LECTURE NOTES

Module-I

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5th Semester

PC 11: Basic Manufacturing Processes

MODULE - I (10 LECTURES)

Foundry: Types of patterns, pattern materials and pattern allowances. Moulding Materials - sand moulding, metal moulding, investment moulding, shell moulding. Composition of molding sand, Silica sand, Zircon sand, binders, additives, Binders - clay, binders for CO2, sand, binder for shell moulding, binders for core sand. Properties of moulding sand and sand testing, Melting furnaces - cupola, resistance furnace, induction and arc furnace, Solidification of castings, design of risers and runners, feeding distance, centre line freezing resistance chills and chaplets. Degasification and inoculation of metals. Casting methods like continuous casting, centrifugal casting, disc casting. Casting defects.

MODULE – II (8 LECTURES)

Welding and cutting: Introduction to gas welding, cutting, Arc welding and equipment's. TIG (GTAW) and MIG (GMAW) welding, resistance welding and thermit welding. Weldablity Modern Welding methods like plasma Arc, Laser Beam, Electron Beam, Ultrasonic, Explosive and friction welding, edge preparation in butt welding. Brazing and soldering, welding defects. Destructive and non-destructive testing of castings and welding.

MODULE – III (08 LECTURES)

Brief introduction to powder metallurgy processes. Plastic deformation of metals: Variables in metal forming and their optimization. Dependence of stress strain diagram on Strain rate and temperature. Hot and cold working of metals, classification of metal forming processes.

Rolling: Pressure and Forces in rolling, types of rolling mills, Rolling defects. Forging: Smith Forging, Drop and Press forging, M/c forging, Forging defects.

MODULE – IV (08 LECTURES)

Extrusions: Direct, Indirect, Impact and Hydrostatic extrusion and their applications, Extrusion of tubes. Wire drawing methods and variables in wire-drawing, Optimum dies shape for extrusion and drawing. Brief introduction to sheet metal working: Bending, Forming and Deep drawing, shearing. Brief introduction to explosive forming, coating and deposition methods.

BOOKS

[1] Manufacturing technology by P.N.Rao, Tata McGraw Hill publication.
[2] Welding Technology by R.A. Little, TMH
[3] Manufacturing Science by A.Ghosh and A K Malick, EWP
[4] Fundamentals of metal casting technology by P.C. Mukherjee, Oxford PIBI.
[5] Mechanical Metallurgy by Dieter, Mc-Graw Hill
[6] Processes and Materials of Manufacture by R.A Lindberg, Prentice hall (India)
[7] A Text Book of Production Engineering by P.C.Sharma, S.Chand.

Digital Learning Resources:

NPTEL MOOCs:

Course Name: Fundamentals of Manufacturing Processes

Course Link: https://nptel.ac.in/courses/108/102/108102047/

Module - I

Foundry

Module: I (Foundry)

There are four basic manufacturing processes for producing desired shape of a product. These are **Casting**, **Forming** (Metal deformation), **Joining** (Welding, Brazing, SolderingFastening, etc.) and **Metal removal** (Machining) processes.

- Casting process exploit the fluidity of a metal in liquid state as it takes shape and solidifies in a mould. It's the primary manufacturing process.
- Deformation processes exploit a remarkable property of metals, which is their ability to flow plastically in the solid state without deterioration of their properties. With the application of suitable pressures, the material is moved to obtain the desired shape with almost no wastage. The required pressures are generally high and the tools and equipment needed are quite expensive. Large production quantities are often necessary to justify the process.
- Joining processes permit complex shapes to be constructed from simpler components and have a wide domain of applications.
- Machining processes provide desired shape with good accuracy and precision but tend to waste material in the generation of removed portions.

Metal Casting Process:

Casting is one of the oldest manufacturing process. It is the first step in making most of the products for which it's called basic manufacturing process.

Steps to be followed for a casting operation:

a) Making mould cavity
b) Liquefy or melt the material by properly heating it in a suitable furnace.
c) Liquid or molten metal is poured into a prepared mould cavity
d) Allowed to solidify
e) Product is taken out of the mould cavity, trimmed and made to shape.

More attention should be given on the following for successfulcasting operation:

(i) Preparation of moulds of patterns

(ii) Melting and pouring of the liquefied metal

(iii) Solidification and further cooling to room temperature

(iv) Defects and inspection

Advantages of casting process:

- 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.
- Possible to cast both ferrous and non-ferrous materials
- Tools are very simple and expensive
- Useful for small lot production
- Weight reduction in design
- No directional property

There are certain parts (like turbine blades) made from metals and alloys that can only be processed this way. Turbine blades: Fully casting + last machining.

Limitations casting process:

- Accuracy and surface finish are not very good for final application.
- Difficult to remove defects due to presence of moisture.
- Metal casting is a labour intensive process.
- Automation

Application casting process:

Cylindrical bocks, wheels, housings, pipes, bells, pistons, piston rings,machine tool beds etc.

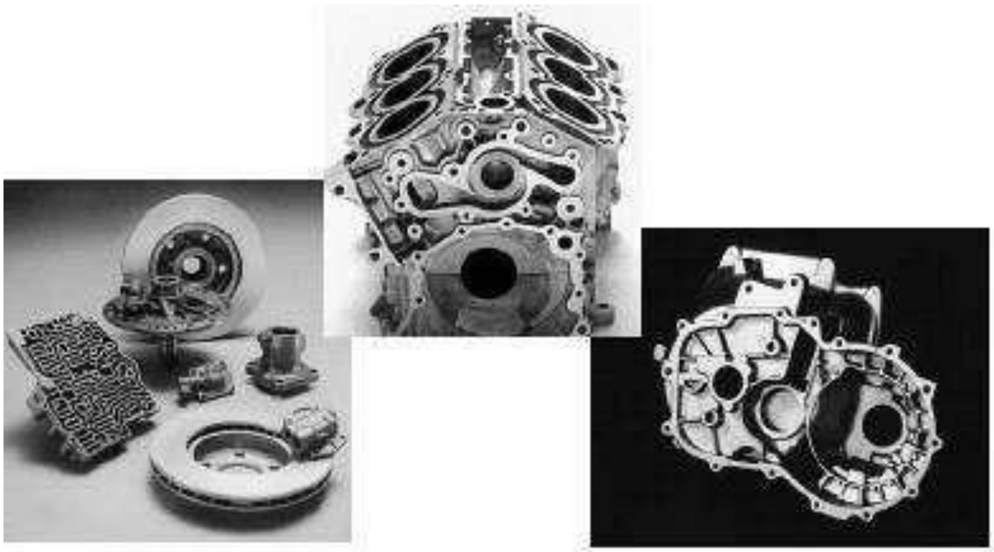


Fig: Typical sand mould

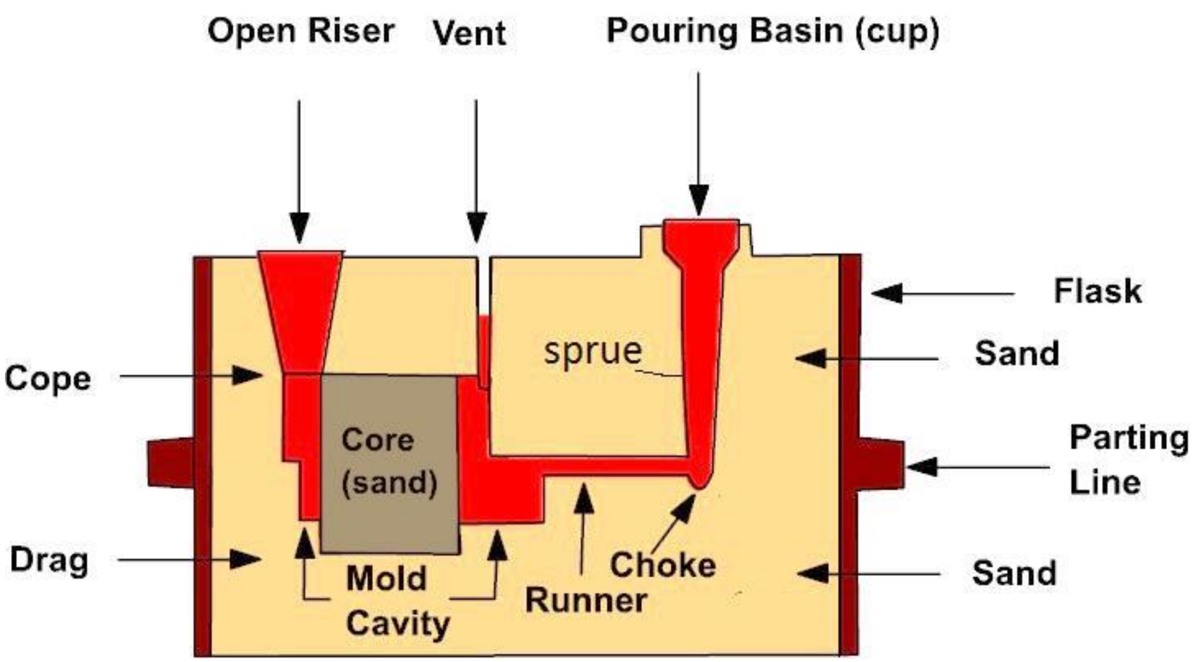


Fig:

Fig: Mould Section and casting nomenclature

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:

Drag: lower moulding flask,cope – upper moulding flask,

Cheek: intermediate moulding flask used in three piece moulding.

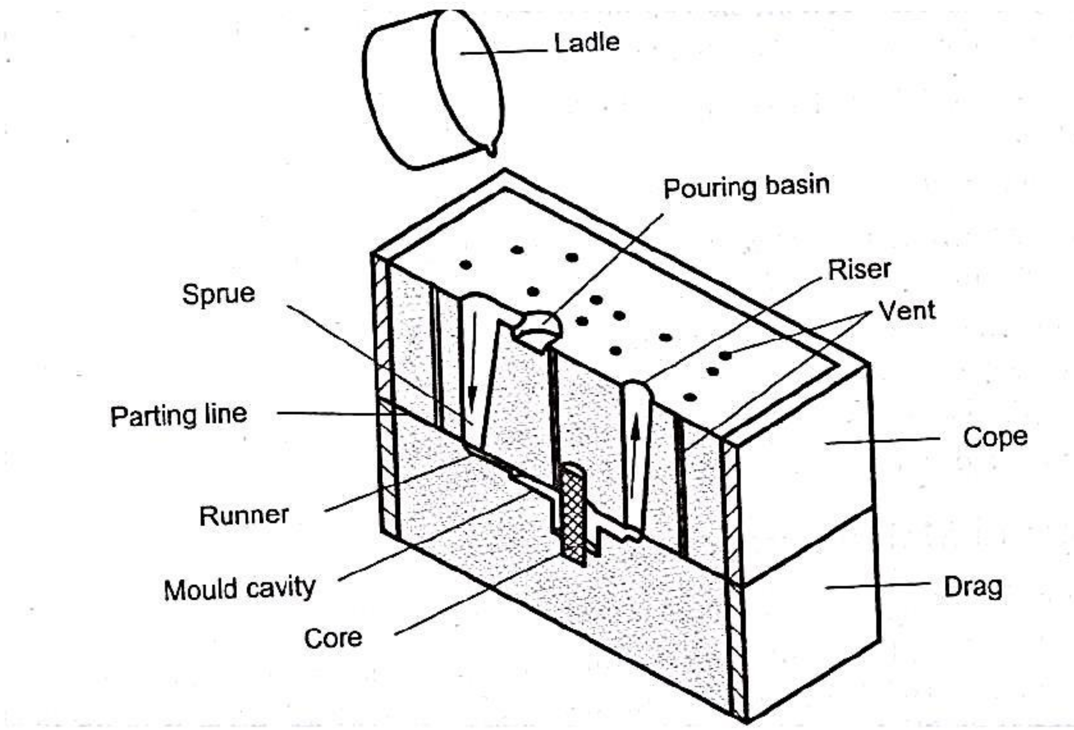


Fig: **Sand mould ready for pouring**

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

Parting line: This is the dividing line between the two moulding flasks thatmakes 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.

Bottom board: Board used to start mould making (wood)

Backing sand: used and burnt sand

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.

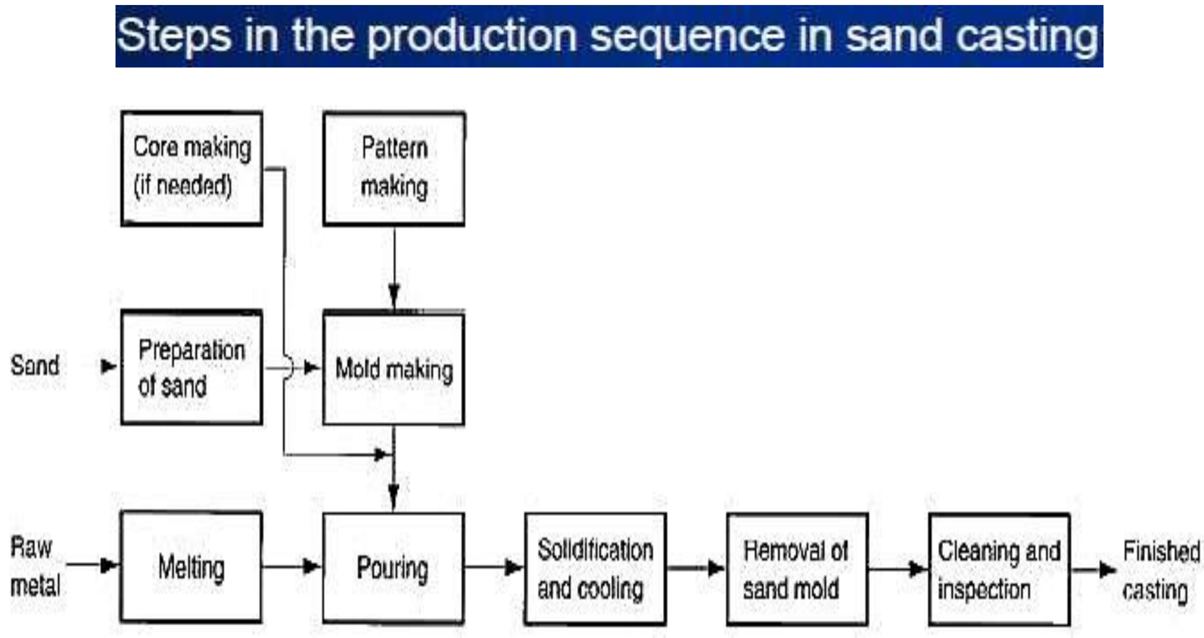
Riser: A column of molten metal placed in the mould to feed the castings as it shrinks and solidifies. Also known as "feed head".

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

Steps in making sand castings:

The basic steps in making sand castings are-

(i) Pattern making,
(ii) Core making,
(iii) Moulding,
(iv) Melting and pouring and
(v) Cleaning



Pattern making: Pattern is the replica of the part to be cast and is used toprepare 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.

Pattern Materials: In general materials – wood, metals & plastics

Wood:

Adv:- Easy availability, Low weight, Easily shaped, Cheap, Care to betaken

Disadv:- Moisture absorption, Distortion, Dimensional change, seasoning Example – Pine, Teak, Deodar

Others – plywood boards and particle boardsReason – Availability in various thicknesses Higher strength

No need for seasoning

- Use – Used for flat type and no three dimensional contour shapesLarge scale casting
- Choice of pattern materials depends on
- Size of casting
- No. of castings to be made from pattern
- Dimensional accuracy required
- A pattern is always made larger than the final part to be made. The excess dimension is known as **Pattern allowance**.

Pattern allowance => shrinkage allowance, machining allowance

- **Shrinkage allowance:** It will take care of contractions of a castingwhich occurs as the metal cools to room temperature.
- **Liquid Shrinkage:** Reduction in volume when the metal changes from liquid state to solid state. Riser which feed the liquid metal to the casting is provided in the mould to compensate for this.
- **Solid Shrinkage:** Reduction in volume caused when metal looses temperature in solid state. Shrinkage allowance is provided on the patterns to account for this. Shrink rule is used to compensate solid shrinkage depending on the material contraction rate.
- Cast iron: One foot (=12 inches) on the **1/8-in-per-foot shrink rule**
- actually measures 12-1/8 inches.
- So, **4 inch** will be **4-1/24 inch** for considering shrinkage allowance.
- **Shrink rule for other materials**

Shrink rule for other materials

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

The shrinkage allowance depends on the coefficient of thermal expansion of the material (**α**). A simple relation indicates that higher the value of ***α***, more is the shrinkage allowance.

For a dimension '*l*', shrinkage allowance is αl ($\theta f - \theta 0$). Here θf is the freezing temperature and $\theta 0$ is the room temperature.

Machining allowance: It will take care of the extra material that will be removed to obtain a finished product. In this the rough surface in the cast product will be removed. The machining allowance depends on the size of the casting, material properties, material distortion, finishing accuracy and machining method.

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

Draft:

Vertical faces of the pattern are to be made tapered to reduce the chances of damage to the mould cavity. It varies with the complexity of the job. Inner details require more allowance than outer. This allowance is more for hand moulding than machine moulding.

Typical Draft Allowances:

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

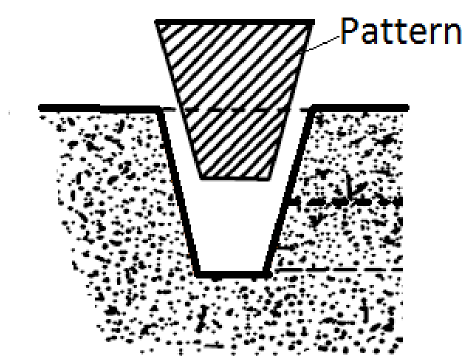


Fig: Pattern having draft allowance on vertical surfaces

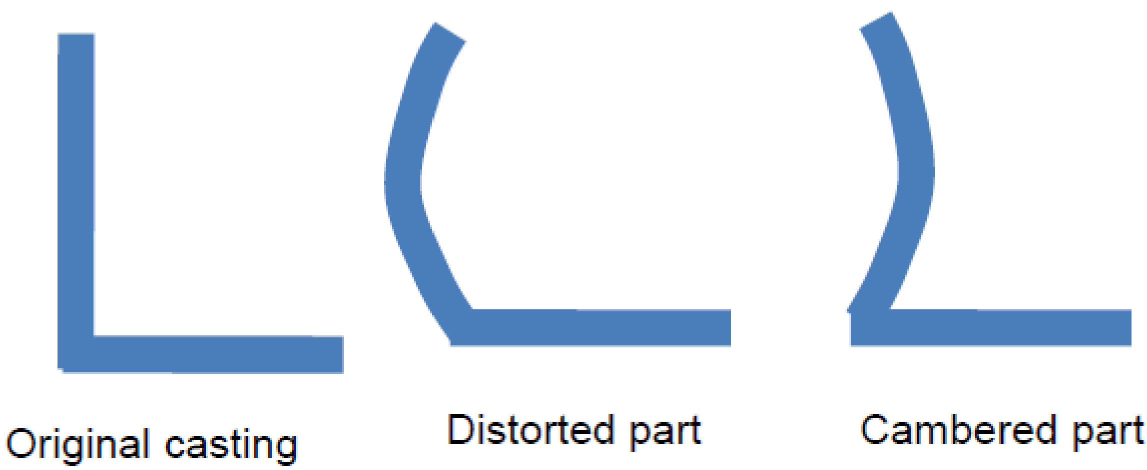
Shake allowance –

This is a negative allowance. Applied to those dimensions which areparallel to parting plane.

Distortion allowance –

Metals just solidified are very weak, which may be distorted. This allowanceis given to the weaker sections like long flat portion, U & V sections, complicated casing, thin & long sections connected to thick sections.

The distortion in casting may occur due to internal stresses. These internal stresses are caused on account of unequal cooling of different sections of the casting and hindered contraction.



TYPES OF PATTERNS:-

Various types of patterns depends on - Complexity of the job

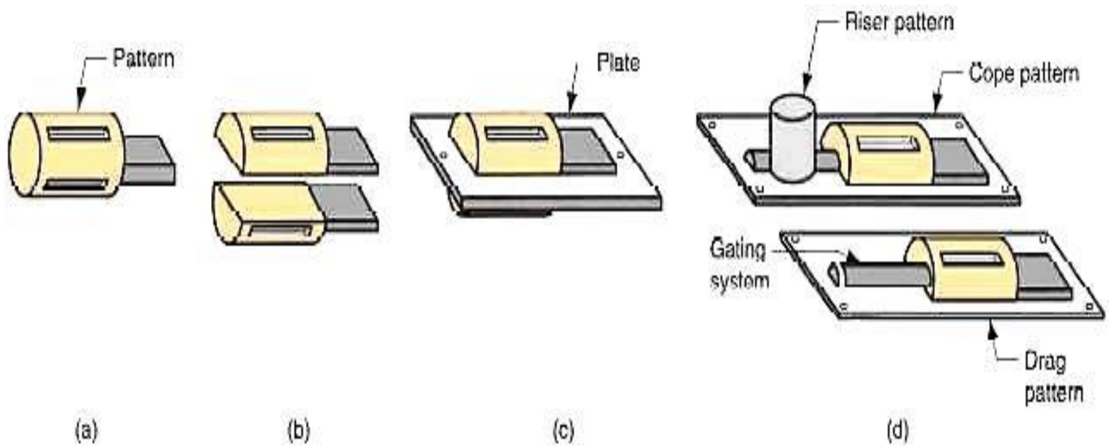
- No of castings required
- Moulding procedure adopted

(a) ***Single piece or solid pattern –*** Inexpensive and simplest oneSingle piece

Simple job

Useful for Small scale productionPattern will be entirely in the drag

One surface is flat and at the parting lineUsed for very small scale production



(b) ***Split or two piece pattern –*** Used for intricate castingSplit along the parting line Used where depth of job is too high Aligned with dowel pins fitted to cope

(c) ***Gated pattern –*** Gating and runner system are integrated with thepattern Improves productivity

(d) ***Cope and drag pattern -*** Similar to split pattern

For cope and drag, separately attached gating system to metal plateHeavy and inconvenient for handling

Useful for Continuous production

(e) ***Match plate pattern –*** Similar to cope and drag patterns with gatingand risering system mounted on a single matching plate

Pattern and match plate are made up of metal (Al) Useful for small casting with high dimensional accuracySuitable for large scale production

Gating system is attached to the match plateExpensive

(f) ***Loose piece pattern –*** Withdrawing of the pattern from the mould is difficult,Useful for highly skilled job, Expensive

(g) ***Follow board pattern –*** Used for structurally weak portionsBottom board is modified as follow board

(h) ***Sweep pattern –*** Useful for axi-symmetrical and prismatic shapeSuitable for large scale production

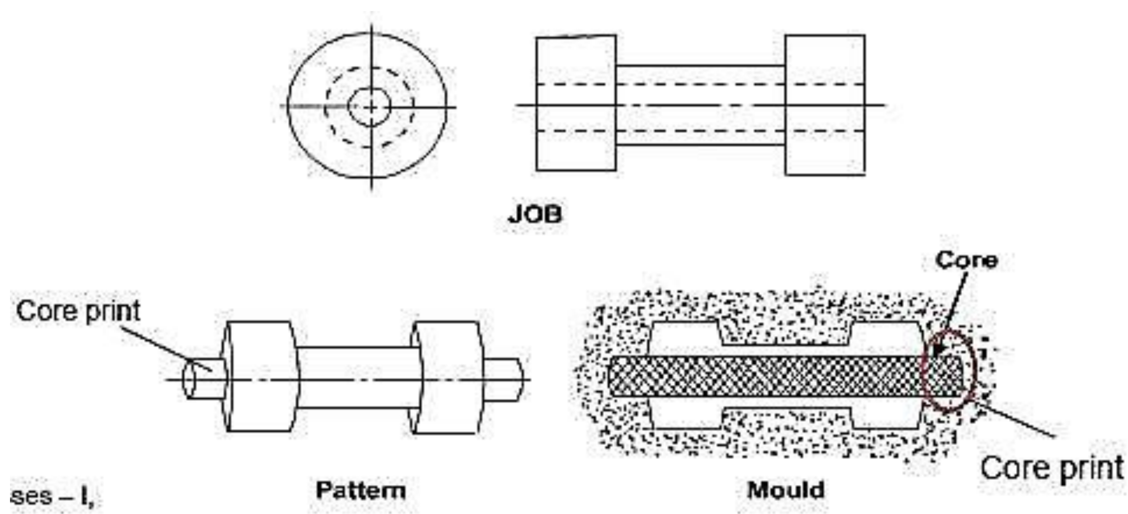
(i) ***Skeleton pattern –*** Stripes of wood are used for building final patternSuitable for large casting

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.

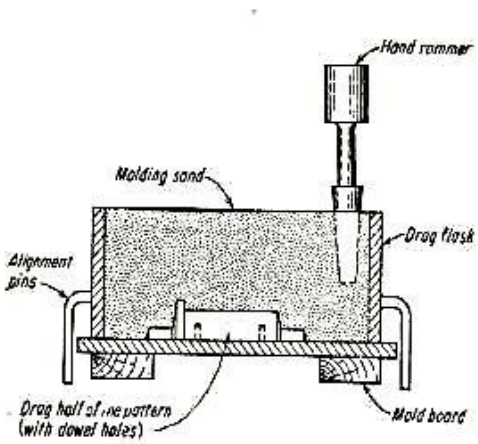
Core and core print: - Cores are used to make holes, recesses etc. incastings

- So where coring is required, provision should be made to support the coreinside the mould 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 mould on which the sand core rests during pouring of the mould.

- The core print must be of adequate size and shape so that it cansupport the weight of the core during the casting operation.

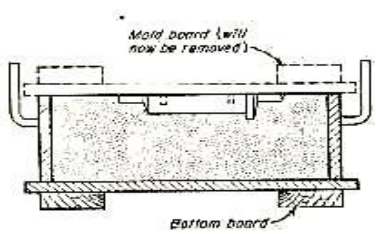


Making a simple sand mould



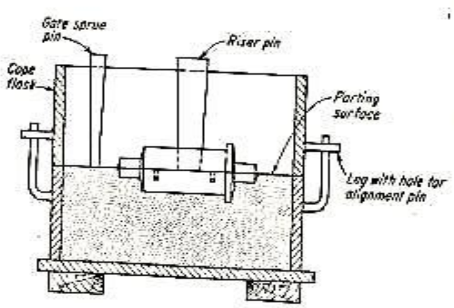
1) The drag flask is placed on the board
2) Dry facing sand is sprinkled over the board
3) Drag half of the pattern is located on the mould board. Dry facing sand will provide a non-sticky layer.
4) Molding sand is then poured in to cover the pattern with the fingers and then the drag is filled completely
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.

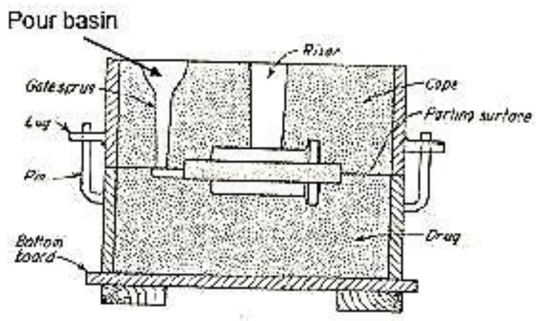
9) The finished drag flask is now made upside down exposing the pattern.



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.

MOULDING MATERIALS:

Different types of moulding materials are

-moulding sand

-system sand (backing sand)

-rebonded sand

-facing sand

-parting sand

-core sand

Choice of moulding materials depends on processing properties.Properties:

1) Refractoriness- Ability to withstand high temperature of molten metal sothat it does not cause fusion

Refractory materials - silica, zirconia, alumina

2) Green strength- Moulding sand containing moisture is known as greensand. The strength of the green sand is known as green strength.

3) Dry strength- When moisture is completely expelled from the moulding sand, it is known as dry sand and the strength of the sand is the dry strength.

4) Hot strength- After moisture elimination, the sand is exposed to higher temperature of molten material. Strength of sand to hold the shape ofmould cavity at this higher temperature is known as hot strength.

5) Permeability – Moulding sand is porous, so it escapes gases through it.This gas evolution capability of moulding sand is known as permeability. Other properties include collapsibility, reusable, good thermal conductivityetc.

MOULDING SAND COMPOSITION:

Main ingredients of moulding sand are silica grain (SiO2), Clay (binder) andmoisture (to activate clay and provide plasticity)

(a) **Silica sand**- this is the major portion of the moulding sand. About 96% of this sand is silica grain. Rests are oxides (Al2O3), sodium (Na2O +K2O) and magnesium oxide (MgO +CaO). Main source of silica sand is riversand (with /without washing). Fusion point of sand is 14500C for cast iron and 15500C for steels. Grain size varies from micrometer to millimetre. The shape of the grains may be round, angular, sub angular or very angular.

(b) **Zircon sand**- The main composition is zirconium silicate (ZrSiO2).Composition- ZrO2- 66.25%, SiO2-30.96%, Al2O3-1.92%, Fe2O3-0.74% and Other - oxides

It is very expensive. In India, it is available at quilon beach, kerela. The fusion point of the sand is 2400^0C.

Advantage - High thermal conductivity

High chilling powerHigh density

Requires very small amount of binder (3%)Use - Precision steel casting

Precision investment casting

(c) **Chromite sand** – The sand is crushed from the chrome ore. The fusionpoint of the sand is 18000C. It requires very small amount of binder (3%). Composition-

Cr_2O_3- 44%

Fe_2O_3 -28%

SiO_2 -2.5%

CaO -0.5%

Al_2O_3 +MgO -25%

Use – heavy steel castings Austenitic manganese steel castings.

(d) **Olivine sand**- This sand composed of the minerals of fosterite(Mg_2SiO_4) and fayalite (Fe_2SiO_4). It is versatile in nature.

CLAY :

Clay is a binding agent mixed to the moulding sand to provide strength. Popular types of clay used are kaolinite or fire clay ($Al_2O_3.2\ SiO_2.2H_2O$) and Bentonite ($Al_2O_3.4\ SiO_2.H_2O\ nH_2O$). Kaolinite has a melting point from 1750 to 17870C where as Bentonite has a melting temperature range of 1250 to 13000C. Bentonite clay absorbs more water and has increased bonding power. To reduce refractoriness, extra mixtures like lime, alkalis and other oxides are added.

Bentonite is further of two types. (a) ***Western bentonite*** and (b) ***southern bentonite***

Western bentonite – It is rich with sodium ion It has better swelling properties. When it mixes with sand, the volume increases 10 to 20 times.High dry strength, so lower risk of erosion.

Better tolerance of variation in water contentLow green strength

High resistance to burn out

Southern Bentonite - It is rich with calcium ion It has low dry strength and high green strength

Its properties can be improved by treating it with soda ash (sodiumcarbonate)
Water:- Used to activate the clay Generally 2 to 8% of water is required
Other materials added:- Cereal binder – (2%) – to increase the strengthPitch (by product of coke) – (3%) – to improve hot strength

Saw dust (2%) – To increase permeability

Testing sand properties:-

Sample preparation can be done by mixing various ingredients like sand, clay and moisture.

During mixing, the lump present in sand should be broken up properly. The clay should be uniformly enveloped and the moisture should be uniformly distributed.
The equipment used for preparation of moulding sand is known as Mueller. This is of two types.

Batch Mueller- Consists of one/two wheels and equal no. of blades connected to a single driving source. The wheels are large and heavy.

(i) Continuous Mueller- In this type, there are two bowls with wheel and ploughs. The mixture is fed through hopper in one bowl. After muelled, it is moved to another bowl. This type of Mueller is suitable for large scale production.

Moisture content:-

1st method - 50g of moulding sand sample is dried at 1050C to 1100C for2hrs. The sample is then weighed.

Wt. diff * 2= % of moisture content

2nd method - Moisture teller can be used for measuring moisture content. The Sand is dried suspending sample on fine metallic screen allowing hotair to flow through sample. This method takes less time in comparison tothe previous one.

3rd method - A measured amount of calcium carbide along with moulding sand in a separate cap is kept in the moisture teller. Both should not come in contact with each other. Apparatus should be shaken vigorously such that the following reaction takes place.

CaC2 + 2H2O – C2H2 + Ca(OH)2

The acetylene coming out will be collected in space above the sand raising the pressure. A pressure gauge connected to the apparatus would give directly the amount of acetylene generated, which is proportional to the moisture present.

Clay content:-

A 50g of sand sample is dried at 1050C to 1100C and is taken in a 1lt.glass flask. 475ml distilled water and 25ml of a 1% solution of caustic soda (NaOH 25g/l) is added to it. The sample is thoroughly stirred (5 mins). The sample is then diluted with fresh water upto 150 mm mark and then left undisturbed for 10mins to settle. The sand settles at bottom and the clay floats. 125mm of this water is siphoned off and again topped to the same level. The process is repeated till water above the sand becomes clear. Then the sand is removed and dried by heating. The difference in weight multiplied by 2 will give the clay % of sand.

Sand grain size:-

For sand grain size measurement, the moulding sand sample should be free from moisture and clay. The dried clay free sand grains are place on the top sieve of sieve shaker (gradually decreasing mesh size). The sieves are shaken continuously for 15 mins. After this the sieves are taken apart and the sand over each sieve is weighed. The amount retained on each sieve is multiplied by the respective weightage factor, summed up and then divided by the total mass f the sample which gives the grain finenessnumber.

GFN= $\Sigma M_i f_i / \Sigma f_i$

M_i= multiplying factor for the ith sieve

F_i= amount of sand retained on the ith sieve

Permeability:-

Rate of flow of air passing through a standard specimen under a standard pressure is known as permeability number.

$P = V H / p A T$

V= volume of air= 2000cm3

H= height of sand specimen= 5.08cmP= air pressure, 980Pa (10g/cm2)

A= cross sectional area of sand specimen= 20.268 cm2T= time in min. for the complete air to pass through

Inserting the above standard values in the expression we get, P= 501.28/P.T

Permeability test is conducted for two types of sands.

(a) Green permeability – permeability of green sand

(b) Dry permeability – permeability of the moulding sand dried at 1050C to1100C to remove the moisture completely.

Strength:-

Measurement of strength of moulding sand is carried out on the universal sand-strength testing M/C. The strength can be measured in compression, shear & tension. The types of sand that can be tested are green, dry, core sands.

Green compressive strength:-

Stress required to rupture the sand specimen under compressive loading refers to the green compressive strength. It is generally in the range of 30to 160KPa.

Green shear strength:-

The stress required to shear the specimen along the axis is represented as green shear strength. The range is 10 to 50 KPa.

Dry strength:-

The test is carried out with a standard specimen dried between 105 to 110°C for 2 hours. The range found is from 140 to 1800KPa.

Mould hardness:-

A spring loaded steel ball (0.9kg) is indented into standard sand specimen prepared. If no penetration occurs, then the hardness will be 100. And when it sinks completely, the hardness will be 0 indicating a very soft mould.

Moulding sand properties:-

The properties of moulding sand depends upon the variables like –

- sand grain shape and size
- Clay types and amount
- moisture content
- method of preparing sand mould

Sand grains:-

The grain shape could be round or angular. Angular sand grains require high amount of binder, where as round sand grains have low permeability.

Similarly the grain size could be of coarse or fine. Coarse grains have morevoid space which increases the permeability. Fine grains have low permeability, but provide better surface finish to the casting produced. The higher the grain size of the sand, higher will be the refractoriness.

Clay and water:-

Optimum amount water is used for a clay content to obtain maximum green strength. During sand preparation, clay is uniformly coated around sand grains. Water reacts with the clay to form a linkage of silica - water — clay- water- silica throughout the moulding sand. Amount of water required depends on the type and amount of clay present. Additional water increases the plasticity and dry strength, but decreases the green strength. There is a maximum limit of green compression strength. This type of sand is known as clay saturated sand and used for cast iron and heavy non ferrous metal casting. This type of sand reduces some of the casting defects like erosion, sand expansion, cuts & washes. These sands have green compression strength in a range of 100 to 250 KPa.

CORES:-

Cores are used for making cavities and hollow portions. These are madeup of sand and are used in permanent moulds. Core are surrounded by molten metal and therefore subjected to thermal and mechanical conditions. So the core should be stronger than the moulding sand. Desired characteristics of a core:-

1. Dry strength- It should be able to resist the metal pressure acting on it.
2. Green strength- It should be strong enough to retain its shape.
3. Refractoriness- Core material should have higher refractoriness.
4. Permeability- Core materials should have high permeability.

5. Collapsibility- (ability to decrease in size). It is likely to provideresistance against shrinkage.
6. Friability- Ability to crumble
7. Smoothness- good finish to the casting
8. Low gas emission- minimum

Core sand:-

The core sand should contain grains, binders and additives.

Sand- The silica sand without clay is used as a core sand material. Coarse silica is used in steel foundries where as fine silica is used for cast iron and non ferrous alloys.

Binders:- The normal binders used are organic in nature, because this will burnt away by the heat of molten metal and make the core collapsible during cooling. The binders generally used are linseed oil, core oil, resins, dextrin, molasses etc. Core oils are the mixture of linseed, soy, fish, petroleum oils and coal tar.

Types of cores:-

Two types:-

(a) Green sand core:- This is obtained by the pattern itself during moulding.Green sand has low strength, so is not suitable for deep holes.

(b) Dry sand core:- This is made with special core sands in separate corebox, baked & placed in mould. Different types of dry sand cores are

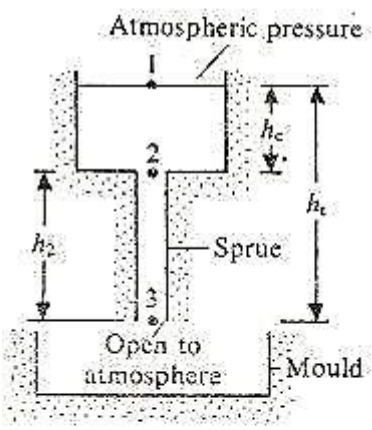
-Unbalanced core -cover core -drop core

-balanced core -vertical core

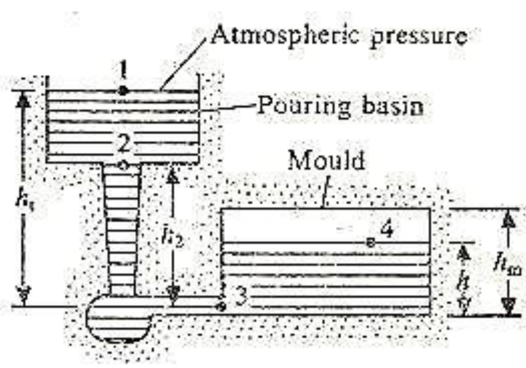
Core prints:- Core prints are used to position the core securely and correctly in mould cavity. It should take care of the weight of the core and upward metallostatic pressure of molten metal.

Pouring, Gating design:

A good gating design should ensure proper distribution of molten metal without excessive temperature loss, turbulence, gas entrapping and slags. If the molten metal is poured very slowly, since time taken to fill the mould cavity will become longer, solidification will start even before the mould is completely filled. This can be restricted by using super heated metal, but in this case solubility will be a problem. If the molten metal is poured very faster, it can erode the mould cavity. So gating design is important and it depends on the metal and molten metal composition. For example, aluminium can get oxidized easily. Gating design is classified mainly into two (modified: three) types: Vertical gating, bottom gating, horizontal gating.



Simple vertical gating

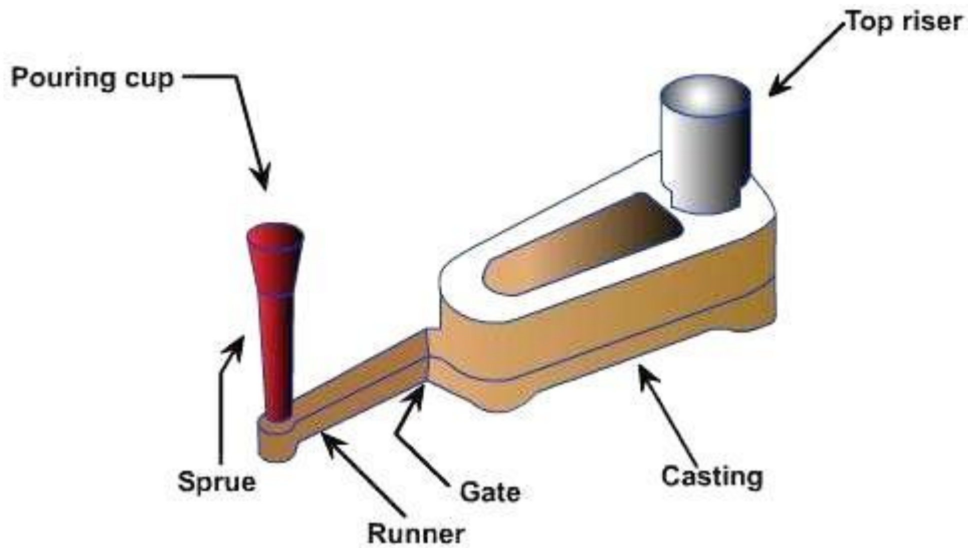


Bottom gating

Vertical gating: the liquid metal is poured vertically, directly to fill the mould with atmospheric pressure at the base end.

Bottom gating: molten metal is poured from top, but filled from bottom to top. This minimizes oxidation and splashing while pouring.

Horizontal gating is a modification of bottom gating, in which some horizontal portions are added for good distribution of molten metal and to avoid turbulence



Analysis of pouring and filling up mould

(a) Vertical gating

For analysis we use energy balance equation like Bernoulli's equation

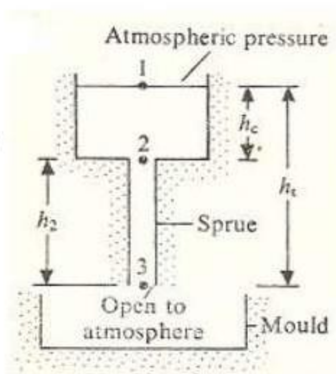
$$h_1 + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} + F_1 = h_3 + \frac{p_3}{\rho g} + \frac{v_3^2}{2g} + F_3$$

Assuming $p_1 = p_3$ and level at 1 is maintained constant, so $v_1 = 0$; frictional losses are neglected.

The energy balance between point 1 and 3 gives,

$$gh_t = v_3^2 / 2 \qquad v_3 = \sqrt{2gh_t}$$

Here v_3 can be referred as velocity at the sprue base or say gate, v_g



Simple vertical gating

Continuity equation: Volumetric flow rate, $Q = A_1v_1 = A_3v_3$

Above two equations say that sprue should be tapered.

As the metal flows into the sprue opening, it increases in velocity and hence the cross-sectional area of the channel must be reduced

Otherwise, as the velocity of the flowing molten metal increases toward the base of the sprue, air can be aspirated into the liquid and taken into the mould cavity.

To prevent this condition, the sprue is designed with a taper, so that the volume flow rate, $Q = Av$ remains the same at the top and bottom of the sprue.

The mould filling time is given by, $t_f = \frac{V}{Q} = \frac{V}{A_g v_3}$

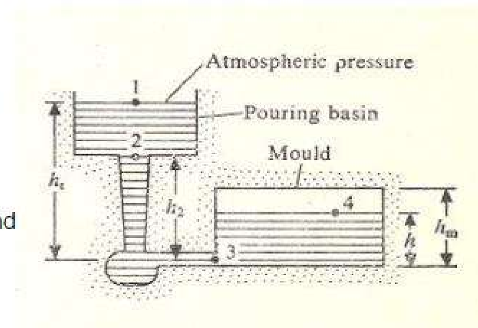
A_g = cross-sectional area of gate; V = volume of mould

Note: This is the minimum time required to fill the mould cavity. Since the analysis ignores friction losses and possible constriction of flow in the gating system; the mould filling time will be longer than what is given by the above equation.

(b) Bottom gating

$$h_1 + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} + F_1 = h_3 + \frac{p_3}{\rho g} + \frac{v_3^2}{2g} + F_3$$

Apply Bernoulli's eqn. between points 1 and 3 and between 3 and 4 is equivalent to modifying V_3 equation in the previous gating.



(b) Bottom gating

$$v_g = v_3 = \sqrt{2g(h_t - h)}$$

Effective head

Between 3 and 4:

Assume:

- V_4 is very small
- All KE at 3 is lost after the liquid metal enters the mould

Assuming in the mould the height moves up by 'dh' in a time 'dt'; A_m and A_g are mould area and gate area, then

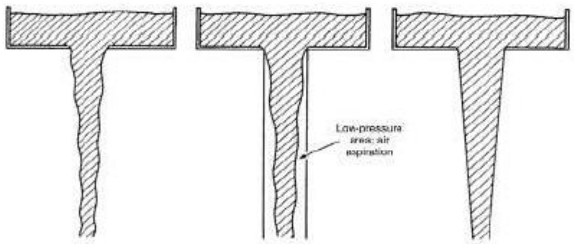
$$A_m dh = A_g v_g dt$$

Combining above two eqns., we get $\frac{1}{\sqrt{2g}} \frac{dh}{\sqrt{h_t - h}} = \frac{A_g}{A_m} dt$

$$\frac{1}{\sqrt{2g}} \int_0^{h_m} \frac{dh}{\sqrt{h_t - h}} = \frac{A_g}{A_m} \int_0^{t_f} dt \Rightarrow t_f = \frac{A_m}{A_g} \frac{1}{\sqrt{2g}} 2(\sqrt{h_t} - \sqrt{h_t - h_m})$$

Aspiration effect

Aspiration effect: entering of gases from baking of organic compounds present in the mould into the molten metal stream. This will produce porous castings. **Pressure anywhere in the liquid stream should not become negative.**



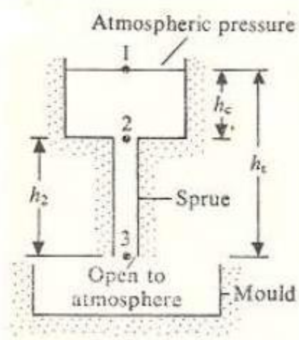
Free falling liquid

Metal flow with aspiration effect

A tapered sprue without aspiration effect

Case 1: straight Vs tapered sprue

Pressure anywhere in the liquid stream should not become negative.

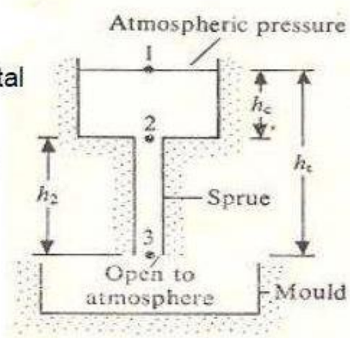


(a) Simple vertical gating

Points 2 & 3

$$gh_2 + \frac{p_2}{\rho_m} + \frac{v_2^2}{2} = \frac{p_3}{\rho_m} + \frac{v_3^2}{2}$$

ρ_m = density of molten metal



(a) Simple vertical gating

Let in the limiting case, $p_2 = p_3$, then from above equation

$$\frac{v_3^2}{2} = gh_2 + \frac{v_2^2}{2}$$

We know that, $v_2 = \frac{A_3}{A_2} v_3 = Rv_3$

Combining above two eqns., $\frac{v_3^2}{2g} = h_2 + \frac{R^2 v_3^2}{2g}$

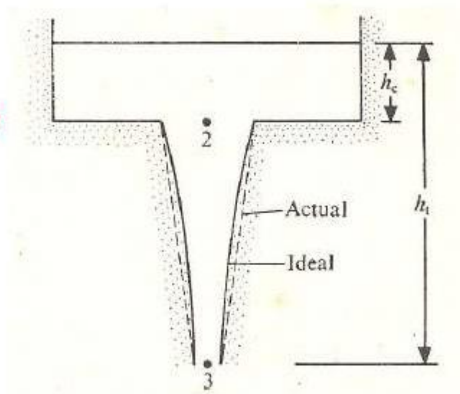
$$R^2 = 1 - \frac{2gh_2}{v_3^2}$$

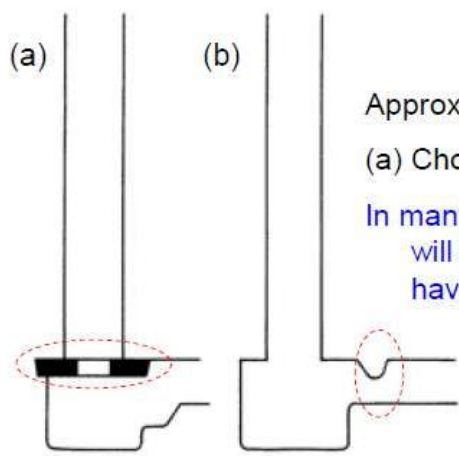
We know that between points 1 and 3, $gh_t = v_3^2 / 2$

Put this in R^2 eqn, we get, $R^2 = 1 - \frac{h_2}{h_t} = \frac{h_c}{h_t}$

$$R = \frac{A_3}{A_2} = \sqrt{\frac{h_c}{h_t}}$$

Ideal and actual profiles of sprue



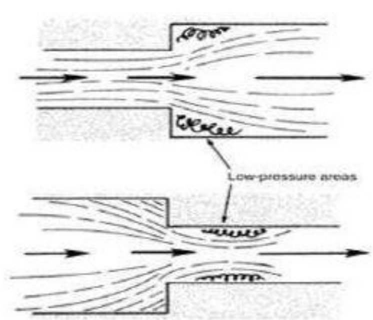


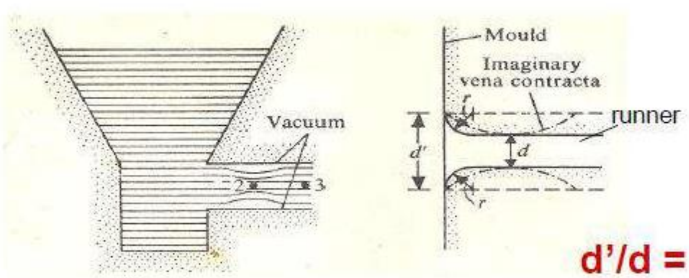
Approximating tapered spure using choke mechanism

(a) Choke core, (b) Runner choke

In many high production casting systems, tapered sprue will not be provided. Instead it is compensated by having chokes at the end of sprue or runner.

Case 2: sudden change in flow direction

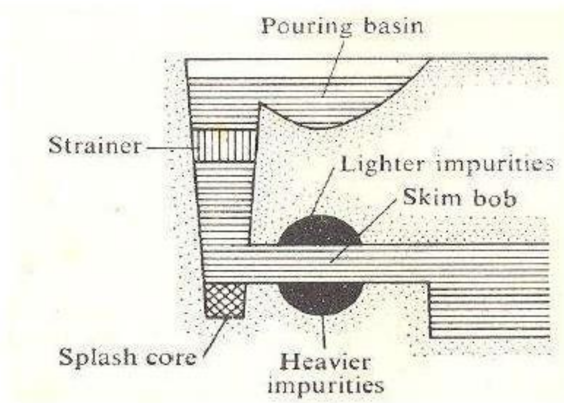




d'/d = 1.3

A sharp change in flow direction is avoided by designing the mould to fit vena contracta.

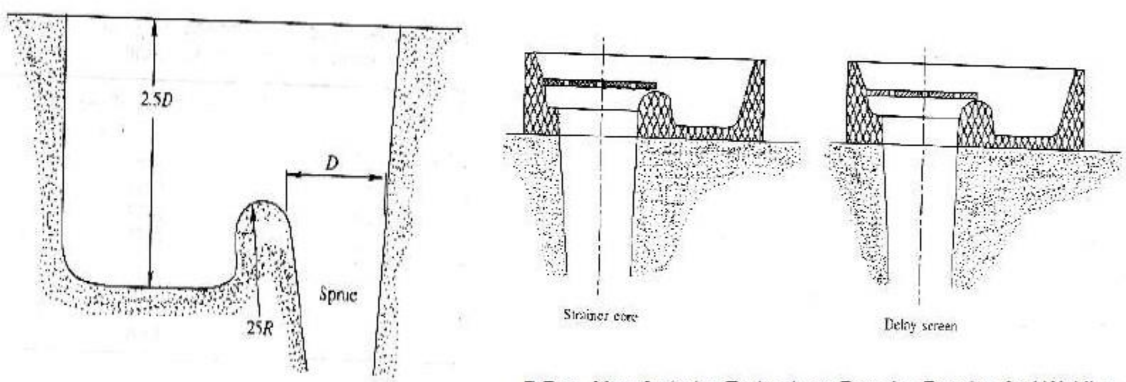
Preventing impurities and turbulence in casting



The items provided in the gating system to avoid impurities and turbulence are:

Pouring basin:

This reduces the eroding force of the liquid metal poured from furnace. This also maintains a constant pouring head. Experience shows that pouring basin depth of 2.5 times the sprue entrance diameter is enough for smooth metal flow. Radius of 25R (mm) is good for smooth entrance of sprue.



P Rao, *Manufacturing Technology: Foundry, Forming And Welding*

Delay screen/Strainer core:
A delay screen is a small piece of perforated screen placed on top of the sprue. This screen actually melts because of the heat from the metal and this delays the entrance of metal into the sprue, maintaining the pouring basin head. This also removes dross in the molten metal.
Strainer core is a ceramic coated screen with many small holes and used for same purpose.

Splash core: provided at the end of the sprue length which reduces the eroding force of the liquid metal

Skim bob: this traps lighter and heavier impurities in the horizontal flow

Gating ratios

Gating ratio: sprue area : runner area : gate area

Non-pressurized:

has choke at the bottom of the sprue base, has total runner area and gate areas higher than the sprue area. No pressure is present in the system and hence no turbulence. But chances of air aspiration is possible. Suitable for Al and Mg alloys.

In this, Gating ratio = 1 : 4 : 4

Pressurized:

Here gate area is smallest, thus maintaining the back pressure throughout the gating system. This backpressure generates turbulence and thereby minimizes the air aspiration even when straight sprue is used.

Not good for light alloys, but good for ferrous castings.

In this, Gating ratio = 1 : 2 : 1

RISER:-

Most alloys shrink during solidification. As a result of this volumetric shrinkage, voids are formed which are known as hot spots. So a reservoir of molten metal is maintained from which the metal can flow steadily intothe casting. These reservoirs are known as risers. Design considerations:- The metal in riser should solidify at the end and the riser volume should be sufficient for compensating the shrinkage in the casting. To solve this problem, the riser should have highervolume.

Types of Riser:-

(a) top riser- This type of riser is open to the atmosphere. It is veryconventional & convenient to make. It looses heat to the atmosphere by radiation & convention. To reduce this, insulation is provided on top suchas plaster of paris and asbestos sheets.

(b) blind riser :- This type of riser is surrounded by the moulding sand and looses heat very slowly.

(c) Internal rise:- It is surrounded on all sides by casting such that heat from casting keeps the metal in the riser hot for a longer time. These are used for cylindrical shapes or hollow cylindrical portions casting.

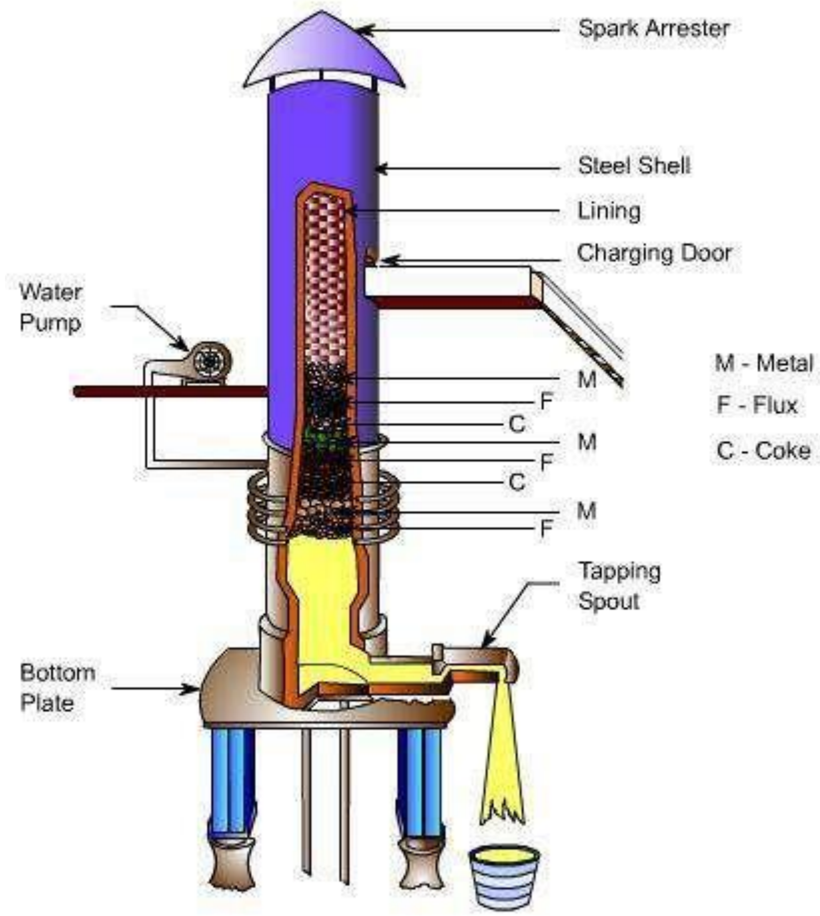
Chill:- Metallic chills are used to provide progressive solidification or to avoid the shrinkage cavities. These are large heat sinks. Use of chill will form a hard spots, which needs further machining.

Melting & casting Quality

Melting is a major factor which controls the quality of casting. The different methods for melting foundry alloys are pit furnace, open hearth furnace, rotary furnace and cupola furnace etc. The choice of furnace dependsamount & type of alloy.

CUPOLA:-

It consists of a cylindrical steel shell with its interior lined with heat resisting fire bricks. There is a drop door at the bottom after closing which proper sand bed could be prepared. This sand bed provides proper refractory bottom for molten metal & coke. Above the sand bed, there is a metal tapping hole which will be initially closed with clay known as ”bot”. Opposite& above the metal tapping hole, there is a slag hole where slag is trapped. Above the slag hole, there is a wind box which is connected to air blowers. Air enters to the cupola through the tuyeres. Above the charging platform, there is a charging hole through which charge is put into the cupola. The charge consists of the pig iron, scrap iron, coke and fluxes.



Schematic diagram of a cupola

Operation:-

First the drop door at the bottom is closed. Sand bed with slope towardstap hole is rammed. Coke bed of suitable height is prepared above thesand bed and is ignited through the tap hole. After proper ignition, alternate layers of charge, flux & coke are fed through the charge door. Then the charge is allowed to soak in the heat and the air blast is turned on. Within 5 to 10mins, the molten metal is collected through the tap hole. When enough metal is collected in the well of the cupola, the slag is drained off through the slag hole. Then the molten metal is collected in the ladles and is transported to the moulds with a minimum time loss.

Fluxes are added in the charge to remove the oxides & other impurities present in the metal. The flux commonly used is lime stone ($CaCO_3$) in a proportion of 2 to 4% of the metal charge. Others fluxes used are dolomite, sodium carbonate, calcium carbide. Flux reacts with oxides to form compounds having low melting point and lighter so that it will float on the metal pool.

Charge calculations:-

Carbon:- When charge comes through the coke bed, some amount of carbon is picked up by the metal depending on the temperature and the time when the metal is in contact with the coke. It is of the order of 0.15% carbon.

Silicon:- It is Oxidised in the cupola and there will be a loss of 10% silicon. It may be as high as 30%. To increase the silicon content, ferrosilicon is added to the metal.

Manganese:- There is a loss of 15 to 20% manganese during melting process. The content of manganese can be increased by the addition of ferromanganese.

Sulphur- There will a sulphur pick up in a range of 0.03 to 0.05%.

Other furnaces:

Other furnaces include

- Open hearth furnace
- Rotary furnace
- Crucible furnace
- Immersion heated furnace

Based on the source of heating, they can be classified as

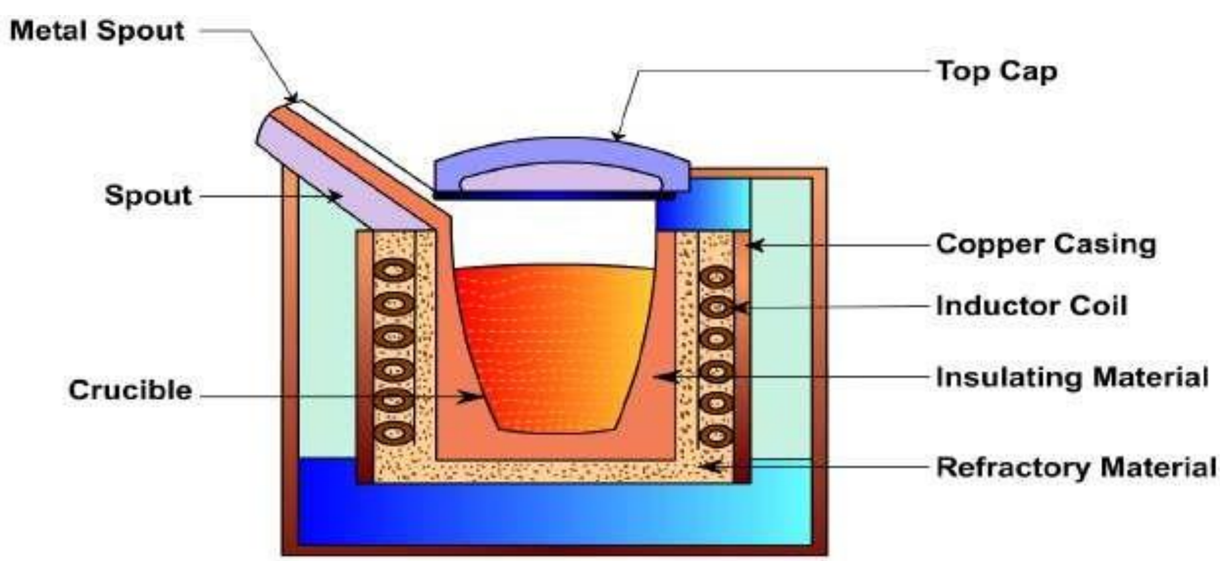
- Electrical heating furnace (arc, resistance or induction)
- Fossil full fired furnace (solid, oil/gaseous fuel)

ELECTRIC ARC FURNACE:

For heavy steel castings, the open hearth type furnace with electric arc/oil fired would be suitable. These furnaces are suitable for ferrous materials. It consists of a bowl shaped bottom known as hearth lined with refractory bricks and granular refractory material. Heat is directly transferred to the charge by electric arc from the electrodes. Tilting mechanism forward is used for metal tapping and backward is for deslagging.

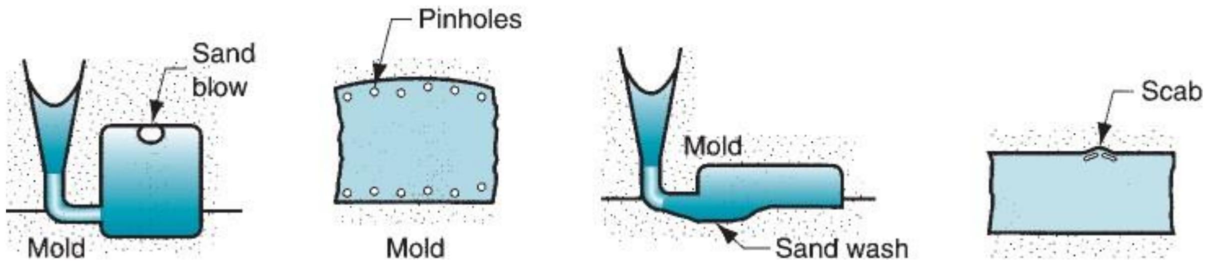
INDUCTION FURNACE:

This type of furnace is suitable for all types of materials. The heat source is isolated from charge and slag. The flux gets necessary heat directly from the charge instead of the heat source. The stirring effect of electric current would cause fluxes to be entrained in the melt.



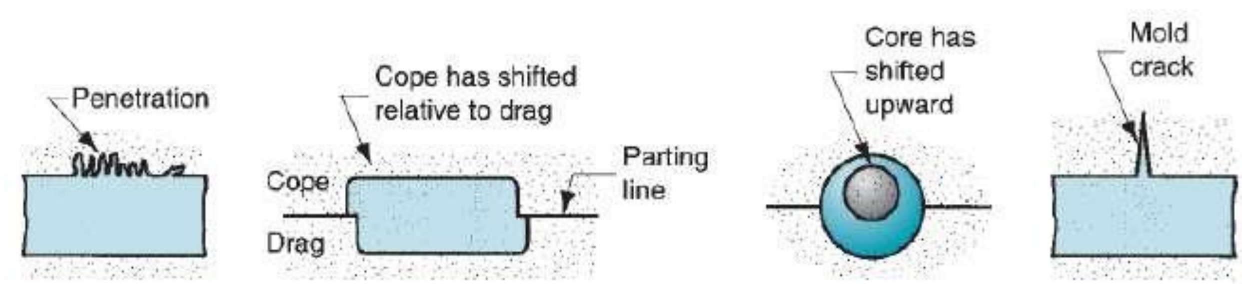
Induction Furnace

Defects in sand castings



Sand blow and Pinholes: defect consisting of a balloon-shaped gas cavity or gas cavities caused by release of mold gases during pouring. It is present just below the casting top surface. Low permeability, bad gas venting, and high moisture content of the sand mold are the usual causes. **Sand wash**: surface dip that results from erosion of the sand mold during pouring. This contour is formed in the surface of the final cast part.

Scab: It is caused by portions of the mold surface flaking off during solidification and gets embedded in the casting surface.

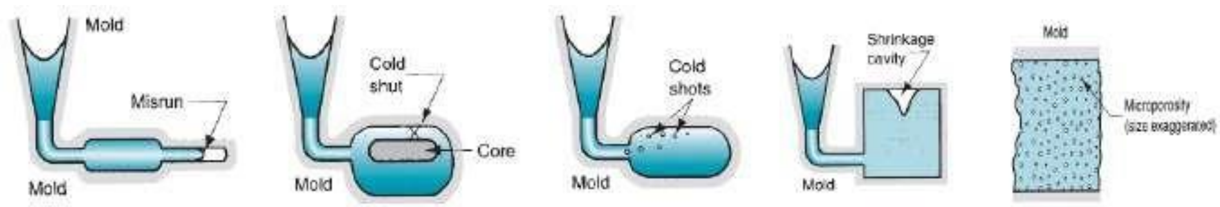


Penetration: surface defect that occurs when the liquid penetrates into the sand mold as the fluidity of liquid metal is high, After solidifying, the casting surface consists of a mixture of sand and metal. Harder ramming of sand mold minimize this defect.

Mold shift: defect caused by displacement of the mold cope in sideward direction relative to the drag. This results in a step in the cast product at the parting line.

Core shift: displacement of core vertically. Core shift and mold shift are caused by buoyancy of the molten metal.

Mold crack: 'fin' like defect in cast part that occurs when mold strength is very less, and a crack develops, through which liquid metal can seep.



Misruns: castings that solidify before completely filling the mold cavity. This occurs because of (1) low fluidity of the molten metal, (2) low pouring temperature, (3) slow pouring, (4) thinner cross-section of the mold cavity. **Cold Shuts:** This defect occurs when two portions of the metal flow together but no fusion occurs between them due to premature freezing. **Cold shots:** forming of solid globules of metal that are entrapped in the casting. Proper pouring procedures and gating system designs can prevent this defect.

Shrinkage cavity: cavity in the surface or an internal void in the casting, caused by solidification shrinkage that restricts the amount of molten metal present in the last region to freeze. It is sometimes called as 'pipe'. Proper riser design can solve this problem.

Microporosity: network of small voids distributed throughout the casting caused by localized solidification shrinkage of the final molten metal.

Inoculation is a common and necessary practice used in foundries that produce gray and ductile iron castings. Often performed just prior to pouring, inoculation refers to a procedural step undertaken to improve the solidified structure of the metal, and therefore its mechanical properties. The process:

* promotes the formation of small and uniformly dispersed Type A graphite in gray iron and increases the nodule count in ductile iron. Type A graphite of the correct size provides the best mechanical properties of the iron;

* minimizes the formation of primary iron carbides (also called chill or white iron)

Degassing processes There are 3 methods of degassing which are in practice

i) Ladle degassing

ii) Stream degassing

iii) Circulation degassing

All these processes are carried out in ladles. Ladle degassing Ladle containing molten steel is placed in a chamber which is then evacuated. After a determined time ladle is removed from the chamber and is teemed for casting. The Arrangement of ladle with porous plug and hopper for degassing Ladle is provided with a porous plug at its bottom to purge argon gas as shown in the figure. In a vacuum chamber the ladle is placed. The vacuum chamber is equipped with a hopper so as to make additions of elements as and when it is needed. For effective degassing of fully killed steel, it is necessary to purge argon through the bottom of the ladle. Stirring the bath enhances rate of gas removal. Vigorous removal of gases causes metal splashing too. Therefore ladle is not filled completely and about 25% of its height is kept as freeboard to accommodate the splashed metal droplets. Pressure is maintained in between 1mmHg to 10mm Hg for effective degassing. During degassing additions are made for deoxidation and alloying. In certain cases ladle is heated to compensate for the loss of heat during degassing. For the effectiveness of degassing , it is necessary that carry-over slag either from BOF or EAF should be as low as possible. Carry-over slag contains FeO and since oxygen content of steel is in equilibrium with FeO content of slag, oxygen content of steel increases. Stirring gas is introduced either from top through the roof by a submerged refractory tube orthrough the porous plug fitted at the bottom of the ladle. Electromagnetic stirring is employed for degassing. For this purpose ladle has to be made of non magnetic austenitic stainless steel or stainless window could be provided. For certain grades of alloy steels, both induction stirring and arc heating are employed for degassing. The final content of gas in steel depends on degree of vacuum and time of treatment. Hydrogen is generally reduced to below 2ppm from 4 to 6ppm, nitrogen content of steel is also reduced. The pick-up of nitrogen from the atmospheric air may occur during open pouring of steel, which must be controlled. Ladles are generally lined with high alumina bricks at upper part of the ladle while the lower portion is lined with fireclay. Stream degassing In stream degassing technology, molten steel is teemed into another vessel which is under vacuum. Sudden exposure of moltenstream in vacuum leads to very rapid degassing due to increased surface area created by breakup of stream into droplets. The majoramount of degassing occurs during the fall of molten stream. Height of the pouring stream is an important design parameter. Stream degassing technology has following variants in the practice i. Ladle to mould degassing Preheated mold with hot top is placed in vacuum chamber. Above the chamber a tundish is placed. Steel tapped in the ladle at superheat equivalent to 30℃ is placed above the tundish. Steel is bottom poured in the tundish. One ingot could weigh around as high as 400tons and several heats from different furnaces are used for casting. Figure 26.2 shows arrangement of vessels Figure 26.2: Arrangement of ladle, tundish and mold to degass molten steel ii. Ladle to ladle degassing In ladle to ladle degassing, a ladle with the stopper rod is placed in a vacuum chamber. Ladle containing molten steel from BOF orEAF is placed on top of the vacuum chamber and the gap is vacuum sealed. Alloy additions are made under vacuum. Stream is allowed to fall in the ladle where molten steel is degassed. Alloy additions are made under vacuum. In some plants degassing is done during tapping. In this arrangement molten steel from EAF is tapped into tundish or ponyladle. From the pony ladle molten stream is allowed to fall into a ladle which is evacuated. Ladle is closed from top with a special cover which contains exhaust opening. Steel with 25℃ to 30℃ superheat is tapped into ladle.

CONTINUOUS CASTING:

In this process the liquid steel is poured into a double walled bottomless water cooled mould where a solid skin is quickly formed having a thickness of 10 to 25 mm and a semi solid skin emerges from open mould bottom which will be further solidified by water sprays. Molten metal is collected in a ladle and is kept over a refractory lined intermediate pouring vessel called tundish and then poured into water cooled vertical copper mould of 450 to 750 mm long. Before starting casting, a dummy starter bar will be kept at the mould bottom. After starting casting process, as the metal level rises to a height, the starter bar will be withdrawn at equal rate that of the steel pouring rate. Initially metal freezes on to the starter bar as well as periphery of the mould. Solidified shell supports the steel liquid as it moves downwards. The steel shell is mechanically supported by rollers as it moves down through the secondary cooling zone with water.

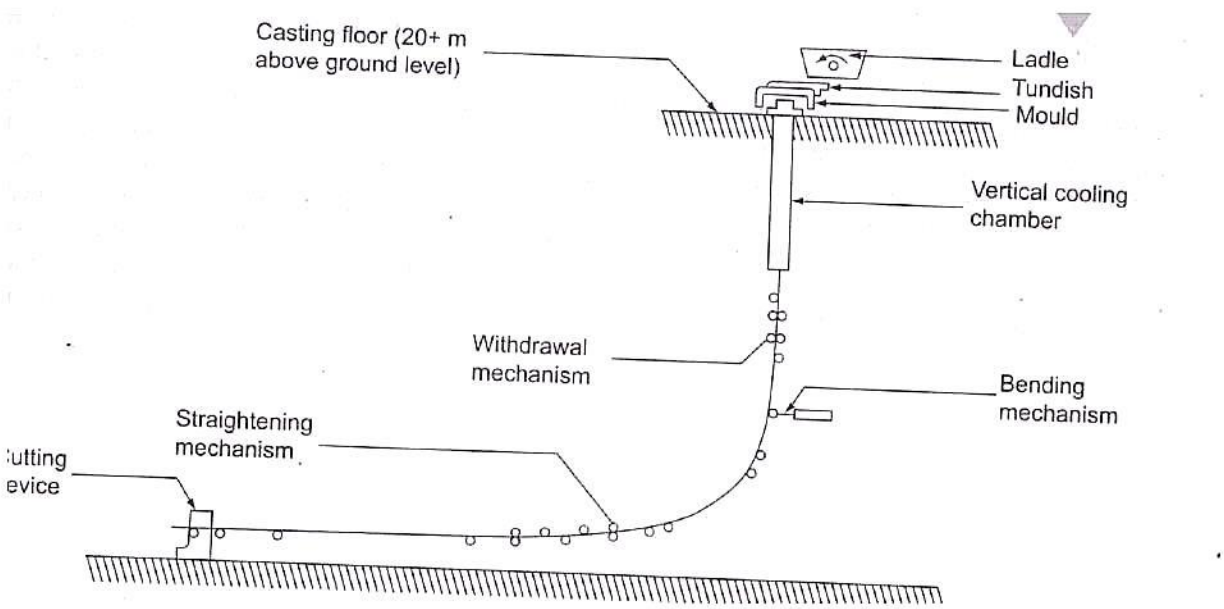


Fig: Continuous casting plant

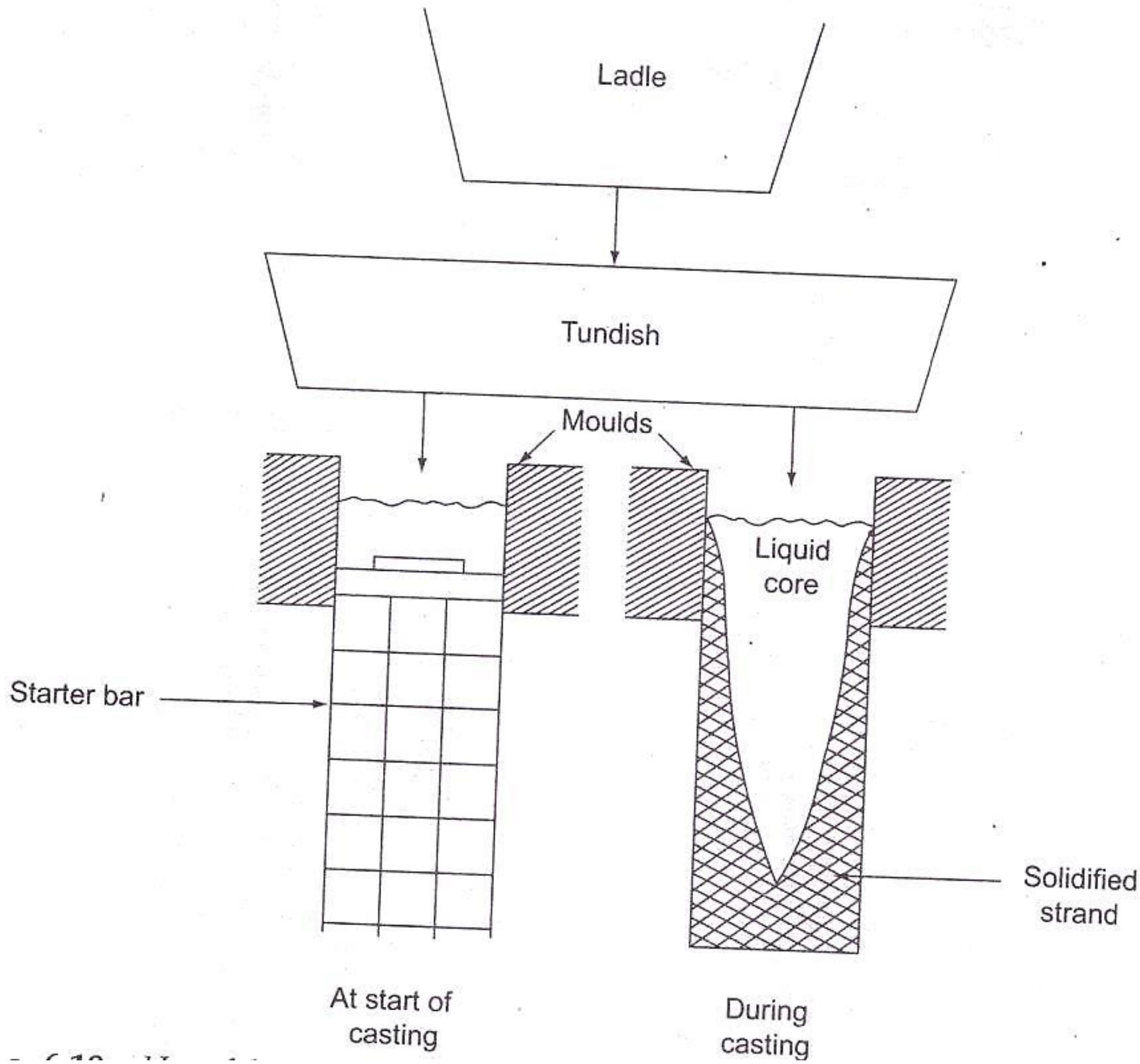
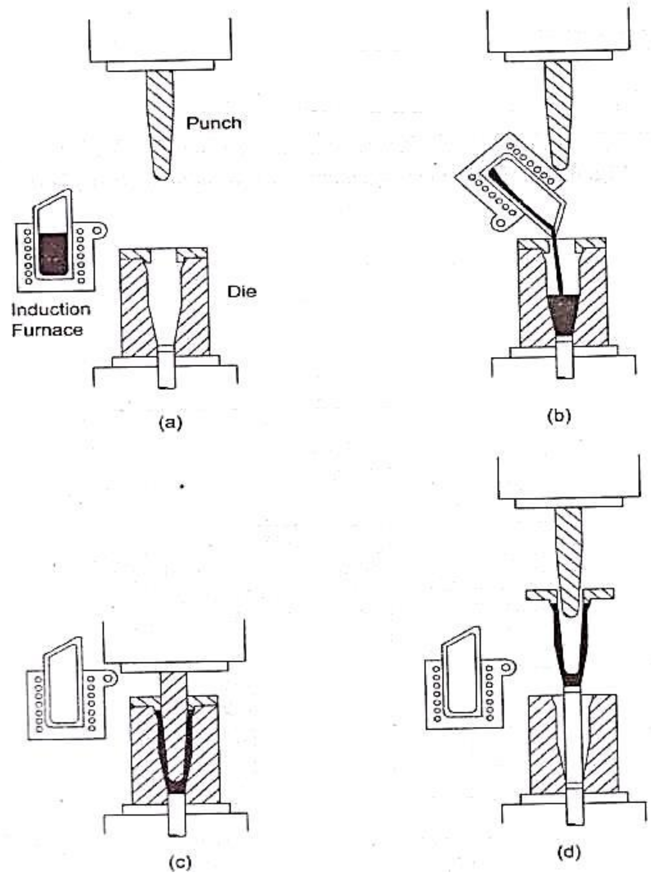


Fig: Use of dummy starter bar at the start of continuous casting process

SQUEEZE CASTING:
It was first developed in Russia. It is a combination of casting and forging process. First the punch and die are separated. The furnace holds the liquid metal at a requisite temperature. Then the metal is put into the die cavity and the punch is lowered to its place forming a tight seal. The metal is under a pressure of 50 to 140 mpa and looses heat rapidly because of the contact with the metallic die. Once the casting is solidified, the punch is retracted.
Adv: very low gas entrapment.Lower shrinkage cavity.
Lower die costs. High quality surface.
Application: Mg, Al, Cu alloy



Investment casting In this casting process, a pattern made of wax is coated with a refractory material to make the mold surface, after which the wax is melted away while pouring the molten metal. “Investment” means “to cover completely” which refers to the coating of the refractory material around the wax pattern. This is a precision casting process. Using this wecan make castings of high accuracy with intricate details.

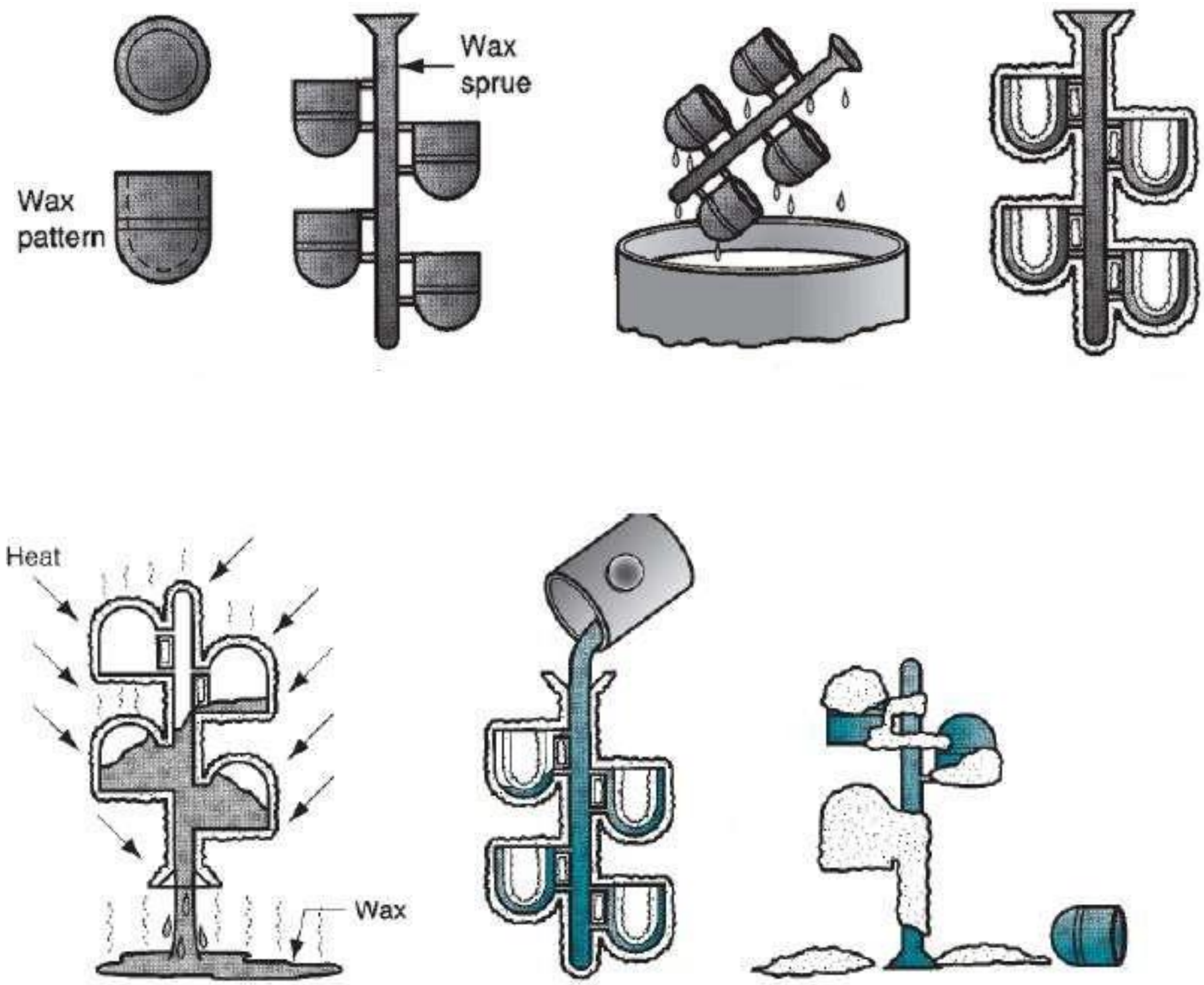


Fig: Wax patterns are first made

1. several patterns can be attached to a sprue to form a pattern tree, if required
2. the pattern tree is coated with a thin layer of refractory material and later covered with thick coating to make the rigid full mold
3. Heating of mold in inverted position to melt the wax and permit it to drip
4. out of the cavity
5. the mold is preheated to a high temperature so that contaminants are eliminated from the mold
6. the molten metal is poured and it solidifies
7. the mold is removed from the finished casting

Refractory coating:

• Slurry of very fine grained silica or other refractory, in powder form, mixed with plaster to bond the mold into shape. The small grain size of the refractory material delivers smooth surface and captures the intricate depths of the wax pattern.

• Mold is allowed to dry in air for about 8 hours to harden the binder.

Advantages:

(1) Complex and intricate parts can be cast
(2) tolerances of 0.075 mm are possible
(3) good surface finish is possible
(4) In general, additional machining is not required – near net shaped part

Applications:

- Steels, stainless steels, high temperature alloys can be cast
- Examples of parts: machine parts, blades, components for turbine engines, jewelry, dental fixtures

Plaster mold and ceramic mold casting

Plaster mold:

- similar to sand casting, except mold is made of POP and not sand
- To minimize contraction, curing time, reduce cracking, additives like talc and silica flour are mixed with the plaster.
- Curing time: 20 mts, baking time: several hours
- Permeability is low. This problem is solved by using a special mold composition and treatment known as the Antioch process. IN this operation, about 50% of sand is mixed with the plaster, heating the mold in an autoclave, and then drying is done. Good permeability is attained by this treatment.
- Used only for Al, Mg, Cu based alloys

Ceramic mold:

- mold is made of refractory ceramic materials which can withstand high temp. than plaster.
- Ceramic molding can be used to cast steels, CI, and other high temp. alloys.

Permanent mold process

Disadvantage of expendable molding processes is that for every casting a new mold is required.

Permanent mold processes:

• using only metal mold for casting

• Molds are generally made of steel, CI

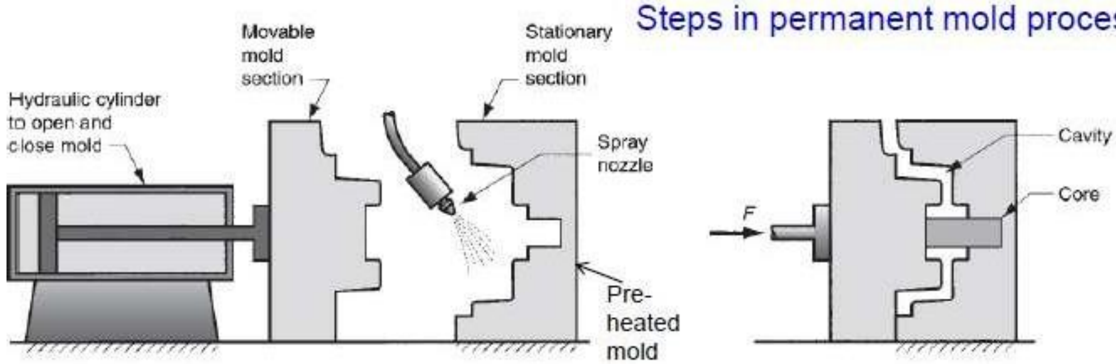
• materials that can be cast: Al, Mg, Cu based alloys, CI (affect the mold life, hence not used)

• cores are also made of metal, but if sand is used then called semi permanent-mold casting

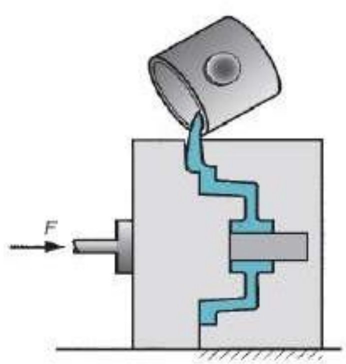
• Advantages: good surface finish, dimension tolerance, rapid solidification causes fine grains to form giving stronger products

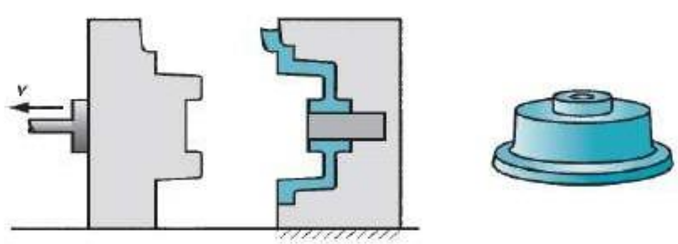
• limitations: restricted to simple part geometries, low melting point metals, mold cost is high. Best suitable for small, large number of parts

Steps in permanent mold process



Preheating facilitates metal flow through the gating system and into the cavity.
The coatings aid heat dissipation and lubricate the mold surfaces for easier separation of the cast product





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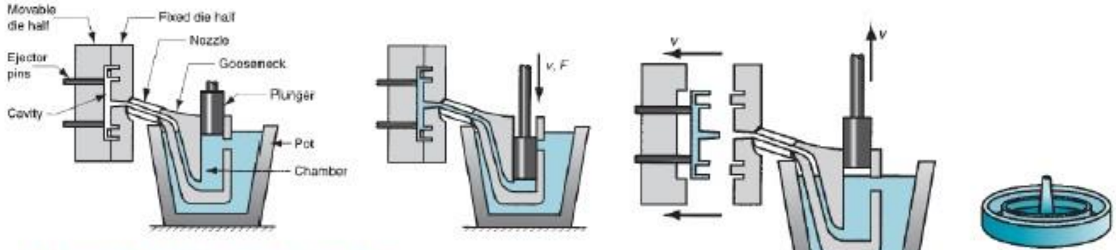
Die casting

In this process, high pressure of app. 7 to 350 MPa is used to pressurize the molten metal into die cavity. The pressure is maintained during solidification.
Category: hot chamber machines, cold chamber machines

hot chamber machines:

- Molten metal is melted in a container attached to the machine, and a piston is used to pressurize metal under high pressure into the die. Typical injection pressures are between 7 and 35 MPa.
- Production rate of 500 parts/hour are common.
- Injection system is submerged into the molten metal and hence pose problem of chemical attack on the machine components. Suitable for zinc, tin, lead, Mg.



Steps in hot chamber casting

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cold chamber machines:

- Molten metal is poured from an external unheated container into the mold cavity and piston is used to inject the molten metal into the die cavity.
- Injection pressure: 14 to 140 MPa.
- Though it is a high production operation, it is not as fast as hot chamber machines.

Steps in cold chamber casting

Die casting molds are made of tool steel, mold steel, maraging steels. Tungsten and molybdenum with good refractory qualities are also used for die cast steel, CI.

Advantages of die casting:

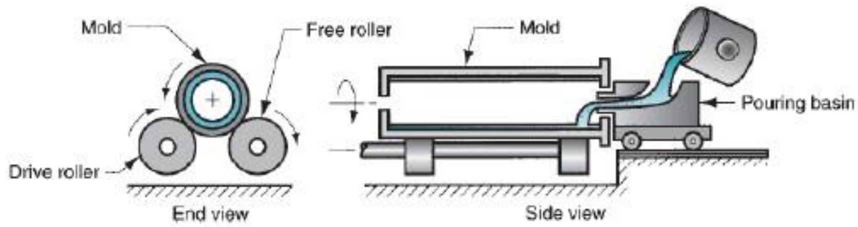
- high production rates and economical
- Close tolerances possible of the order of ±0.076 mm
- thin section with 0.5 mm can be made
- small grain size and good strength casting can be made because of rapid cooling

Centrifugal casting

- In this method, the mold is rotated at high speed so that the molten metal is distributed by the centrifugal force to the outer regions of the die cavity

- includes : true centrifugal casting, semicentrifugal casting

True centrifugal casting:



- Molten metal is poured into a rotating mold to produce a tubular part (pipes, tubes, bushings, and rings)
- Molten metal is poured into a horizontal rotating mold at one end. The high-speed rotation results in centrifugal forces that cause the metal to take the shape of the mold cavity. The outside shape of the casting can be non-round, but inside shape of the casting is perfectly round, due to the radial symmetry w.r.t. forces

- Orientation of the mold can be **horizontal or vertical**

For horizontal centrifugal casting:

$$\text{centrifugal force} = F = \frac{mv^2}{R}$$

Where F – force in N, m – mass in kg, v – velocity in m/s, R – inner radius of mold in m

Here we define G-factor (GF) as the ratio of centrifugal force to weight.

$$GF = \frac{(\frac{mv^2}{R})}{mg} = \frac{v^2}{Rg}$$

For horizontal centrifugal casting, GF is equal to 60 to 80

Putting $v = 2\pi RN/60$ in the above eqn. and after rearrangement gives,

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

Where N is rotational speed in rev/min., D is inner diameter of mold in m

If the G-factor is very less, because of the reduced centrifugal force, the liquid metal will not remain forced against the mold wall during the upper half of the circular path but will go into the cavity. This means that slipping occurs between the molten metal and the mold wall, which indicates that rotational speed of the metal is less than that of the mold.

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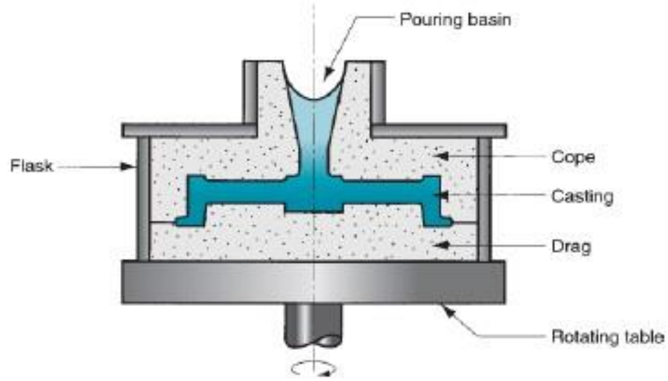
Semicentrifugal casting:



In this process, centrifugal force is used to produce non-tubular parts (solid), and not tubular parts. GF will be around 15 by controlling the rotation speed. Molds are provided with riser at the center.

Generally the density of metal will be more at the outer sections and not at the center of rotation. So parts in which the center region (less denser region) can be removed by machining (like wheels, pulleys) are usually produced with this method.