1.1 INTRODUCTION

Manufacturing is the backbone of any industrialized nation. Manufacturing and technical staff in industry must know the various manufacturing processes, materials being processed, tools and equipments for manufacturing different components or products with optimal process plan using proper precautions and specified safety rules to avoid accidents. Beside above, all kinds of the future engineers must know the basic requirements of workshop activities in term of man, machine, material, methods, money and other infrastructure facilities needed to be positioned properly for optimal shop layouts or plant layout and other support services effectively adjusted or located in the industry or plant within a well planned manufacturing organization.

The complete understanding of basic manufacturing processes and workshop technology is highly difficult for any one to claim expertise over it. The study deals with several aspects of workshops practices also for imparting the basic working knowledge of the different engineering materials, tools, equipments, manufacturing processes, basic concepts of electromechanical controls of machine tools, production criteria's, characteristics and uses of various testing instruments and measuring or inspecting devices for checking components or products manufactured in various manufacturing shops in an industrial environment. It also describes and demonstrates the use of different hand tools (measuring, marking, holding and supporting tools, cutting etc.), equipments, machinery and various methods of manufacturing that facilitate shaping or forming the different existing raw materials into suitable usable forms. It deals
with the study of industrial environment which involves the practical knowledge in the area of ferrous and non ferrous materials, their properties and uses. It should provide the knowledge of basic workshop processes namely bench work and fitting, sheet metal, carpentry, pattern making, mould making, foundry, smithy, forging, metal working and heat treatment, welding, fastening, machine shop, surface finishing and coatings, assembling inspection and quality control. It emphasizes on basic knowledge regarding composition, properties and uses of different raw materials, various production processes, replacement of or improvement over a large number of old processes, new and compact designs, better accuracy in dimensions, quicker methods of production, better surface finishes, more alternatives to the existing
materials and tooling systems, automatic and numerical control systems, higher mechanization and greater output.

MANUFACTURING PROCESS AND PRODUCTION PROCESS

Manufacturing is derived from the Latin word manufactus, means made by hand. In modern context it involves making products from raw material by using various processes, by making use of hand tools, machinery or even computers. It is therefore a study of the processes Required to make parts and to assemble them in machines. Process Engineering, in its application to engineering industries, shows how the different problems related to development of various machines may be solved by a study of physical, chemical and other laws governing the manufacturing process. The study of manufacturing reveals those parameters which can be most efficiently being influenced to increase production and raise its accuracy. Advance manufacturing engineering involves the following concepts—

1. Process planning.
2. Process sheets.
3. Route sheets.
4. Tooling.
5. Cutting tools, machine tools (traditional, numerical control (NC), and computerized Numerical control (CNC).
6. Jigs and Fixtures.
7. Dies and Moulds.
8. Manufacturing Information Generation.
9. CNC part programs.
10. Robot programmers.
11. Flexible Manufacturing Systems (FMS), Group Technology (GT) and Computer Integrated manufacturing (CIM).

PRODUCTION PROCESS

It is the process followed in a plant for converting semi- finished products or raw materials into finished products or raw materials into finished products. The art of converting raw material into finished goods with application of different types of tools, equipment’s, machine tools, manufacturing set ups and manufacturing processes, is known as production. Generally there are three basic types of production system that are given as under.

1. Job production
2. Batch production
3. Mass production

Job production comprises of an operator or group of operators to work upon a single job and complete it before proceeding to the next similar or different job. The production requirement in the job production system is extremely low. It requires fixed type of layout for developing same products. Manufacturing of products (less in number say 200 to 800) with variety of

Similar parts with very little variation in size and shape is called batch production. Whenever the production of batch is over, the same manufacturing facility is used for production of other batch product or items. The batch may be for once or of periodical type or of repeated kinds after some irregular interval. Such manufacturing concepts are leading to GT and FMS technology. Manufacturing of products in this case requires process or functional layout. Whereas mass production involves production of large number of identical products (say more than 50000) that needs line layout type of plant layout which is highly rigid type and involves automation and huge amount of investment in special purpose machines to increase the production

CLASSIFICATION OF MANUFACTURING PROCESS:

The manufacturing processes can be classified as: 1. Forming Processes 2. Moulding Processes 3. Machining Processes 4. Assembly Processes 5. Finishing Processes.

1. Forming Processes:

In the metal industry, some of the primary forming operations may take place such as the rolling of basic shapes in steel, aluminium etc. Some of the common shapes so obtained from these processes are bars, sheets, billets, I-beams etc. Which are standard shapes. These shapes can be used for further processing. Other forming processes may be drop-forging, stamping, extrusion, press work, punching, drawing etc.

2. Moulding Processes:

Some products require moulding processes such as sand casting, die-casting etc. to get basic shape or form which may or may not require further processing. The selection of the particular process will depend upon to size of the job, quantity to be produced, accuracy, and complexity desired and economy

Machining process

Metal machining is accomplished through basic machine tool processes which involve the generation of cylindrical surfaces, flat surfaces, complex curves and holes. The machine tools selected to accomplish this task depend on the size and shape of the part to be machined, the quality of finish required and production rate required.

The examples of such processes are: turning, shaping, drilling, boring, grinding etc. In these machining operations metal is removed from the part in the form of small chips by the cutting action of tool. The cutting action is accomplished by either rotating or reciprocating action of the tool relating to the part.

4. Assembly Processes:

These processes assemble the parts and materials using welding, riveting, soldering, brazing, mechanical fastening and adhesive joining etc.

5. Finishing Processes:

These processes are carried out for the aesthetic aspects, to achieve accuracy, surface finish or to increase life of the product. Such processes include cleaning, blasting, deburring, puffing, honing, lapping, polishing, painting etc.

CONCEPT OF METAL CASTING

What is Metal Casting

Metal casting is defined as the process in which molten metal is poured into a mould that contains a hollow cavity of a desired geometrical shape and allowed to cool down to form a solidified part.

Figure 1. Metal-casting

Primarily, casting produces **ingots** and **shapes**. An **ingot** is a casting produced into a simple shape and intended for further processing such as metal extrusion, forging, etc. **Shape casting** is for near or net shape castings to produce complex geometries which are closer to the
finalpart.

Types of Metal Casting

Metal casting can be divided into two groups by the basic nature of the mould design. i.e. **expendable mould** and **permanent mould castings**. It can be further subdivided into groups depending on their pattern material.

- Expendable Mould
    - Permanent pattern

        - Sand casting
        - Plaster moulding
        - Shell mould
        - Ceramic mould
    - Expendable pattern
        - Lost foam
        - Investment casting
- Permanent mould
    - Gravity casting
    - Low pressure/vacuum
    - Die casting

Following factors need to be considered before choosing a suitable metal casting for a given engineering product design.

- Part shape and size
- Required quantity
- Required tolerance
- Material

Expendable mould casting

Expendable mould casting, as the name suggests uses a temporary non-reusable mould to produce the final casting as the mould will be broken to get the casting out. These moulds are typically made of materials such as sand, ceramics & plaster. These are generally bonded using binders called bonding agent to improve its properties. Complex intricate geometries can be cast using expendable mould casting.

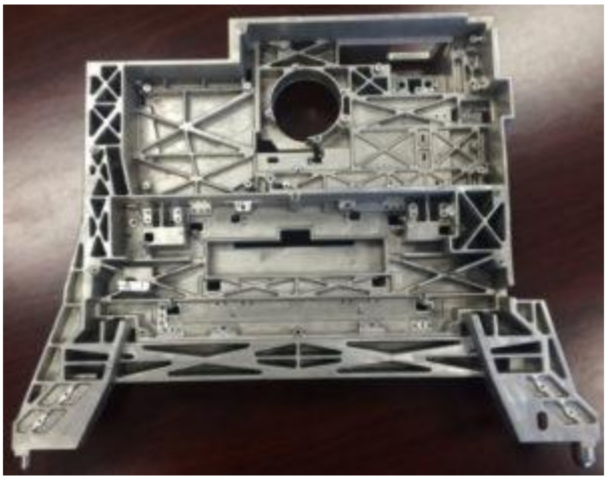


Figure aluminium alloy a356 copier frame plaster mould aluminium casting(credit_link)

Permanent mould casting

Sometimes called non-expendable mould casting, permanent mould casting uses permanent moulds that are reused after each production cycle. Although permanent mould casting produces repeatable parts due to re-use of the same mould, it can only produce simple castings as the mould needs to be opened to remove the castings.

Figure 3. Permanent mould casting (credit – Alibaba)

Composite mould casting

As the name suggests these uses both expendable and re-useable casting moulds to produce castings. These normally include materials such as sand, wood, graphite and metal.

Figure 4. Composite mould casting (credit – highlywell-china)

How does metal casting work

Metal casting steps: the following basic steps involved casting process

1. **Patternmaking** – A replica of the part to be cast is made using a suitable material such as wood, metal plastic or plaster.
2. **Mould making** – Mould making is a multi-step process in which patterns and cores are used to create a mould. The type and how the moulds are made would vary depending on the type of metal casting. For example, sand casting uses sand inside a flask to create moulds and die casting uses hardened tool steel moulds.
3. **Metal melting & pouring** – Liquid is then melted and poured into the mould cavity either by gravity or by high pressure. Then the cast is allowed to solidify before the cast parts are removed from the mould. Again, the cast part removal will vary depending on the type of metal casting.
4. **Post processing** – In this final step, the cast metal object is removed from the mould and then fettled. During the fettling, the object is cleaned of any moulding material, and rough edges are removed. The following fig clearly illustrated the casting process

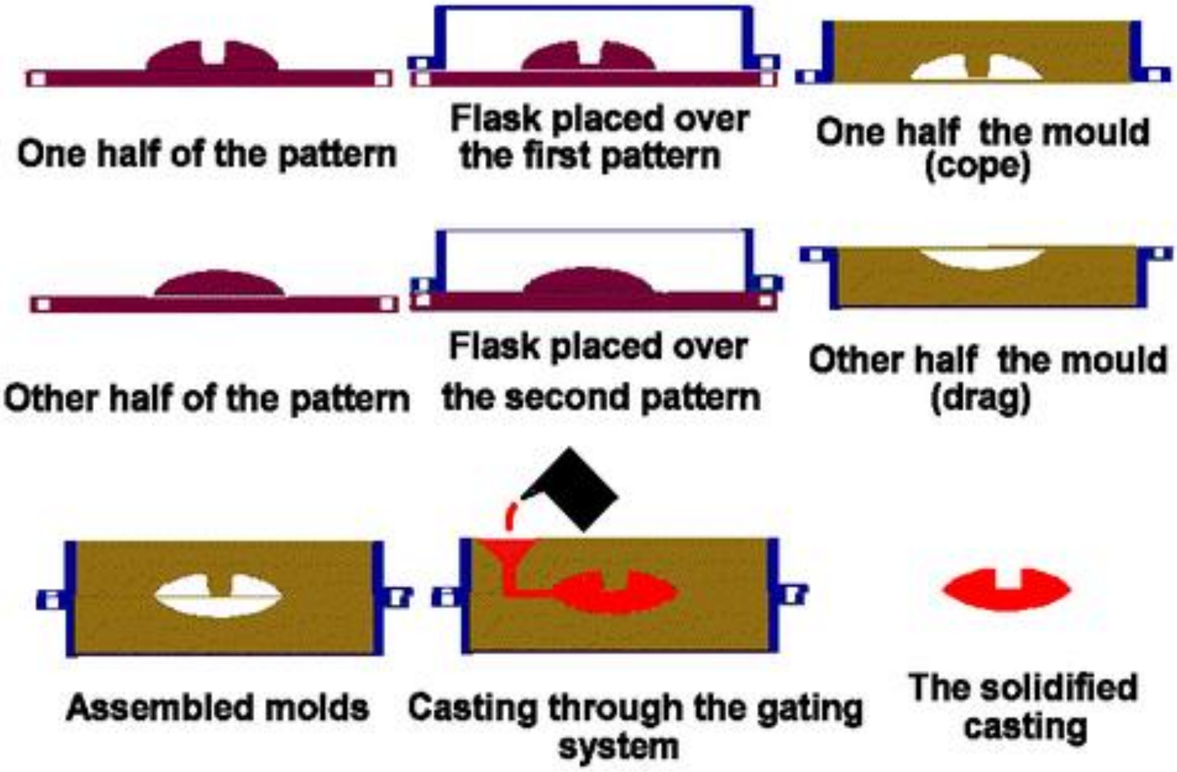
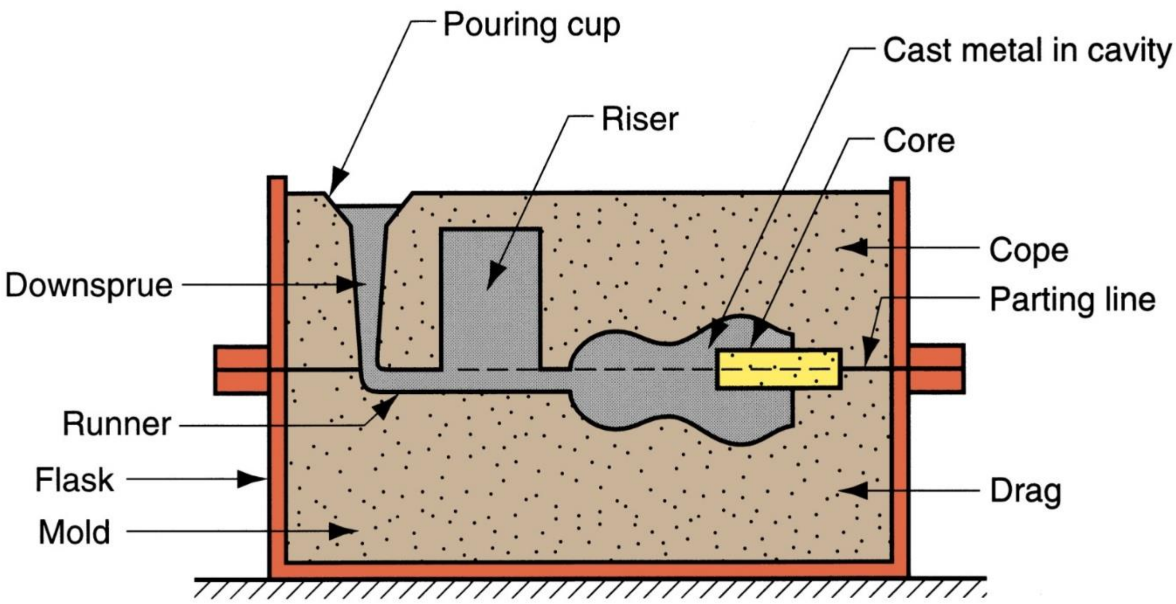


Fig : Basic steps involved during casting process



(b)

Schematic representation of casting process

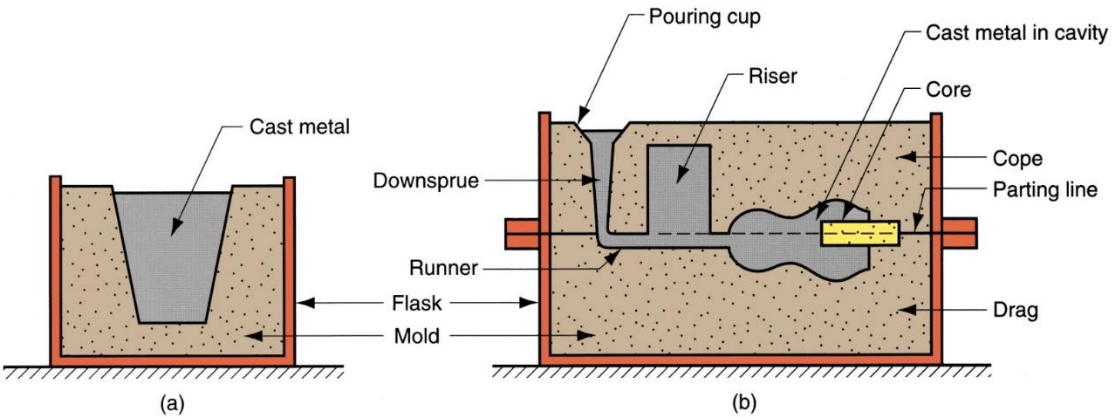
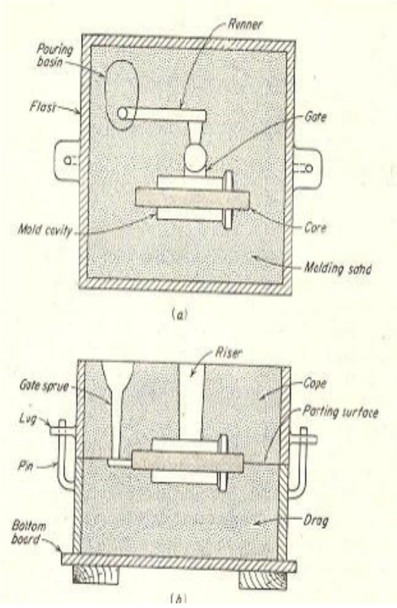
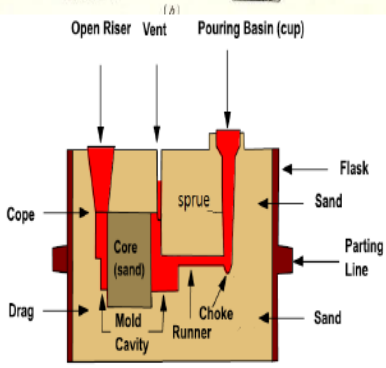


Fig: Two forms of mold: (a) open mold, simply a container in the shape of the desired part; and (b) closed mold, in which the mold geometry is more complex and requires a gating system (passageway) leading into the cavity

Terms Used In Casting Process:

Important casting terms





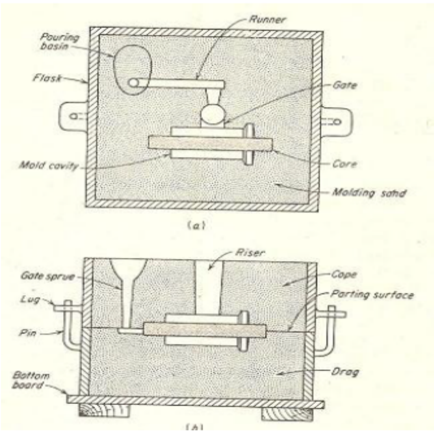
Flask: A metal or wood frame, without fixed top or bottom, in which the mould is formed. Depending upon the position of the flask in the moulding structure, it is referred to by various names such as <u>drag</u> – lower moulding flask, <u>cope</u> – upper moulding flask, <u>cheek</u> – intermediate moulding flask used in three piece moulding.

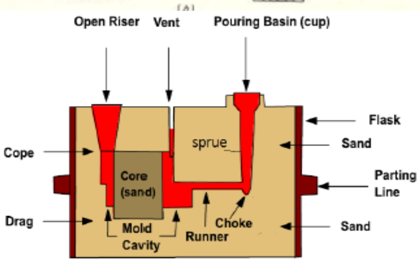
Pattern: It is the replica of the final object to be made. The mould cavity is made with the help of pattern.

Parting line: This is the dividing line between the two moulding flasks that makes up the mould.

Moulding 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.

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





Core: A separate part of the mould, made of sand and generally baked, which is used to create openings and various shaped cavities in the castings.

Pouring basin: A small funnel shaped cavity at the 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. In many cases it controls the flow of metal into the mould.

Runner: The channel through which the molten metal is carried from the sprue to the gate.

Gate: A channel through which the molten metal enters the mould cavity.

Chaplets: Chaplets are used to support the cores inside the mould cavity to take care of its own weight and overcome the metallostatic force.

Riser: A column of molten metal placed in the mould to feed the castings as it shrinks and solidifies. Also known as “feed head”.

Vent: Small opening in the mould to facilitate escape of air and gases.

Elements of the gating system

One of the most common metal casting process is Sand casting and its mould is made of two halves. Contained inside a box called flask, the upper half is called the cope and the bottom half is called the drag. As shown in the image (Figure 5) below the flask is also divided into two halves. The line that separates the two halves is called the **parting line.**

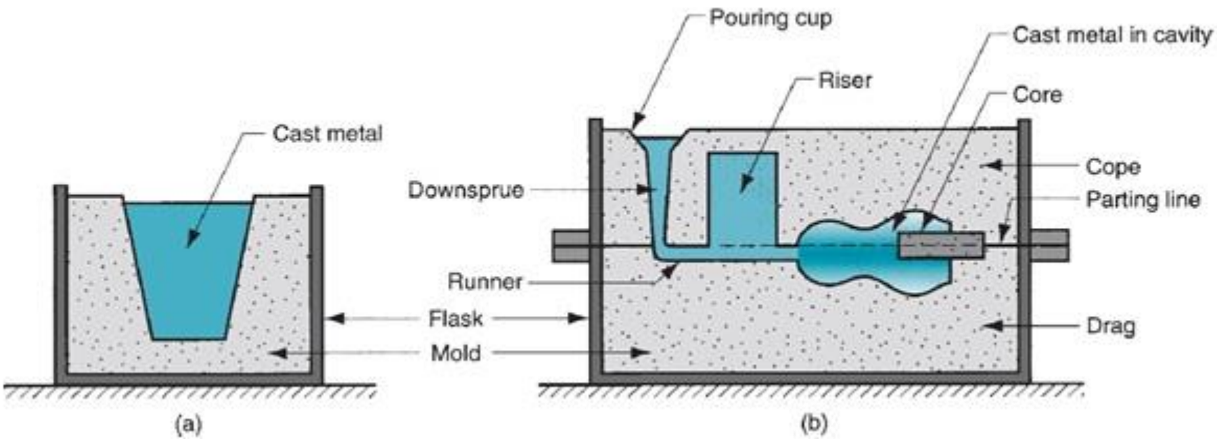


Figure 5 Metal casting gating system (source: Groover (2010))

The gating system is the channel or the path by which the molten metal flows into the cavity. As shown above, the gating system consists of a pouring cup and a down sprue through which the metal enters the runner that leads into the main cavity. Pouring cup minimises the splash and turbulence when the metal flows through the sprue which is tapered to aid the flow. Most of the casting suffers from shrinkage during cooling and to minimise the shrinkage issue, a riser is used. A riser is a simple reservoir in the mould that feeds molten material to the shrinking sections to compensate as it solidifies. There are four different types of risers, viz. top riser, side riser, blind riser and open riser.

Material suitability

Although almost all the metals can be used, the most commons ones are iron, steel, aluminium, magnesium and copper-based alloys such as bronze. Zinc, aluminium, magnesium and brass are widely used in die casting whereas aluminium alloy, brass alloy, cast iron and cast steel are very popular sand-casting materials.

Typical application

Nearly every engineering product we use from washing machines to pillar drills, cars to bicycles are manufactured using metal parts which are most likely to be made using one of the metal casting processes. This age-old manufacturing process has improved its precision and tolerances over time. Typically, castings are used to make car engine blocks, crankshafts, power tool housings such as, pillar drills, plumbing parts, turbine blades, metal statues, some gears and gearbox housings.

Advantages and disadvantages of metal casting

As with any other manufacturing processes, a basic understanding of the process, its underlying science, its pros and cons are essential for manufacturing low-cost quality engineer products.

Advantages of metal casting

- Metal casting can produce complex shapes
- Features like internal cavities or hollow sections can be easily achieved
- Large components can be produced in one-piece cast
- Materials that are difficult or expensive to manufacture using other manufacturing process can be cast
- Compared to other manufacturing processes, casting is cheaper for medium to large quantities
- Almost all the metals can be cast
- Near net shape often without or very minor post-processing

Because of the above reasons metal casting is one of the important net shape manufacturing technologies. Others include net shape forging, stamping of sheet metal, additive manufacturing and metal injection moulding.

Disadvantages of metal casting

- Relatively coarse surface finish and hence wider tolerance has to be allowed and

  not suitable for mating interfaces

- Metal casting such as shell moulding has a limit in terms of size and the pattern
- Patterns are time-consuming and expensive to make although additive manufacturing processes such as binder jetting are being used lately to make a mould
- Die casting can be very expensive for smaller to medium quantities due to high

  die cost
- Part size and material choices depend on the casting process chosen. For instance, only non-ferrous metal can be used for permanent mould castings

Application of castings in different fields

- Transport : Automobile, aerospace, railways and shipping
- Heavy Equipment : Construction, farming and mining
- Machine Tools : Machining, casting, plastics molding, forging, extrusion and forming
- Plant Machinery : Chemical, petroleum, paper, sugar, textile, steel and thermal plants
- Defence : Vehicles, artillery, munitions, storage and supporting equipment
- Electrical Equipment Machines : Motors, generators, pumps and compressors
- Hardware : Plumbing industry pipes, joints, valves and fittings
- Household : Appliances, kitchen and gardening equipment, furniture and fittings
- Art Objects : Sculptures, idols, furniture, lamp stands and decorative items

SOLIDFICATION OF METALS:

Solidification Time: Chvorinov's Rule.

The **amount of heat that must be removed** from a casting to cause it to solidify is **directly proportional to the amount of superheating** and the **amount of metal** in the casting, or the casting volume. Conversely, the **ability to remove heat** from a casting is **directly related to the amount of exposed surface area** through which the heat can be extracted and the insulating value of the *mould*. These observations are reflected in Chvorinov's rule, which states that *ts,* the total solidification time, can be computed by:

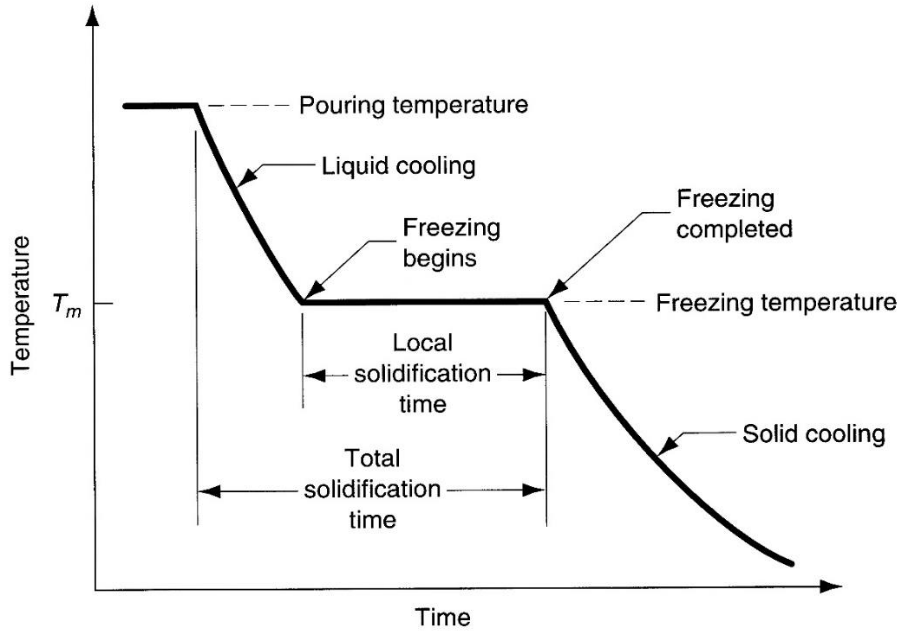
***TST* = *B* (*V/A*)*n* where *n* = 1.5 to 2.0**

The total solidification time is the time from pouring to the completion of solidification; *V* is the volume of the casting; ***A*** is the surface area; and ***B*** is the **mould constant**, which depends on the characteristics of the metal being cast (its density, heat capacity, and heat of fusion), the mould material (its density, thermal conductivity, and heat capacity), the mould thickness, and the amount of superheat.

Test specimens can be cast to determine *B* for a given mould material, metal, and condition of casting. This value can then be used to compute the solidification times for other castings made under the same conditions. Since a riser and a casting are both within the same *mould* and fill with the same metal under the same conditions, Chvorinov's rule can be used to ensure that the casting will solidify before the riser. This is necessary if the liquid within the riser is to effectively feed the casting to compensate for solidification shrinkage.

Some factors affecting solidification process

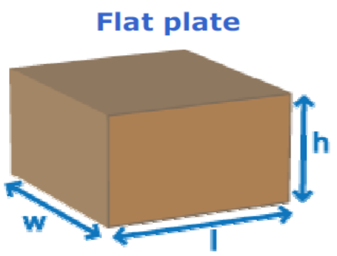
- Due to chilling action of mold wall, a thin skin of solid metal is formed at the interface immediately after pouring
- Skin thickness increases to form a shell around the molten metal as solidification progresses
- Rate of freezing depends on heat transfer into mold, as well as thermal properties of the metal



Cooling curve for a pure metal during casting

Problems on Solidification Time: Chvorinov's Rule.

1. In the casting of steel under certain mold conditions, the mold constant in Chvorinov's Rule is known to be **4.0 min/cm^2**, based on previous experience. The casting is a **flat plate** (fig. 1) whose length **l= 30 cm,** width **w= 10 cm,** and thickness **h= 20 mm.** Determine how long it will take for the casting to solidify.

	**Area** $A = 2(lh) + 2(lw) + 2(wh)$ **Volume** $V = l \times h \times w$

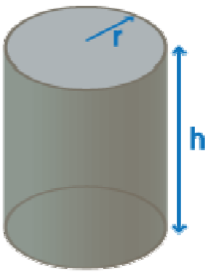
Solution:

Area A = 2(30 x 10) + 2(30 x 2) + 2(10 x 2) = 760 cm^2

Volume V = 30 x 10 x 2 = 600 cm^3

Chvorinov's Rule: $T_{TS} = C_m (V/A)^2$ = 4(600/760)^2 = **2.49 min**

2. A **cylindrical-shaped part** (fig. 2) is to be cast out of aluminum. The radius of the cylinder **r= 250 mm** and its thickness **h= 20 mm**. If the mold constant C_m **= 2.0 sec/mm^2** in Chvorinov's Rule, how long will it take the casting to solidify?

cylinder 	**Area** **A = 2πr^2 + 2πrh** **Volume** **V = πr^{2}h**

Solution:

Area $A = 2\pi r^2 + 2\pi r h = 2\pi (250)^2 + 2\pi (250)(20)$ = 424,115 mm^2

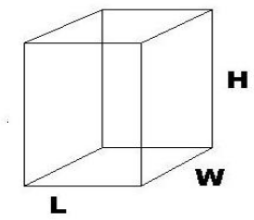
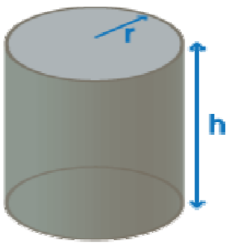
Volume $V = \pi r^2 h = \pi (250)^2 (20)$ = 3,926,991 mm^3

Chvorinov's Rule: $T_{TS} = C_m (V/A)^2$ = 2 (3,926,991 / 424,115)^2 = **171.5 s = 2.86 min**

3. In casting experiments performed using a certain alloy and type of sand mold, it took **155 sec for a cube-shaped casting to solidify**. The cube was **50 mm** on a side.

(a) Determine the value C_m of the **mold constant** in Chvorinov's Rule.

(b) If the same alloy and mold type were used, find the **total solidification time** T_{TS} for a cylindrical casting in which the diameter **r = 15 mm** and length **h = 50 mm**.

Cube (L=W=H) 	Area A = 2(lh) + 2(lw) + 2(wh) Volume V = l x h x w
	Surface Area = $2\pi r^2 + 2\pi rh$ Volume = $\pi r^2 h$

Solution:

(a) Area $A = 6 \times (50)^2 = 15{,}000\ mm^2$

Volume $V = (50)^3 = 125{,}000\ mm^3$

$(V/A) = 125{,}000 / 15{,}000 = 8.333$ mm

$\boldsymbol{C_m} = T_{TS} / (V/A)^2 = 155 / (8.333)^2 = \mathbf{2.232\ s/mm^2}$

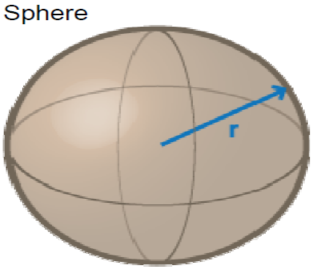
(b) Cylindrical casting with r = 15 mm and h = 50 mm.

Area $A = 2\pi r^2 + 2\pi rh = 2\pi\,(15)^2 + 2\pi(15)(50) = 6126\ mm^2$

Volume $V = \pi r^2\ h = \pi(15)^2\,(50) = 35{,}343\ mm^3$

$V/A = 35{,}343 / 6126 = 5.77$

$\boldsymbol{T_{TS}} = 2.232\,(5.77)^2 =$ **74.3 s = 1.24 min.**

Sphere 	Surface area = $4\pi r^2$ Volume = $4/3\pi r^3$

4 A molten drop of liquid metal which is in spherical form will solidify in 10 sec.

With 2 mm radius. What is the solidification time of same molten mass having double radius.

Solution:

Given: 1) t_{s1} = 10 sec. R_1 =-2mm

2) t_{s2} =? $R_2 = 2R_1$

AS drop shape is sphere $\frac{V}{AS} = \left[\frac{D}{6}\right] = \left[\frac{R}{3}\right]$

$ts\ \alpha \left(\frac{V}{AS}\right)^2$

$t_{s2} / t_{s1} = (R_2/3)^2 / (R_1/3)^2 = R_2^2 / R_1^2 = (2R_1)^2 / R_1^{\,2}$

$ts_2 = ts_1 \times 4 = 4 \times 10 = 40$ sec.

5. A cubical casting will solidify in 5min. what is solidification time of same molten drop which is 8 times heavier than original casting

Solution:

Given: 5min, t_{s2} =?

Shape is cubical (V/ As = a/6)

Molten drop = 8 original casting $m_2 = 8\ m_1$

$\rho_2 V_2 = 8\ \rho_1 V_1$

$V_2 = 8\ V_1$

$a_2^3 = 8\ a_1^3$

$a_2 = 2a_1$

$t_{s1}\ \alpha \left(\frac{V}{AS}\right)^2\ \alpha \left(\frac{a}{6}\right)^2$

$ts_2 / ts_1 = a_2^2 / a_1^2 = 4a_1^2 / a_1^2$

$t_{s2} = 4 \times t_{s1} = 4 \times 5 = 20$ min.

Classification of casting Processes

Casting processes can be classified into following FOUR categories:

1. Conventional Molding Processes
   a. Green Sand Molding
   b. Dry Sand Molding
   c. Flask less Molding
2. Chemical Sand Molding Processes
   a. Shell Molding
   b. Sodium Silicate Molding
   c. No-Bake Molding
3. Permanent Mold Processes
   a. Gravity Die casting
   b. Low and High Pressure Die Casting
4. Special Casting Processes
   a. Lost Wax
   b. Ceramics Shell Molding
   c. Evaporative Pattern Casting
   d. Vacuum Sealed Molding
   e. Centrifugal Casting

Sand Casting Process

Definition of Sand Casting: In sand casting which is also known as sand molded casting, an object is produced by sand mold. The process involves pouring of the molten metal in to the mold cavity. The molten metal is then cooled to the room temperature. The metal is solidified. After cooling, the metal object is separated from the mold.

Steps in making sand castings

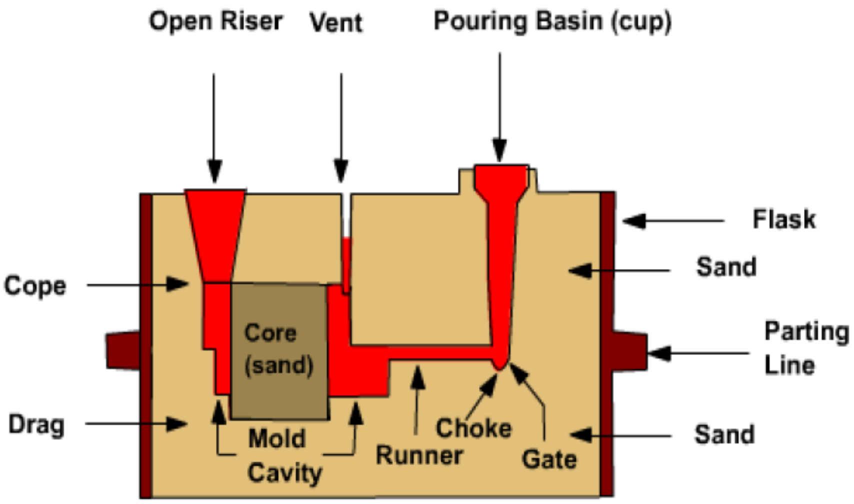
The six basic steps in making sand castings are,
(i) Pattern making, (ii) Core making, (iii) Moulding, (iv) Melting and pouring, (v) Cleaning

Pattern making

- Pattern: Replica of the part to be cast and is used to prepare the mould cavity. It is the physical model of the casting used to make the mould. Made of either wood or metal.

-The mould is made by packing some readily formed aggregate material, such as moulding sand, surrounding the pattern. When the pattern is withdrawn, its imprint provides the mould cavity. This cavity is filled with metal to become the casting.

- If the casting is to be hollow, additional patterns called 'cores', are used to form these cavities.



Core making
Cores are placed into a mould cavity to form the interior surfaces of castings. Thus the void space is filled with molten metal and eventually becomes the casting.

Moulding
Moulding is nothing but the mould preparation activities for receiving molten metal.
Moulding usually involves: (i) preparing the consolidated sand mould around a pattern held within a supporting metal frame, (ii) removing the pattern to leave the mould cavity with cores.

Mould cavity is the primary cavity.

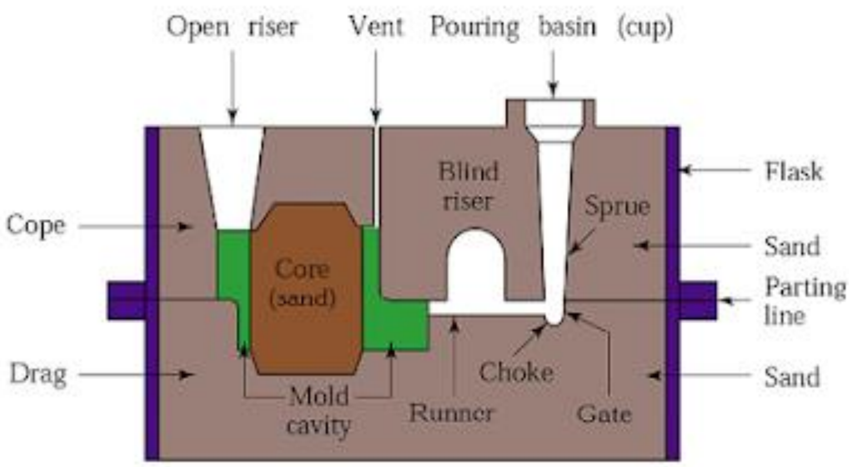
The mould cavity contains the liquid metal and it acts as a negative of the desired product.

The mould also contains secondary cavities for pouring and channeling the liquid material in to the primary cavity and will act a reservoir, if required.

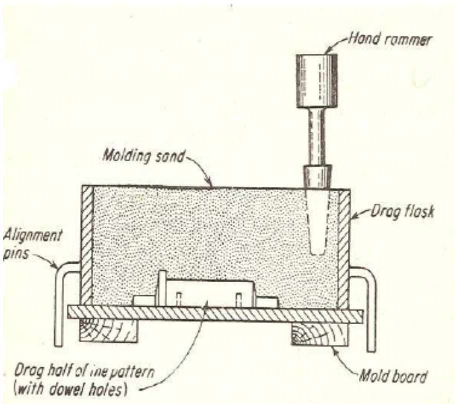
Melting and Pouring
The preparation of molten metal for casting is referred to simply as melting. The molten metal is transferred to the pouring area where the moulds are filled.

Cleaning
Cleaning involves 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.

Process:

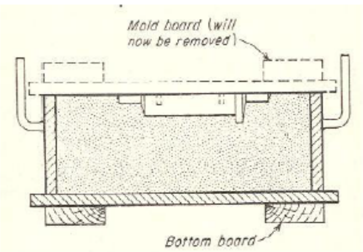


Making a simple sand mould



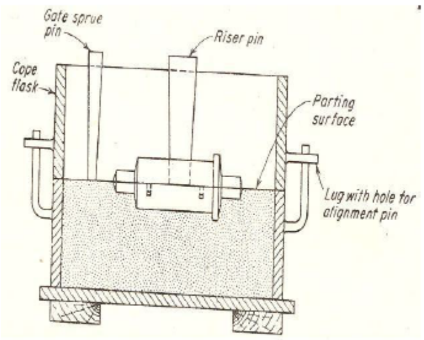
1) The drag flask is placed on the board
2) Dry facing sand is sprinkled over the board
3) Drag half of the pattern is located on the mould board. Dry facing sand will provide a non-sticky layer.
4) Molding sand is then poured in to cover the pattern with the fingers and then the drag is filled completely
5) Sand is then tightly packed in the drag by means of hand rammers. Peen hammers (used first close to drag pattern) and butt hammers (used for surface ramming) are used.

6) The ramming must be proper i.e. it must neither be too hard or soft. Too soft ramming will generate weak mould and imprint of the pattern will not be good. Too hard ramming will not allow gases/air to escape and hence bubbles are created in casting resulting in defects called 'blows'. Moreover, the making of runners and gates will be difficult.
7) After the ramming is finished, the excess sand is leveled/removed with a straight bar known as strike rod.



8) Vent holes are made in the drag to the full depth of the flask as well as to the pattern to facilitate the removal of gases during pouring and solidification. Done by vent rod.

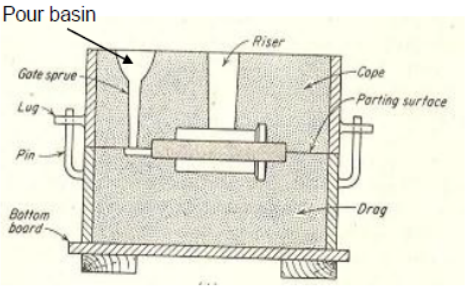
9) The finished drag flask is now made upside down exposing the pattern.



10) Cope half of the pattern is then placed on the drag pattern using locating pins. The cope flask is also located with the help of pins. The dry parting sand is sprinkled all over the drag surface and on the pattern.

11) A sprue pin for making the sprue passage is located at some distance from the pattern edge. Riser pin is placed at an appropriate place.

12) Filling, ramming and venting of the cope is done in the same manner.



13) The sprue and riser are removed and a pouring basin is made at the top to pour the liquid metal.
14) Pattern from the cope and drag is removed.
15) Runners and gates are made by cutting the parting surface with a gate cutter. A gate cutter is a piece of sheet metal bent to the desired radius.
16) The core for making a central hole is now placed into the mould cavity in the drag. Rests in core prints.
17) Mould is now assembled and ready for pouring.

Sand casting advantages and disadvantages

Advantages of Sand casting

- Large parts can be produced
- Complex shapes can be casted easily
- Large selection of metal to choose from
- Tooling and equipment cost is low compared to some other metal forming processes
- Scrap metal can be recycled
- Short lead compared to other similar processes

Disadvantages of Sand casting

- Low material strength
- Low dimensional accuracy
- Poor surface finish
- High porosity
- Secondary machining operation often required
- Processing cost is high compared to tooling and material cost

- Safety hazards to humans and environmental problems
- Removal of pattern of the thin and small parts is very difficult

CONCEPT OF 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.

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.

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

The usual pattern materials are wood, metal, and plastics. The most commonly used pattern material is wood, since it is readily available and of low weight. Also, it can be easily shaped and is relatively cheap. The main disadvantage of wood is its absorption of moisture, which can cause distortion and dimensional changes. Hence, proper seasoning and upkeep of wood is almost a pre-requisite for large-scale use of wood as a pattern material.

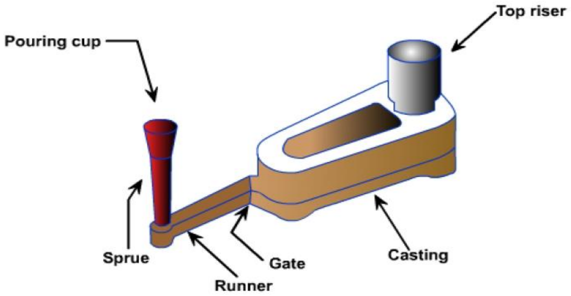


Figure 2: A typical pattern attached with gating and risering system

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

The explanation of the above 5 types of allowances is as follows…

1. Shrinkage Allowance:

During cooling of the material in the Casting process, in all the three stages, the material is getting shrinking (reducing its dimensions or volume). But, shrinkage allowance taking place in 1st two stages is called Liquid Shrinkage.

- Shrinkage in 3rd – the stage is called Solid shrinkage.
- Liquid shrinkages are always compensated by providing a riser in the casting process.
- Liquid shrinkages are always specified as “% by Volume”.
- Out of the different metals cast in the industry, “Aluminum(Al) ” is having the highest liquid shrinkage which is about 6%.
- Solid shrinkage is specified as (Percentage/Dimensions).
- Solid shrinkage is influenced by four factors.

2. Machining Allowance:

The extra dimension provided on the casting and it will be removed by machining after the casting has been completed is called Machining Allowance.

3. Draft Allowance:

Making the vertical surfaces of the pattern into inclined surfaces is called Draft Allowance.

4. Shake Allowance:

To maintain the required size of the casting, the original size of the pattern has to be reduced by an amount called Shake Allowance.

5. Distortion Allowance:

To get the vertical legs of U shaped[Distortion Allowance complete]. the original pattern has to be bend inverse so that during solidification, the legs are bending outwards and becoming vertical legs.

The amount by which the legs are bending Inverse is called as Distortion or Bending allowance. This is the complete explanation of all types of allowances in a detailed manner.

Shrinkage or Contraction 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.

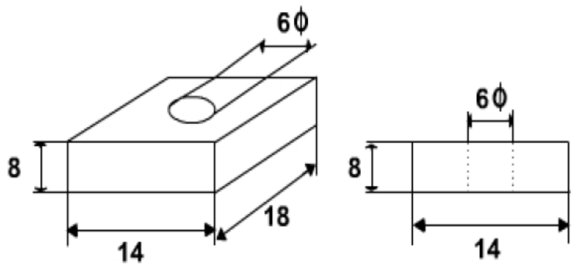
ii. **Solid Shrinkage:** it refers to the reduction in volume caused when metal loses temperature in solid state. To account for this, shrinkage allowance is provided on the patterns. The rate of contraction with temperature is dependent on the material. For example steel contracts to a higher degree compared to aluminum. To compensate the solid shrinkage, a shrink rule must be used in laying out the measurements for the pattern. A shrink rule for cast iron is 1/8 inch longer per foot than a standard rule. If a gear blank of 4 inch in diameter was planned to produce out of cast iron, the shrink rule in measuring it 4 inch would actually measure 4 1/ 24 inch, thus compensating for the shrinkage. The various rate of contraction of various materials are given

Table 1 : Rate of Contraction of Various Metals

Material	Dimension	Shrinkage allowance (inch/ft)
Grey Cast Iron	Up to 2 feet 2 feet to 4 feet over 4 feet	0.125 0.105 0.083
Cast Steel	Up to 2 feet 2 feet to 6 feet over 6 feet	0.251 0.191 0.155
Aluminum	Up to 4 feet 4 feet to 6 feet over 6 feet	0.155 0.143 0.125
Magnesium	Up to 4 feet Over 4 feet	0.173 0.155

Exercise 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. <u>All Dimensions are in Inches</u>



Solution 1

The shrinkage allowance for cast iron for size up to 2 feet is o.125 inch per feet (<u>as per Table 1</u>)

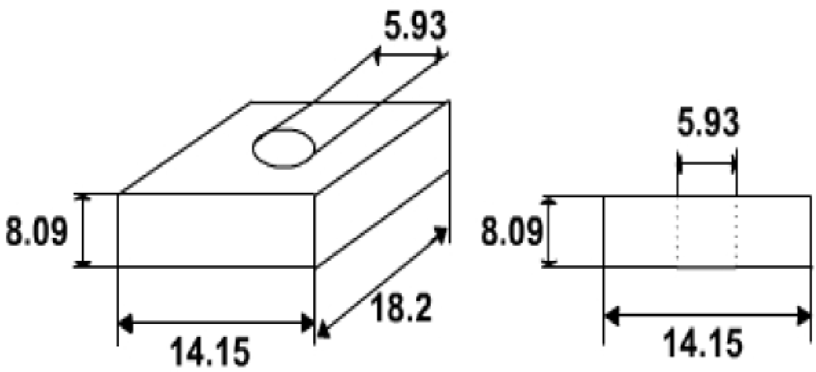
For dimension 18 inch, allowance = 18 *X* 0.125 / 12 = 0.1875 inch » 0.2 inch

For dimension 14 inch, allowance = 14 *X* 0.125 / 12 = 0.146 inch » 0.15 inch

For dimension 8 inch, allowance = 8 X 0.125 / 12 = 0.0833 inch » 0. 09 inch

For dimension 6 inch, allowance = 6 X 0.125 / 12 = 0.0625 inch » 0. 07 inch

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 3 (a) 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 3 (b) 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.

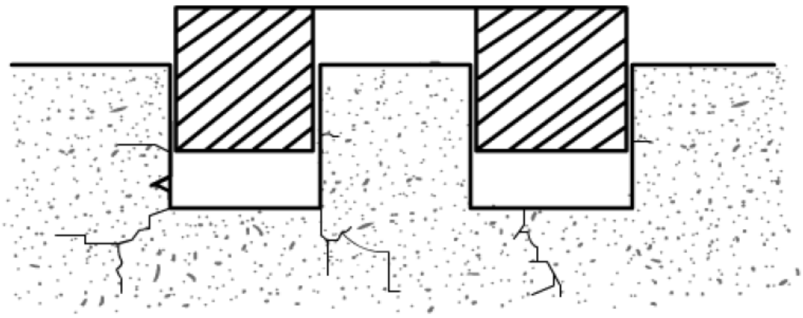


Figure 3 (a) Pattern Having No Draft on Vertical Edges

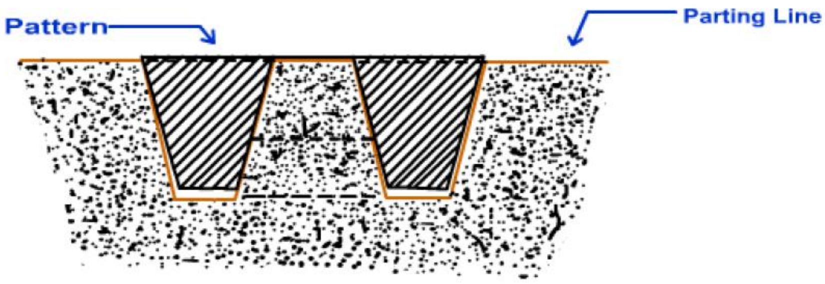


Figure 3 (b) Pattern Having Draft on Vertical Edges

Draft allowance varies with the complexity of the sand job. But in general inner details of the pattern require higher draft than outer surfaces. The amount of draft depends upon the length of the vertical side of the pattern to be extracted the intricacy of the pattern; The method of molding and pattern material. Table 2 provides a general guide lines for the draft allowance.

Table 2 : Draft Allowances of Various Metals

Pattern material	Height of the given surface (inch)	Draft angle (External surface)	Draft angle (Internal surface)
Wood	1 1 to 2 2 to 4 4 to 8 8 to 32	3.00 1.50 1.00 0.75 0.50	3.00 2.50 1.50 1.00 1.00
Metal and plastic	1 1 to 2 2 to 4 4 to 8 8 to 32	1.50 1.00 0.75 0.50 0.50	3.00 2.00 1.00 1.00 0.75

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. The machining allowances recommended for different metal is given in Table 3

Table 3 : Machining Allowances of Various Metals

Metal	Dimension (inch)	Allowance (inch)
Cast iron	Up to 12 12 to 20 20 to 40	0.12 0.20 0.25
Cast steel	Up to 6 6 to 20 20 to 40	0.12 0.25 0.30
Non ferrous	Up to 8 8 to 12 12 to 40	0.09 0.12 0.16

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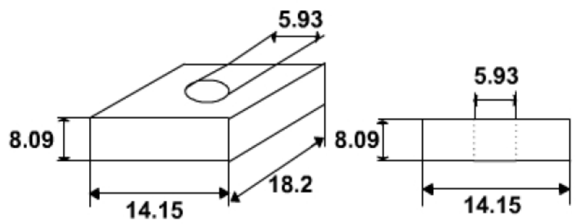
Exercise 2 The casting shown is to be made in cast iron using a wooden pattern. Assuming only machining allowance, calculate the dimension of the pattern. All Dimensions are in Inches



Solution 2

The machining allowance for cast iron for size, up to 12 inch is o.12 inch and from 12 inch to 20 inch is 0.20 inch ((Table 3)

For dimension 18 inch, allowance = 0.20 inch

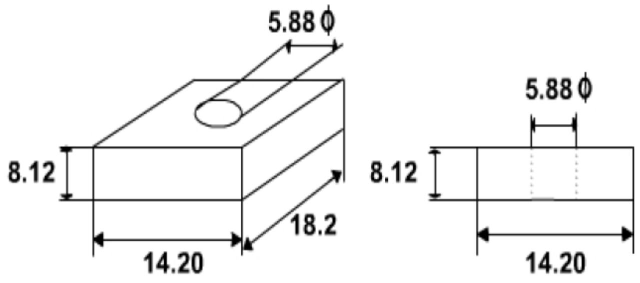
For dimension 14 inch, allowance = 0.20 inch

For dimension 8 inch, allowance = 0.12 inch

For dimension 6 inch, allowance = 0.12 inch

The pattern drawing with required dimension is shown in Figure below

The pattern drawing with required dimension is shown in Figure below



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 (Figure 4). 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)

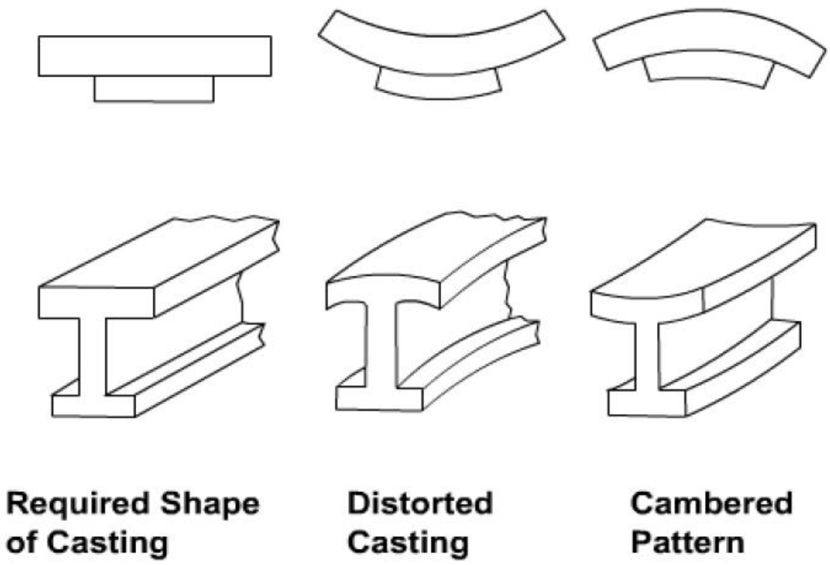


Figure 4: Distortions in Casting

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.

Core and Core Prints Castings are often required to have holes, recesses, etc. of various sizes and shapes. These impressions can be obtained by using cores. So where coring is required, provision should be made to support the core inside the mold cavity. Core prints are used to serve this purpose. The core print is an added projection on the pattern and it forms a seat in the mold on which the sand core rests during pouring of the mold. The core print must be of adequate size and shape so that it can support the weight of the core during the casting operation. Depending upon the requirement a core can be placed horizontal, vertical and can be hanged inside the mold cavity. A typical job, its pattern and the mold cavity with core and core print is shown in Figure 5

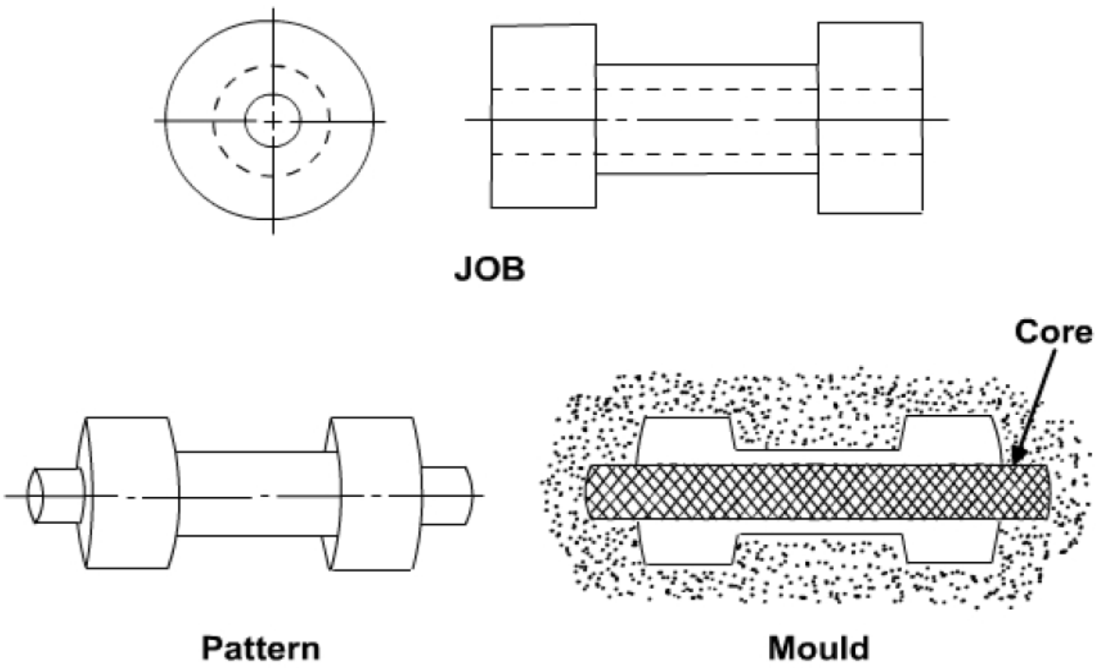
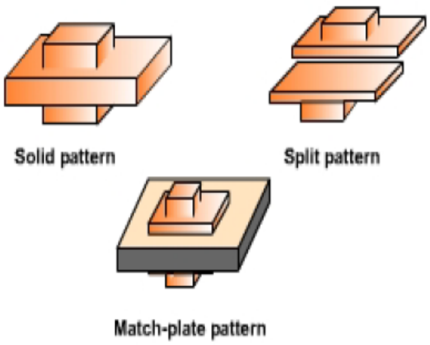


Figure 5: A Typical Job, its Pattern and the Mold Cavity

Types of Pattern

Patterns are of various types, each satisfying certain casting requirements.

1. Single piece pattern
2. Split or two piece pattern
3. Match plate pattern



Single Piece Pattern

The one piece or single pattern is the most inexpensive of all types of patterns. This type of pattern is used only in cases where the job is very simple and does not create any withdrawal problems. It is also used for application in very small-scale production or in prototype development. This type of pattern is expected to be entirely in the drag and one of the surface is is expected to be flat which is used as the parting plane. A gating system is made in the mold by cutting sand with the help of sand tools. If no such flat surface exists, the molding becomes complicated. A typical one-piece pattern is shown in Figure 6.

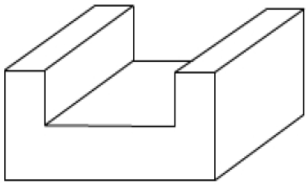


Figure 6: A Typical One Piece Pattern

Split or Two Piece Pattern Split or two piece pattern is most widely used type of pattern for intricate castings. It is split along the parting surface, the position of which is determined by the shape of the casting. One half of the pattern is molded in drag and the other half in cope. The two halves of the pattern must be aligned properly by making use of the dowel pins, which are fitted, to the cope half of the pattern. These dowel pins match with the precisely made holes in the drag half of the pattern. A typical split pattern of a cast iron wheel Figure 7 (a) is shown in Figure 7 (b).

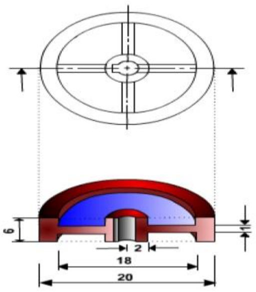


Figure 7 (a): The Details of a Cast Iron Wheel

Green Sand Molding

Green sand is the most diversified molding method used in metal casting operations. The process utilizes a mold made of compressed or compacted moist sand. The term "green" denotes the presence of moisture in the molding sand. The mold material consists of silica sand mixed with a suitable bonding agent (usually clay) and moisture.

Advantages

1. Most metals can be cast by this method.
2. Pattern costs and material costs are relatively low.
3. No Limitation with respect to size of casting and type of metal or alloy used

Disadvantages

Surface Finish of the castings obtained by this process is not good and machining is often required to achieve the finished product.

Molding Material and Properties

A large variety of molding materials is used in foundries for manufacturing molds and cores. They include molding sand, system sand or backing sand, facing sand, parting sand, and core sand. The choice of molding materials is based on their processing properties. The properties that are generally required in molding materials are:

Refractoriness

It is the ability of the molding material to resist the temperature of the liquid metal to be poured so that it does not get fused with the metal. The refractoriness of the silica sand is highest.

Permeability During pouring and subsequent solidification of a casting, a large amount of gases and steam is generated. These gases are those that have been absorbed by the metal during melting, air absorbed from the atmosphere and the steam generated by the molding and core sand. If these gases are not allowed to escape from the mold, they would be entrapped inside the casting and cause casting defects. To overcome this problem the molding material must be porous. Proper venting of the mold also helps in escaping the gases that are generated inside the mold cavity.

Green Strength The molding sand that contains moisture is termed as green sand. The green sand particles must have the ability to cling to each other to impart sufficient strength to the mold. The green sand must have enough strength so that the constructed mold retains its shape.

Dry Strength When the molten metal is poured in the mold, the sand around the mold cavity is quickly converted into dry sand as the moisture in the sand evaporates due to the heat of the molten metal. At this stage the molding sand must posses the sufficient strength to retain the exact shape of the mold cavity and at the same time it must be able to withstand the metallostatic pressure of the liquid material.

Hot Strength As soon as the moisture is eliminated, the sand would reach at a high temperature when the metal in the mold is still in liquid state. The strength of the sand that is required to hold the shape of the cavity is called hot strength.

Collapsibility The molding sand should also have collapsibility so that during the contraction of the solidified casting it does not provide any resistance, which may result in cracks in the castings. Besides these specific properties the molding material should be cheap, reusable and should have good thermal conductivity.

Molding Sand Composition The main ingredients of any molding sand are:

Base sand,

Binder, and

Moisture

Binder Binders are of many types such as:

1. Clay binders,
2. Organic binders and
3. Inorganic binders

Clay binders are most commonly used binding agents mixed with the molding sands to provide the strength.

The most popular clay types are: Kaolinite or fire clay (Al_2O_3 2 SiO_2 2 H_2O) and Bentonite (Al_2O_3 4 SiO_2 nH_2O) of the two the Bentonite can absorb more water which increases its bonding power.

Moisture

Clay acquires its bonding action only in the presence of the required amount of moisture. When water is added to clay, it penetrates the mixture and forms a microfilm, which coats the surface of each flake of the clay. The amount of water used should be properly controlled. This is because a part of the water, which coats the surface of the clay flakes, helps in bonding, while the remainder helps in improving the plasticity.

Dry Sand Molding

When it is desired that the gas forming materials are lowered in the molds, air-dried molds are sometimes preferred to green sand molds. Two types of drying of molds are often required.

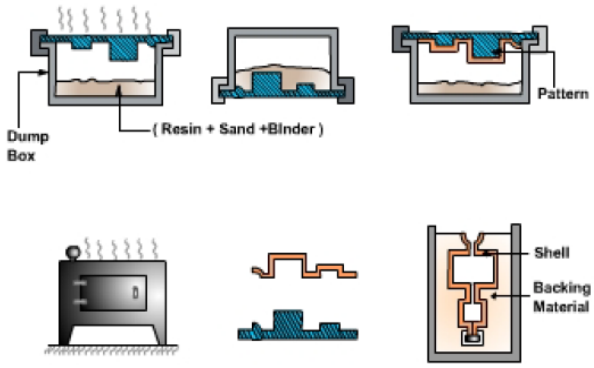
1. Skin drying and
2. Complete mold drying.

In skin drying a firm mold face is produced. Shakeout of the mold is almost as good as that obtained with green sand molding. The most common method of drying the refractory mold coating uses hot air, gas or oil flame. Skin drying of the mold can be accomplished with the aid of torches, directed at the mold surface.

Shell Molding Process

It is a process in which, the sand mixed with a thermosetting resin is allowed to come in contact with a heated pattern plate (200 ^{O}C), this causes a skin (Shell) of about 3.5 mm of sand/plastic mixture to adhere to the pattern.. Then the shell is removed from the pattern. The cope and drag shells are kept in a flask with necessary backup material and the molten metal is poured into the mold.

This process can produce complex parts with good surface finish 1.25 µm to 3.75 µm, and dimensional tolerance of 0.5 %. A good surface finish and good size tolerance reduce the need for machining. The process overall is quite cost effective due to reduced machining and cleanup costs. The materials that can be used with this process are cast irons, and aluminum and copper alloys.



Comparative Advantages, Disadvantages and Applications for Various Casting Methods:

Sand Casting		
Advantages	**Disadvantages**	**Recommended Application**
Least Expensive in small quantities (less than 100) Ferrous and non - ferrous metals may be cast Possible to cast very large parts. • Least expensive tooling	Dimensional accuracy inferior to other processes, requires larger tolerances Castings usually exceed calculated weight Surface finish of ferrous castings usually exceeds 125 RMS	Use when strength/weight ratio permits Tolerances, surface finish and low machining cost does not warrant a more expensive process
Permanent and Semi-permanent Mold Casting		
Less expensive than Investment or Die Castings Dimensional Tolerances closer than Sand Castings Castings are dense and pressure tight	Only non-ferrous metals may be cast by this process Less competitive with Sand Cast process when three or more sand cores are required Higher tooling cost than Sand Cast	Use when process recommended for parts subjected to hydrostatic pressure Ideal for parts having low profile, no cores and quantities in excess of 300
Plaster Cast		

Smooth "As Cast" finish (25 RMS) Closer dimensional tolerance than Sand Cast • Intricate shapes and fine details including thinner "As Cast" walls are possible • Large parts cost less to cast than by Investment process	More costly than Sand or Permanent Mold-Casting Limited number of sources Requires minimum of 1 deg. draft	Use when parts require smooth "As Cast" surface finish and closer tolerances than possible with Sand or Permanent Mold Processes
Investment Cast		
Close dimensional tolerance Complex shape, fine detail, intricate core sections and thin walls are possible Ferrous and non-ferrous metals may be cast As-Cast" finish (64 - 125 RMS)	Costs are higher than Sand, Permanent Mold or Plaster process Castings	Use when Complexity precludes use of Sand or Permanent Mold Castings The process cost is justified through savings in machining or brazing Weight savings justifies increased cost
Die Casting		
Good dimensional tolerances are possible Excellent part-part dimensional consistency Parts require a minimal post machining	Economical only in very large quantities due to high tool cost Not recommended for hydrostatic pressure applications For Castings where penetrant (die) or radiographic inspection are not required. Difficult to guarantee minimum mechanical properties	Use when quantity of parts justifies the high tooling cost Parts are not structural and are subjected to hydrostatic pressure