

Introduction to manufacturing processes

Casting processes: Moulding materials and their requirements; Patterns: Types and various pattern materials. Various casting methods, viz., sand casting investment casting, pressure die casting, centrifugal casting, continuous casting, thin roll casting; Mould design; Casting defects and their remedies. (14 classes)

Metal forming processes: Various metal forming techniques and their analysis, viz., forging, rolling, extrusion, wire drawing, sheet metal working, spinning, swaging, thread rolling; Super plastic deformation; Metal forming defects. (14 classes)

Metal joining processes: brazing, soldering, welding; Solid state welding methods; resistance welding; arc welding; submerged arc welding; inert gas welding; Welding defects, inspection. (9 classes)

Powder metallurgy & its applications (3 classes)

Texts:

1. A Ghosh and A K Mallik, *Manufacturing Science*, Wiley Eastern, 1986.
2. P Rao, *Manufacturing Technology: Foundry, Forming And Welding*, Tata McGraw Hill, 2008.
3. M.P. Groover, *Introduction to manufacturing processes*, John Wiley & Sons, 2012
4. Prashant P Date, *Introduction to manufacturing technologies Principles and technologies*, Jaico publications, 2010 (new book)

References:

1. J S Campbell, *Principles Of Manufacturing Materials And Processes*, Tata McGraw Hill, 1995.
2. P C Pandey and C K Singh, *Production Engineering Sciences*, Standard Publishers Ltd., 2003.
3. S Kalpakjian and S R Schmid, *Manufacturing Processes for Engineering Materials*, Pearson education, 2009.
4. E. Paul Degarmo, J T Black, Ronald A Kohser, *Materials and processes in manufacturing*, John wiley and sons, 8th edition, 1999

Tentative grading pattern:

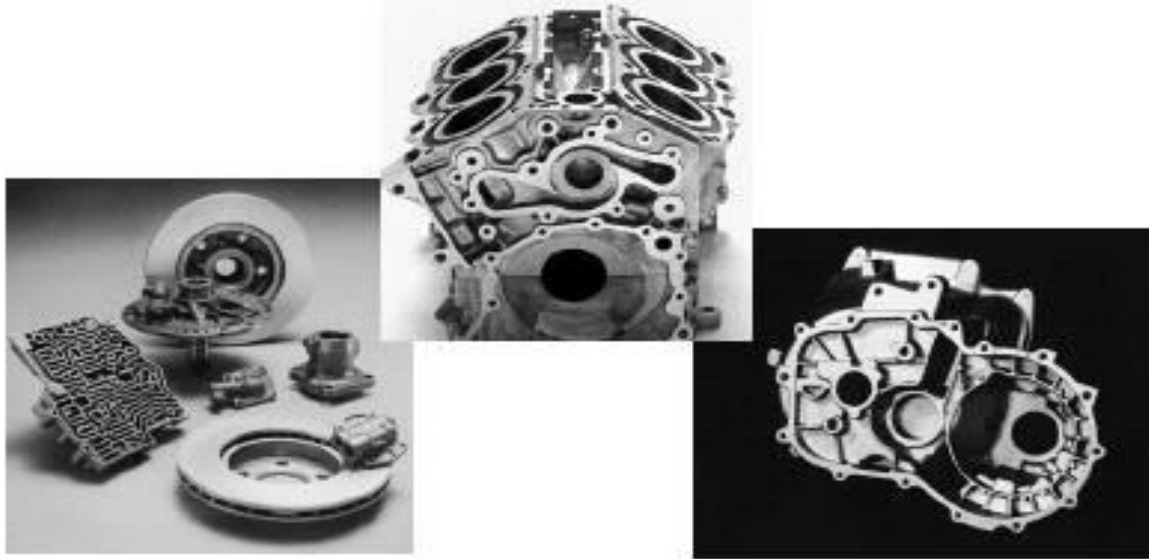
QUIZ 1: 10; QUIZ 2: 15; MID SEM: 30; END SEM: 45; ASSIGNMENT: 10

Metal casting processes

- Casting is one of the oldest manufacturing process. It is the first step in making most of the products.
- **Steps:**
 - Making mould cavity
 - Material is first liquefied by properly heating it in a suitable furnace.
 - Liquid is poured into a prepared mould cavity
 - allowed to solidify
 - product is taken out of the mould cavity, trimmed and made to shape

We should concentrate on the following for successful casting 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



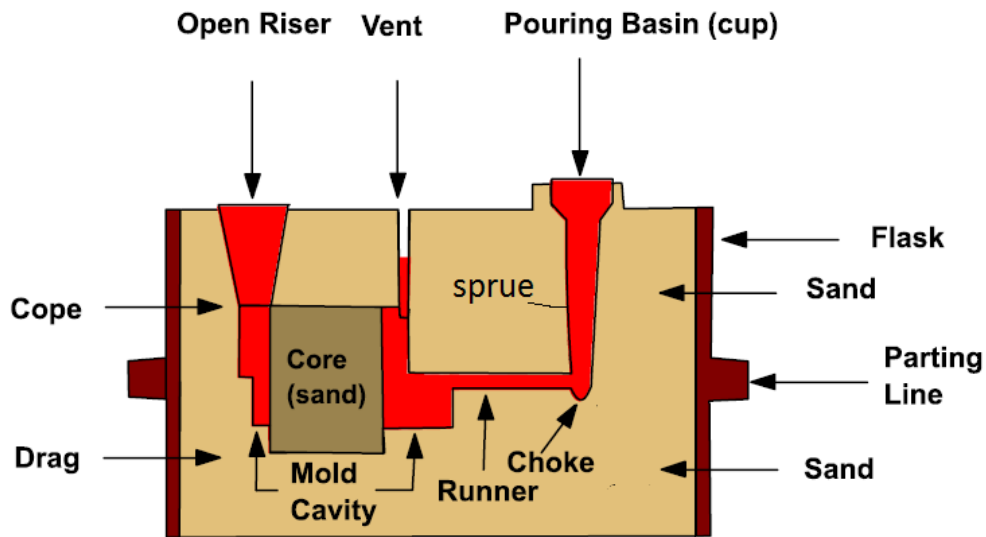
Advantages

- 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 practically any material: ferrous or non-ferrous.
- The necessary tools required for casting moulds are very simple and inexpensive. As a result, for production of a small lot, it is the ideal process.
- 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.
- Size and weight of the product is not a limitation for the casting process.

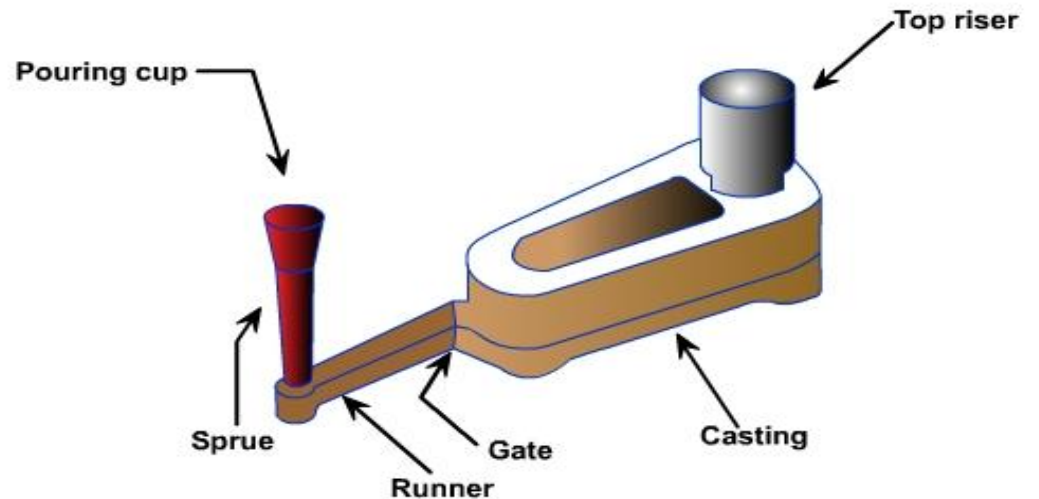
Limitations

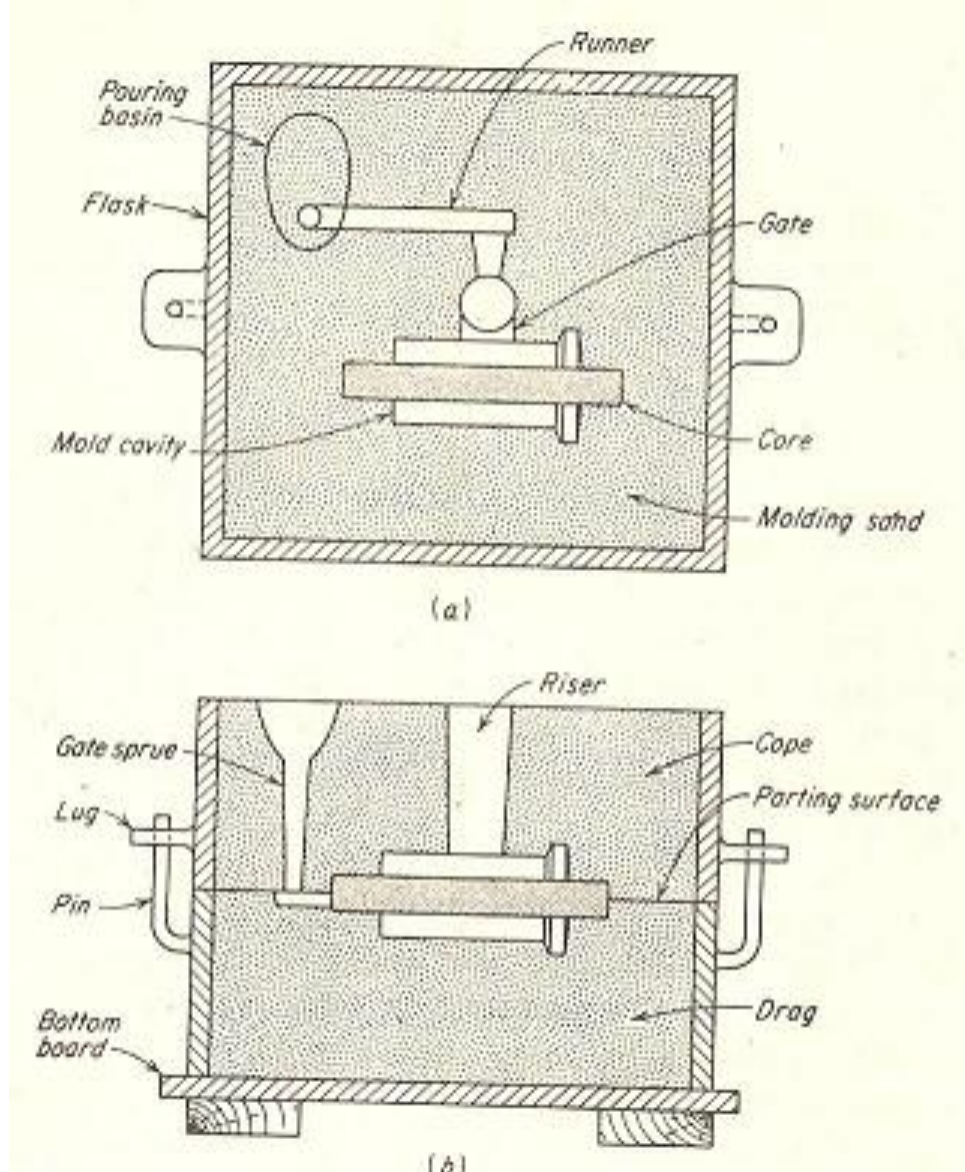
- Dimensional accuracy and surface finish of the castings made by sand casting processes are a limitation to this technique.
- Many new casting processes have been developed which can take into consideration the aspects of dimensional accuracy and surface finish. Some of these processes are die casting process, investment casting process, vacuum-sealed moulding process, and shell moulding process.
- Metal casting is a labour intensive process
- Automation: a question

Typical sand mould



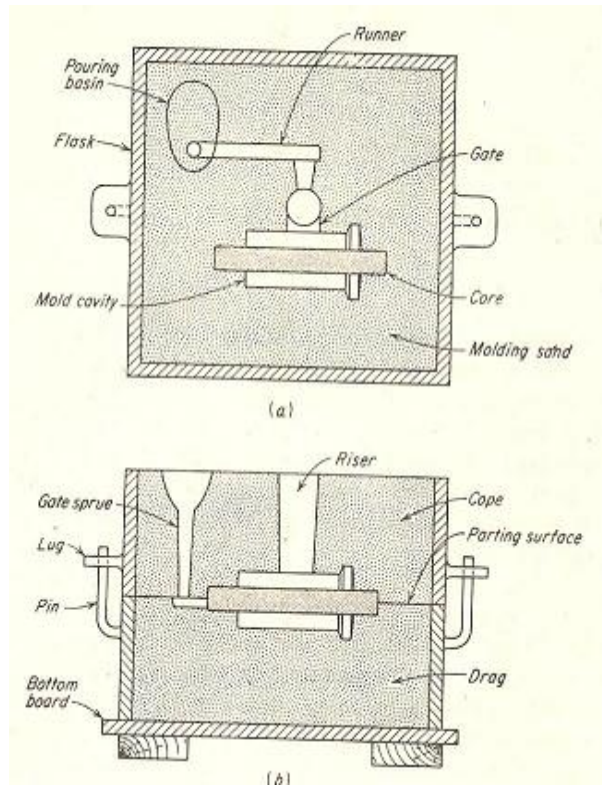
Mould Section and casting nomenclature





Mould Section and casting nomenclature, (a) top view, (b) front view

Important casting terms



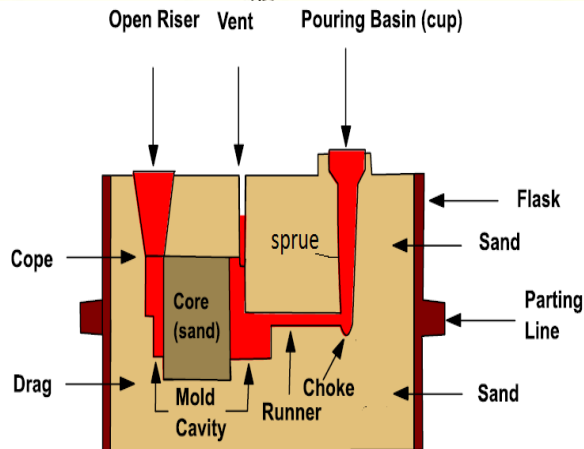
Flask: A metal or wood frame, without fixed top or bottom, in which the mould is formed. Depending upon the position of the flask in the moulding structure, it is referred to by various names such as drag – lower moulding flask, cope – upper moulding flask, cheek – intermediate moulding flask used in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

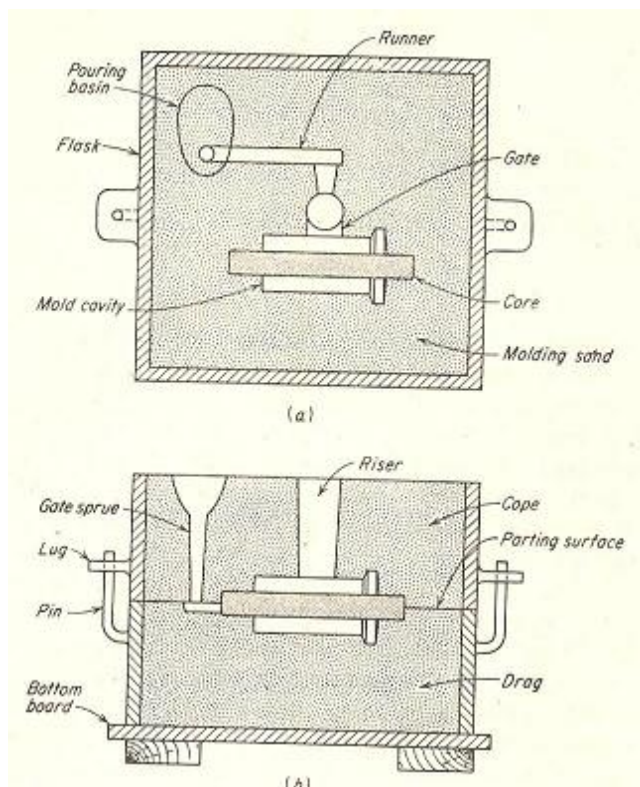
Pattern: It is the replica of the final object to be made. The mould cavity is made with the help of pattern.

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.

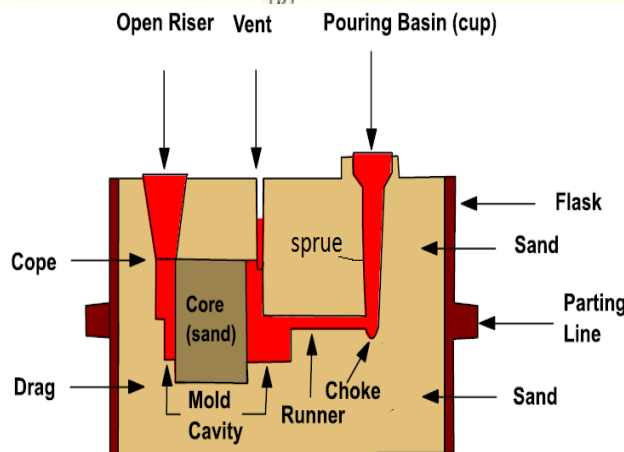
Runner: The channel through which the molten metal is carried from the sprue to the gate.

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.



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.

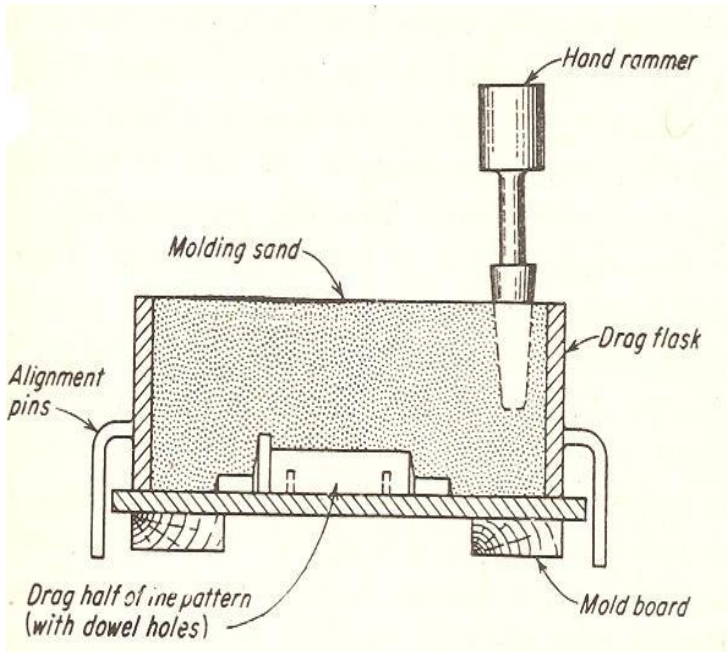
Melting and Pouring

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.

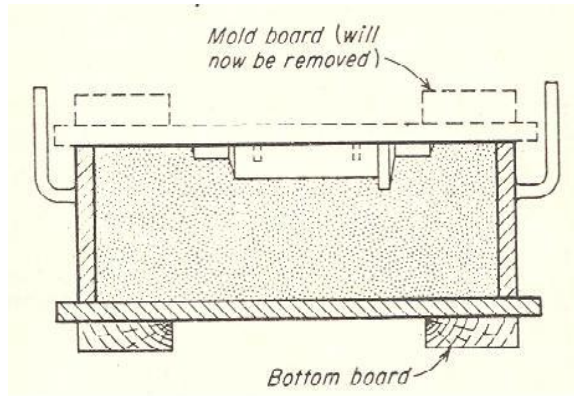
Making a simple sand mould



- 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.

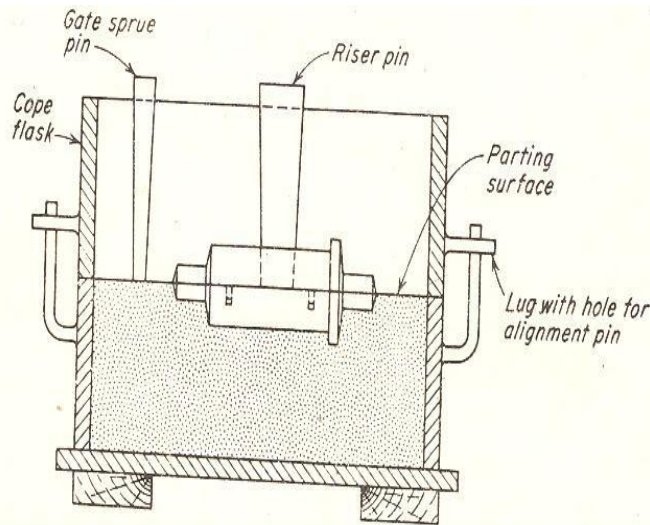
7) After the ramming is finished, the excess sand is leveled/removed with a straight bar known as strike rod.



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.

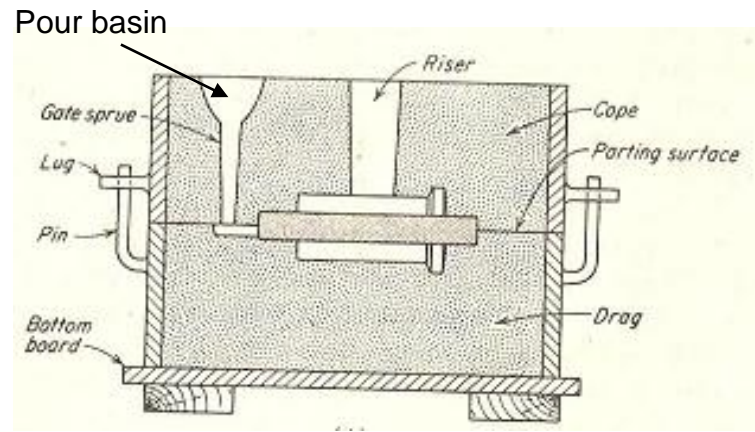
9) The finished drag flask is now made upside down exposing the pattern.

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.

Pattern

The pattern and the part to be made are not same. They differ in the following aspects.

1. 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

2. Shrinkage allowance: will take care of contractions of a casting which 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 loses 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

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

2. 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.
3. For a dimension ' l ', shrinkage allowance is $\alpha l (\theta_f - \theta_0)$. Here θ_f is the freezing temperature and θ_0 is the room temperature.
4. **Machining allowance:** 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	0.12
	12 to 20	0.20
	20 to 40	0.25
Cast steel	Up to 6	0.12
	6 to 20	0.25
	20 to 40	0.30
Non ferrous	Up to 8	0.09
	8 to 12	0.12
	12 to 40	0.16

5. Draft allowance:

All the surfaces parallel to the direction in which the pattern will be removed are tapered slightly inward to facilitate safe removal of the pattern. This is called 'draft allowance'.

General usage:

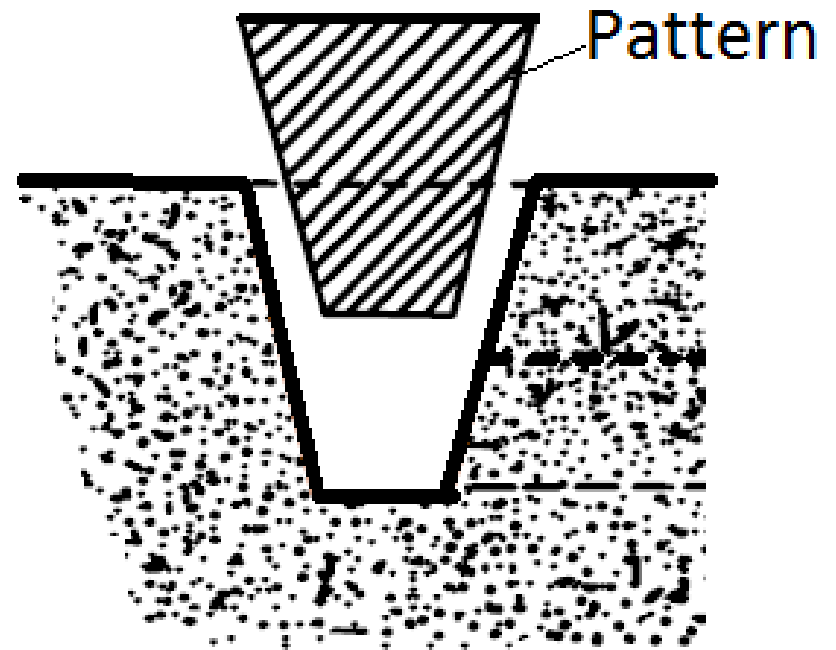
External surfaces ; Internal surfaces, holes, pockets

Typical Draft Allowances

Pattern material	Height of the given surface (inch)	Draft angle (External surface)	Draft angle (Internal surface)
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

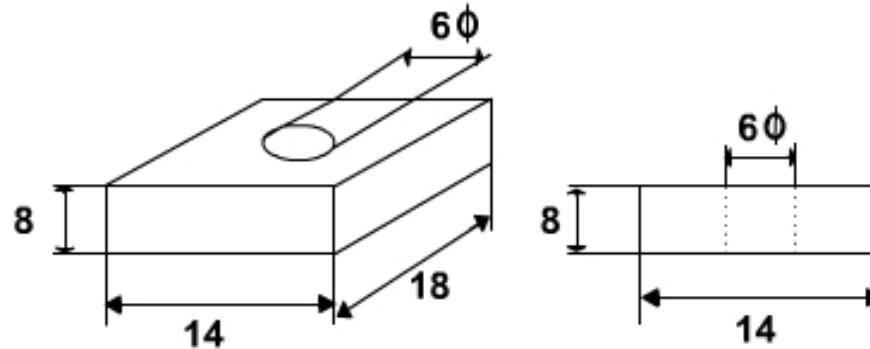
 **cracks**

Pattern having no draft on vertical surfaces

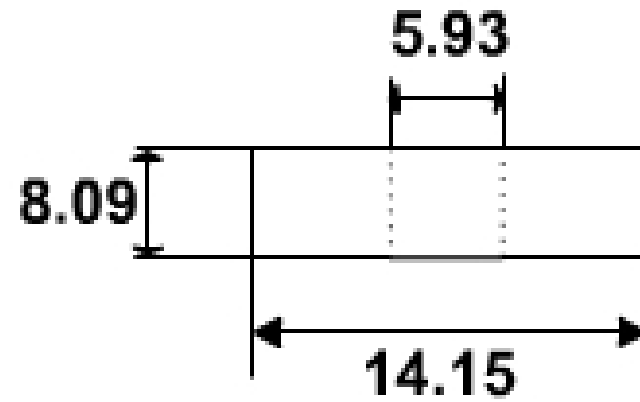
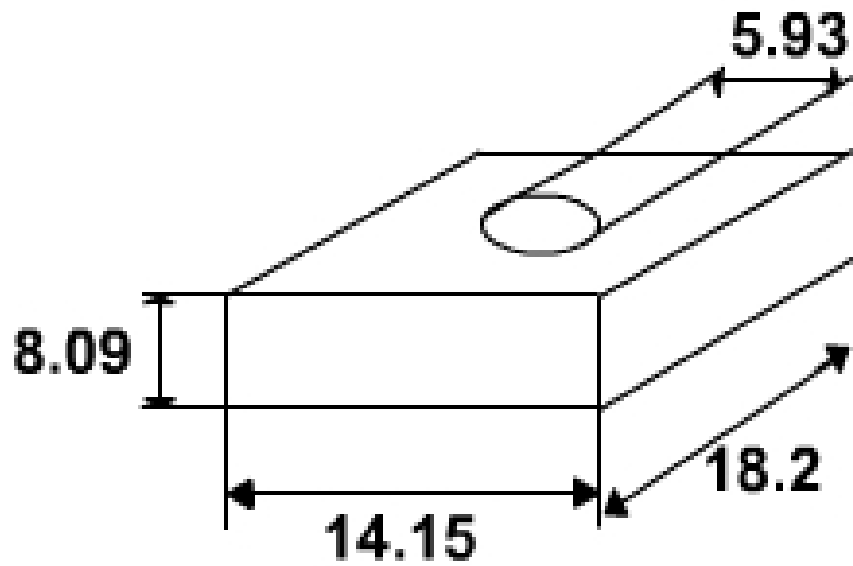


Pattern having draft allowance on vertical surfaces

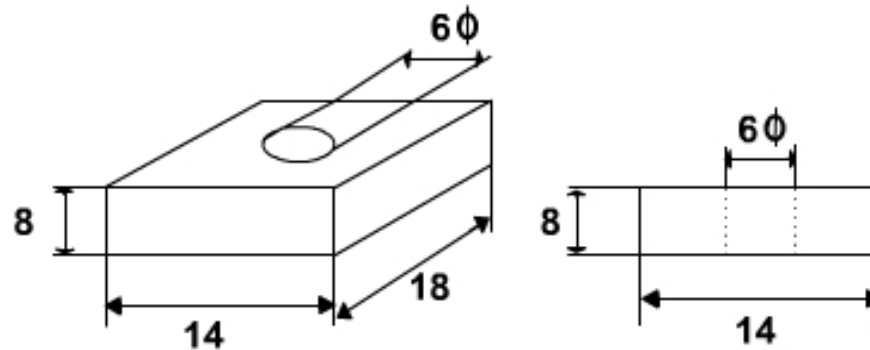
The casting shown is to be made in CI using a wooden pattern. Assuming only shrinkage allowance, calculate the dimensions of the pattern. **All dimensions are in inches**



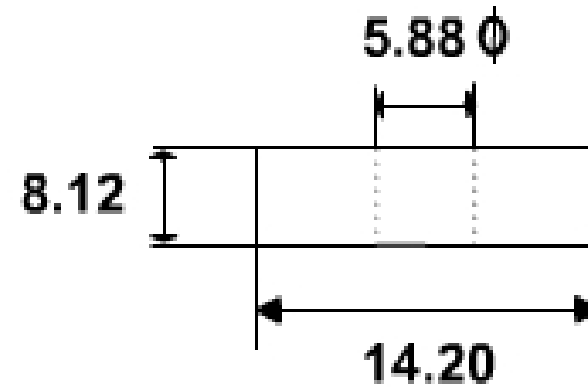
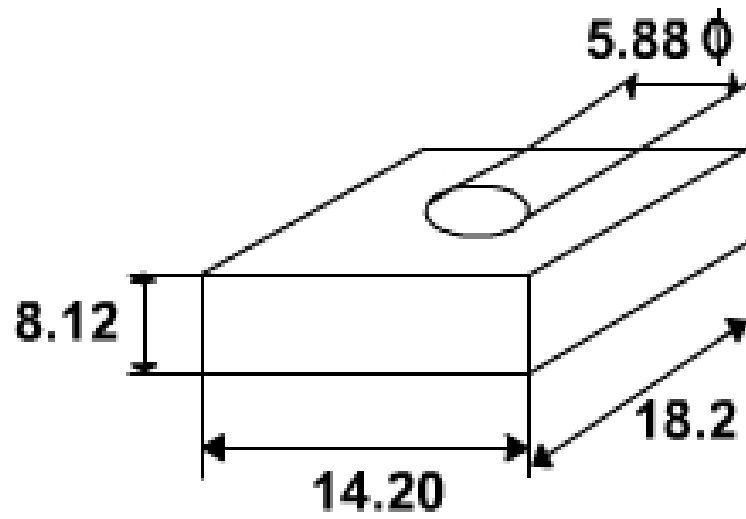
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The casting shown is to be made in CI using a wooden pattern. Assuming only machining allowance, calculate the dimension of the pattern. All dimensions are in Inches

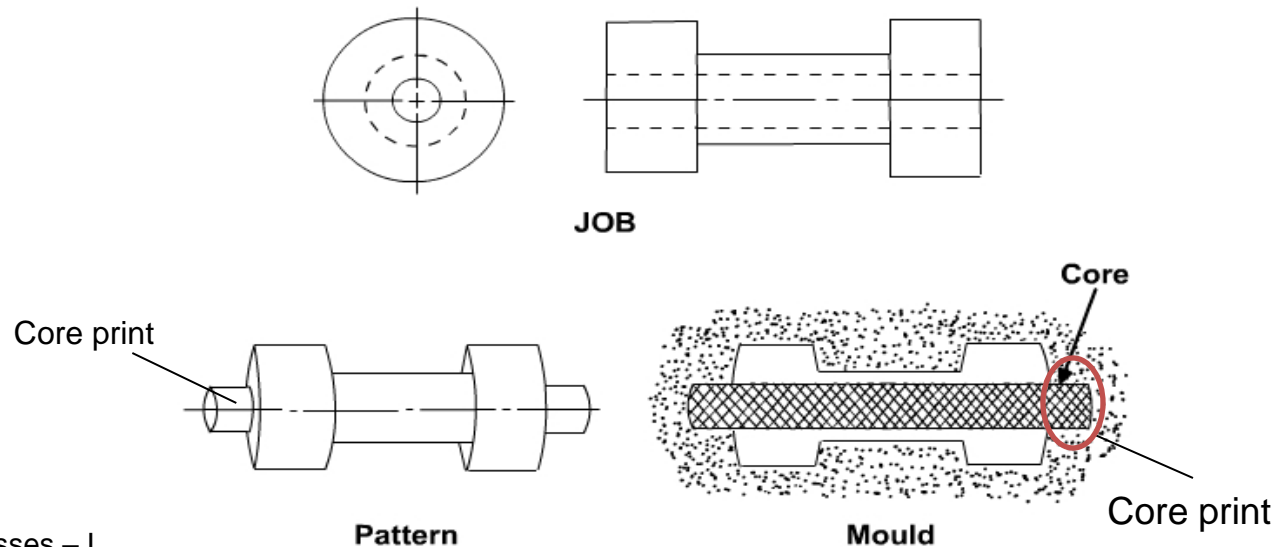


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6. Core and core print:

- Cores are used to make holes, recesses etc. in castings
- So where coring is required, provision should be made to support the core inside 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 can support the weight of the core during the casting operation.



7. Distortion allowance (camber)

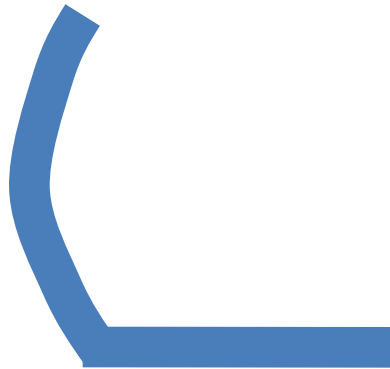
- Vertical edges will be curved or distorted
- This is prevented by shaped pattern converge slightly (inward) so that the casting after distortion will have its sides vertical
- The distortion in casting may occur due to internal stresses. These internal stresses are caused on account of unequal cooling of different sections of the casting and hindered contraction.

Prevention:

- providing sufficient machining allowance to cover the distortion affect
- Providing suitable allowance on the pattern, called camber or distortion allowance (inverse reflection)



Original casting

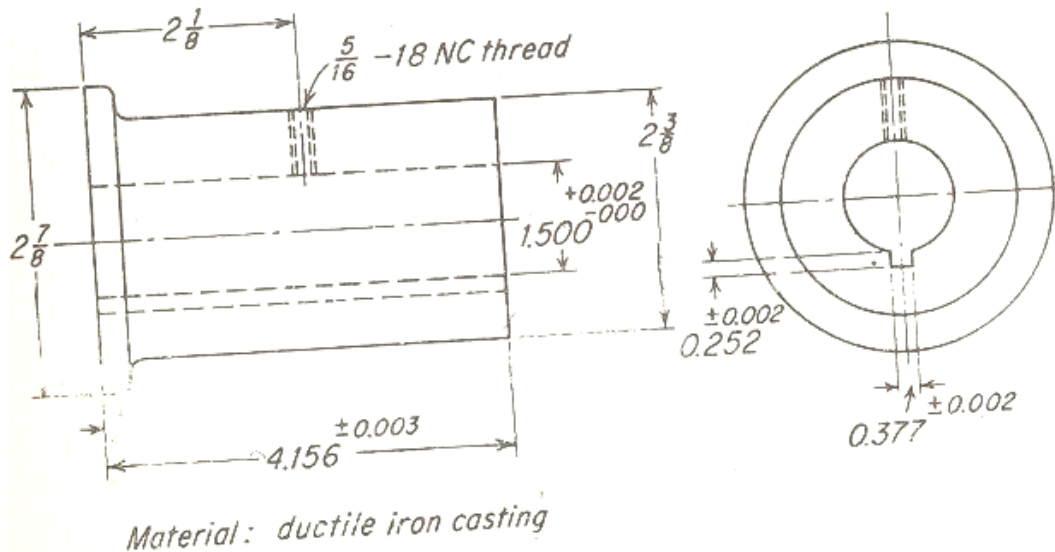


Distorted part



Cambered part

8. The tapped hole and slot will not be sand cast. They will be made by machining operations.
9. The pattern shown is made in two halves which are located by dowel pins. This is called '**split pattern**'.
10. **Pattern material:** wood => light, easily workable, minimum tendency for checking and warping



Pattern materials

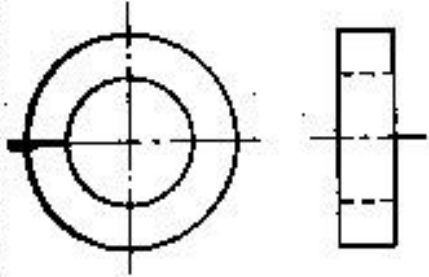
- Patterns for sand castings are subjected to considerable wear and tear due to ramming action that is required and the abrasive action of the sand
- Should be impervious to moisture because of changing surroundings
- Made of: wood, metal, plastics, plaster and synthetic materials
- Woods => white pine, sugar pine; The wood should be straight grain, light, easy to work, little tendency to develop crack and warp.
- More durable: Mahogany
- For large castings: metal such as cast iron or aluminium
- When metal pattern are cast from the wooden master pattern, double shrinkage must be provided on the wooden master pattern
- Assume metal pattern is made of aluminium and castings are made of CI, the shrinkage allowance for the wooden master pattern is:

$5/32$ inch per foot for Al+ $1/8$ inch per foot CI = $9/32$ inch per foot

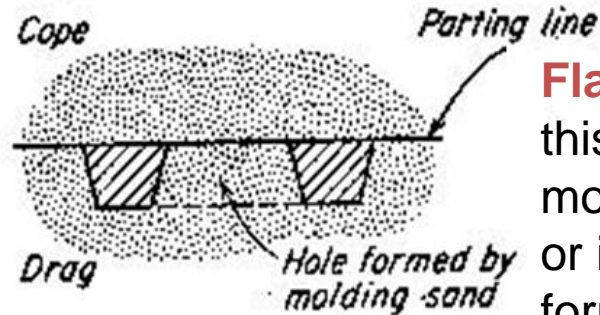
Solid shrinkage for cast metals

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Different ways for making a casting mold



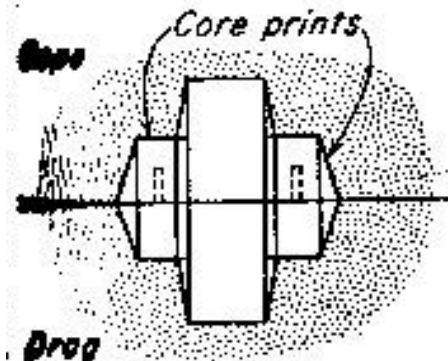
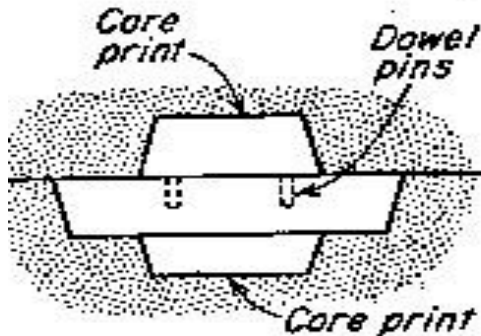
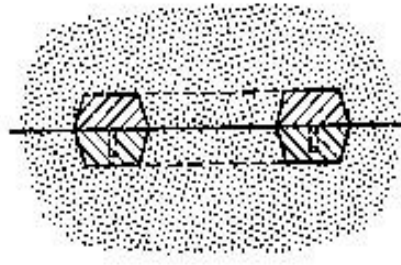
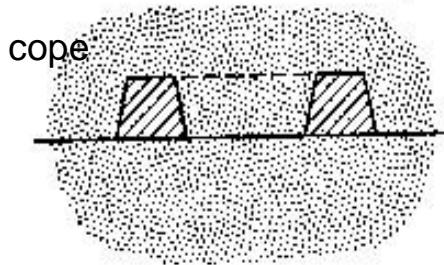
Simple bushing:
Sand casting to be molded



Flat back pattern can be used for this. In this after completing, the mold cavity is either in the drag side or in cope side or in both. The hole is formed by the molding sand.

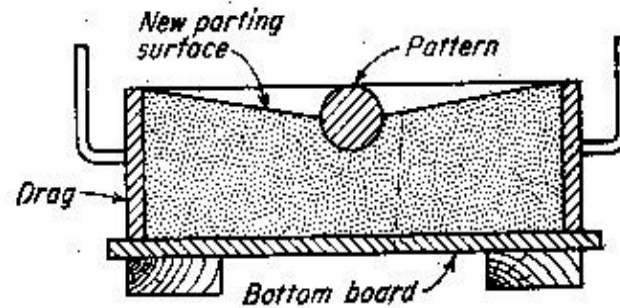
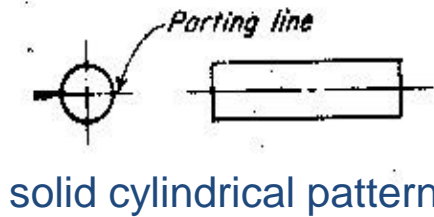
The outside edge around the flat back is the parting line and it is the starting place for draft.

This is the simplest and easiest method.



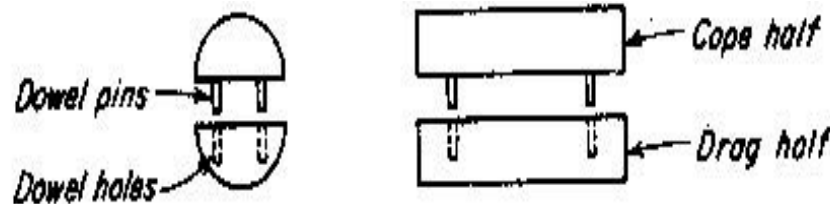
Using a dry sand core to obtain the core and this is split pattern. The axis of the hole (and core print) is vertical in first case.

The second case is same as first, except that the hole axis is horizontal.



Consider a solid cylindrical pattern as shown above. The pattern is placed on the molding board, rammed and rolled over. In order to withdraw the pattern from the sand, some of the sand is removed and smoothed as shown. This creates a new parting surface. Thus a parting line is made which joins parting line around the pattern. The operation of removing the sand and making a new parting surface is called 'Coping down'.

The mold is completed by ramming up the cope in a usual manner.

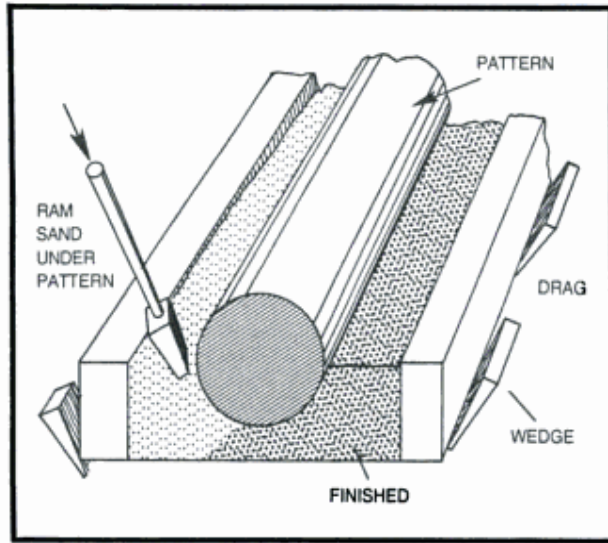


Split pattern for molding cylindrical casting

Other methods:

- cylindrical pattern standing on the end, if it were not too long
- cylindrical pattern can be molded using split pattern/mold also as shown in above figure.

Bedding-in method

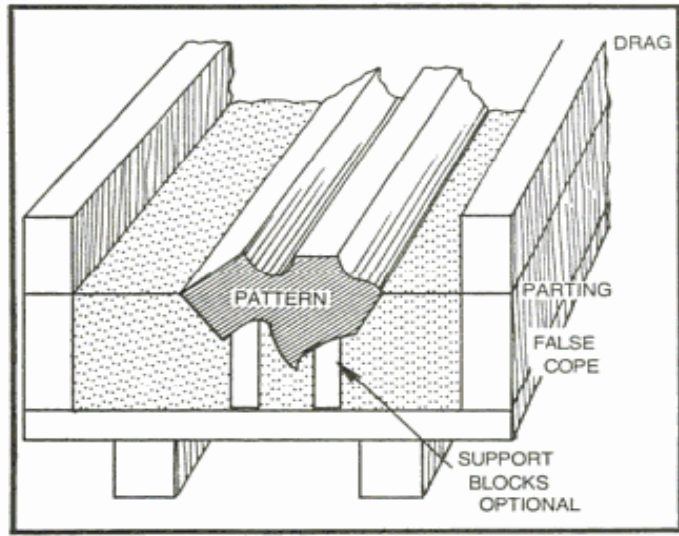


A complete handbook of sand casting, C.W. Ammen

- The solid cylindrical pattern can also be molded using 'bedding-in method'.
- In this method, first the drag is partially filled with molding sand and rammed.
- After sufficient ramming, the pattern is pressed into the sand. In this, to have proper ramming of sand, the sand close to the pattern is tucked and rammed tightly.
- Sometimes, the pattern is removed and the sand is surface tested for soft spots. In case of soft spots, ramming is continued with additional sand till the sand is packed tightly.

- The pattern is again pressed downwards to have a properly rammed mold cavity.
- Bedding-in is done so that the parting line is about level with the surrounding flat sand surface.
- Whenever a pattern is bedded-in, the drag need not be rolled over.
- Bedding-in can be employed for making larger molds using pit molding

False cope (sometimes called 'odd side')



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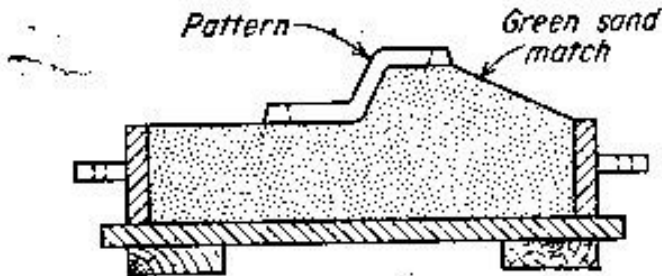
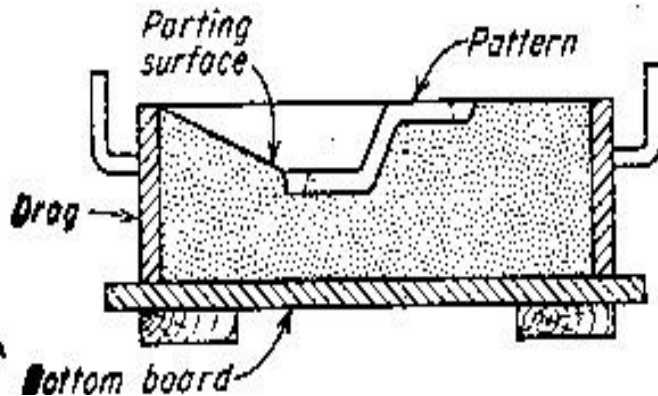
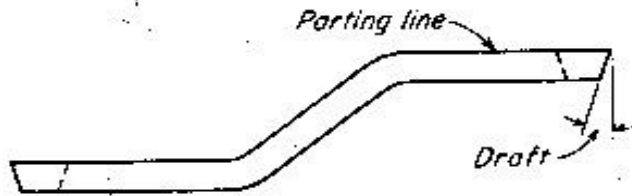
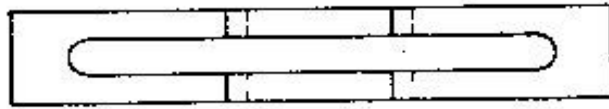
False cope technique is another method of molding the solid cylindrical pattern. This is similar to bedding-in method, except that it is not required to ram the sand tightly under the pattern, or the pattern shape is such that it is not possible to ram the sand tightly. The pattern is first bedded into the cope without giving importance to the ramming of sand beneath the pattern and a smooth parting surface is made.

The cope and pattern is then dusted with parting sand and drag part of flask is placed on top of the cope. Ramming is then completed in a usual manner.

The entire assembly is clamped and rolled over on a sand bed. The clamps are removed and the cope, cope bottom board are removed and destroyed.

The empty cope is then placed on the drag and usual ramming is performed. It should be observed that the cope, first used, is a dummy block for creating the drag correctly. This is called 'FALSE COPE'.

Green sand match



Green sand match ready for further drag making

The main reason for making a green sand match is that the coping down operations can be reduced to a greater extent, reducing the costs and time.

Take an example like a pattern with a parting line not lying in one plane (shown in first figure).

This pattern should be supported on a moldboard at the elevated end by a wood piece.

Once the ramming, rolling over and coping down are completed, the drag will look like as shown in second figure.

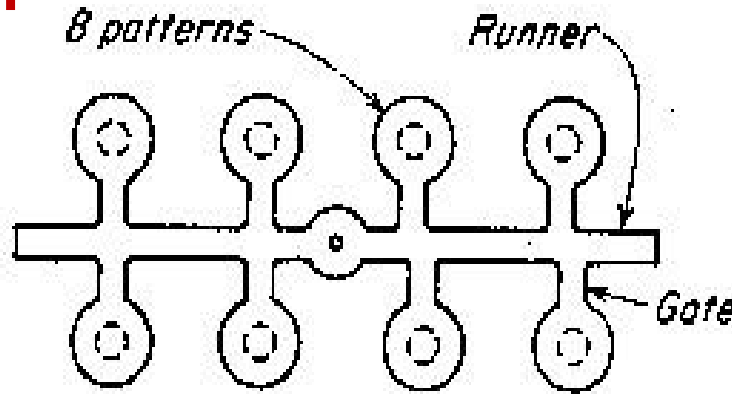
On top of this drag, a green sand match may be rammed up extra hard without sprue and riser pins.

The completed **green sand match** with pattern in place is shown in last figure.

The sand match is now retained with the uneven parting surface to support pattern and for further making of rammed drags.

Also called hard sand match, POP match, cement match

Gated pattern



Gated pattern for making eight small patterns

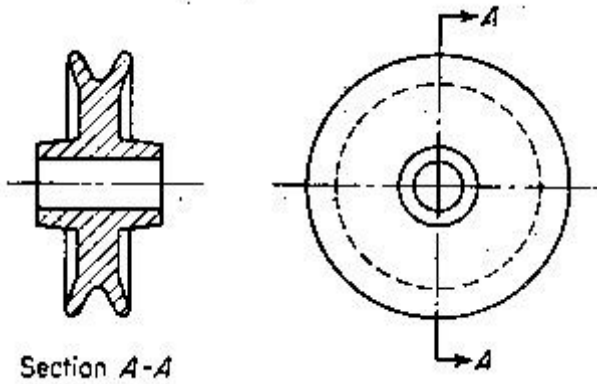
In this, the gate is made part of the pattern.

In general, a gated pattern consists of many small patterns fastened together through gating.

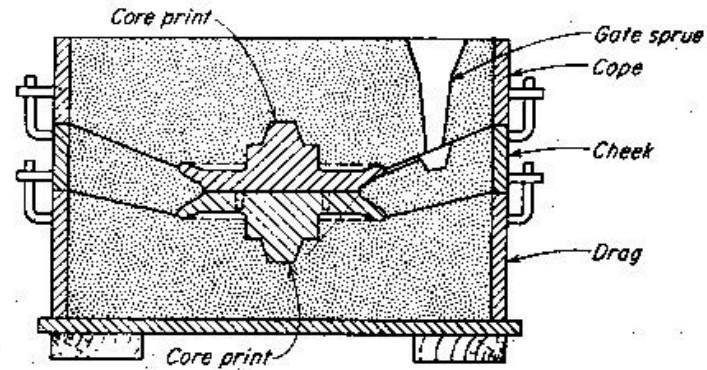
Since gates, runners are part of the pattern, time and cost are not spent in making them separately.

A number of patterns are rapped and drawn from the mold at the same time, saving additional time.

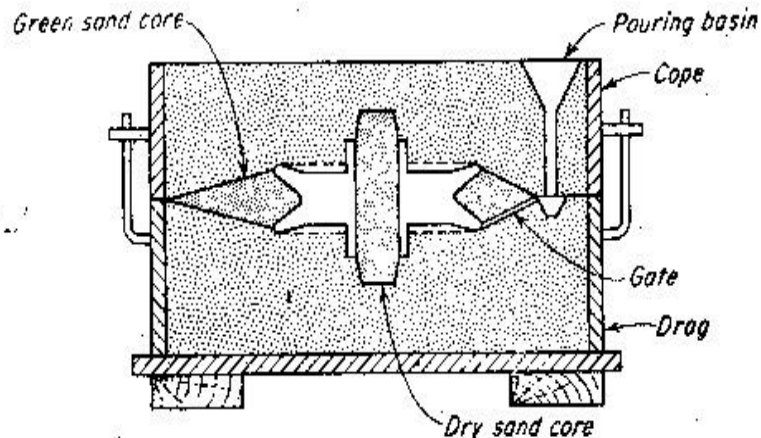
Patterns requiring two or more parting surfaces



Sheave wheel to be molded



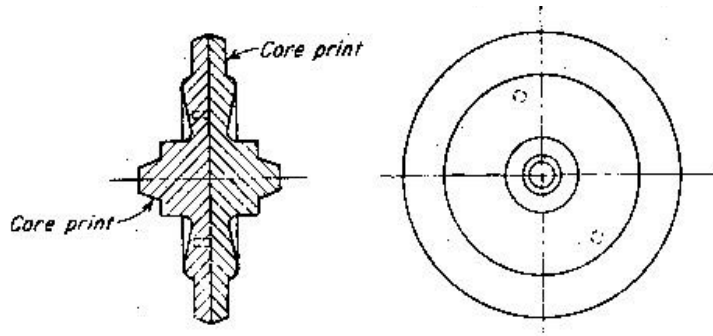
Three part mold for sheave wheel casting



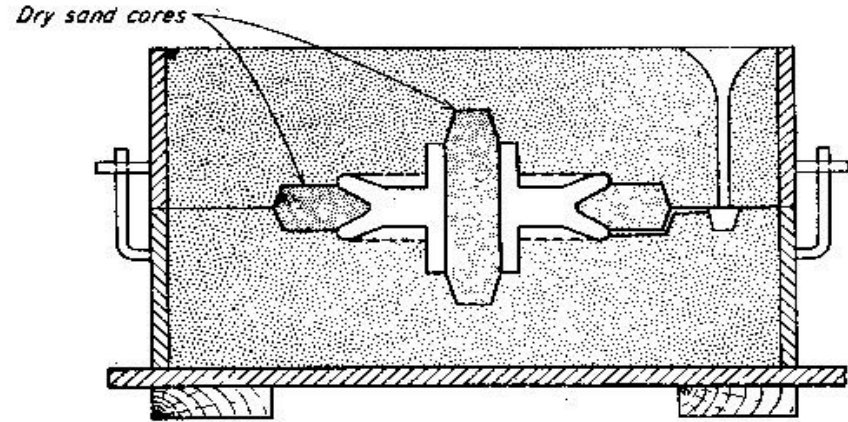
Using green sand core for making sheave wheel casting

- First method of making a sheave wheel mold is through three part flask, having a middle flask region called 'cheek'.
- another way is by using special green sand core.

Cores for exterior casting surfaces

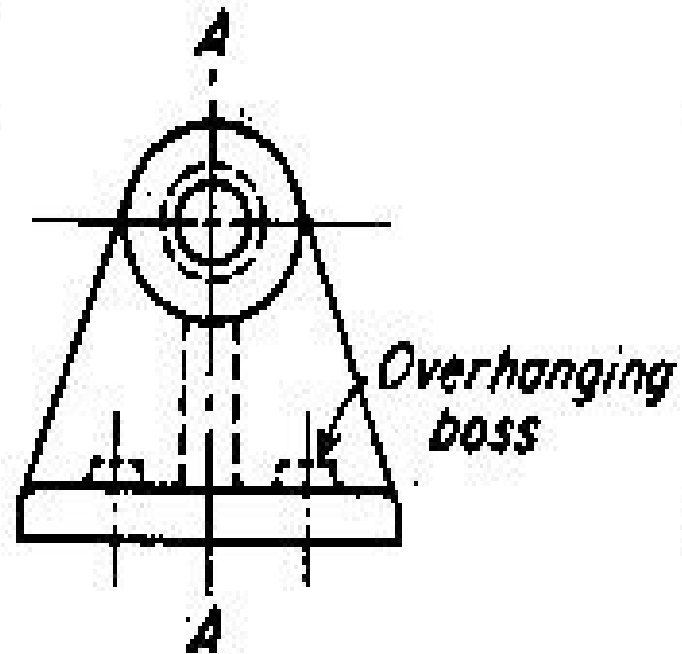
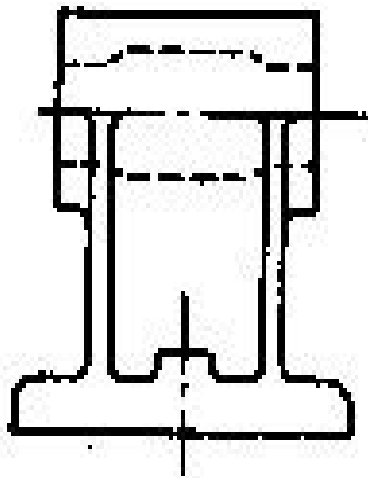


Pattern for making a sheave wheel casting using a dry sand core for groove making



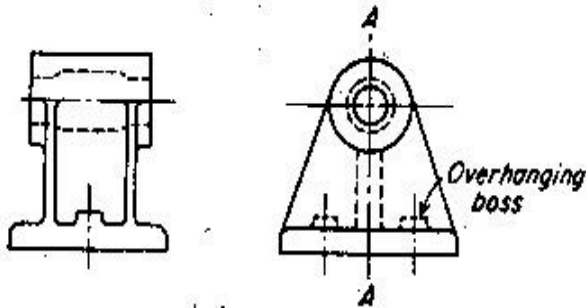
Mold with dry sand cores for making a sheave wheel casting

- Dry sand cores can be used for making the grooves
- Usage of core box is required for making core which makes this method not suitable below certain quantity
- For large quantity, this method is preferred

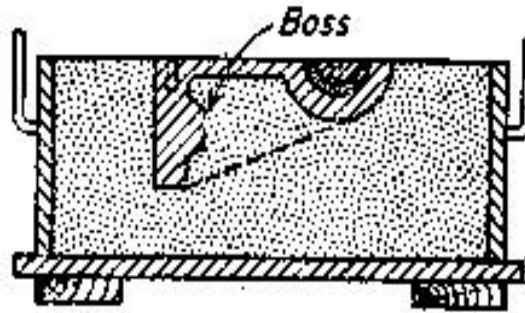


Bearing frame casting having overhanging bosses

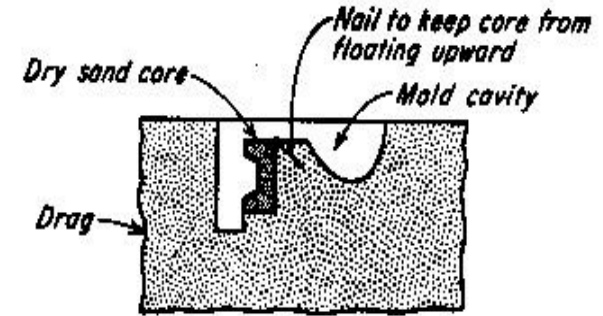
Cores for exterior casting surfaces



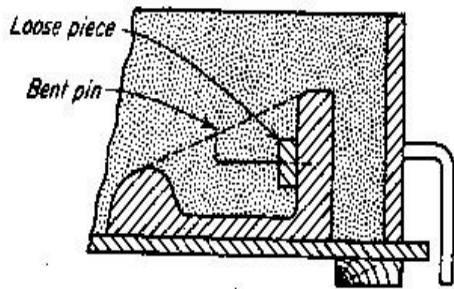
Bearing frame casting
having overhanging bosses



Drag showing half of the pattern
rammed up in the molding sand

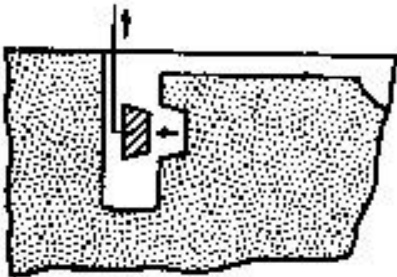


Using a dry sand core held
using a nail to produce a
boss



Using a dry core sand:

- The over-hanging bosses are made using core prints, dry sand core in place
- The dry sand core part is held in mold by using a nail to keep the core from floating upward. Chaplets can also be used (described later).

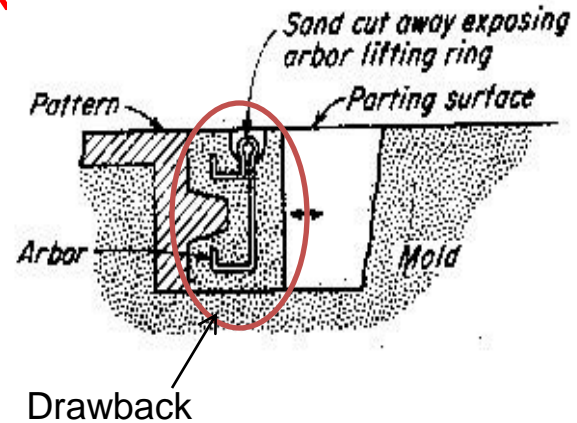
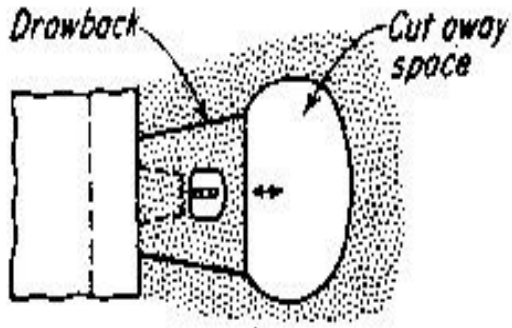


Using a loose piece:

- A loose piece is held by using a bent pin
- Ramming is done properly around the loose piece. Later pattern and pin are withdrawn carefully as shown.
- **Disadvantage:** shifting of loose piece while ramming
- Loose pieces are used in core boxes for making cores with backdraft (horizontal depression or projection)

Using a loose piece

Using Drawback



Drawback is employed for patterns with backdrafts (**horizontal depression or projection**).

A drawback consists of mold that can be drawn back in order to remove the pattern.

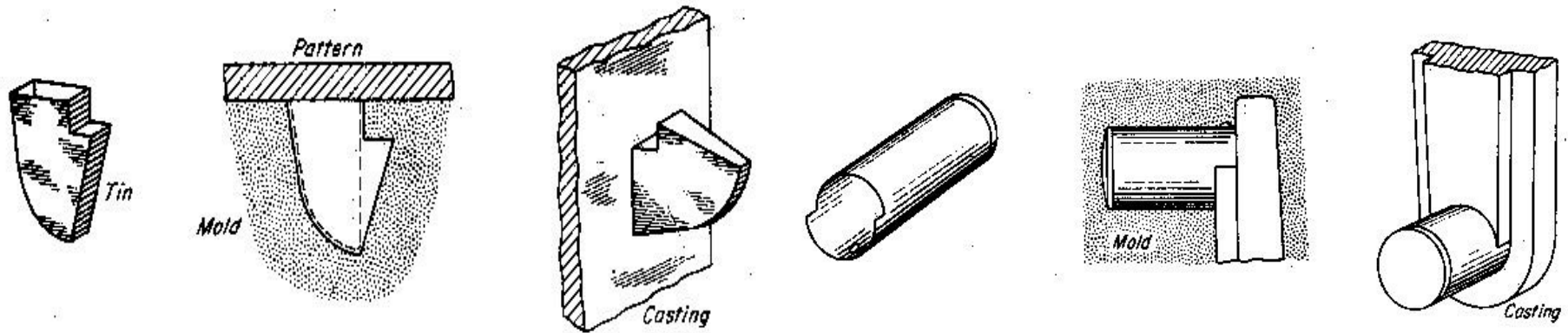
As shown in figure, a drawback is rammed around a rigid support called '**arbor**' that is used to move it.

Drawback is like a green sand core rammed up against the mold instead of making it in core box.

Once the pattern is removed, the drawback is located in the original place. It is backed up with additional sand so that it will not displace during fluid filling.

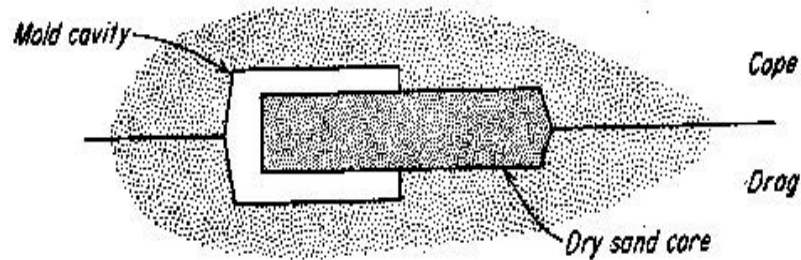
It is also used for large molds for certain castings.

Tins

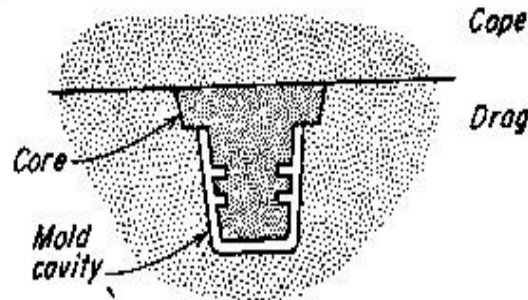
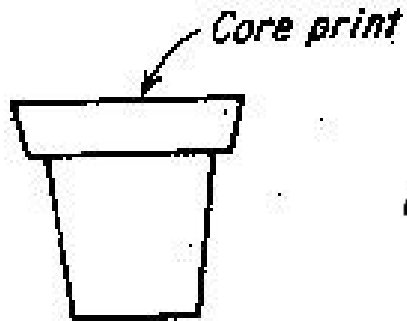


- Tins are made of sheet metal shapes that are used with patterns to make certain internal and external shapes, but at the same time patterns can be removed from the mold cavity
- They are thin hollow sheet metal shells that are attached to pattern before the pattern is rammed up in sand
- When the pattern is withdrawn, they remain in mold and should fuse into the casting
- For ferrous castings, a tin plated sheet steel of about 0.012 inch thick is used

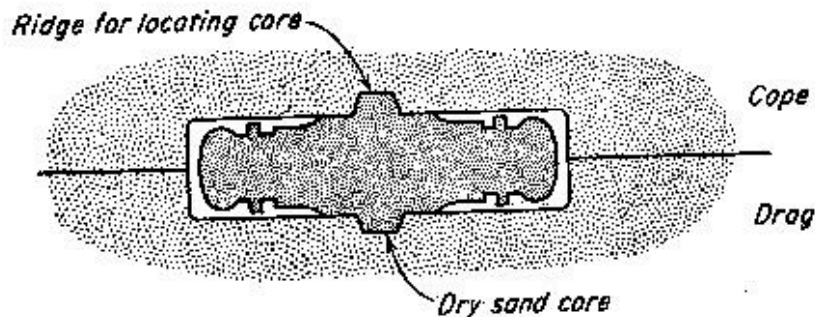
Core and core print



Where a core does not extend entirely through the casting, it should be fixed/balanced properly as shown. Too long cores can not be balanced properly.

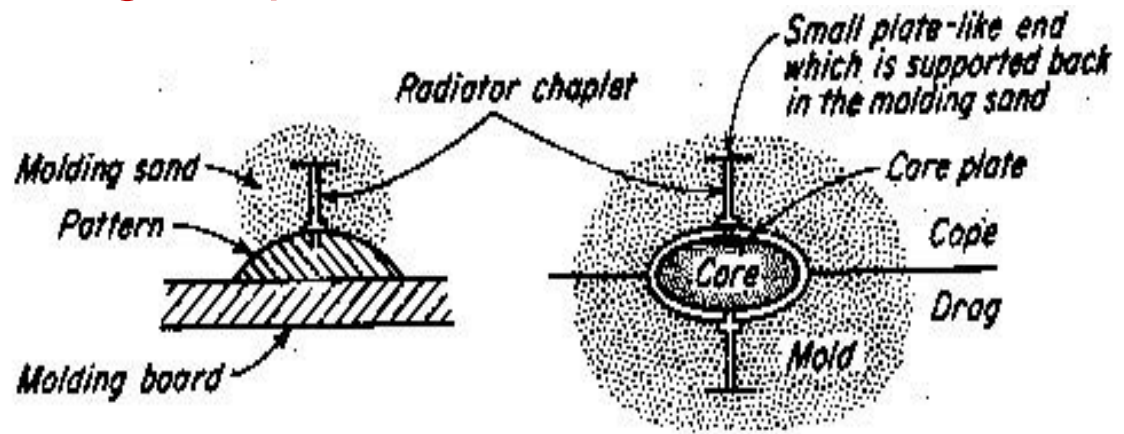
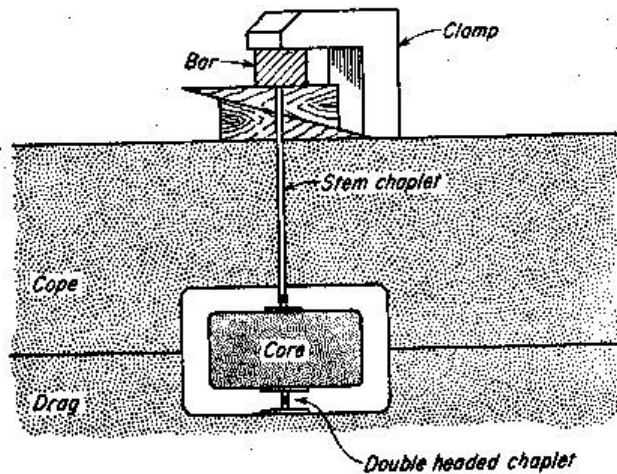


A pattern with a hanging core print is shown for making a piston. The core in the mold acts as a cover for mold cavity and hence cope is not needed.



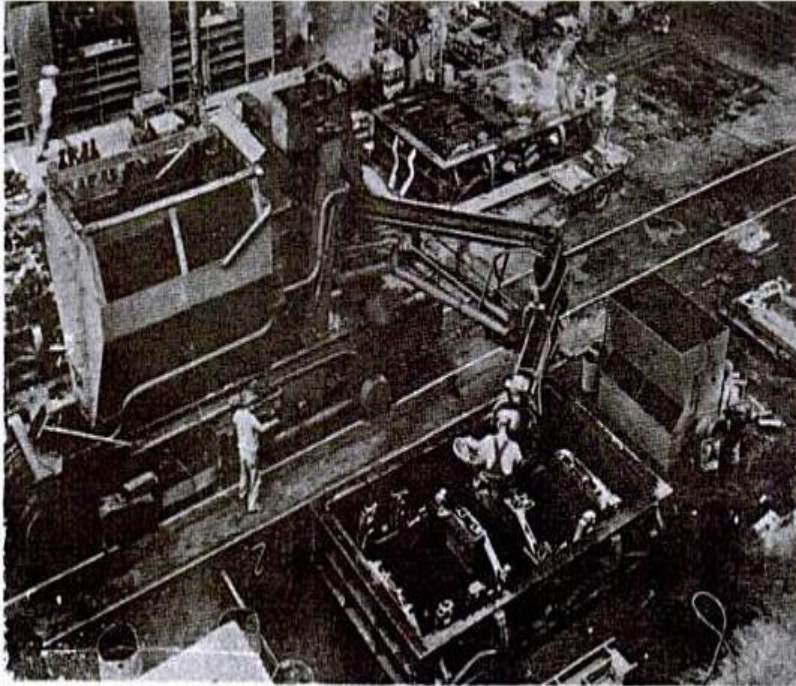
A method for molding two pistons at a time having one balanced core.

Using chaplets



- Chaplets are used to support a core and are placed between a core and the mold wall.
- As the mold is filled with molten metal, the chaplet prevents the core to float and move upwards dislocating from its position.
- The part of chaplet in mold will be fused into the casting.
- chaplets not fused properly will create mechanical weakness and mold wall leak.
- They are generally made heavier rather than lighter, such that they seldom unite with the surrounding metal.
- Tin or copper plated chaplets are used for ferrous castings to avoid rusting.
- Radiator chaplets having a flat square ends are fixed in the pattern itself and will provide good support to core along with rammed sand.

Ramming a large mold



- First few inches of sand over the pattern should be carefully rammed and tightly packed.
- soft spots, packets should be rammed properly
- Large mold of considerable depth should be rammed layer by layer
- Floor rammers that are heavy and measure up to 5 feet long can be used. The molder will stand on the rammed sand.
- Nowadays pneumatic rammer is operated by compressed air with a butt shaped end
- Ramming should be done as close to vertical surfaces of pattern

Pit molding

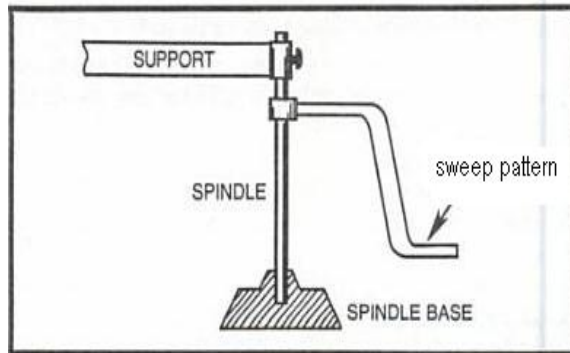


Pit mold for diesel engine

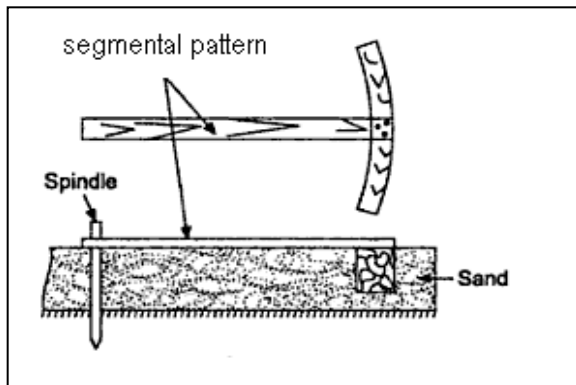
- Large castings are made in pits in foundry floor. Reinforced concrete is used to make sides and bottom of pits.
- a bed of charcoal is used at the bottom of a pit to aid the escape of gases.
- bedding-in technique may be used since rolling over of drag is not possible.
- appropriate placing of pattern is done.
- several cores can be used for making delicate shapes.
- Pit molding may take few days to weeks for completion, and hence binders are added to the molding sand which harden when air-dried.
- sometimes, the mold cavity is heated to harden with time, by placing a stove down into the mold cavity and covering the entire mold to keep the heat inside the cavity.
- slow cooling of molten metal is allowed so that the internal stresses can be minimized.

Low cost patterns for large molding

Meant for large, but few, castings: sweep, segmental pattern, partial pattern, skeleton pattern

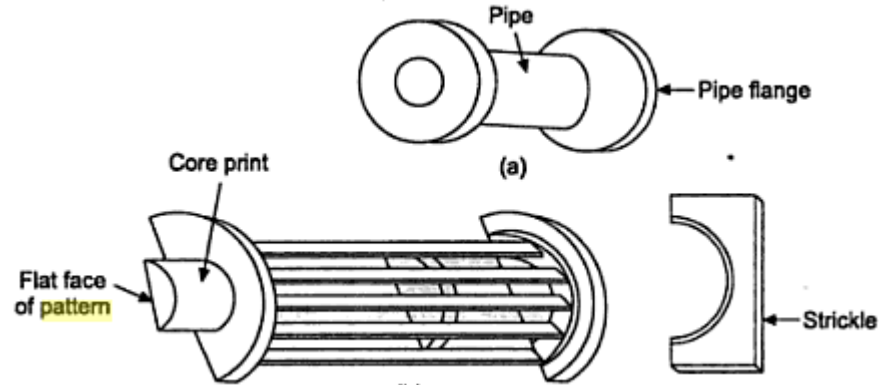
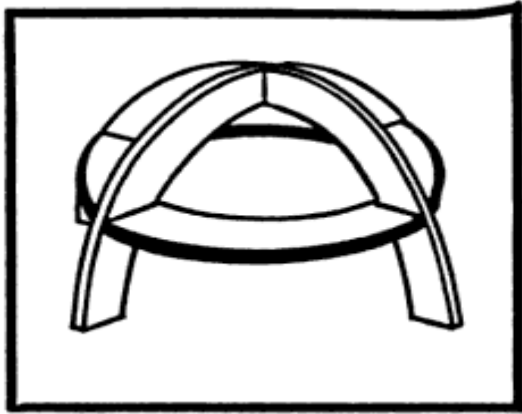


Sweep pattern: A sweep pattern consists of a board having a profile of the desired mold, which is revolved around a spindle or guide produces the mold. Two are used – one for sweeping the cope and other for drag.



Segmental pattern: meant for circular ring shaped large sections. Instead of using a full pattern, part pattern is used. Once molding is done at one place, it is rotated to the adjacent region and molding is done.

Skeleton pattern:



Manufacturing Processes, By Kaushish

This consists of frame of wood representing the interior and exterior forms. Strickles (like strike off bars) are used to remove excess sand which is purposely rammed with extra thickness than required for desired mold surfaces

Loam molding: Loam consists of 50% clay as compared to ordinary molding sand. Mixed consistently to resemble mortar. Loam is applied on the surface of the brick framework. The molds are dried in ovens before put into use.

This was used for making casting bells for cathedrals or cannons for war in 13th century

Ingredients used in sand for making molds/cores

Refractory sand grains	Binder	Facing material	Cushion
Silica Zircon (has chilling properties) Olivine Magnesite Dolomite Illimanite Carbon Coke	For bonding materials see next table <i>Note:</i> Clay required with practically all binders.	Sea coal Pitch (dry powder) Graphite Coke Silica flour	Wood flour Cereal hulls Cereal Cellulose Sea coal Coke Perlite (a siliceous lava, quick heating causes bubbles of steam, also has insulating properties)

Binders Used in Sand Casting for Molds, Cores

Clays:

- Fire clay (kaolinite)
- Southern bentonite (calcium montmorillonite)
- Western bentonite (sodium montmorillonite)
- Secondary mica clays (illite)

Oils:*

- Vegetables (e.g. linseed oil)
- Marine animal (e.g., whale oil)
- Mineral (used for diluting oils given above)

Synthetic resins, thermosetting: *‡

- Urea formaldehyde
- Phenol Formaldehyde

Cereal binders made from corn:*

- Gelatinized starch (made by wet milling, contains starch and gluten)
- Gelatinized corn flour (made by dry-milling hominy)
- Dextrin (made from starch, a water-soluble sugar)

Wood –product binders: *‡

- Natural resin (e.g., rosin, thermoplastic)
- Sulfite binders (contain lignin, produced in the paper pulp process)
- Water-soluble gums, resins, and organic chemicals

Protein binders (containing nitrogen):*

- Glue
- Casien

Other binders:

- Portland cement[†]
- Pitch (a coal-tar product)^{*†}
- Molasses (usually applied in water as a spray)
- Cements (e.g., rubber cement)[†]
- Sodium silicate (water glass, CO₂ hardening binders)[†]

* Harden by baking.

† Harden at room temperature.

‡ Available as either a liquid or a dry powder.

Natural and Synthetic molding sand

Natural molding sand:

This is ready for use as it is dug from the ground. Good natural molding sand are obtained from Albany, New york etc.

The following average compositions are seen in natural molding sand:

65.5% silica grains, 21.7% clay content, 12.8% undesirable impurities.

Too much clay content and other impurities fill up the gaps between the sand grains. This will hinder the necessary passage of steam and other gases during pouring of the mold.

Synthetic molding sand

Synthetic molding sand is made by mixing together specially selected high quality clay free silica, with about 5% of clay. They are tailor made to give most desirable results.

Some of the advantages of synthetic molding sand are:

1. Refractory grain sizes are more uniform,
2. Higher refractoriness (= 3000°F),
3. less bonding agent is required (about 1/3rd of the clay percentage found in natural molding sand),
4. More suitable for use with mechanical equipment

Advantages of natural molding sand: 1. moisture content range is wide, 2. molds can be repaired easily

Core making

- Generally Cores are used for making interior surfaces of hollow castings and now-a-days it is used for making exterior surfaces and for other purposes.
- Green sand cores contain ordinary molding sand and dry sand core contains hardened or baked sand.
- Core mix contains clay free silica sand. This is suitably mixed with binders, water and other ingredients to produce a core mix.
- Synthetic core binders have some unusual properties like shorter baking times and excellent collapsibilities which reduces the defect castings.
- Urea formaldehyde binders burn out faster and collapse at lower temperature as compared to phenol formaldehyde binders. Thus urea formaldehyde binders are suitable for use at lower temperature metals like Al, Mg, thin sections of brass, bronze.
- Phenol formaldehyde binders are employed for thick sections of CI, steel castings

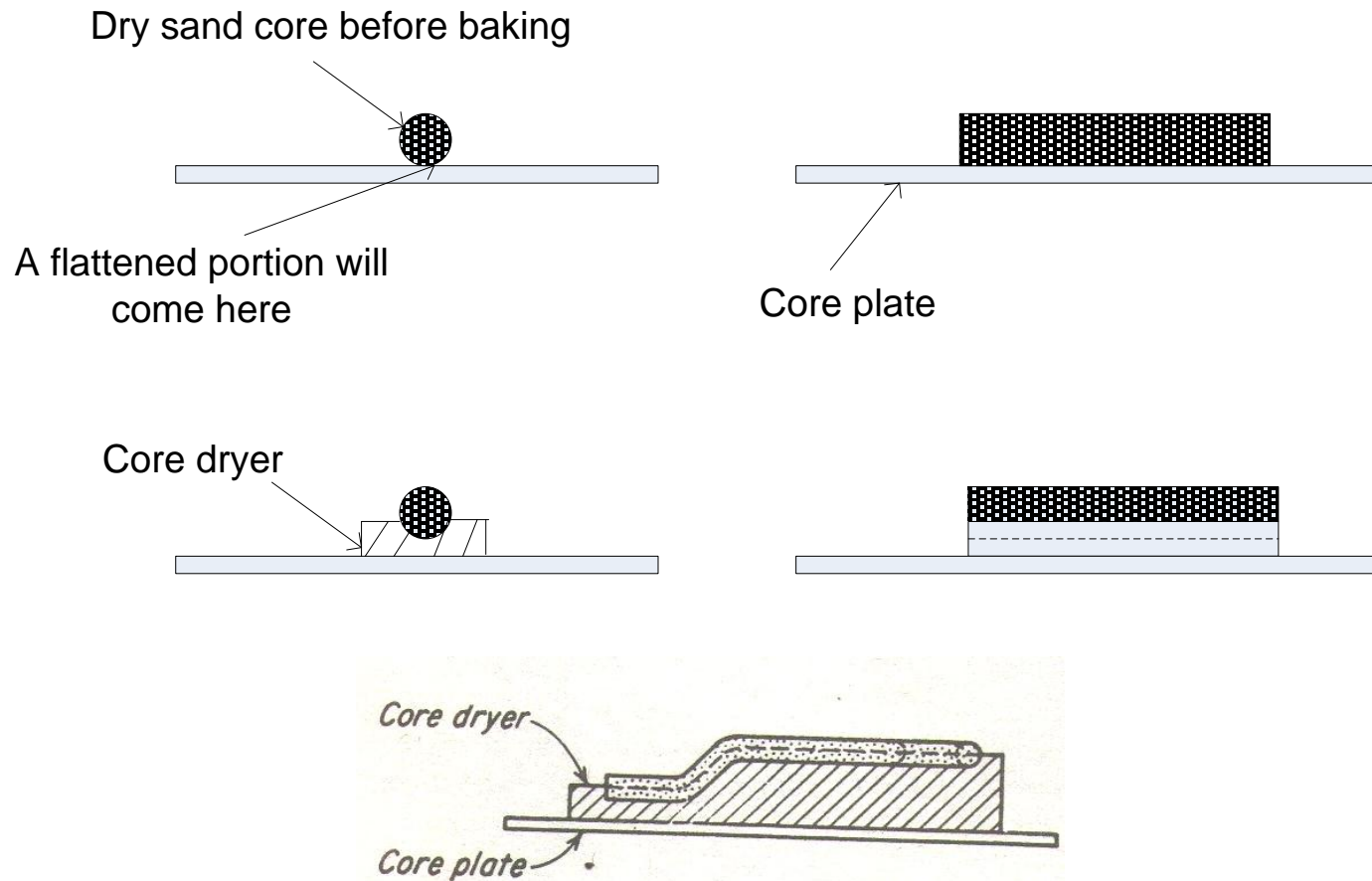
Core characteristics

Good dry sand cores should have the following characteristics:

1. Good dry strength and hardness after baking
2. Sufficient green strength to retain the shape before baking
3. Refractoriness
4. Surface smoothness
5. Permeability
6. Lowest possible amount of gas created during the pouring of casting

Core dryers

- cores must be supported properly in the green state, before they are baked, hardened.
- Curved surfaces of the cores will be flattened if placed on the flat core plates
- Cores should be prevented from sagging and breaking
- Flat surfaces are required for supporting the cores. These are called 'Core dryers'. They are designed to support the cores.



- Core dryers may be made as metal castings, with thin sections in order to absorb minimum heat.
- They are perforated for easy escape of gases.
- For large quantity production, many core dryers are required.

Loose pieces in core boxes

- Loose pieces are required for cores having backdraft on vertical sides. Such a loose piece will form an entire side of the core.
- The loose piece remains on the core, which will be removed later by horizontal movement.

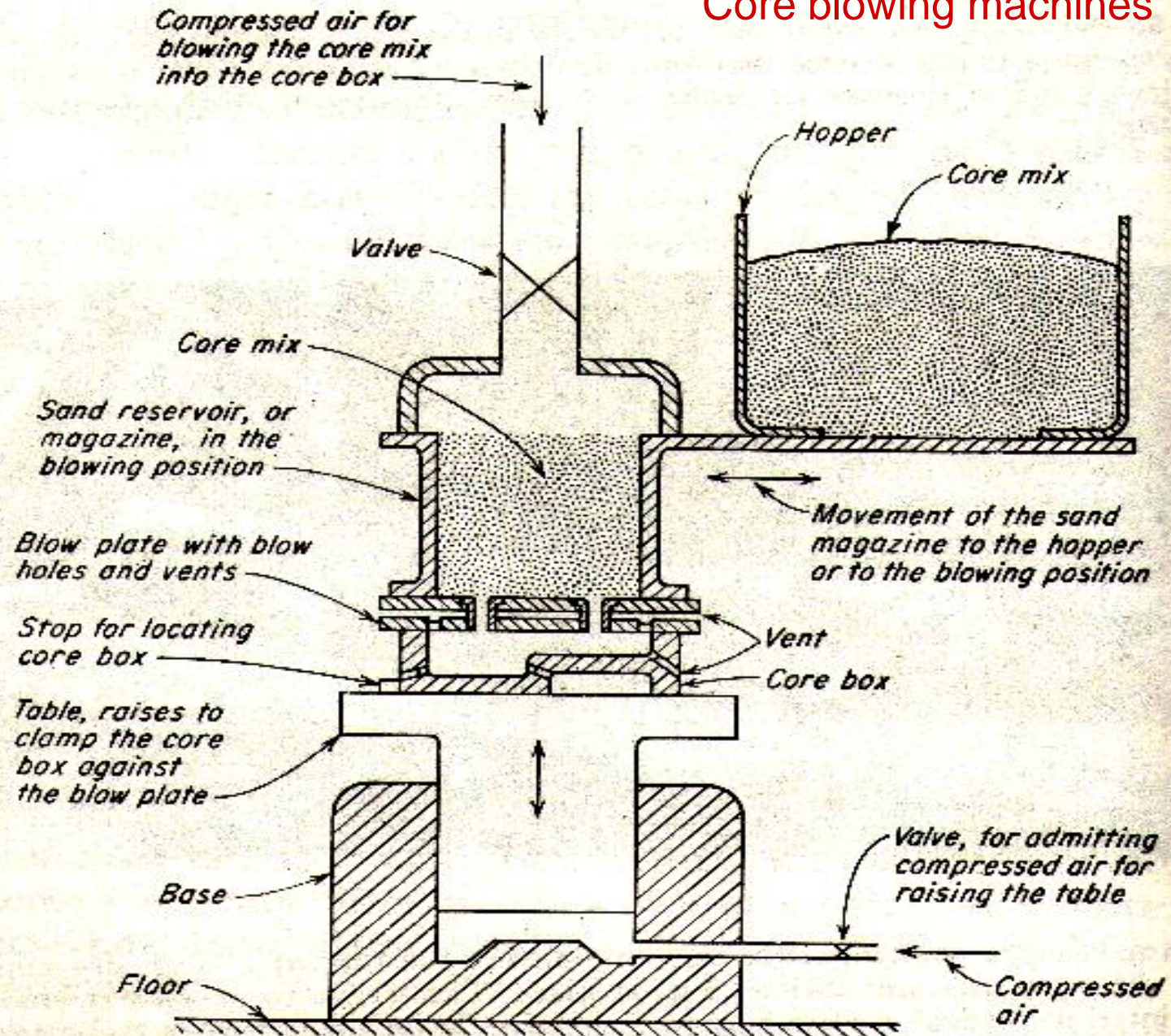
Core wires, rods, arbors

- Small core have sufficient strength after baking to withstand the molten metal upward force. For iron castings the lifting force is four times the weight of a core.
- Certain cores and slender cores which do not have strength are supported by embedding wires, rods, arbors into the core sections.
- Wires are meant for small cores, where as arbors are CI or steel based skeleton structures. Removing arbors is an issue here, sometimes arbors are made in parts, bolted together to facilitate easy removal. Hooks are provided in the arbors for easy removal. They sometimes project outside the core prints.

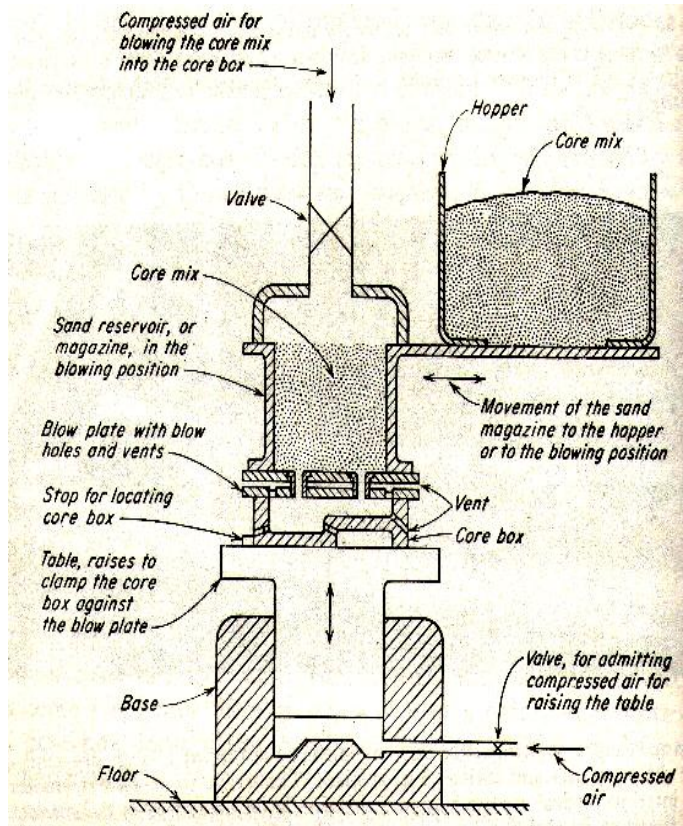
Core venting

- Proper core venting is required especially if the cores are surrounded largely by molten metal. The cores containing binders will produce gases, steam because of the heat generated due to molten metal.
- These gases should be vented out through core prints so that defects like 'blows' can be avoided.
- Large cores are sometimes made hollow.

Core blowing machines



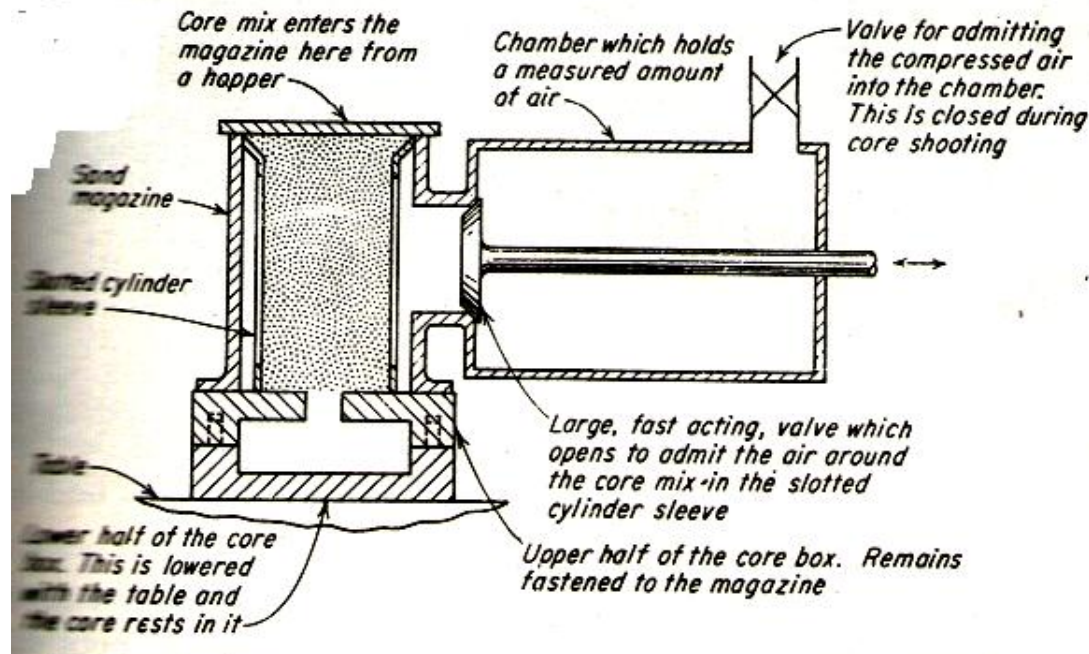
Core blowing machines



- Core blowing machines are mainly suitable for large quantity parts manufacturing.
- The sand reservoir is first moved below the hopper, where it is filled with sand.
- The sand reservoir is then moved to the blowing position. The core box is placed on the table and pressed up with the blow plate.
- The core box is rapidly filled with sand using a blower at the top with the help of compressed air at high pressures.
- The air thus got trapped in the core box is vented out by suitable vents provided in the core box.
- It is generally understood that because of blowing operation, larger grains tend to move to the interior of the core and finer grains at the surface, creating a smoother surface.

Core box equipment for core blowing

- Core box should be complemented with core dryers for proper support, a blow plate to fasten to the reservoir
- The core box contains blowing holes and the number, locations, size of the blowing holes are important in proper filling of the core box. This prevents the presence of soft cores and soft spots.
- vent area to blowing hole area is 5:1
- Sometimes the sand grains may not be conveyed properly due to the presence of entrapped air channels.
- For continuous operation of the machine, many duplicate core boxes should be used. Conveyors are also used to handle the operations properly.
- The upper half of the core box is sometimes used as the blow plate that is fastened to the sand magazine.
- **CORE SHOOTING** can also be used to prevent some of the difficulties of core blowing.



CORE SHOOTING MACHINE

- Compressed air is admitted into the chamber and the chamber is closed during core shooting
- large, fast acting valve is opened to admit the air around sand magazine
- this pressurizes the core mix and because of which sand gets filled in the core box

Core baking

- After cores are made and placed on the core dryer, they are taken to ovens for baking
- Baking removes moisture and hardens core binders
- generally core sand is a poor conductor of heat and hence heat penetrates slowly into the interior sections of the cores
- In a core having thin and thick sections, the thin sections will be over baked, while thick sections will be optimally baked
- Over baking of cores will result in destroying the binders and hence core will be just a heap of sand
- Large core will be baked differently on the surface and in interiors, especially if the oven is too hot
- cores that are not baked fully will create an excess of gas and cause blows in castings

Core ovens

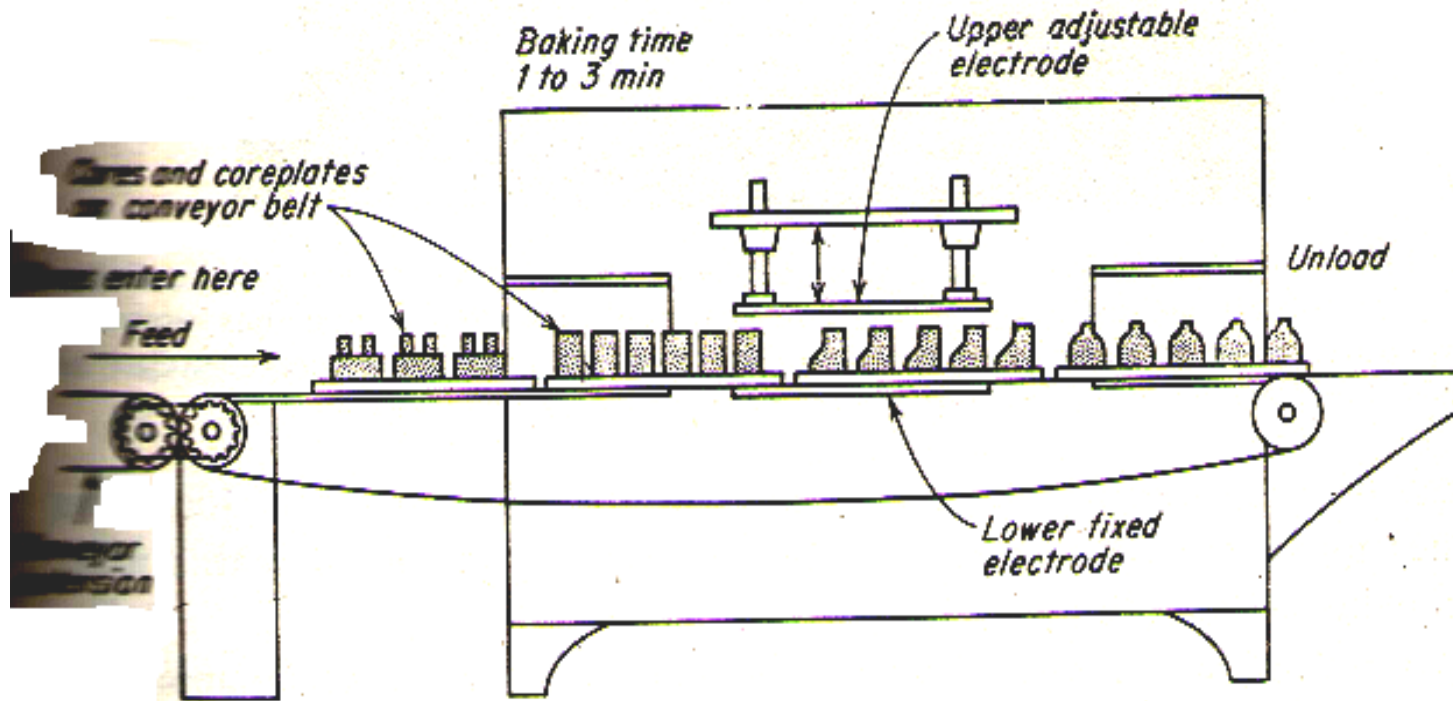
Continuous ovens:

- Are those through which the core moves slowly on the conveyor.
- Continuous loading and unloading is followed and hence the baking time is controlled by the rate of travel of the conveyor.
- Generally same sized cores are used in this.

Batch type ovens:

- No movement of cores occur
- Electricity, gas, oil are used for heating and temperature is maintained uniformly and closely controlled by suitable instruments.
- Temperature is of the order of 450°F and this depends upon the binder.
- heating elements are properly spaced to have uniform/same temperature distribution throughout the container.
- replacing new air from outside is done through blowers so that moisture can be controlled.

Dielectric core baking



J S Campbell, *Principles Of Manufacturing Materials And Processes*

- Rapid baking is possible by dielectric heating.
- Induction heating: used for heating materials which are conductors of electricity, like metals, and is done in continuously varying magnetic field.
- Dielectric heating is done for non-conductors of electricity. In this alternating electric field is established betn two parallel plates which act as an electric condenser.

- The material to be heated is placed in between these parallel electrodes
- With a high frequency electric current (15 million times/sec) in ON condition, heat is generated into the molecules.
- IN this case, the interior of the cores are heated rapidly as outer surfaces.
- Thermosetting synthetic resin binders, which cure app. at 250°F and which do not require oxidation are well suited for dielectric heating.
- Small sized samples can be baked within 30 secs, while large sections need few minutes
- less chance of over baking or under baking

Core coatings

- A fine refractory coating or facing is generally applied on the core surface by spraying or by dipping the core into a tank containing facing liquid
- this is done to have a smoother cast surface by preventing the penetration of molten metal into spaces between sand grains.
- **Facing materials:** finely ground graphite, silica, zircon flour
- after coating, the layer is dried, usually by torches, burners

Green sand cores

- Yield considerable cost savings.
- Handling them and keeping them in mold is tricky.
- **Method 1:** A green sand core can be rammed up on the dry sand core base.
- **Method 2:** Ram the green sand core around an arbor, by which it can be lifted.

Sand testing

Criteria used for sand testing:

Moisture content, green and dry sand permeabilities, compression, tension, transverse and shear strengths, deformation during compression tests, green and dry hardness, clay content, grain-size distribution, combustible content, pressure, volume of gases evolved, flowability, sintering point, resistance to spalling etc.

Moulding sand preparation and moisture content determination:

The moisture content controls practically all other properties of the sand. It is a varying property since water content constantly evaporates during mold preparation.

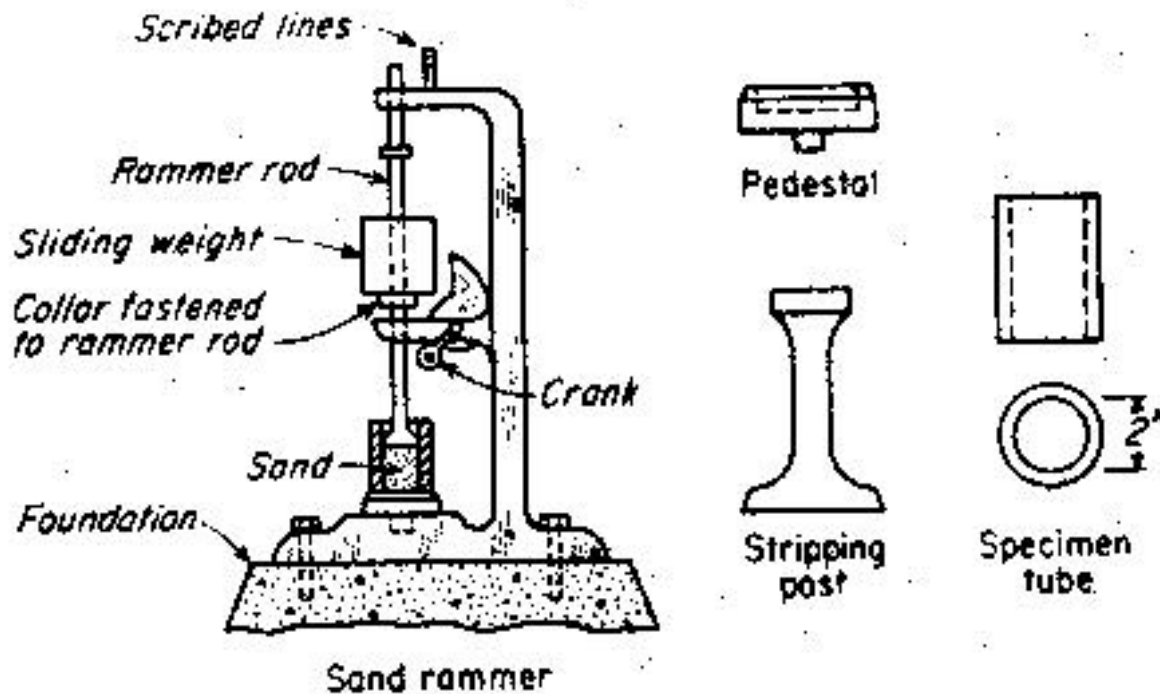
Purpose: adding sufficient water to bring the moisture content to within desired limits, uniform distribution of water, adequate coating of colloidal clay to each sand grain.

Moisture content determination:

- The simplest method is to dry a sample thoroughly at a few degrees above 212°F and to consider its loss in weight as moisture.
- Drying can be done in a thermostatically controlled oven or in a instrument designed for this purpose
- There is one MOISTURE TELLER which blows air through a 50 gm sample of sand that is placed in a plate.

Testing rammed sand:

- Green permeability, green compression and few other properties are tested when the sand is in rammed condition.
- The rammed densities should be within some range which is actually encountered in the sand molds
- A predetermined weight of sand is placed into the hardened steel tube, which is closed at the bottom by a pedestal
- actually the tube filled with sand and the pedestal are weighed
- the entire set up is placed into the sand rammer and the rammer is dropped few times depending on particular standards, like three times etc.



J S Campbell, *Principles Of Manufacturing Materials And Processes*

- the weight used will be a standard one. Depending on the ramming times, a standard density is obtained.
- once the ramming is completed, the height of the rammed sand is evaluated and this should be equal to 2 inches in length. If it is equal to this height, required density is expected to be in the rammed sand.
- If the sand height is outside the range, the entire procedure will be repeated.

Green compression strength

The sand specimen is compressed between two plates connected to the ram of the universal testing machine.

The load at which the sand sample breaks will give the compression strength.

The same tests can be performed at high temperatures in furnaces to find the compression strength at elevated temperatures.

Deformation and green hardness

During compression tests, the deformation of the sample can be recorded. The toughness can be obtained from its ultimate strength times its corresponding deformation.

Green hardness is the hardness of the rammed sand that is measured by hardness tester like Brinell hardness tester. A $\frac{1}{2}$ inch diameter, spring loaded ball indenter is forced into the rammed sand surface. The resistance to penetration will give the hardness of the sand surface.

Heating the metal

Furnaces are used to heat (and melt) the metal to a molten temperature sufficient for casting. The total heat energy required is the sum of

- (1) the heat to raise the temperature to the melting point,
- (2) the heat of fusion to convert it from solid to liquid, and
- (3) the heat to raise the molten metal to the desired temperature for pouring

This is expressed as:

$$H = \rho V \left\{ \underset{(1)}{C_s (T_m - T_a)} + \underset{(2)}{H_f} + \underset{(3)}{C_l (T_p - T_m)} \right\}$$

H : total heat required to increase the temperature of the metal to the pouring temp (in J)

ρ : density (in g/cm³)

V : Volume of metal used for heating (in cm³)

C_s : Specific heat for the solid (in J/gC)

T_m : Melting temperature of the metal (in C)

T_a : Ambient temperature (or starting) (in C)

H_f : Heat of fusion (in J/g)

C_l : specific heat of the liquid metal (in J/gC)

T_p : Temperature of the pouring liquid (in C)

Assumptions valid for the above eqn. are,

1. Specific heat and other thermal properties of a solid metal are constant and not dependent on temperature, but not really true especially if the metal undergoes a phase change during heating.
2. Sometimes specific heat of metal in solid and liquid states are assumed same, but not really true
3. Single melting point which is not valid for alloys as there is a temperature range between solidus and liquidus temperature.
Thus, the heat of fusion cannot be applied so simply as indicated above.
4. There are no heat losses to the environment during heating, but not really true

A disk 40 cm in diameter and 5 cm thick is to be casted of pure aluminum in an open mold operation. The melting temperature of aluminum = 660°C and the pouring temperature will be 800°C. Assume that the amount of aluminum heated will be 5% more than needed to fill the mold cavity. Compute the amount of heat that must be added to the metal to heat it to the pouring temperature, starting from a room temperature of 25°C. The heat of fusion of aluminum = 389.3 J/g. density = 2.7 g/cm³ and specific heat C = 0.88 J/g-°C. Assume the specific heat has the same value for solid and molten aluminum.

Ans: Heat required = 19,082,756 J

$$H = \rho V \{ C_s (T_m - T_a) + H_f + C_l (T_p - T_m) \}$$

A sufficient amount of pure copper is to be heated for casting a large plate in an open mold. The plate has dimensions: $L = 20$ in, $W = 10$ in, and $D = 3$ in. Compute the amount of heat that must be added to the metal to heat it to a temperature of 2150 F for pouring. Assume that the amount of metal heated will be 10% more than needed to fill the mold cavity. Properties of the metal are: density = 0.324 lbm/in³, melting point = 1981 F, specific heat of the metal = 0.093 Btu/lbm-F in the solid state and 0.090 Btu/lbm-F in the liquid state; and heat of fusion = 80 Btu/lbm.

Ans: Heat required = 58265 btu

$$H = \rho V \{ C_s (T_m - T_a) + H_f + C_l (T_p - T_m) \}$$

Melting of metals

Gases in metals:

The gases in metal is important in deciding the defect free castings. In metal castings, gases may be **mechanically trapped**, **generated due to variation in their solubility at different temperatures and phases**, generated because of chemical reaction.

Gases generally present are: hydrogen, nitrogen

Hydrogen: Based on the solubility of hydrogen, metals are divided as

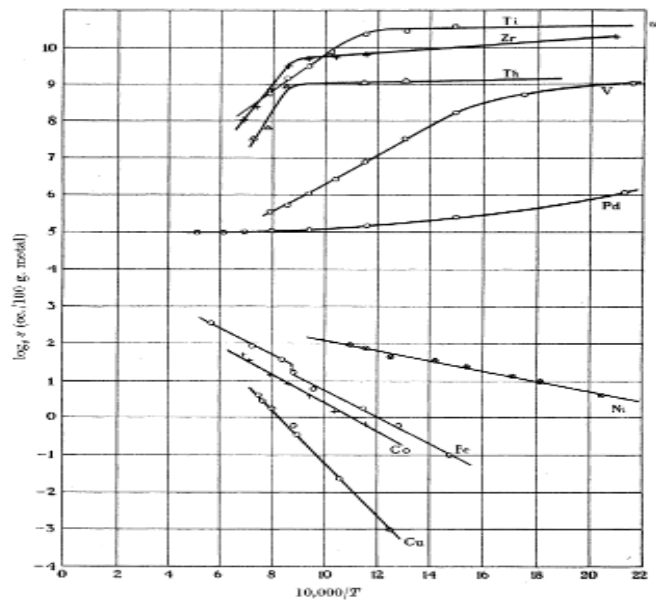
Endothermic (metals like Al, Mg, Cu, Fe, Ni), Exothermic (like Ti, Zr)

The solubility of hydrogen in various metals are shown in figure. Here solubility S is the volume of H_2 gas absorbed by 100 g. of metal. The solubility of hydrogen in solid and liquid phases (pressure = 1 atm) at solidus temperature is given in table.

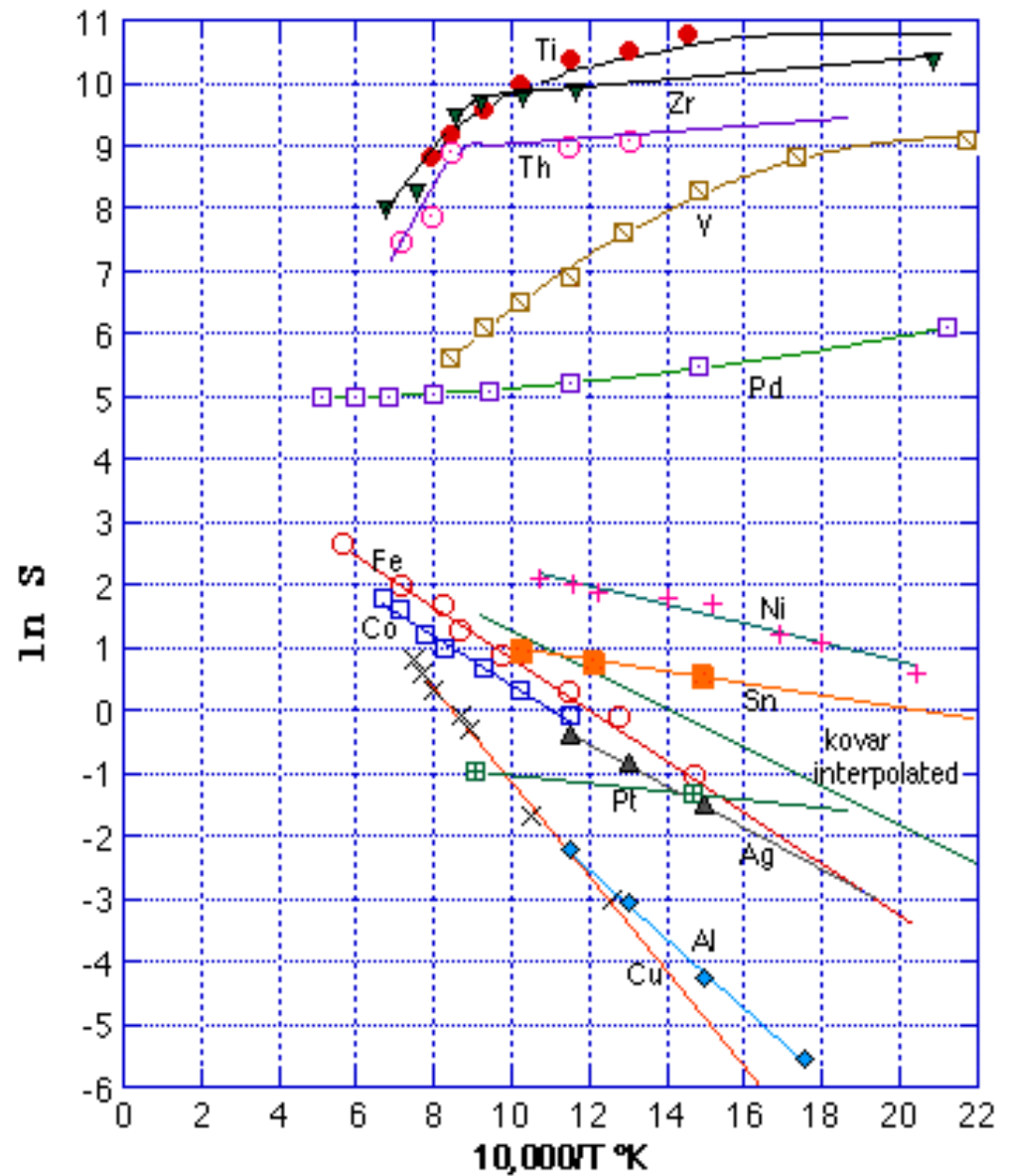
$$S = C \exp\left[-E_s / (k\theta)\right]$$

E_s : heat of solution of one mol of hydrogen; sign determines endothermic or exothermic

Metal	Liquid solubility (cc/kg)	Solid solubility (cc/kg)
Fe	270	70
Mg	260	180
Cu	55	20
Al	7	0.4



Both are Similar graphs



A Theoretical Formula for the Solubility of Hydrogen in Metals, R. H. Fowler and C. J. Smithells, Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences, V160, 1937, p. 37

Sievert's law states that the amt. of hydrogen (and nitrogen) dissolved in a metal varies in proportion with square root of partial pressure of hydrogen in the atmosphere over the melt.

$$\% \text{ hydrogen present} = K \sqrt{p_{H_2}}$$

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$$N_{eq} (wt\%) = K_{eq} \sqrt{P_{N_2}} = \sqrt{P_{N_2}} \cdot \exp \left(- \frac{\Delta G_1^0}{RT} \right)$$

Std. free energy for nitrogen in liquid iron
 Partial pressure of N₂ in atmosphere over the melt
 Gas constant
 Temperature (K)

Sources of hydrogen in a melt are furnace dampness, air, oil and grease.

Most of the hydrogen removal techniques are based on the above equation – this is by reducing the partial pressure of hydrogen by bubbling dry insoluble gases through the molten melt.

Hydrogen removal:

For non-ferrous metals, chlorine, nitrogen, helium or argon is used.

For ferrous metals and Ni based alloys, nitrogen cannot be used. They form nitrides that affects the grain size. In this case, carbon monoxide is used.

Nitrogen removal: carbon monoxide can be used. A marked decrease in solubility of nitrogen in ferrous metal leads to porosity in casting. **Vacuum melting is used nowadays for preventing the solution of gases in metals.**

Pouring, Gating design

A good gating design should ensure proper distribution of molten metal without excessive temperature loss, turbulence, gas entrapping and slags.

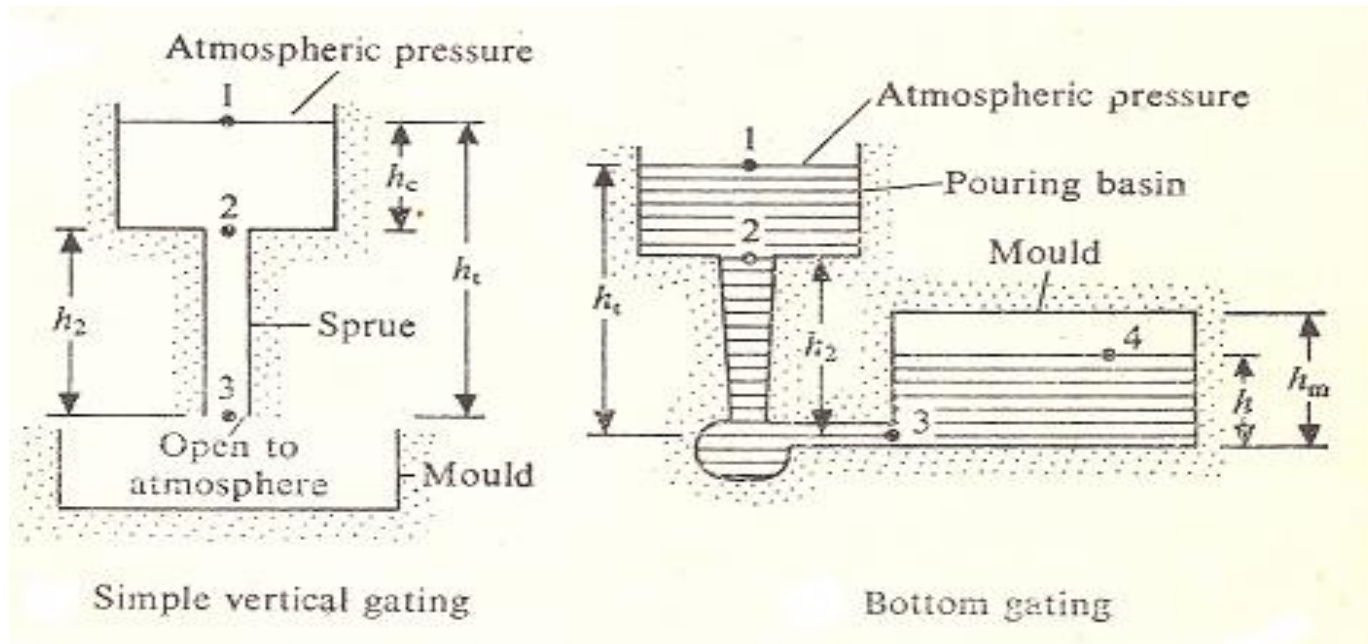
If the molten metal is poured very slowly, since time taken to fill the mould cavity will become longer, solidification will start even before the mould is completely filled. This can be restricted by using super heated metal, but in this case solubility will be a problem.

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



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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.

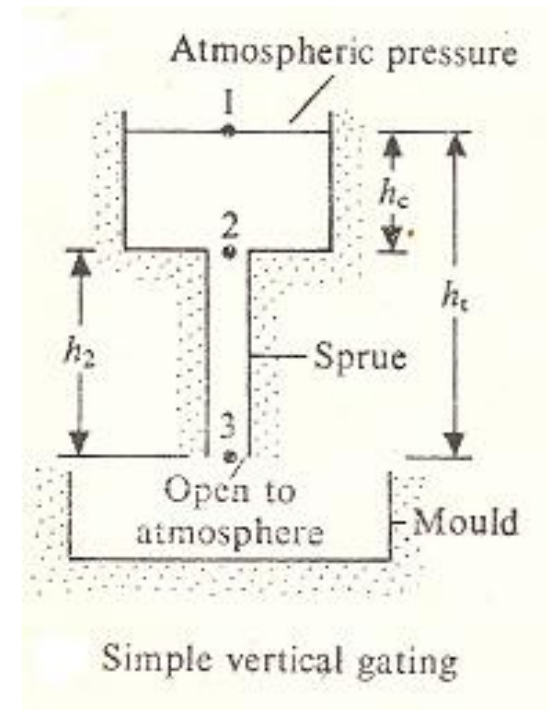
The energy balance between point 1 and 3 gives,

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

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

Continuity equation: Volumetric flow rate, $Q = A_1 v_1 = A_3 v_3$

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.

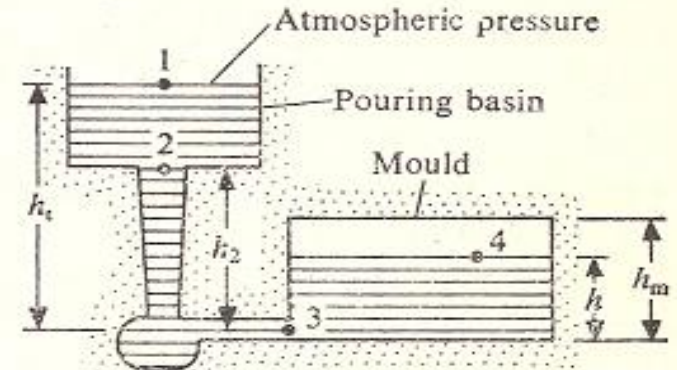
$$v_g = v_3 = \sqrt{2g(h_t - h)}$$

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



(b) Bottom gating

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

$$\frac{1}{\sqrt{2g}} \frac{dh}{\sqrt{h_t - h}} = \frac{A_g}{A_m} dt$$

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

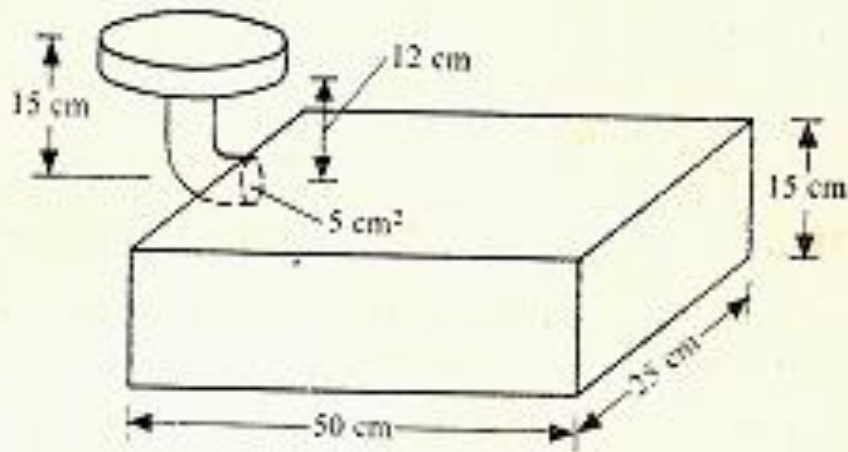


$$t_f = \frac{A_m}{A_g} \frac{1}{\sqrt{2g}} 2(\sqrt{h_t} - \sqrt{h_t - h_m})$$

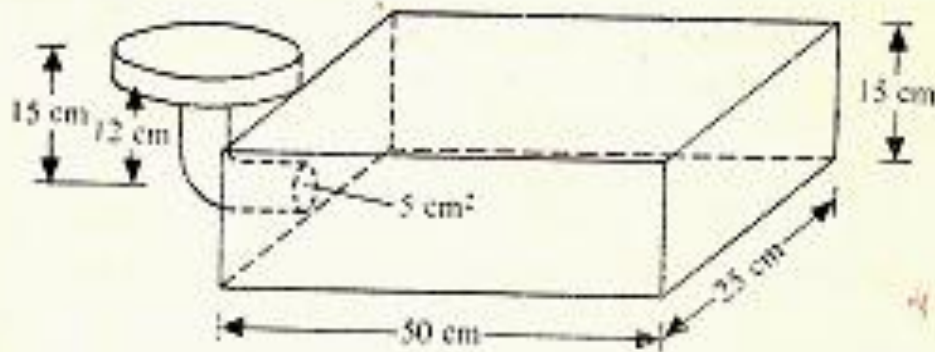
(Check integration)

Find the filling time for both the mould types. Area of C.S. of gate = 5 cm^2

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(a) Top gating



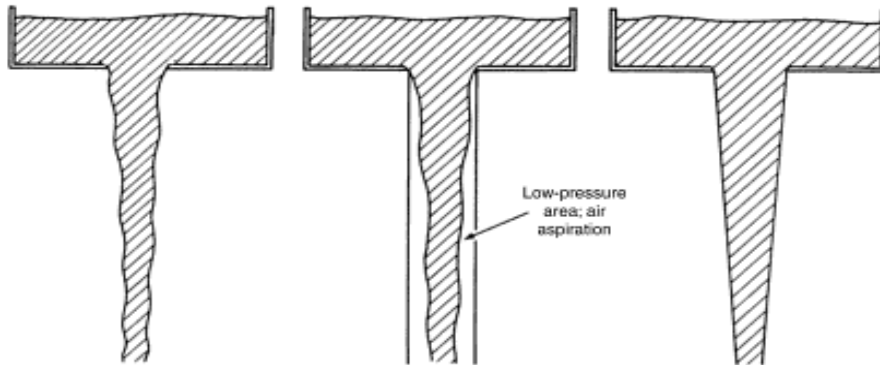
(b) Bottom gating

Answer:

$$t_f = 21.86 \text{ sec}; 43.71 \text{ sec.}$$

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.**



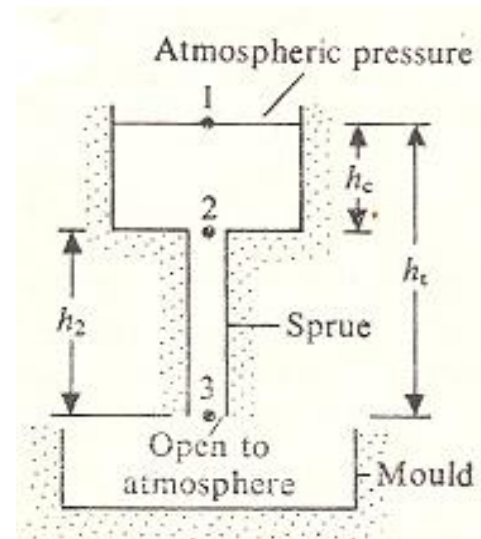
Free falling liquid

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

$$gh_2 + \frac{p_2}{\rho_m} + \frac{v_2^2}{2} = \frac{p_3}{\rho_m} + \frac{v_3^2}{2} \quad \rho_m = \text{density of molten metal}$$

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

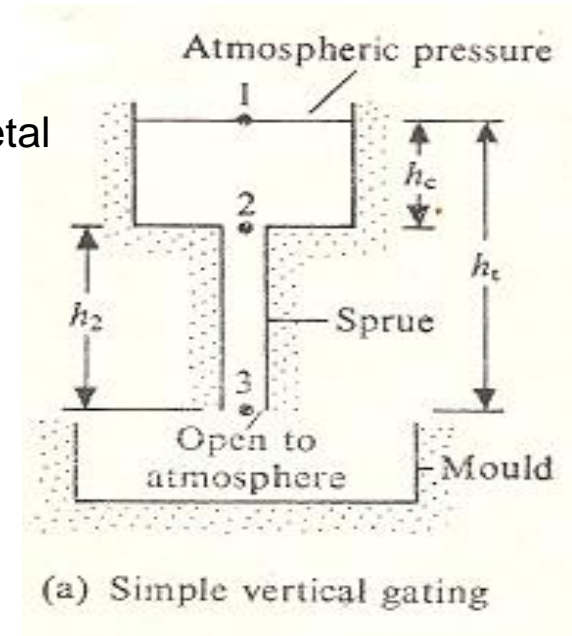
Combining above two eqns., $\frac{v_3^2}{2g} = h_2 + \frac{R^2 v_3^2}{2g}$

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

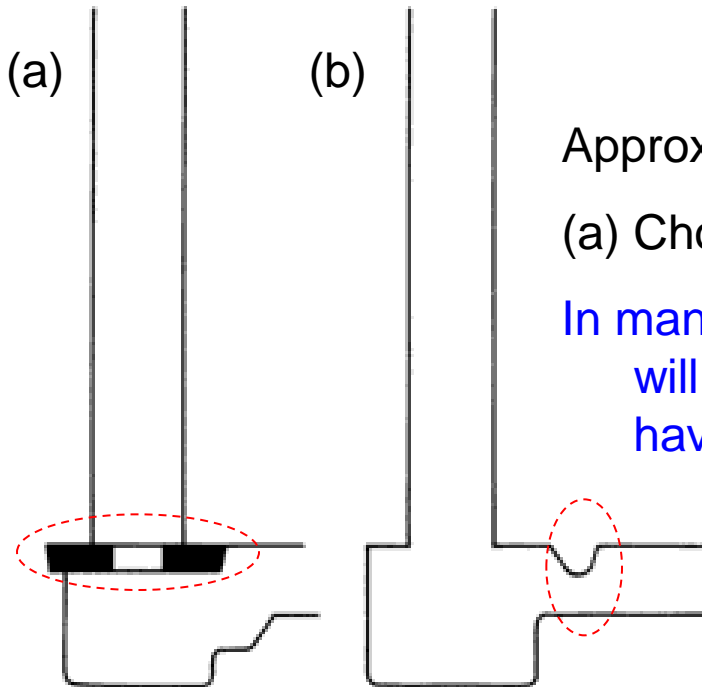
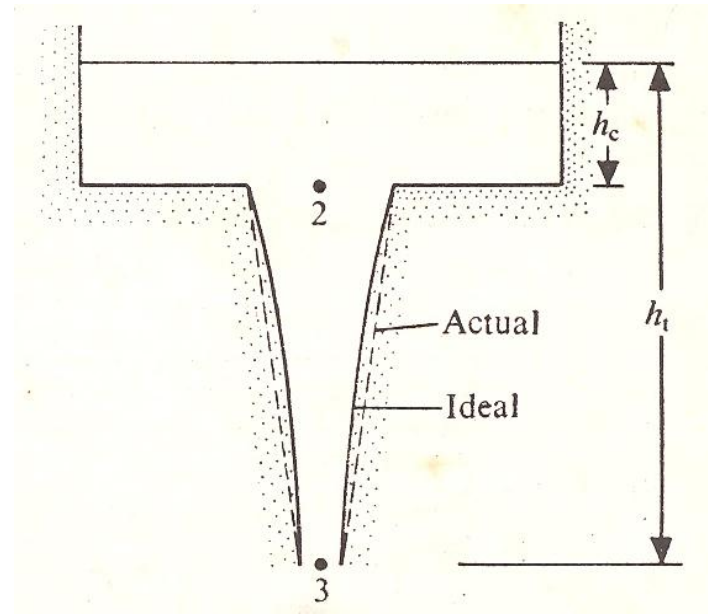
We know that between points 1 and 3, $gh_t = v_3^2 / 2$

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

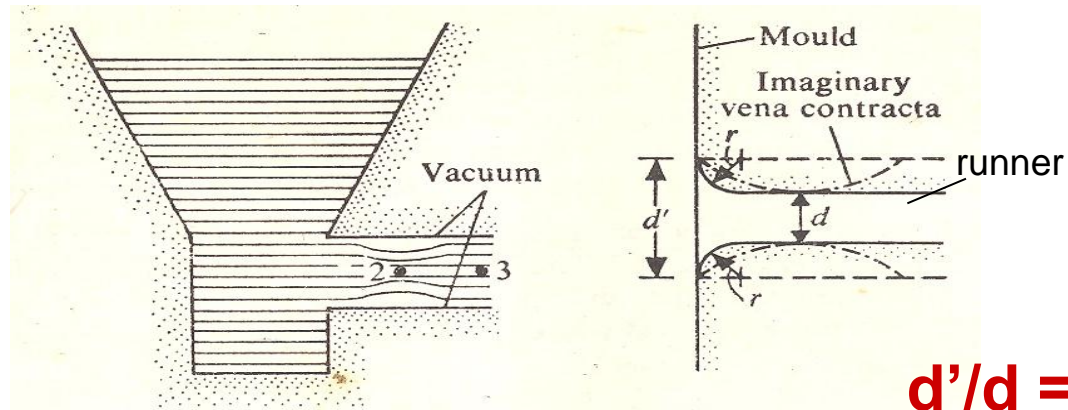
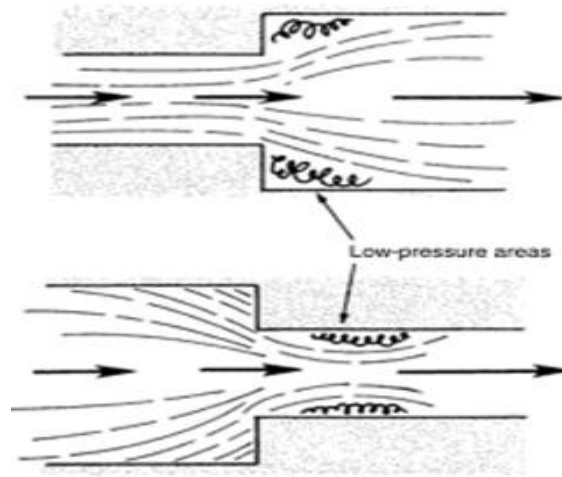


Approximating tapered sprue using choke mechanism

(a) Choke core, (b) Runner choke

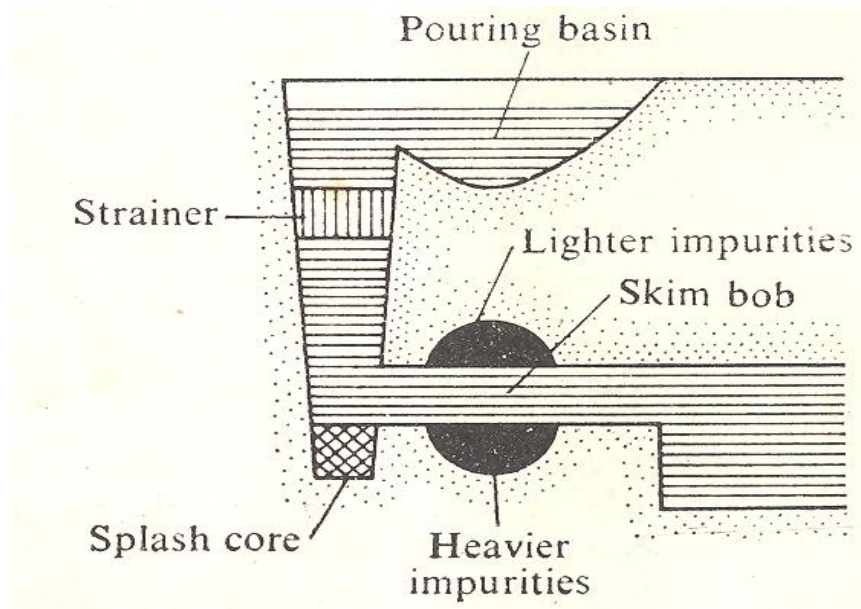
In many high production casting systems, tapered sprue will not be provided. Instead it is compensated by having chokes at the end of sprue or runner.

Case 2: sudden change in flow direction



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

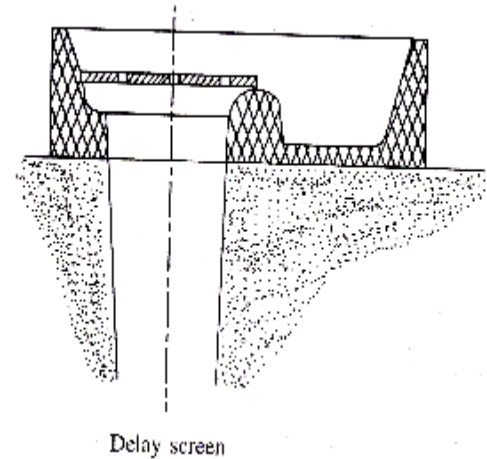
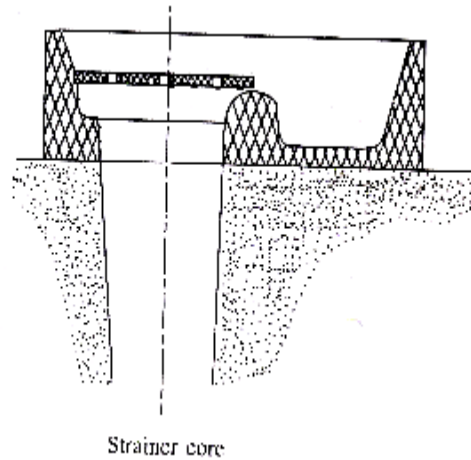
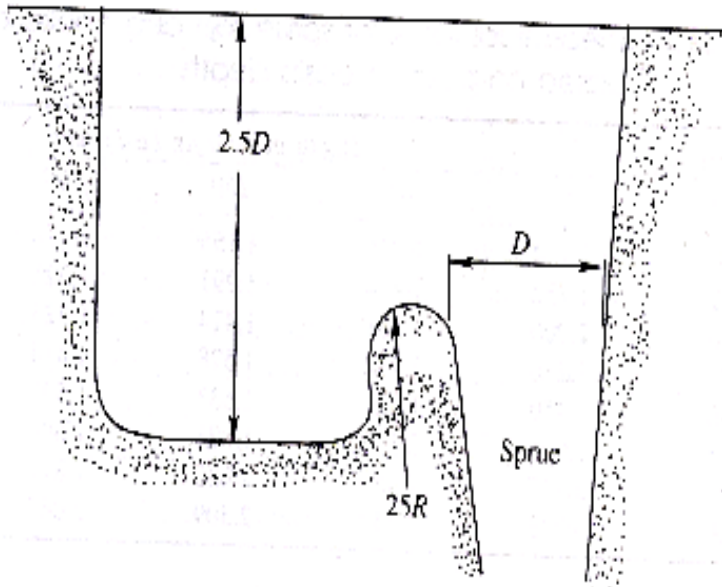
Preventing impurities and turbulence in casting



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

Gating ratios used in practice

Aluminium	1 : 2 : 1
	1 : 1.2 : 2
	1 : 2 : 4
	1 : 3 : 3
	1 : 4 : 4
Aluminium bronze	1 : 6 : 6
	1 : 2.88 : 4.8
Brass	1 : 1 : 1
	1 : 1 : 3
	1.6 : 1.3 : 1
Copper	2 : 8 : 1
	3 : 9 : 1
Ductile iron	1.15 : 1.1 : 1
	1.25 : 1.13 : 1
	1.33 : 2.67 : 1
Grey cast iron	1 : 1.3 : 1.1
	1 : 4 : 4
	1.4 : 1.2 : 1
	2 : 1.5 : 1
	2 : 1.8 : 1
	2 : 3 : 1
	4 : 3 : 1
Magnesium	1 : 2 : 2
	1 : 4 : 4
Malleable iron	1 : 2 : 9.5
	1.5 : 1 : 2.5
Steels	2 : 1 : 4.9
	1 : 1 : 7
	1 : 2 : 1
	1 : 2 : 1.5
	1 : 2 : 2
	1 : 3 : 3
	1.6 : 1.3 : 1

The flow rate of liquid metal into the downsprue of a mold = 1 liter/sec. The cross-sectional area at the top of the sprue = 800 mm² and its length = 175 mm. What area should be used at the base of the sprue to avoid aspiration of the molten metal?

Ans: A = 540 mm²

- convert Q in lit/sec to mm³/sec
- Find $v = \sqrt{2gh}$
- Base area, A = Q/v

Molten metal can be poured into the pouring cup of a sand mold at a steady rate of 1000 cm³/s. The molten metal overflows the pouring cup and flows into the downsprue. The cross-section of the sprue is round, with a diameter at the top = 3.4 cm. If the sprue is 25 cm long, determine the proper diameter at its base so as to maintain the same volume flow rate.

Ans: D = 2.4 cm

- Find velocity at base, $v = \sqrt{2gh}$
- find area at base, A = Q/v
- Find D = $\sqrt{4A/\pi}$

During pouring into a sand mold, the molten metal can be poured into the downsprue at a constant flow rate during the time it takes to fill the mold. At the end of pouring the sprue is filled and there is negligible metal in the pouring cup.

The downsprue is 6.0 in long. Its cross-sectional area at the top = 0.8 in^2 and at the base = 0.6 in^2 .

The cross-sectional area of the runner leading from the sprue also = 0.6 in^2 , and it is 8.0 in long before leading into the mold cavity, whose volume = 65 in^3 .

The volume of the riser located along the runner near the mold cavity = 25 in^3 . It takes a total of 3.0 sec to fill the entire mold (including cavity, riser, runner, and sprue). This is more than the theoretical time required, indicating a loss of velocity due to friction in the sprue and runner.

Find: (a) the theoretical velocity and flow rate at the base of the downsprue; (b) the total volume of the mold; (c) the actual velocity and flow rate at the base of the sprue; and (d) the loss of head in the gating system due to friction.

Ans: (a) 68.1 in/sec, 40.8 in³/sec; (b) 99 in³; (c) 33 in³/sec, 55 in/sec; (d) 2.086 in

Effect of friction and velocity distribution

The velocity of the liquid metal in the sprue and gate are assumed constant. This depends on the nature of flow and shape of the channel.

Moreover no frictional losses are considered. In real cases, friction losses are always present, specifically when there is sudden contraction and expansion in cross-sections.

The non-uniform velocity distribution is accounted for by modifying the KE term in the energy balance equation by replacing $(v)^2$ by $\frac{\bar{v}^2}{\beta}$ where β is a constant and \bar{v} is the average velocity.

For circular conduit, β is equal to 0.5 for laminar flow and 1 for turbulent flow.

The energy loss due to friction in a circular channel (per unit mass) is given by, $E_{f1} = \frac{4fl\bar{v}^2}{2d}$

Here l and d are length and diameter of channel. The value of f (friction factor) depends on the nature of flow and channel smoothness. This E_{f1} should be added to energy at point 2 (say there are two points 1 and 2 discussed earlier).

For smooth channel: $f = 16/R_e$ where $R_e < 2000$ for laminar flow

$$\frac{1}{\sqrt{f}} = 4 \log_{10}(R_e \sqrt{f}) - 0.4 \quad \text{for turbulent flow } (R_e > 2000)$$

$$f = 0.079(R_e)^{-0.25} \quad \text{for the range } 2100 < Re < 10^5 \text{ (simplified from above eqn.)}$$

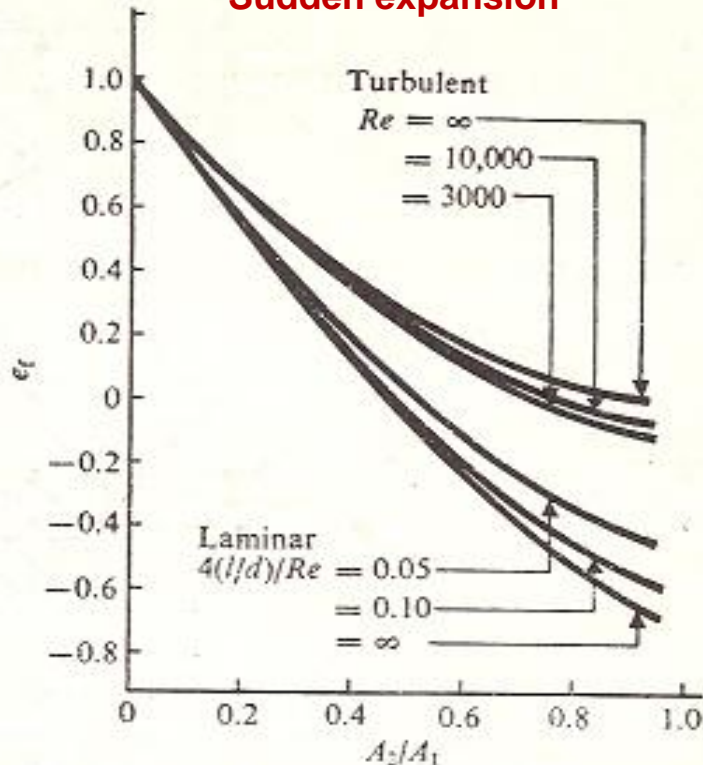
Frictional losses also occur due to sudden change in flow direction like in 90° bends. In such cases, proper (l/d) ratio should be considered in E_{f1} equation.

The energy loss due to sudden contraction and enlargement of flow area (per unit mass),

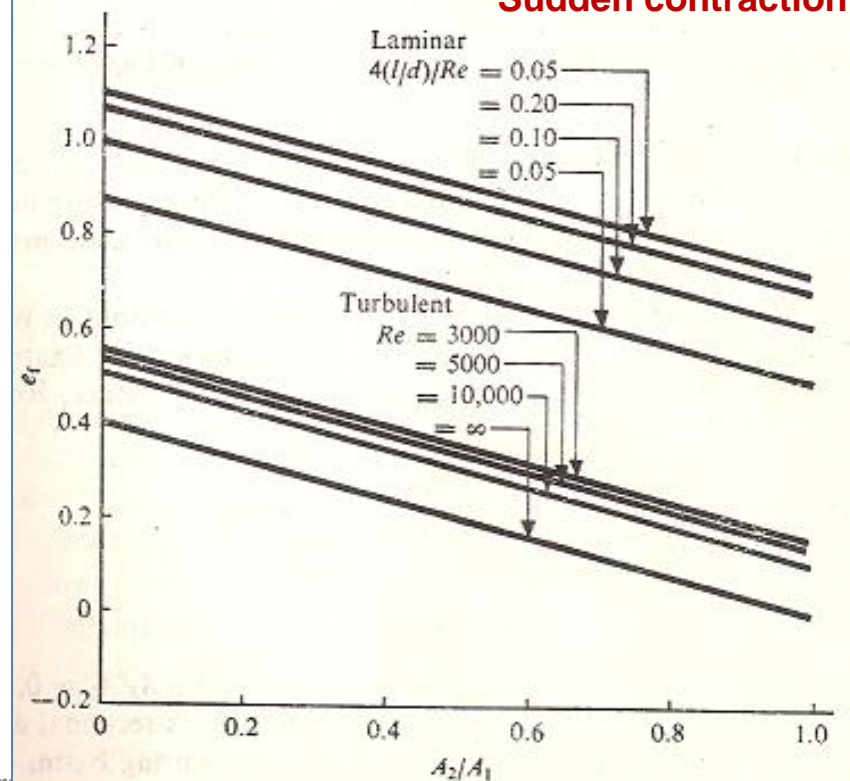
$$E_{f2} = \frac{\bar{v}^2}{2} e_f \quad . \text{ Here } \bar{v} \text{ is the average velocity of the fluid in smaller CS region and}$$

e_f is the friction loss factor and it depends on the ratio of flow area and Re . In this e_f depends on sudden expansion or sudden contraction as shown in figure.

Sudden expansion



Sudden contraction



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

The energy balance eqn. between points 1 and 3, after accounting for sudden contraction loss at 2 is given by,

$$\frac{p_1}{\rho_m} + 0 + gh_t = \frac{p_3}{\rho_m} + \frac{\bar{v}_3^2}{2\beta} + Ef_1 + Ef_2$$

By having $P_1 = P_3$, and using equations $E_{f1} = \frac{4f\bar{v}^2}{2d}$ and $E_{f2} = \frac{\bar{v}^2}{2} e_f$, we get

$$\boxed{v_3 = C_D \sqrt{2gh_t}} \quad \text{where} \quad C_D = \left(\frac{1}{\beta} + e_f + 4f \frac{l}{d} \right)^{-1/2}$$

$C_D = \text{discharge coefficient}$

If the sprue has got a bend or fitting,

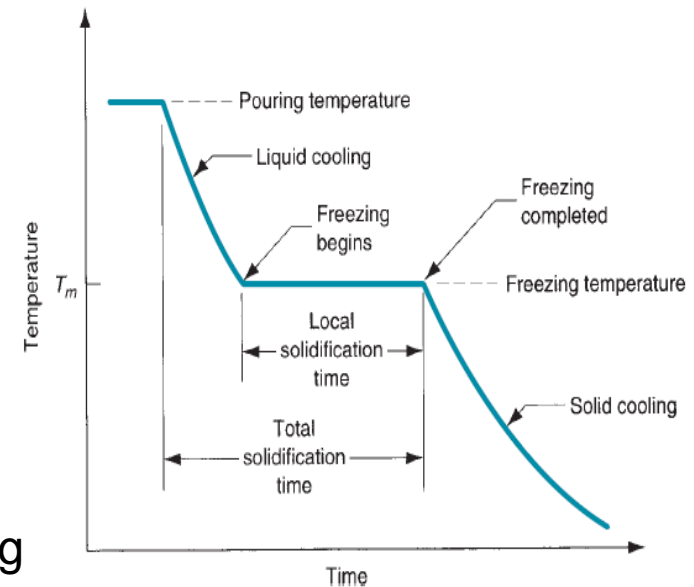
$$C_D = \left\{ \frac{1}{\beta} + e_f + 4f \left[\frac{l}{d} + \left(\frac{L}{D} \right)_{eq} \right] \right\}^{-1/2}$$

Here l and d are length and diameter of channel (like sprue), $(L/D)_{eq}$ is for the bend.

Cooling and Solidification

Solidification of pure metals

- Change of molten metal to solid state
- Solidification of pure metals and alloys are different
- The cooling curve of pure metals is shown in figure. Here solidification occurs at constant temperature equal to its freezing point.
- The solidification occurs at prescribed time duration.
- **Local solidification time:** time between freezing start and freezing completion. In this time, the molten metal heat of fusion is delivered into mould.
- **Total solidification time:** time between pouring and final solidification
- First liquid cooling occurs till freezing starts. Then solidification occurs for a time duration, till freezing completes. Even after solidification is over, solid cooling occurs at a particular rate as shown in the figure.

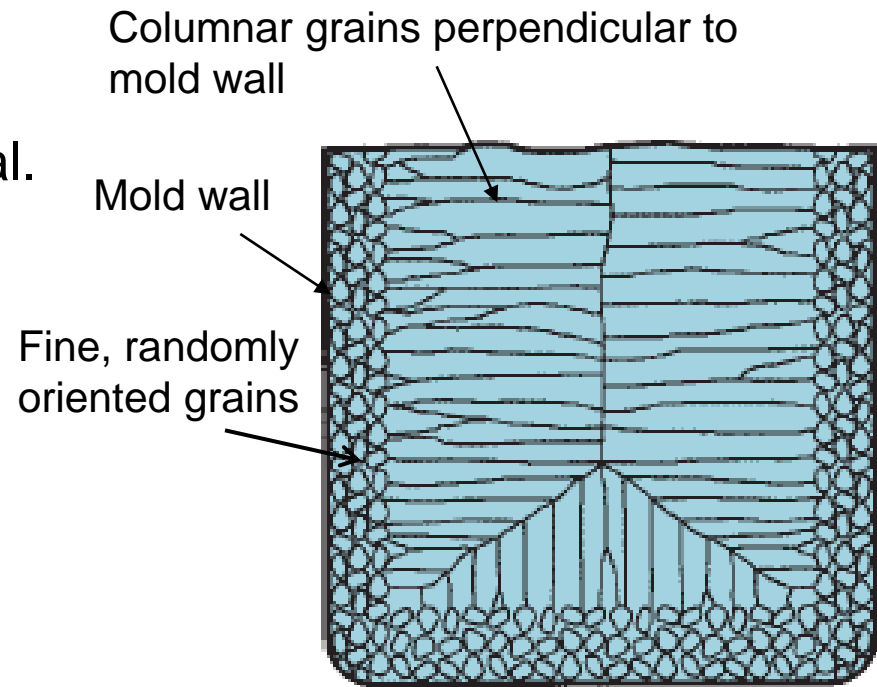


The grain structure in pure metals depends on the heat transfer into the mold and thermal properties of the metal.

The mold wall acts as a chiller and hence solidification starts first in the molten metal closer to the mold wall.

A thin skin of solid metal is first formed near the mold wall. The solidification continues inwards towards the mold center.

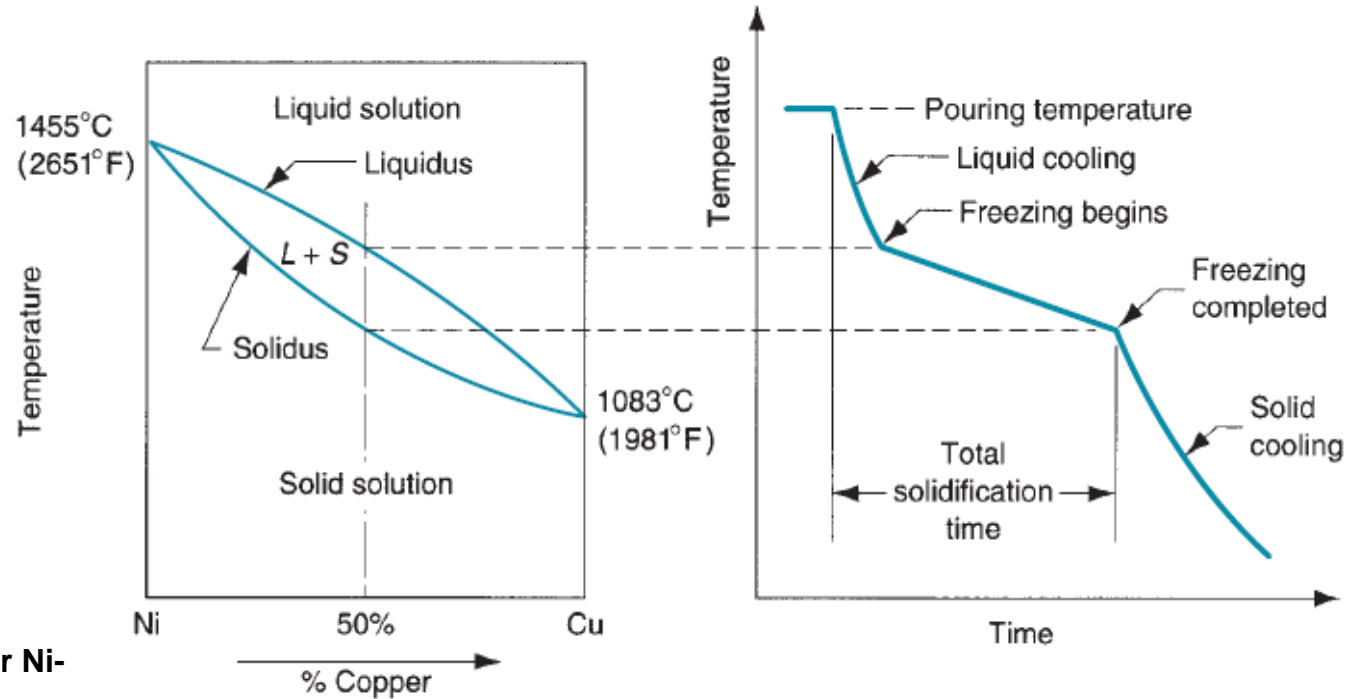
The initial skin formed near the mold wall has gone through fast removal of heat and hence fine, equiaxed and randomly oriented grains are formed.



Grain structure in casting of pure metals

When the solidification continues inwardly, heat is removed through the mold wall and thin solid skin. Here the grains grow as needles with preferred orientation. As these needles enlarge, side branches develop, and as these branches grow, further branches form at right angles to the first branches. **This type of grain growth is referred to as dendritic growth.** It occurs at the freezing of pure metals and in alloys.

Solidification of alloys



Phase diagram for Ni-Cu alloy system

Cooling curve for 50%Ni-50% Cu during casting

- **Important:** Mushy zone formation, segregation of elements
- In alloys, solidification will not occur at a particular temperature. It happens at a temperature range. This range depends on the alloy composition.
- Referring above figure, solidification occurs between liquidus line and solidus line. Freezing starts at liquidus temperature and ends at solidus temperature. A skin layer is formed at the mold end and the dendrites grow in a similar fashion normal to the mold wall.

- However, because of the temperature difference between the liquidus and solidus line, the nature of the dendritic growth is such that **an advancing zone is formed in which both liquid and solid metal exist together**. The solid portions are the dendrite structures that have formed sufficiently to hold small regions of liquid metal in the matrix. **This solid–liquid region has a soft consistency and hence called the mushy zone**. Depending on the conditions of solidification, the mushy zone can be a narrow zone, or it can exist throughout the casting.
- Slowly the liquid islands solidify as the temperature of the casting goes down to the solidus.
- **Another complexity is the segregation of elements**. As solidification continues and the dendrites grow, an imbalance in composition between the solidified metal and the remaining molten metal will develop. This composition imbalance will finally result in the segregation of the elements.
- Segregation of elements can be microscopic and macroscopic. At microscopic level, chemical composition varies with each grain. This is due to out of balancing of composition between the first solidified region and the last solidified region. Thus, the variation in chemical composition within single grains of the casting is generated.

- At macroscopic level, the chemical composition varies throughout the entire casting. Since the regions of the casting that freeze first (say near the mold walls) are richer in one component than the other, the remaining molten metal has got reduction in that component by the time freezing occurs at the mold center. This creates difference in composition at different cross sections of the casting. This is called **ingot segregation**.

Eutectic alloys:

In these alloys, solidification occurs at a constant temperature rather than over a temperature range. For these alloys, the solidus and liquidus are at the same temperature.

Example:

(i) 61.9% tin and 38.1% lead has a melting point of 183°C . This composition is the eutectic composition of the Pb-Sn alloy system. The temperature 183°C is its eutectic temperature.

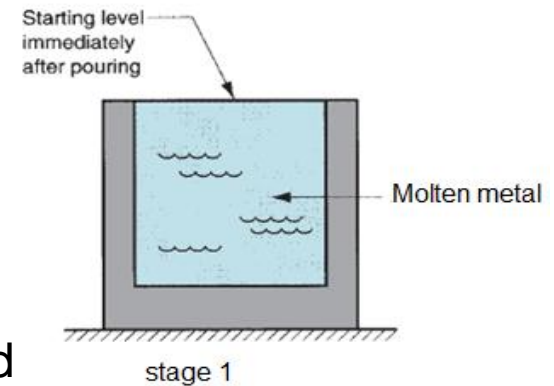
(ii) Aluminum–silicon (11.6% Si) and cast iron (4.3% C)

Solidification shrinkage

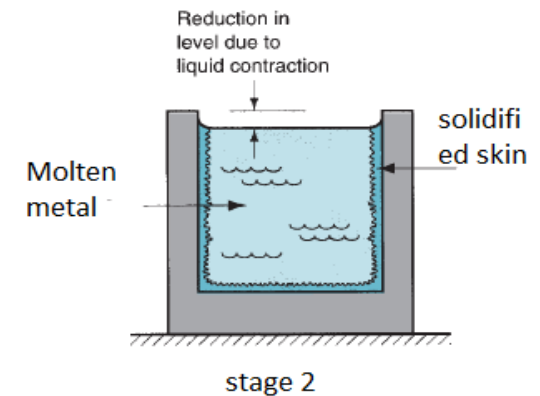
Major three stages in shrinkage:

- (i) Contraction of liquid before solidification during cooling
- (ii) Contraction during liquid to solid phase change
- (iii) Contraction of solid metal during cooling to RT

Stage 1: The level of poured molten metal is shown in a mold container.



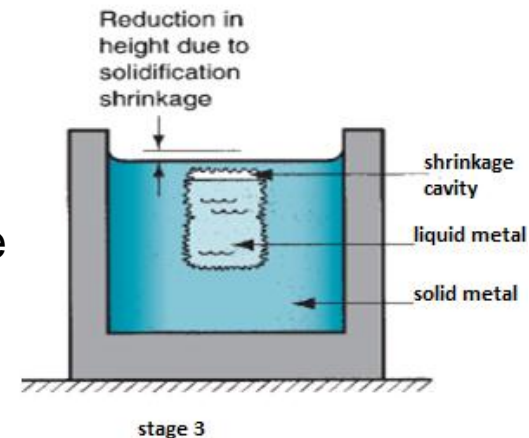
Stage 2: Solidification front has started at the mold wall. The level of liquid metal has reduced at the open surface due to liquid contraction. The amount of liquid contraction is app. 0.5%.



Stage 3: Two effects are seen in this stage.

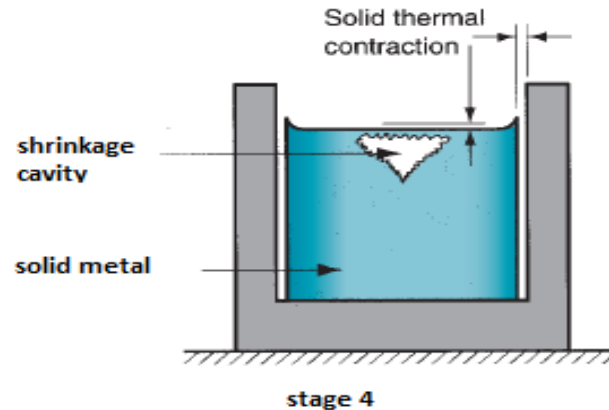
First effect – contraction causes further reduction in the height of the casting.

Second effect – top centre portion is the last to get freezed. The amount of liquid metal present to feed the top centre portion of the casting becomes restricted. Absence of metal in this region creates a void in the casting. This will be converted into 'shrinkage cavity'.



Stage 4:

Once solidified, both height and diameter contracts resulting in **shrinkage cavity** at the top centre. **This will be seen as a 'Pipe', in case casting is done in a tube like container which does not have mold wall at the bottom.**



Solidification shrinkage occurs almost in all metals because the solid phase has a higher density than the liquid phase.

The phase transformation that occurs during solidification causes a reduction in the volume per unit weight of metal. But cast iron containing high carbon content is an exception, whose solidification during the final stages is complicated by graphitization, which results in expansion. This will tend to oppose the decrease in cast volume associated with the phase change.

Compensation for shrinkage cavity : by providing riser, by following shrink rule to have shrinkage allowances

Directional solidification

There are few methods by which damages due to shrinkage can be minimized. They are **directional solidification** methods.

Method 1: Providing risers:

It is desirable for the regions of the casting far away from the liquid metal supply to freeze first and for solidification to progress from these remote regions toward the location of riser. In this way, molten metal will continually be available from the risers to prevent shrinkage voids during freezing.

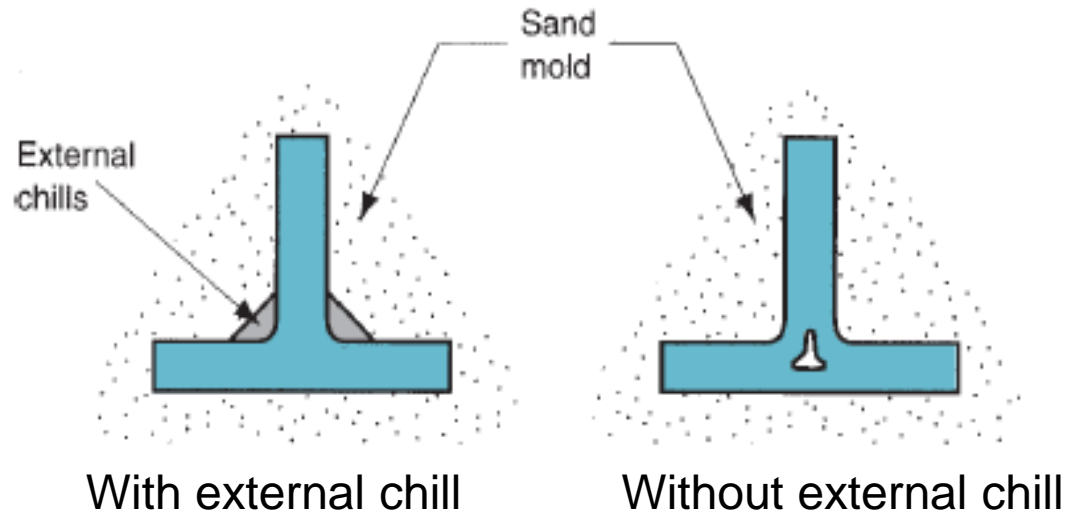
For example, the regions of the cast with lower V/A ratios should be placed far away from the riser location. Solidification will start from these locations and it will progress towards the riser location where bulkier sections of the cast are present. Hence the bulkier sections will continually received molten metal from the risers till freezing.

Method 2: Providing chills:

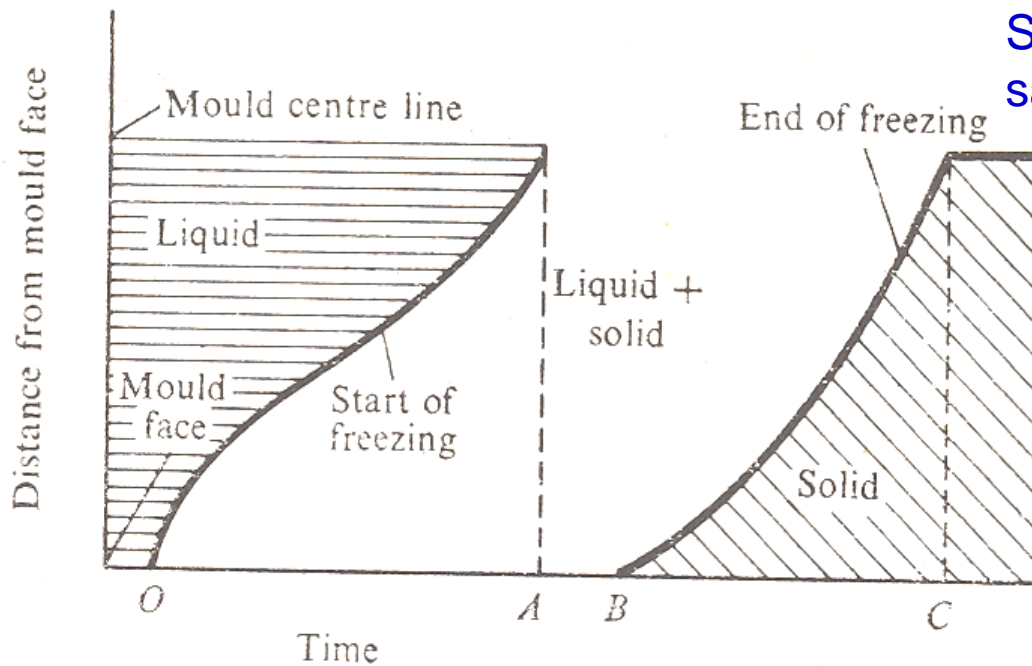
Chills can be provided at appropriate locations in order to have rapid solidification at those points. Internal and external chills can be provided.

Internal chills: small metal parts are placed inside the mould cavity before pouring so that the molten metal will solidify first around these parts. The internal chill should have a chemical composition similar to the metal being poured, so that it can be made out of same cast metal.

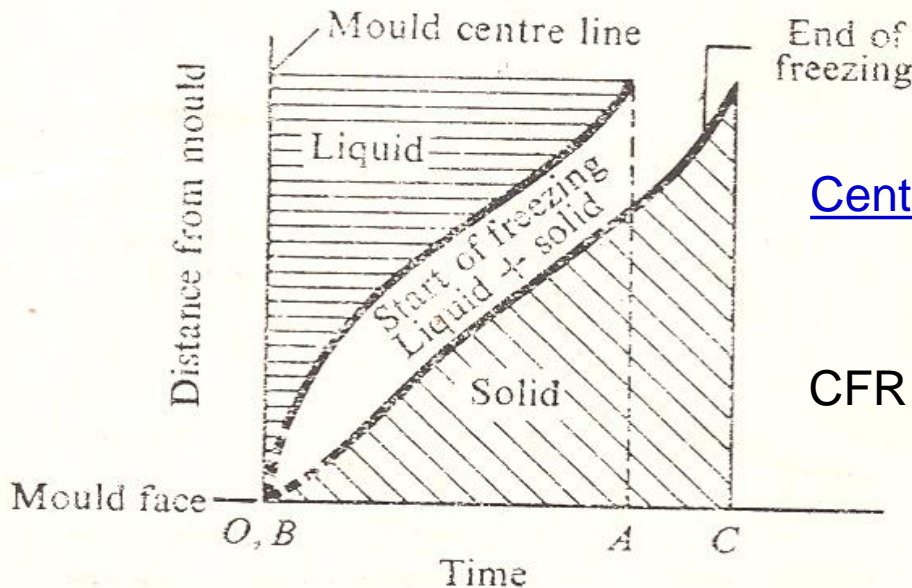
External chills: They are metal inserts kept in mould walls that can extract heat from the molten metal more rapidly than the surrounding sand in order to promote localized solidification. They are mainly used in sections of the casting that are difficult to supply with molten metal.



Solidification diagram for ordinary sand mould



Solidification diagram for chilled mould



Centre-line feeding resistance (CFR)

time interval between start and end of freezing at centre line (AC)

$$\text{CFR} = \frac{\text{time interval between start and end of freezing at centre line (AC)}}{\text{total solidification time of casting (OC)}}$$

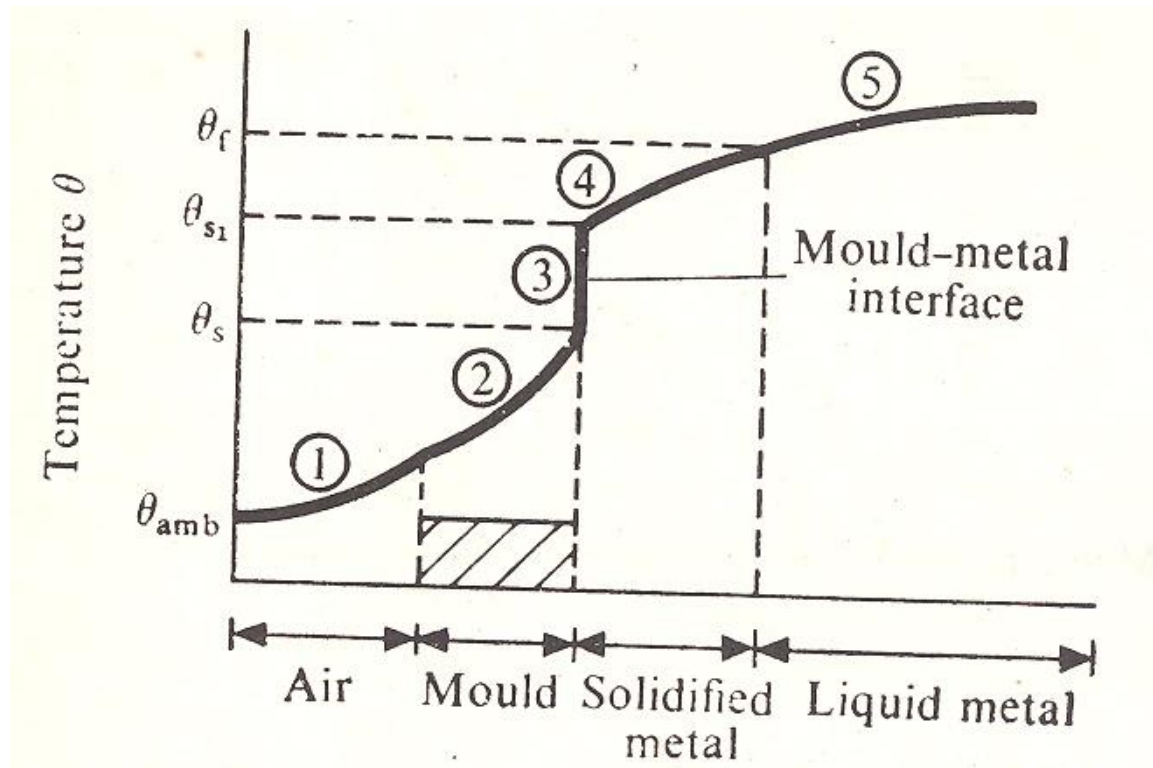
CFR > 70% : FEEDING IS CONSIDERED TO BE DIFFICULT

Rate of solidification

IN order to place the riser properly and it does not solidify before the casting, we should know about the (i) time taken by the casting to solidify, and (ii) distance to which solidification is completed from the mold surface.

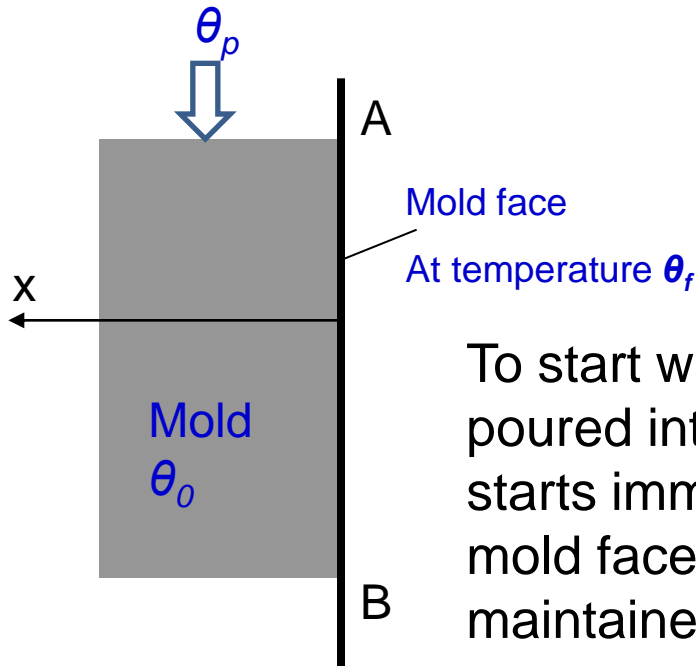
We know that the heat rejected by the molten metal is dissipated through the mould wall. The heat thus released passes through FIVE different layers.

The temperature distribution in these layers is shown in figure.



Solidification of casting in an insulating mold

During solidification of large casting like in sand casting, the entire thermal resistance is offered by the mold. **Hence we will consider region 2 only (from previous fig.).**



Consider the mold face AB as shown in figure. The large mold is at temperature θ_0 initially. Assume that the mold is extended up to infinity in x-direction.

To start with (at $t = 0$), the liquid metal at θ_p temperature is poured into the mold. Let us assume that solidification starts immediately near the mold surface and hence the mold face temperature be θ_f at $t = 0$. This temperature is maintained till freezing is completed.

The rate of heat flow through the mold face at any instant ' t ' is given by,

$$\dot{Q} = \frac{kA(\theta_f - \theta_0)}{\sqrt{\pi\alpha t}}$$

Here α is the thermal diffusivity of the mold material, $\alpha = k/(\rho c)$ where k = conductivity, ρ = density, c = specific heat of mold material.

Remember $\dot{Q} = -kA \frac{\partial \theta_x}{\partial x}$

Thus, the total heat quantity flow across the mold face up to a certain time ' t_0 ' is given by,

$$Q_{t0} = \int_0^{t_0} \dot{Q} dt = \frac{2kA(\theta_f - \theta_0)}{\sqrt{\pi\alpha}} \sqrt{t_0} \quad \left\{ t_0 \Rightarrow t_s; Q_{t0} \Rightarrow Q_{ts} \right\}$$

If the molten metal has a latent heat ' L ', a specific heat c_m , and density ρ_m , the heat liquid metal rejects to solidify is,

$$Q_R = \rho_m V [L + c_m (\theta_p - \theta_f)]$$

The **solidification time, say t_s** , is given by assuming the total heat crossing the mold face and the heat rejected are equal, i.e.,

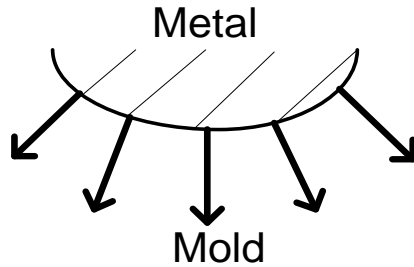
$$Q_{ts} = Q_R$$

Chvorinov's rule

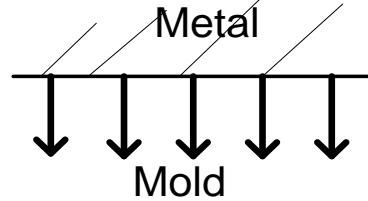
After simplification, $t_s = \gamma \left(\frac{V}{A} \right)^2$ where $\gamma = \left(\frac{\rho_m \sqrt{\pi\alpha} [L + c_m (\theta_p - \theta_f)]}{2k(\theta_f - \theta_0)} \right)^2$

Remember that we have used a plane contour (AB), but practically any shaped contour can be used.

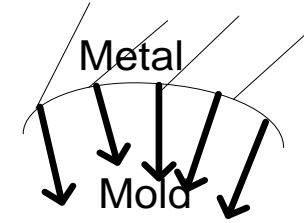
The different metal-mold interfaces possible are:



Convex surface



Plane surface



Concave surface

In order to consider the effect of metal-mold interfaces, we introduce two parameters like,

$$\beta = \frac{V / A}{\sqrt{\alpha t_s}}; \lambda = \frac{\theta_f - \theta_0}{\rho_m L'} \rho c$$

Here ρ_m is for molten metal and ρ, c for sand;

$$L' = L + c_m (\theta_p - \theta_f)$$

For infinite plane,
$$\beta = \lambda \frac{2}{\sqrt{\pi}}$$

For infinite long cylinder,
$$\beta = \lambda \left(\frac{2}{\sqrt{\pi}} + \frac{1}{4\beta} \right)$$

For a sphere,
$$\beta = \lambda \left(\frac{2}{\sqrt{\pi}} + \frac{1}{3\beta} \right)$$

Find the solidification time of the two iron castings when both are poured (with no superheats) into the sand molds at initial temperature 28°C .

(i) A slab shaped casting of 10 cm thickness, (ii) a sphere of 10 cm in dia.

Iron: freezing temp: 1540°C ; $L = 272 \text{ kJ/kg}$; density = 7850 kg/m^3

Sand: $c = 1.17 \text{ kJ/kg-K}$; $k = 0.865 \text{ W/mk}$; density = 1600 kg/m^3

Ans: (i) 0.675 hr, (ii) 0.055 hr

Riser design

The riser can be designed as per Chvorinov's rule mentioned earlier. The following example will illustrate the same.

A cylindrical riser must be designed for a sand-casting mold. The casting itself is a steel rectangular plate with dimensions 7.5 cm x 12.5 cm x 2.0 cm. Previous observations have indicated that the solidification time for this casting is 1.6 min. The cylinder for the riser will have a diameter-to-height ratio as 1.0. Determine the dimensions of the riser so that its solidification time is 2.0 min.

For casting:

$$\begin{aligned} V/A \text{ ratio} &= (7.5 \times 12.5 \times 2) / 2(7.5 \times 12.5 + 12.5 \times 2 + 7.5 \times 2) \\ &= 187.5 / 267.5 = 0.7 \end{aligned}$$

$$\gamma = \frac{t_s}{\left(\frac{V}{A}\right)^2} = 1.6 / (0.7)^2 = 3.26 \text{ min/cm}^2$$

For riser: $D/H = 1$ and $t_s = 2$ min; $V = \pi D^2 H/4$; $A = \pi D H + 2\pi D^2/4$

From $D/H = 1 \Rightarrow D = H$ then

$$V = \pi D^3/4; A = \pi D^2 + 2\pi D^2/4 = 1.5 \pi D^2$$

So, $V/A = D/6$.

Now by Chvorinov's rule, $2.0 = 3.26 (D/6)^2 \Rightarrow$

$D = 4.7$ cm and $H = 4.7$ cm (riser dimensions)

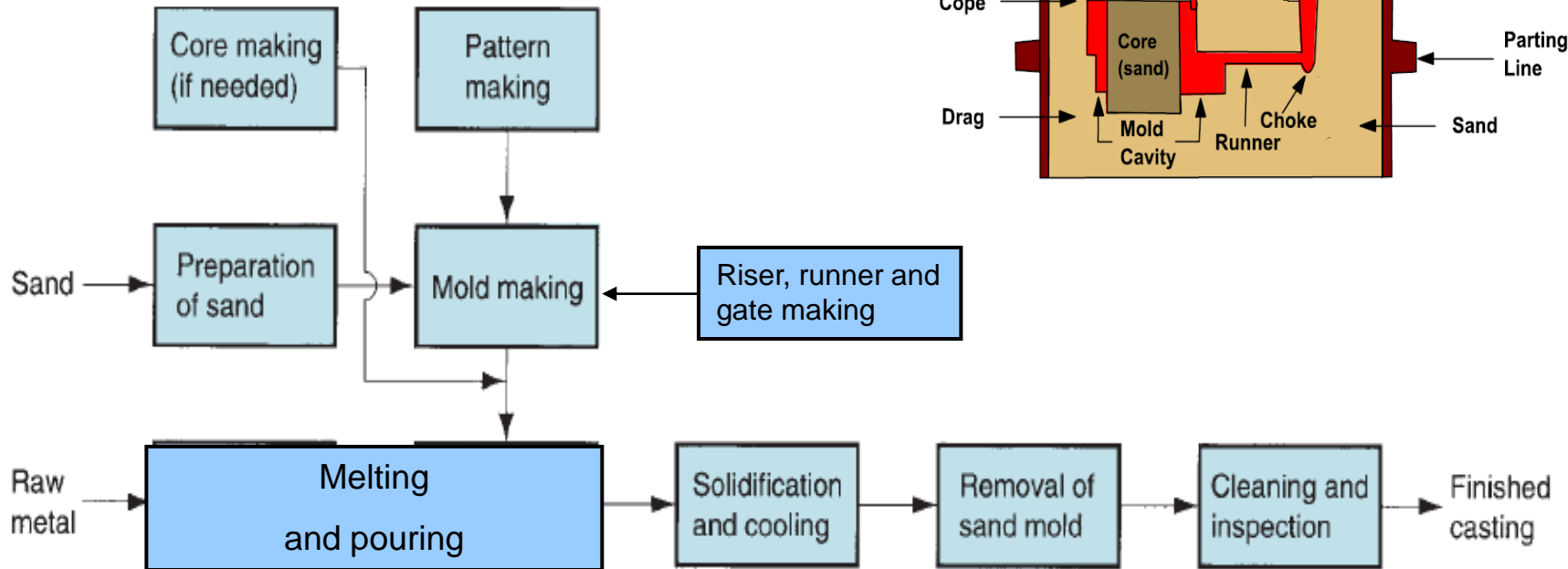
Note that the volume of the riser in this problem is

$V = \pi/4 (4.7)^2 (4.7) = 81.5 \text{ cm}^3$, which is just 44% of the volume of the cast plate, though its solidification time is 25% longer.

Casting processes

Sand Casting

We have already seen sand casting processes. The steps involved in this process is shown here briefly.



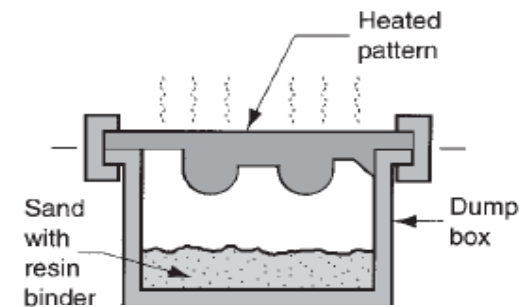
Other casting: Two types – (I) Expendable moulding, (II) Permanent moulding

Expendable moulding processes

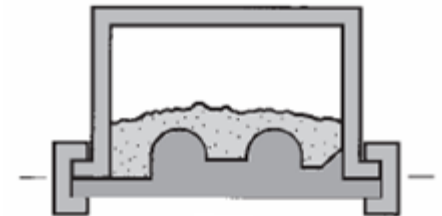
Shell moulding

The shell moulding is a casting process in which the mould is a thin shell of 9 mm thick. This is made of sand held together by thermosetting resin binder.

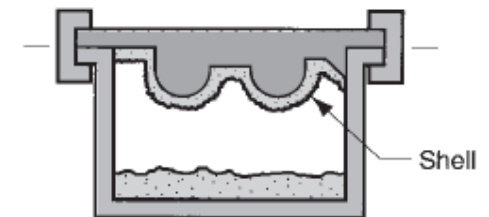
A metal pattern is heated and placed over a box containing sand mixed with thermosetting resin



The dump box is inverted so that sand and resin mixture fall on the hot pattern, causing a layer of the mixture to partially cure on the pattern surface to form a hard shell



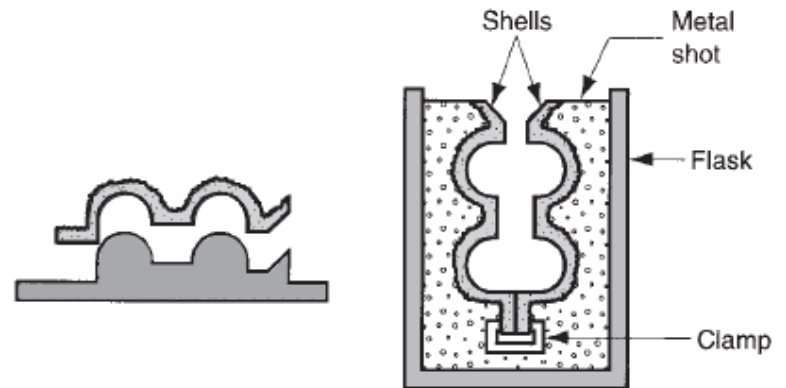
The box is positioned to the previous stage, so that loose, uncured particles drop away



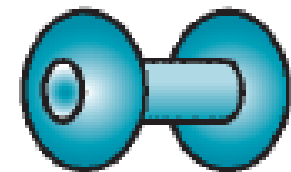
sand shell is heated in oven for several minutes to complete curing



The shell mold is removed from the pattern and two halves of the shell mold are assembled, supported by sand or metal shot in a box, and pouring is completed



The part made by this method is shown here



Advantages of shell moulding process

- The surface of the shell mould is smoother than conventional green sand mould. This permits easier flow of molten metal during pouring and better surface finish on the final casting.
- Surface finish of the order of $2.5\text{ }\mu\text{m}$ can be obtained. Good dimensional tolerances of the order of $\pm 0.25\text{ mm}$ can be reached in a small to medium sized parts.
- Machining operations are reduced because of good surface finish.
- can be mechanized for mass production and will be economical too.

Disadvantages

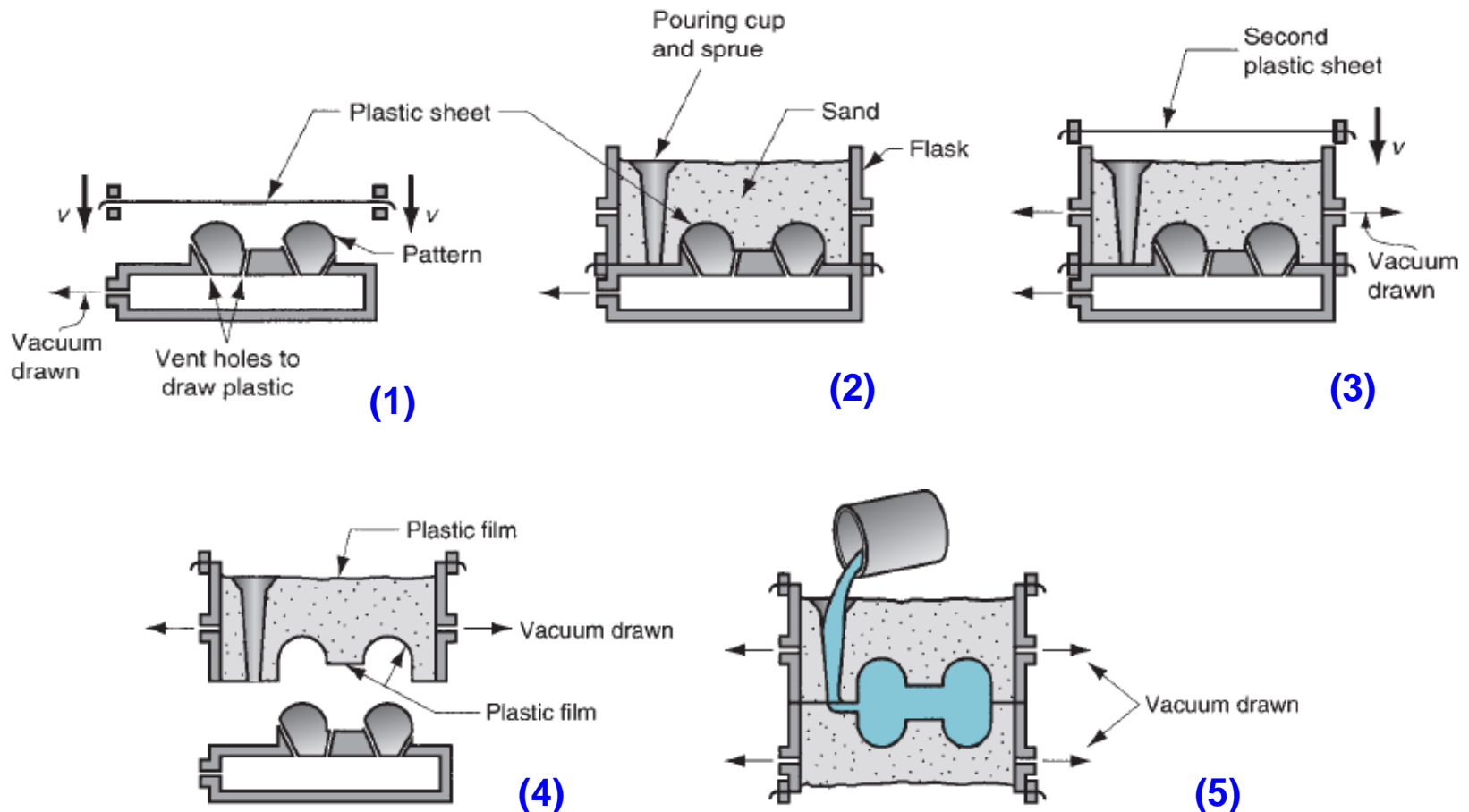
- expensive metal pattern is required, and hence not suitable for small quantities.

Examples of parts made using shell molding include gears, valve bodies, bushings, and camshafts.

Vacuum moulding

In this process, a sand mold is held together by vacuum pressure and not by a chemical binder.

The term vacuum in this process refers to the making of the mold, rather than the casting operation. Casting operation is same as any other process.



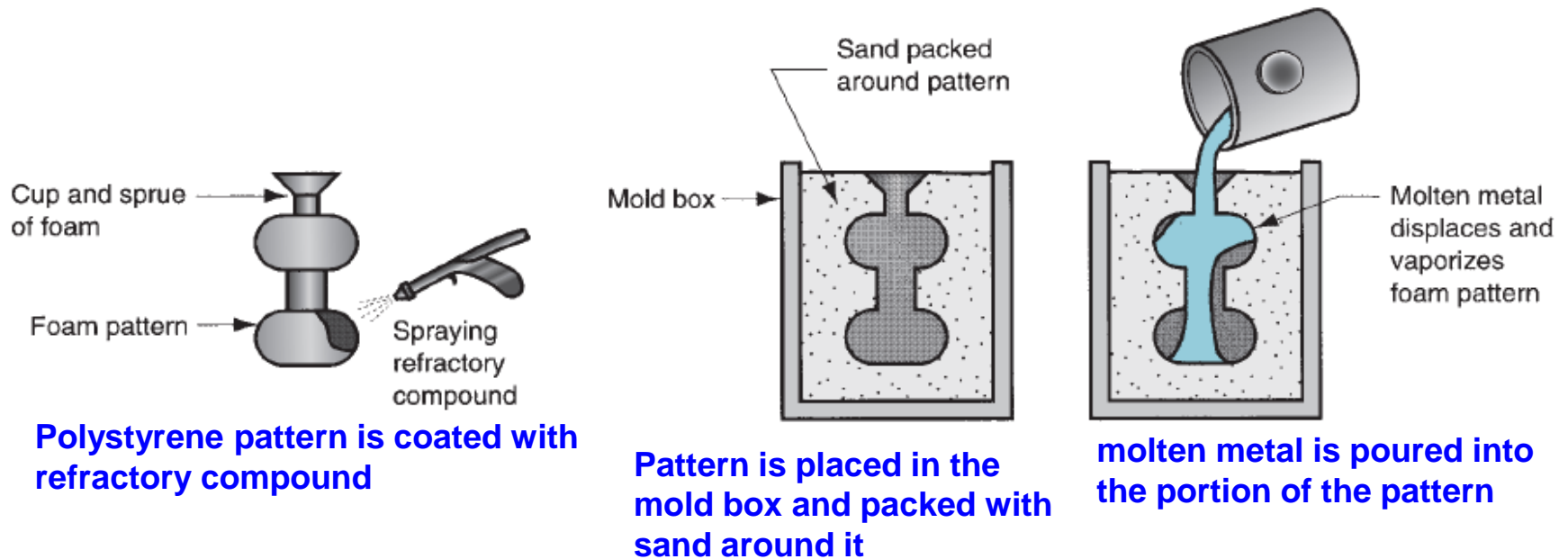
Advantages:

- No binders are used and hence sand is readily recovered in vacuum molding
- Mechanical ramming is not required
- Since no water is mixed with the sand, moisture related defects are absent from the product

Disadvantages:

- relatively slow and not readily adaptable to mechanization

EXPANDED POLYSTYRENE PROCESS



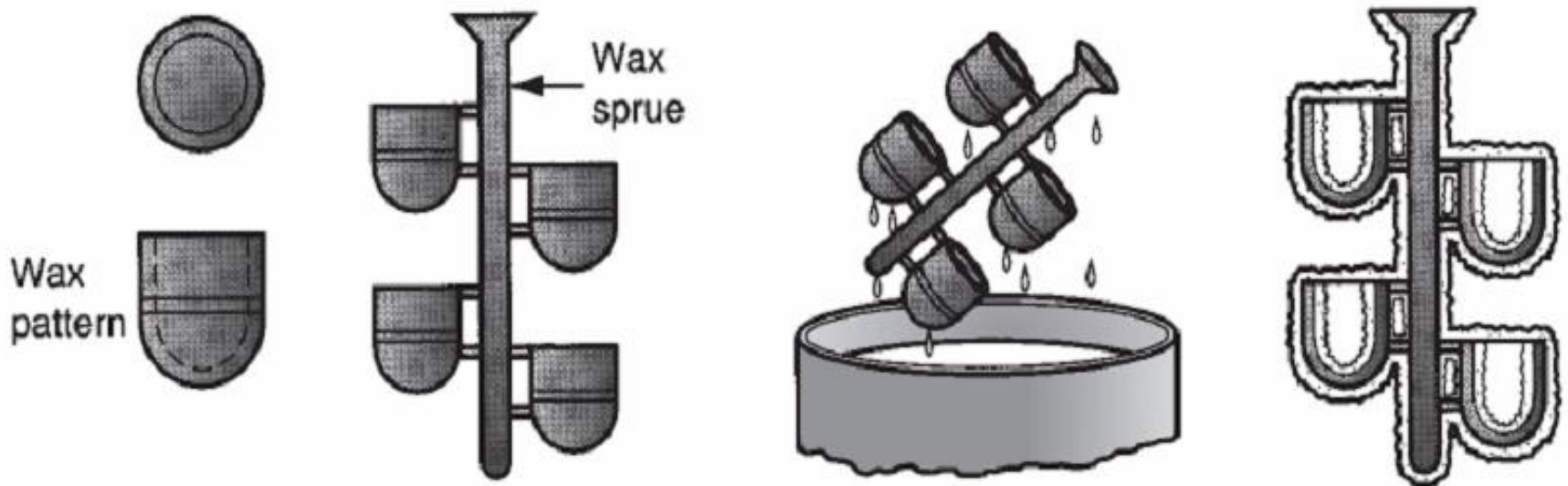
- In this process, a mold of sand packed around a polystyrene foam pattern is used. This pattern will vaporize when the molten metal is poured into the mold.
- The refractory compound will provide a smoother surface on the pattern and to improve its high temperature resistance.
- Molding sands usually include bonding agents.
- Also called as lost-foam process, lost pattern process, evaporative-foam process.
- The foam pattern includes risers, sprue, gating system, internal core.
- Parting lines and draft considerations are reduced.

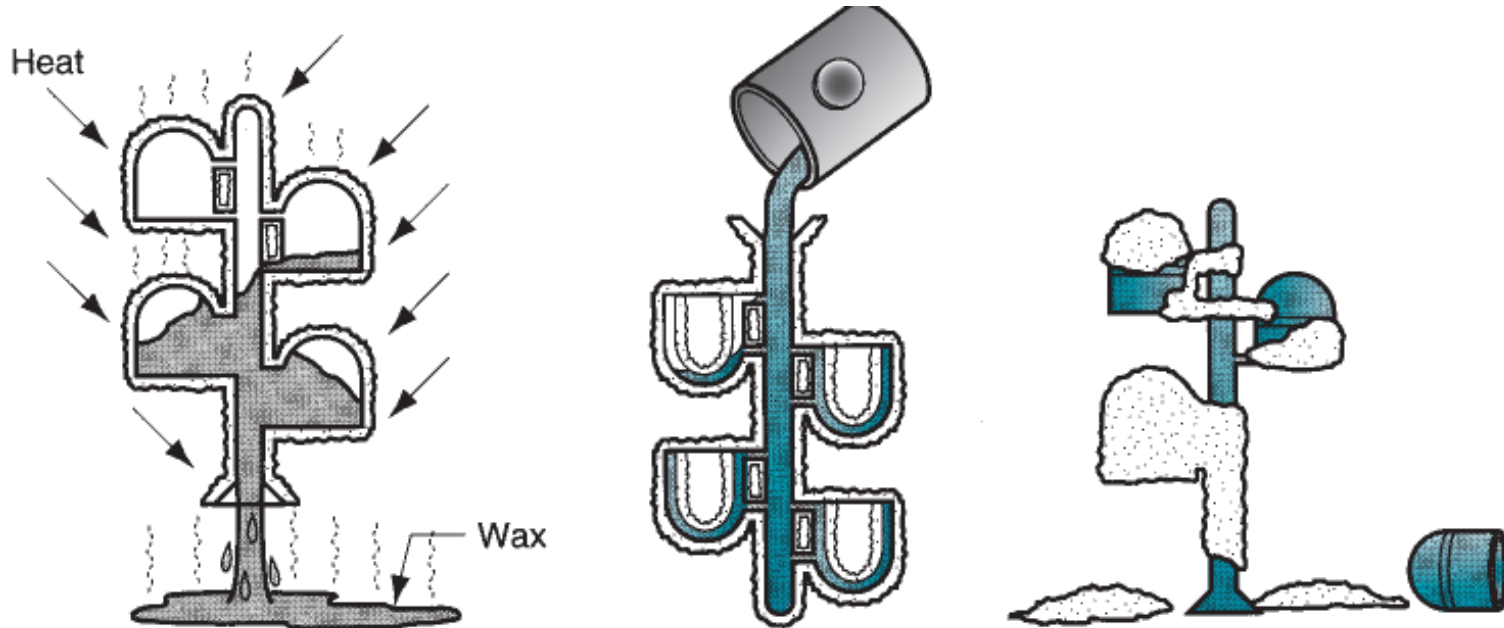
Investment casting

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 we can make castings of high accuracy with intricate details.





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

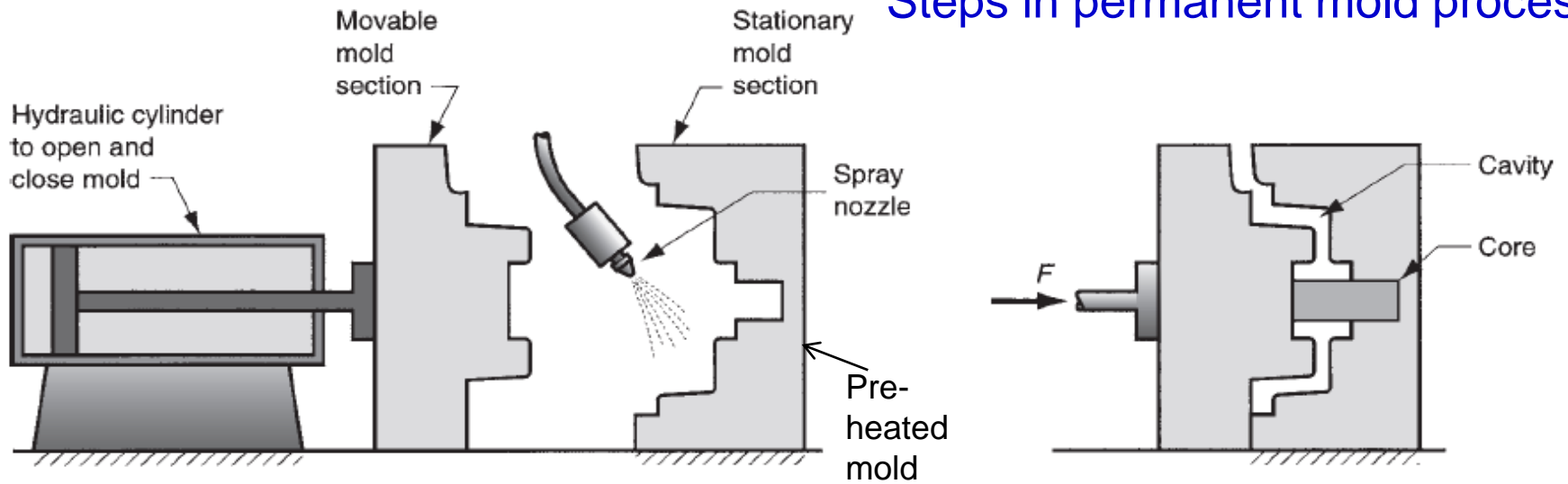
Permanent mold process

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

Permanent mold processes:

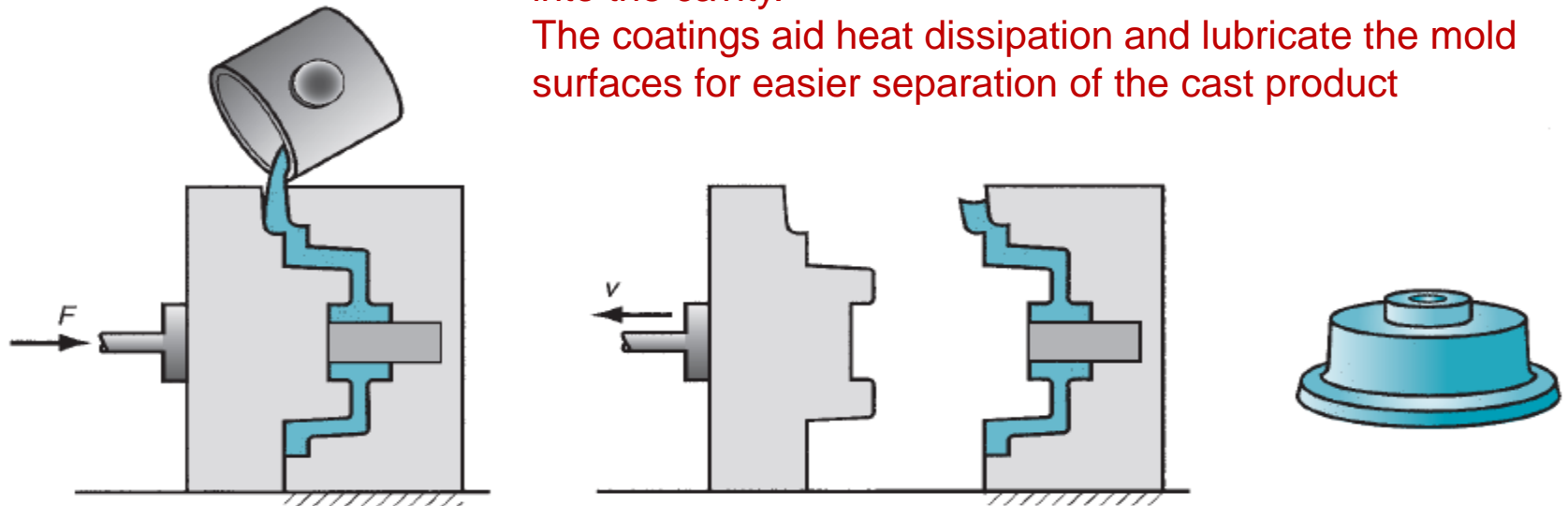
- using only metal mold for casting
- Molds are generally made of steel, CI
- materials that can be cast: Al, Mg, Cu based alloys, CI (affect the mold life, hence not used)
- cores are also made of metal, but if sand is used then called **semi permanent-mold casting**
- **Advantages:** good surface finish, 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

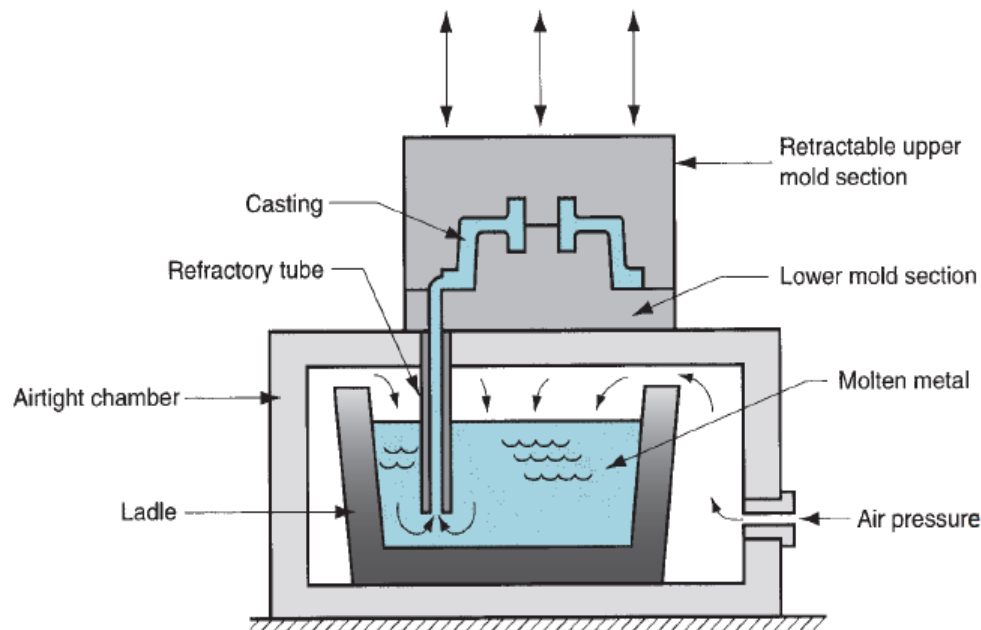


Variations of permanent mold casting

Low pressure casting:

- In the earlier casting process, metal flow in mold cavity is by gravity pull, but in low pressure casting, liquid metal is forced into the cavity under low pressure, app. 0.1 MPa, from beneath the surface so that metal flow is upward.
- **advantage:** molten metal is not exposed to air; gas porosity and oxidation defects are minimized

Vacuum permanent mold casting: variation of low pressure casting, but in this vacuum is used to draw the molten metal into the mold cavity.



Low pressure casting

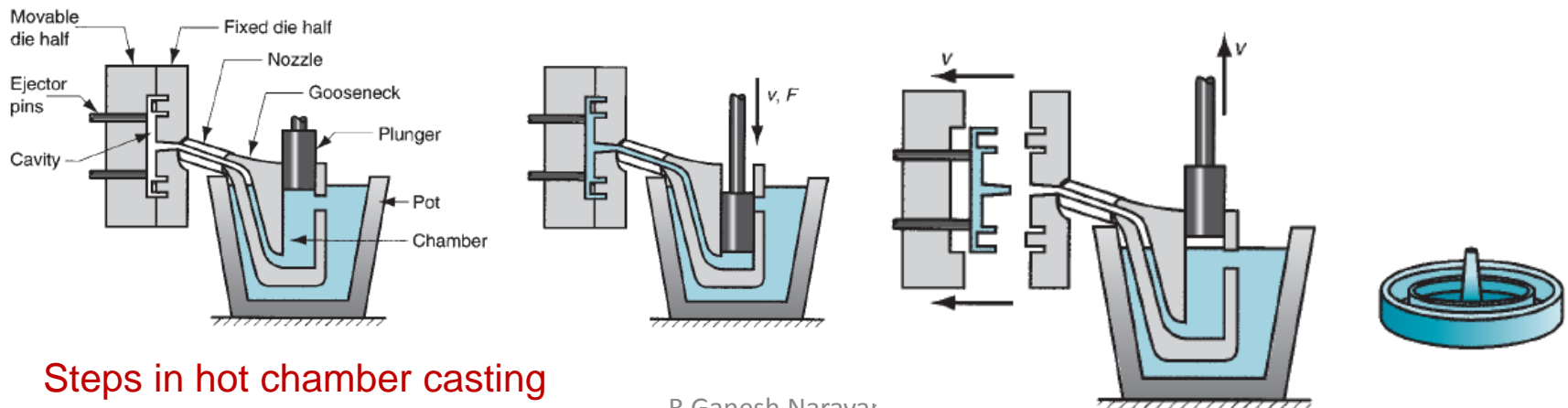
Die casting

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:

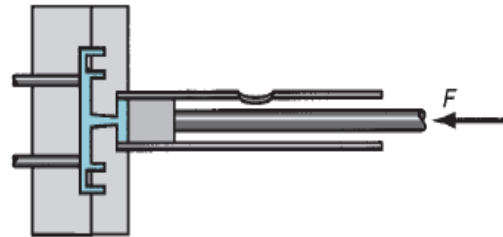
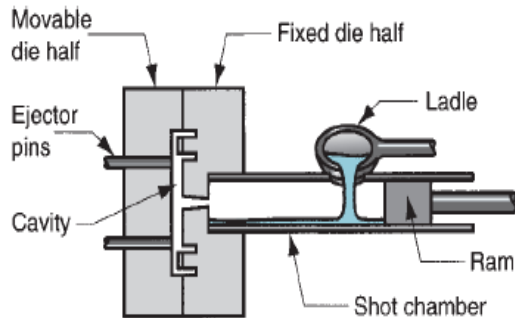
- Molten metal is melted in a container attached to the machine, and a piston is used to pressurize metal under high pressure into the die. Typical injection pressures are between 7 and 35 MPa.
- Production rate of 500 parts/hour are common.
- Injection system is submerged into the molten metal and hence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



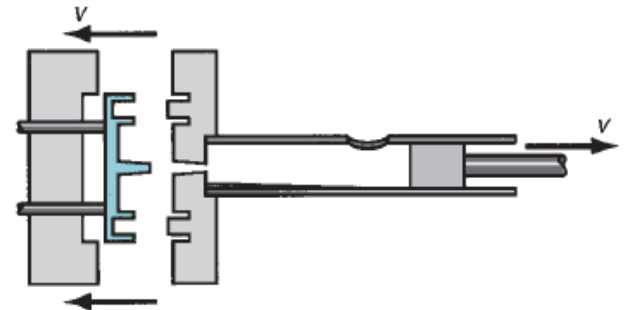
Steps in hot chamber casting

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.

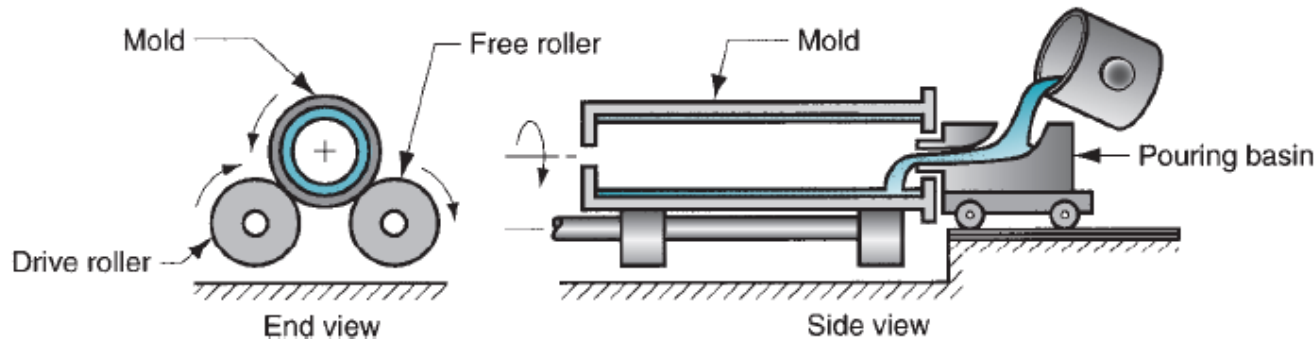
Advantages of die casting:

- 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.

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

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.

Vertical centrifugal casting:

In this because of the effect of gravity acting on the liquid metal, casting wall will be thicker at the base than at the top. The difference in inner and outer radius can be related to speed of rotation as,

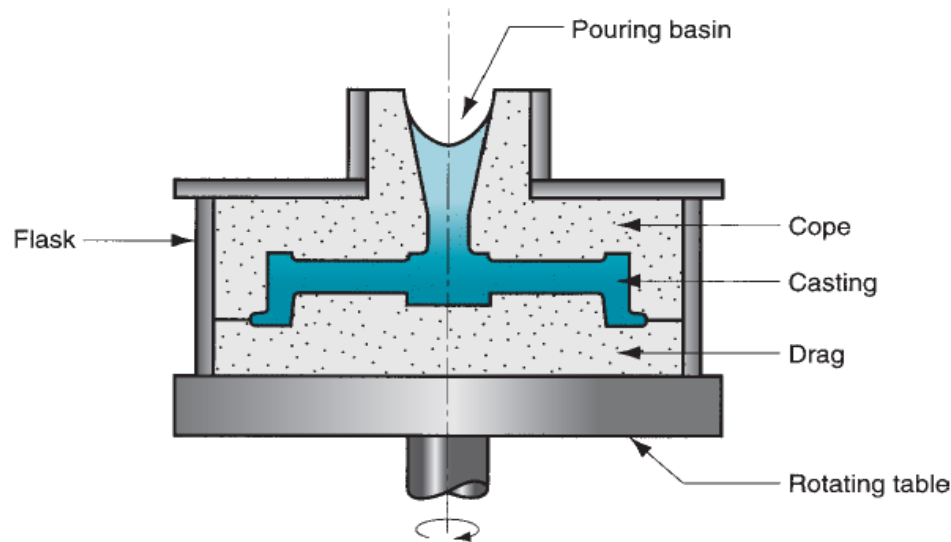
$$N = \frac{30}{\pi} \sqrt{\frac{2gL}{R_{it}^2 - R_{ib}^2}}$$

where
 L - vertical length of the casting in m,
 R_{it} - inner radius at the top of the casting in m,
 R_{ib} - inner radius at the bottom of the casting in m

It is observed from the eqn. that for $R_{it} = R_{ib}$, the speed of rotation N will be infinite, which is practically impossible.

Solidification shrinkage at the exterior of the cast tube will not be an issue, because the centrifugal force continually moves molten metal toward the mold wall during freezing. Impurities in the casting will be on the inner wall and can be removed by machining after solidification.

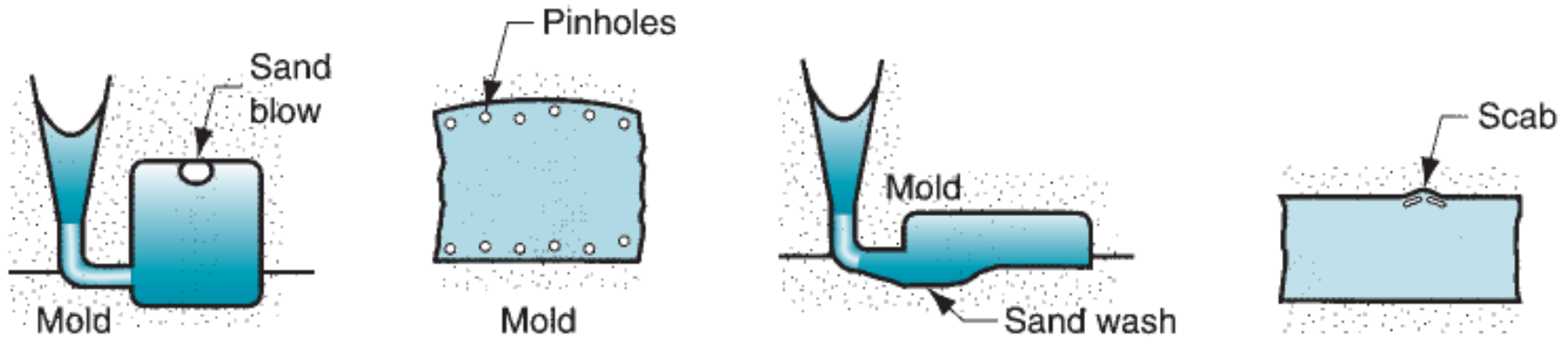
Semicentrifugal casting:



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.

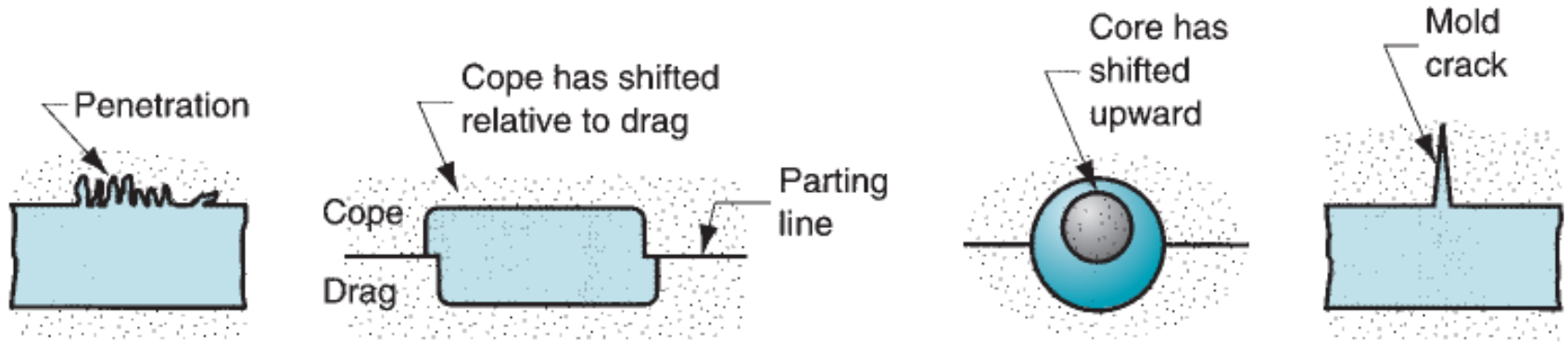
Defects in sand castings



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.



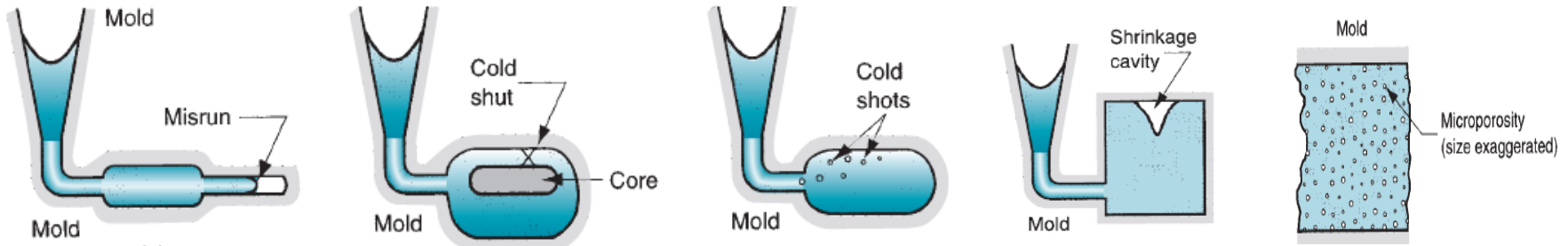
Penetration: surface defect that occurs when the liquid penetrates into the sand mold as the fluidity of liquid metal is high, After solidifying, the casting surface consists of a mixture of sand and metal. Harder ramming of sand mold minimize this defect.

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.

Common defects in casting



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.