object to be made. The mold cavity is made with the help of pattern.
3. **Parting line:** This is the dividing line between the two molding flasks that makes up the mold.
4. **Molding sand:** Sand, which binds strongly without losing its permeability to air or gases. It is a mixture of silica sand, clay, and moisture in appropriate proportions.
5. **Facing sand:** The small amount of carbonaceous material sprinkled on the inner surface of the mold cavity to give a better surface finish to the castings.
6. **Core:** A separate part of the mold, made of sand and generally baked, which is used to create openings and various shaped cavities in the castings.
7. **Pouring basin:** A small funnel shaped cavity at the top of the mold into which the molten metal is poured.
8. **Sprue:** The passage through which the molten metal, from the pouring basin, reaches the mold cavity. In many cases it controls the flow of metal into the mold.
9. **Runner:** The channel through which the molten metal is carried from the sprue to the gate.
10. **Gate:** A channel through which the molten metal enters the mold cavity.
11. **Chaplets:** Chaplets are used to support the cores inside the mold cavity to take care of its own weight and overcome the metallostatic force.
12. **Riser:** A column of molten metal placed in the mold to feed the castings as it shrinks and solidifies. Also known as "feed head".
13. **Vent:** Small opening in the mold to facilitate escape of air and gases.

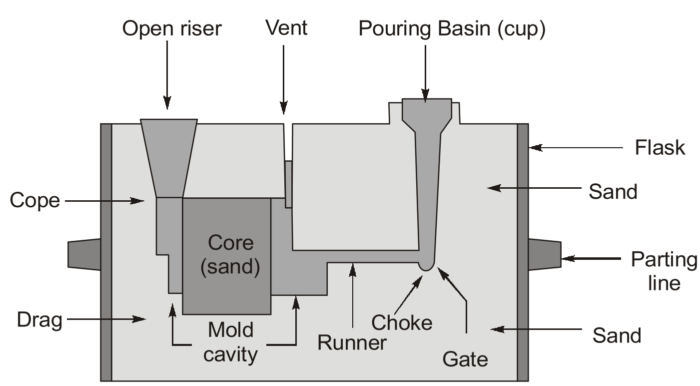


Fig. Mold section showing some casting terms

14. **Casting yield:** The casting yield is the proportion of the actual casting mass, w, to the mass of metal poured into the mould, W, expressed as a percentage.

1.2 Steps of Making Sand Casting

There are six basic steps for making a sand casting

Pattern making

The pattern is a physical model of the casting used to make the mold. The mold is made by packing some readily formed aggregate material, such as molding sand, around the pattern. When the pattern is withdrawn, its imprint provides the mold cavity, which is ultimately filled with metal to become the casting. If the casting is to be hollow, as in the case of pipe fittings, additional patterns, referred to as cores, are used to form these cavities.

Core making

Cores are forms, usually made of sand, which are placed into a mold cavity to form the interior surfaces of castings. Thus the void space between the core and mold-cavity surface is what eventually becomes the casting.

Molding

Molding consists of all operations necessary to prepare a mold for receiving molten metal. Molding usually involves placing a molding aggregate around a pattern held with a supporting frame, withdrawing the pattern to leave the mold cavity, setting the cores in the mold cavity and finishing and closing the mold.

Melting and Pouring

The preparation of molten metal for casting is referred to simply as melting. Melting is usually done in a specifically designated area of the foundry, and the molten metal is transferred to the pouring area where the molds are filled.

Cleaning

Cleaning refers to all operations necessary to the removal of sand, scale, and excess metal from the casting. Burned-on sand and scale are removed to improved the surface appearance of the casting. Excess metal, in the form of fins, wires, parting line fins, and gates, is removed. Inspection of the casting for defects and general quality is performed.

1.3 Pattern

The pattern is the principal tool during the casting process. It is the replica of the object to be made by the casting process, with some modifications. The main modifications are the addition of pattern allowances, and the provision of core prints. If the casting is to be hollow, additional patterns called cores are used to create these cavities in the finished product. The quality of the casting produced depends upon the material of the pattern, its design, and construction. The costs of the pattern and the related equipment are reflected in the cost of the casting. The use of an expensive pattern is justified when the quantity of castings required is substantial.

1.3.1 Functions of the Pattern

1. A pattern prepares a mold cavity for the purpose of making a casting.
2. A pattern may contain projections known as core prints if the casting requires a core and need to be made hollow.
3. Runner, gates, and risers used for feeding molten metal in the mold cavity may form a part of the pattern.
4. Patterns properly made and having finished and smooth surfaces reduce casting defects.
5. A properly constructed pattern minimizes the overall cost of the castings.

1.3.2 Pattern Material

Patterns may be constructed from the following materials. Each material has its own advantages, limitations, and field of application. Some materials used for making patterns are: wood, metals and alloys, plastic, plaster of Paris, plastic and rubbers, wax, and resins. To be suitable for use, the pattern material should be:

1. Easily worked, shaped and joined
2. Light in weight

3. Strong, hard and durable
4. Resistant to wear and abrasion
5. Resistant to corrosion, and to chemical reactions
6. Dimensionally stable and unaffected by variations in temperature and humidity
7. Available at low cost

For pattern making the following materials are commonly used :

1. Wood
2. Metal
3. Plastic
4. Quick setting compounds.

1. Wood :

- The wood used for pattern making should be properly dried and seasoned.
- It should be straight grained.
- It should be free from knots.
- It should be free from insects and excessive sap wood.

Advantages:

(i) Cheapness.
(ii) Ease of availability.
(iii) Lightness.
(iv) Ease of obtaining smooth surface and preserving surface; by applying coating of shellac.
(v) Ability to be worked an easily.
(vi) Ease of joining.
(vii) Ease of fabricating to numerous shapes.

Limitations:

(i) Easily affected by moisture, its shape changes by change in moisture content.
(ii) It wears out quickly by sand abrasion.
(iii) It may warp during improper storing.
(iv) It cannot stand rough usage.
(v) Inherently non-uniform in structure.

2. Metal. Where durability and strength are required, patterns are made from metals.

- A metal pattern can be either cast from master wooden pattern or may be machined by the usual methods of machining.
- Metal patterns are usually used in machine moulding.

Advantages :

(i) Resistant to wear, abrasion, corrosion and swelling.
(ii) Possess a smooth surface.
(iii) Ability to withstand rough handling.
(iv) Do not undergo deformation in storage.
(v) More durable and accurate in size than wooden patterns.

Limitations :

(i) Cannot be repaired easily.
(ii) More expensive than wooden patterns.
(iii) Ferrous patterns may get rusted.
(iv) Heavier than wooden patterns.

3. **Plastic.** The plastics when used as pattern material entail the following advantages :
(i) Highly resistant to corrosion.
(ii) Lighter and stronger than wood pattern.
(iii) Strong and dimension ally stable.
(iv) The production process is facilitated.
(v) Moulding sand sticks less to plastics than to wood.
(vi) The surface of pattern is smooth.
(vii) No moisture absorption.

- The various plastics which are employed for the production of patterns are the compositions based on epoxy, phenol formaldehyde and polyester resins ; polyacrylates, polyethylene, polyvinyl chloride, etc.

4. **Quick setting compounds :**

- Gypsum patterns are capable of producing castings with intricate details and to very close tolerances.
- Gypsum can be easily formed, has plasticity and can be easily repaired.

1.4 Pattern Allowances

Pattern allowance is a vital feature as it affects the dimensional characteristics of the casting. Thus, when the pattern is produced, certain allowances must be given on the sizes specified in the finished component drawing so that a casting with the particular specification can be made. The selection of correct allowances greatly helps to reduce machining costs and avoid rejections. The allowances usually considered on patterns and core boxes are as follows:

1. Shrinkage or contraction allowance
2. Draft or taper allowance
3. Machining or finish allowance
4. Distortion or camber allowance
5. Rapping allowance

All most all cast metals shrink or contract volumetrically on cooling. The metal shrinkage is of two types:

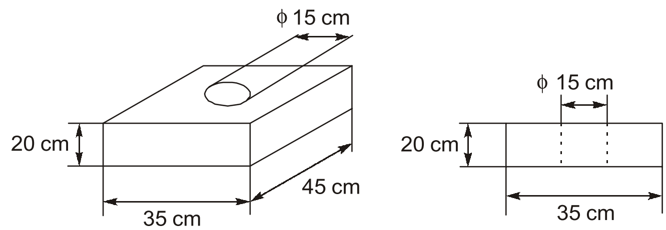
(i) Liquid Shrinkage: it refers to the reduction in volume when the metal changes from liquid state to solid state at the solidus temperature. To account for this shrinkage; riser, which feed the liquid metal to the casting, are provided in the mold.

(ii) Solid Shrinkage: it refers to the reduction in volume caused when metal loses temperature in solid state. To account for this, shrinkage allowance is provided on the patterns.

Table Shrinkage allowance for important material

Material	Allowance
Bismuth	Negligible
Cast iron	10 mm/ meter length
Aluminium	12-15 mm/ meter length
Bronze, Brass, Copper	15 mm/ meter length
Pure Aluminium	17 mm/ meter length
Steel	20 mm/ meter length
Zinc, lead	25 mm/ meter length
Liquid shrinkage > solid shrinkage > Phase transformation shrinkage	

Example 1.1 The casting shown is to be made in cast iron using a wooden pattern. Assuming only shrinkage allowance, calculate the dimension of the pattern if shrinkage allowance for cast iron is 0.012 cm per cm of length. All Dimensions are in cm.



Solution :

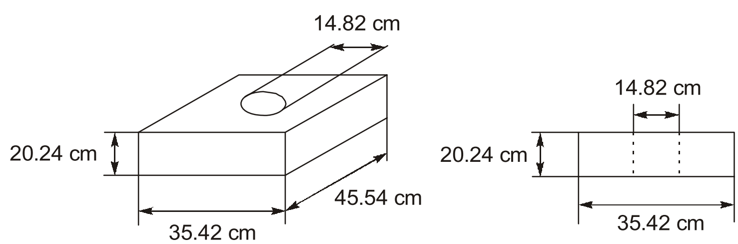
For dimension 45 cm, allowance = $45 \times 0.012 = 0.54$ cm

For dimension 35 cm, allowance = $35 \times 0.012 = 0.42$ cm

For dimension 20 cm, allowance = $20 \times 0.012 = 0.24$ cm

For dimension 15 cm, allowance = $15 \times 0.012 = 0.18$ cm

The pattern drawing with required dimension is shown below:



Draft or Taper Allowance

By draft is meant the taper provided by the pattern maker on all vertical surfaces of the pattern so that it can be removed from the sand without tearing away the sides of the sand mold and without excessive rapping by the molder. Figure (a) given below shows a pattern having no draft allowance being removed from the pattern. In this case, till the pattern is completely lifted out, its sides will remain in contact with the walls of the mold, thus tending to break it. Figure (b) given below is an illustration of a pattern having proper draft allowance. Here, the moment the pattern lifting commences, all of its surfaces are well away from the sand surface. Thus the pattern can be removed without damaging the mold cavity.

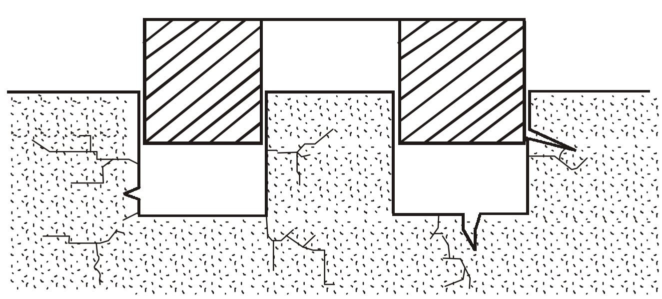


Fig. (a) Pattern having no draft in vertical edges

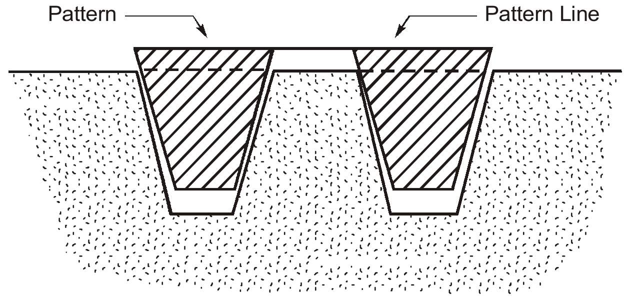


Fig. (b) Pattern having draft along vertical edges

Machining or Finish Allowance

The finish and accuracy achieved in sand casting are generally poor and therefore when the casting is functionally required to be of good surface finish or dimensionally accurate, it is generally achieved by subsequent machining. Machining or finish allowances are therefore added in the pattern dimension. The amount of machining allowance to be provided for is affected by the method of molding and casting used viz. hand molding or machine molding, sand casting or metal mold casting. The amount of machining allowance is also affected by the size and shape of the casting; the casting orientation; the metal; and the degree of accuracy and finish required.

Distortion or Camber Allowance

Sometimes castings get distorted, during solidification, due to their typical shape. For example, if the casting has the form of the letter U, V, T, or L etc. it will tend to contract at the closed end causing the vertical legs to look slightly inclined. This can be prevented by making the legs of the U, V, T, or L shaped pattern converge slightly (inward) so that the casting after distortion will have its sides vertical.

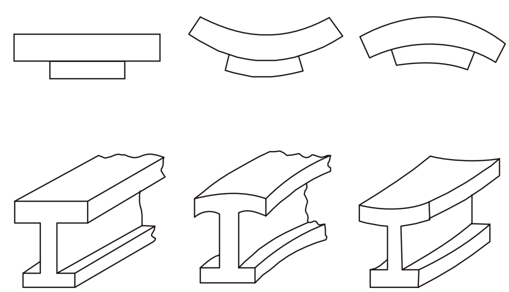


Fig. Distortion in casting

The distortion in casting may occur due to internal stresses. These internal stresses are caused on account of unequal cooling of different section of the casting and hindered contraction. Measure taken to prevent the distortion in casting include:

(i) Modification of casting design

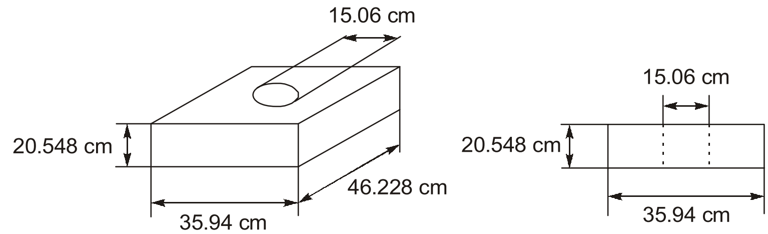
(ii) Providing sufficient machining allowance to cover the distortion affect

(iii) Providing suitable allowance on the pattern, called camber or distortion allowance (inverse reflection)

Rapping Allowance

Before the withdrawal from the sand mold, the pattern is rapped all around the vertical faces to enlarge the mold cavity slightly, which facilitate its removal. Since it enlarges the final casting made, it is desirable that the original pattern dimension should be reduced to account for this increase. There is no sure way of quantifying this allowance, since it is highly dependent on the foundry personnel practice involved. It is a negative allowance and is to be applied only to those dimensions that are parallel to the parting plane.

Example 1.2 The casting shown is to be made in cast iron using a wooden pattern. Assuming only machining allowance, calculate the dimension of the pattern if machining allowance for cast iron for size, up to 30.48 cm is 0.3048 cm and from 30.48 cm to 50.8 cm is 0.508 cm. All Dimensions are in cm.



Solution :

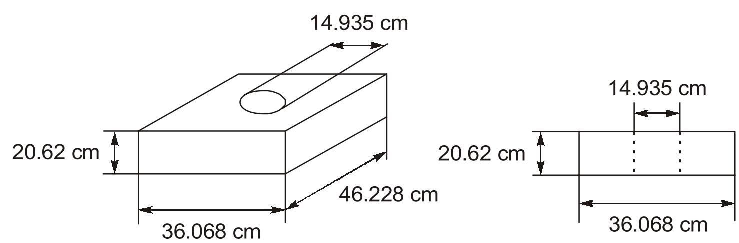
The machining allowance for cast iron for size, up to 30.48 cm is 0.3048 cm and from 30.48 cm to 50.8 cm is 0.508 cm. For dimension 45.72 cm, allowance = 0.508 cm

For dimension 35.56 cm, allowance = 0.508 cm

For dimension 20.32 cm, allowance = 0.3048 cm

For dimension 15.24 cm, allowance = 0.3048 cm

The pattern drawing with required dimension is shown in figure below:



1.5 Pattern Types

Types of patterns depend upon the following factors :

(i) The shape and size of casting.

(ii) Number of castings required.

(iii) Method of moulding employed.

(iv) Anticipated difficulty of the moulding operation.

The following types of patterns are commonly used :

1. Solid or single piece pattern.
2. Split pattern.
3. Loose piece pattern.
4. Match plate pattern.
5. Gated pattern.
6. Skeleton pattern.
7. Sweep pattern.
8. Cope and drag pattern.
9. Follow board pattern.
10. Segmental pattern.
11. Shell pattern.
12. Lagged-up pattern.

1. **Solid or single piece pattern :** Refer to the figure.

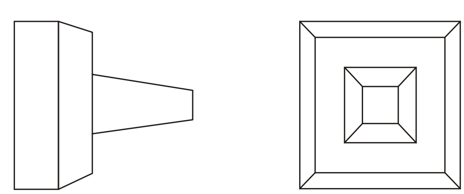
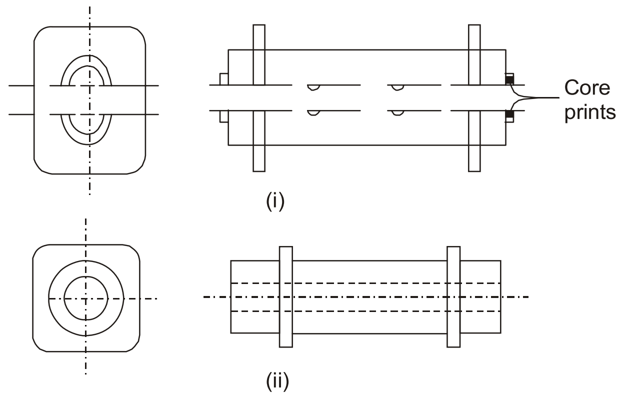


Fig. Solid pattern

- It is simplest of all the patterns and the cheapest.
- It is made in one piece and carries no joint, partition or loose pieces.
- Depending upon the shape, it can be moulded in one or two boxes.
- Its use can be made to a limited extent of production only since its moulding involves a large number of manual operations like gate cutting, providing runners and risers and the like.

2. **Split pattern :** Refer to figure given below.

- Most of the patterns are not made in a single piece because of the difficulties encountered in moulding them. In order to eliminate this difficulty, some patterns are made in two or more pieces.



(i) Two halves of pattern. (ii) Prepared casting

Fig. A split pattern

- A pattern consisting of two pieces is called a two piece split pattern. One-half of the pattern rests in the lower part of the moulding box known as drag and the other half in the upper part of the moulding box known as cope. The line of separation of the parts is called parting line or parting surface.
- Sometimes a pattern is constructed in three or more parts for complicated castings. Such a pattern is called multi-piece pattern (see figure).

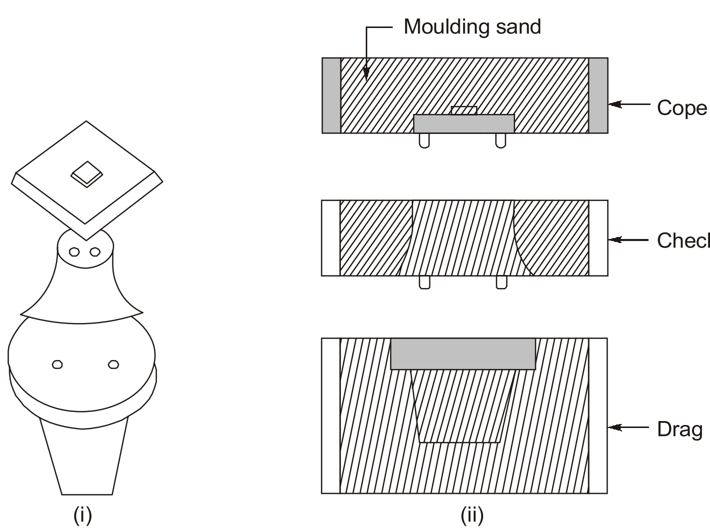


Fig. Multipiece pattern

3. **Loose piece pattern :** Refer to Figure.

   In some cases a pattern has to be made with projections or overhanging parts. These projections make the removal of the pattern difficult. Therefore such projections are made in loose pieces and are fastened loosely to the main pattern by means of wooden or wire dowel pins. These pins are taken out during moulding operation. After moulding the main pattern is withdrawn first and then the loose piece is removed by using a lifter.

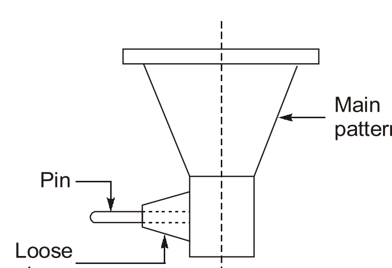


Fig. Loose piece pattern

Student's Assignments 1

Q.1 Which one of the following materials will require the largest size of riser for the same size of casting?
(a) Aluminium (b) Cast iron
(c) Steel (d) Copper.

Q.2 In solidification of metal during casting, compensation for solid contraction is
(a) Provided by the oversize pattern
(b) Achieved by properly placed risers
(c) Obtained by promoting directional solidification
(d) Made by providing chills

Q.3 Disposable patterns are made of
(a) Wood (b) Rubber
(c) Metal (d) Polystyrene

Q.4 The pattern adopted for those castings where there are some portions which are structurally weak and are likely to break by the force of ramming are called:
(a) Loose piece pattern
(b) Follow board pattern
(c) Skeleton pattern
(d) Single piece pattern

Q.5 Fluidity in casting (CI) operation is greatly influenced by
(a) Melting temperature of molten metal
(b) Pouring temperature of molten metal
(c) Finish of the mould
(d) Carbon content of molten metal

Q.6 The gating ratio 2: 8: 1 for copper in gating system design refers to the ratio of areas of:
(a) Sprue: Runner: Ingate
(b) Runner: Ingate: Sprue
(c) Runner: Sprue: Ingate
(d) Ingate: Runner: Sprue

Q.7 For a given volume of a riser, if the solidification time of the molten metal in riser needs to be quadrupled, the surface area of the riser should be made
(a) one-fourth (b) half
(c) double (d) four times

Q.8 According to Chvorinov's equation, the solidification time of a casting is proportional to:
(a) v^2 (b) v
(c) $1/v$ (d) $1/v^2$
where, v = volume of casting

Q.9 Chills are used in casting moulds to
(a) Achieve directional solidification
(b) Reduce possibility of blow holes
(c) Reduce the freezing time
(d) Increase the smoothness of cast surface

Q.10 When an alloy solidifies over a range of temperature, the resulting casting structure is:
(a) Wholly equi-axed
(b) Wholly columnar
(c) Partially columnar partially equi-axed
(d) Dendritic

Q.11 In shell moulding, how can the shell thickness be accurately maintained?
(a) By controlling the time during which the pattern is in contact with mould
(b) By controlling the time during which the pattern is heated
(c) By maintaining the temperature of the pattern in the range of 175°C – 380°C
(d) By the type of binder used

Q.12 Which of the following casting processes uses expendable pattern and expendable mould?
(a) Shell mould casting
(b) Investment casting
(c) Pressure die casting
(d) Centrifugal casting

Q.13 In full mould (cavity-less) casting process, the pattern is made of
(a) Expanded polystyrene
(b) wax
(c) Epoxy
(d) Plaster of paris

Q.14 Which one of the following processes produces a casting when pressure forces the molten metal into the mould cavity?

Student's Assignments 2

Q.29 In a horizontal centrifugal casting, G-factor (GF) is defined as the ratio of centrifugal force to weight. If for a horizontal centrifugal casting, G-factor is 60, inner diameter of mould is 0.5073 m and outer diameter of mould is 0.5301, then the rotational speed N in rev/min is
(a) 455 rpm (b) 450 rpm
(c) 460 rpm (d) None of these

Q.30 A cylindrical side riser must be designed for a sand casting mold. The casting itself is a steel rectangular plate with a dimensions 7.5 cm × 12.5 cm × 2.0 cm. Previous observations have indicated that the solidification time for this casting is 1.6 min. The cylindrical riser will have a diameter to height ratio as 1.8. The diameter of riser is ______ cm so that its solidification time will be 3.0 min.

Q.31 Gating ratio of 1 : 2 : 2 for a cast iron casting of section thickness 10 mm, weighing 25 kg. If pouring time is given by,

$$t = k\sqrt{w}\text{ , sec}$$

where k = 2.3, and w = casting weight (kg), flow efficiency factor c = 0.89, and density of iron is 8.0×10^{-3} kg/cm^3. What is the diameter of sprue at the top when area of sprue at the top is twice to the sprue base area? Assume a height of sprue is 200 mm.
(a) 140.028 mm (b) 1.40 cm
(c) 1.98 cm (d) 198.02 mm

Q.32 The time required to fill the mould (in min) for a sand casting of dimension 40 mm × 10 mm × 10 mm using top gating with metal flow rate of 25 cm^3/min (design should be such that the pressure anywhere in sprue should not be less than atmospheric pressure) is ________.

Q.33 A critical dimension in casting of plain carbon steel is 29 mm which has to be maintained. If master pattern is made up of aluminium. Calculate the dimension of wooden pattern, which is to be used for making the aluminium pattern. Given shrinkage allowance for aluminium is 13 mm/m and for plain carbon steel is 21 mm/m. The critical dimension (in mm) of wooden pattern will be ________. (Correct upto 3 decimal place).

ANSWERS

1. (c)	2. (a)	3. (d)	4. (b)
5. (b)	6. (a)	7. (b)	8. (a)
9. (a)	10. (d)	11. (a)	12. (b)
13. (a)	14. (c)	15. (d)	16. (b)
17. (a)	18. (b)	19. (c)	20. (d)
21. (539.67)	22. (0.576)	23. (148)	24. (c)
25. (d)	26. (40)	27. (0.11478)	28. (a)
29. (c)	30. (7.29)	31. (c)	32. (0.16)
33. (29.991)			

HINTS

17. (a)
No binders are used in sand.
Features of vacuum sand moulding are:
- No binders are used.
- Mechanical ramming is not required.
- No water is mixed.
- Relatively slow process.

18. (b)
Polystyrene pattern: Expandable polystyrene process is also known as lost form process, lost pattern process or evaporative foam process. As we pour the liquid metal, wax pattern evaporates and cavity is formed .

19. (c)
In pressurized gating the back pressure is maintained throughout the gating which minimises the air aspiration even when straight sprue is used.

20. (d)
In permanent mold casting processes, molds are generally made of steel or CI.

21. (539.67) (537 to 542)
Given, metal flow rate,

$$Q = 1 \text{ litre/sec} = 10^6 \text{ mm}^3\text{/sec}$$

$$v = \sqrt{2gh} = \sqrt{2 \times 9810 \times 175}$$

$$= 1852.970 \text{ mm/sec}$$

Base area, $A = \frac{Q}{v} = \frac{10^6}{1852.970}$

$= 539.67 \text{ mm}^2$

22. (0.576) (0.575 to 0.577)

Shrinkage allowance

$= \alpha l(\theta_f - \theta_0)$

$= 1.2 \times 10^{-5} \times 32\,(1530 - 30)$

$= 0.576 \text{ mm}$

23. (148)(147.7 to 148.8)

Sand density $= 1.6 \text{ g/cm}^3 = 0.0016 \text{ kg/cm}^3$

core volume, $V = \frac{20}{0.0016} = 12500 \text{ cm}^3$

$\rho_{Alloy} = 2.81 \text{ g/cm}^3$

$= 0.00281 \text{ kg/cm}^3$

weight of displaced Al-Cu alloy

$W = 12500 \times (0.00281)$

$= 35.125 \text{ kg}$

Buoyancy force $F_b = W_m - W_c$

$= (35.125 - 20) \times 9.81$

$= 148.37 \text{ N}$

24. (c)

High corrosion resistance

26. (40)

Given: Volume of casting $= (10)^3 = 1000 \text{ cm}^3$

Surface area of casting $= 6 \times 10^2 = 600 \text{ cm}^3$

Time required to solidify, $T_s = r\left(\frac{V}{A}\right)^2$

$T_s = 1.44 \times 10^5 \text{ sec/m}^2 \times \left(\frac{1000}{600}\text{cm}\right)^2$

$= 1.44 \times 10 \text{ sec/cm}^2 \times 2.778 \text{ cm}^2 = 40 \text{ sec}$

$T_s = 40 \text{ sec}$

27. (0.11478) (0.11 to 0.12)

$$t = k\left(1.41 + \frac{T}{14.59}\right)\sqrt{w} \text{ sec}$$

$T = 1.1525 \text{ cm} = 11.525 \text{ mm}$

$$t = \frac{28}{40}\left[1.41 + \frac{11.525}{14.59}\right] \times \sqrt{20} \text{ sec} = 6.8868 \text{ sec}$$

$$= \frac{6.8868}{60} \text{ minutes}$$

$= 0.11478 \text{ minutes}$

29. (c)

$$GF = \frac{mv^2/R}{mg} = \frac{v^2}{Rg}, \quad v = \frac{\pi DN}{60}$$

$$= \frac{\pi^2 D^2 N^2}{3600 \times Rg}$$

$$= \frac{\pi^2 \times D^2 \times N^2 \times 2}{3600 \times D \times g}$$

$$= \frac{\pi^2 \times D^2 \times N^2}{1800 \times g}$$

$$N = \sqrt{\frac{GF \times 1800 \times g}{\pi^2 D}}$$

$$= \frac{30}{\pi}\sqrt{\frac{2g(GF)}{D}}$$

Here D is inner diameter of mold for horizontal centrifugal casting,

$$N = \frac{30}{\pi}\sqrt{\frac{2 \times 9.81 \times 60}{0.5073}}$$

$= 460 \text{ rpm}$

30. (7.29) (7.0 to 7.4)

For casting, $\frac{V}{A}$ ratio

$$\frac{V}{A} = \frac{7.5 \times 12.5 \times 2}{2(7.5 \times 12.5 + 12.5 \times 2 + 7.5 \times 2)}$$

$$= \frac{187.5}{267.5} = 0.7 \text{ cm}$$

$$t_s = r\left(\frac{V}{A}\right)^2$$

$\Rightarrow \quad r = \frac{1.6}{(0.7)^2} = 3.26 \text{ min/cm}^2$

for $\quad \frac{D}{H} = 1.8, \; V = \frac{\pi}{4}D^2 H,$

$A = \pi DH + \frac{2\pi}{4}D^2$

$D = 1.8H$

$V = \frac{\pi}{4}(1.8H)^2 \times H,$

$A = \pi \times 1.8H^2 + \frac{\pi}{2}(1.8H)^2$

$A = \pi \times 1.8H^2 + 1.62\pi H^2$

$= \pi(3.42H^2)$

$V = 0.81\pi H^3$

$$\frac{V}{A} = \frac{081\pi H^3}{\pi(3.42H^2)} = 0.2368H$$