Pouring, Gating design

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

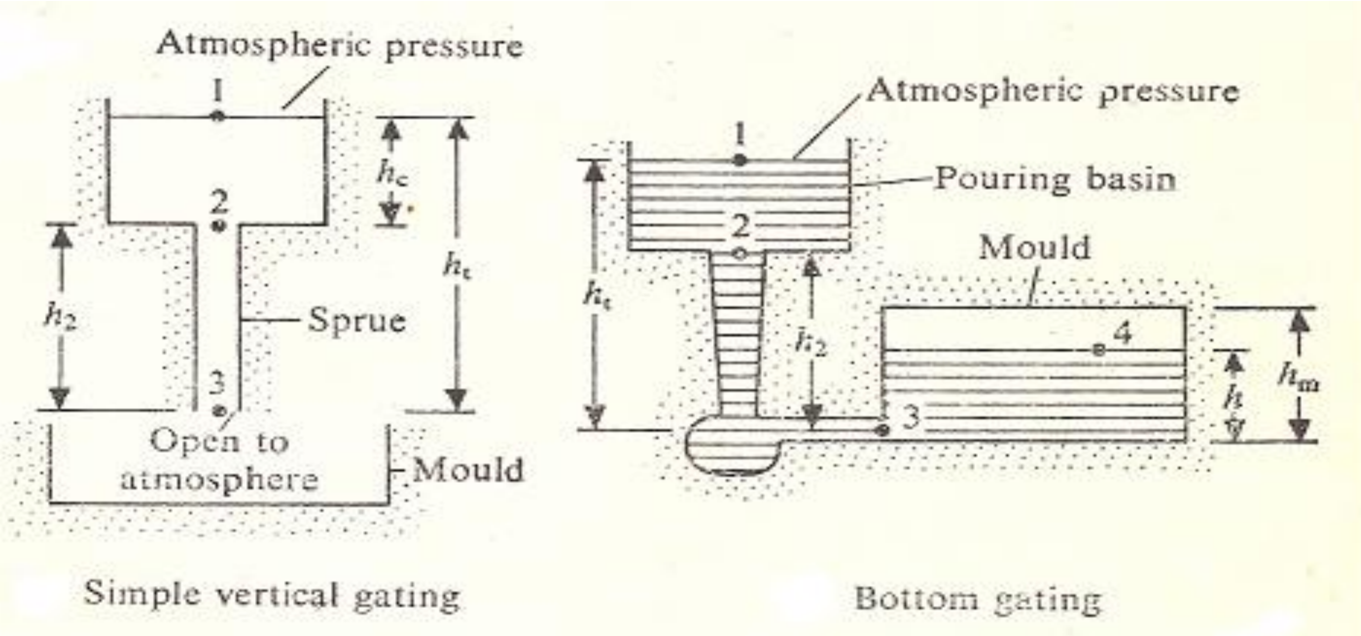
If the molten metal is poured very slowly, since time taken to fill the mould cavity will become longer, solidification will start even before the mould is completely filled. This can be restricted by using super heated metal, but in this case solubility will be a problem.

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.

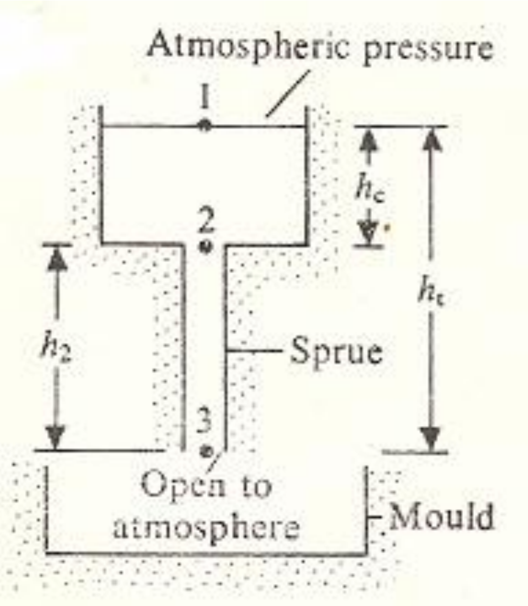
Horizontal gating is a modification of bottom gating, in which some horizontal portions are added for good distribution of molten metal and to avoid turbulence

Analysis of pouring and filling up mould

(a) Vertical gating

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

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



Simple vertical gating

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

The energy balance between point 1 and 3 gives,

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

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.

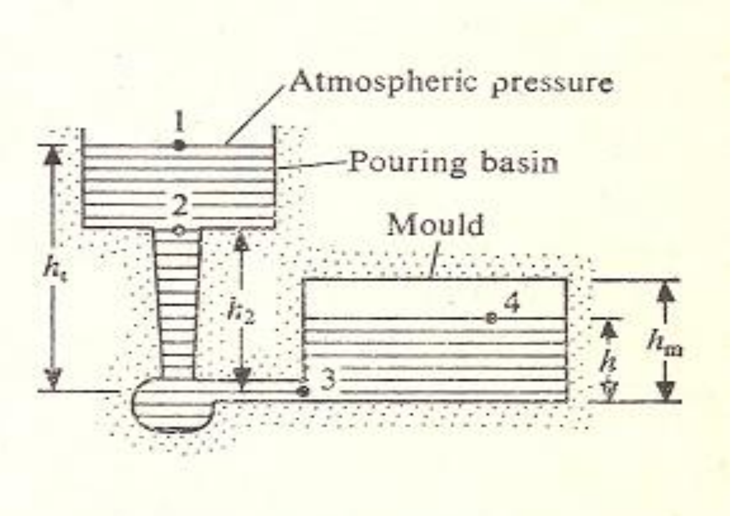
The mould filling time is given by, $\boxed{t_f = \frac{V}{Q} = \frac{V}{A_g v_3}}$

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

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



(b) Bottom gating

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

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

$$A_m dh = A_g v_g dt$$

Combining above two eqns., we get

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

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

(Check integration)

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

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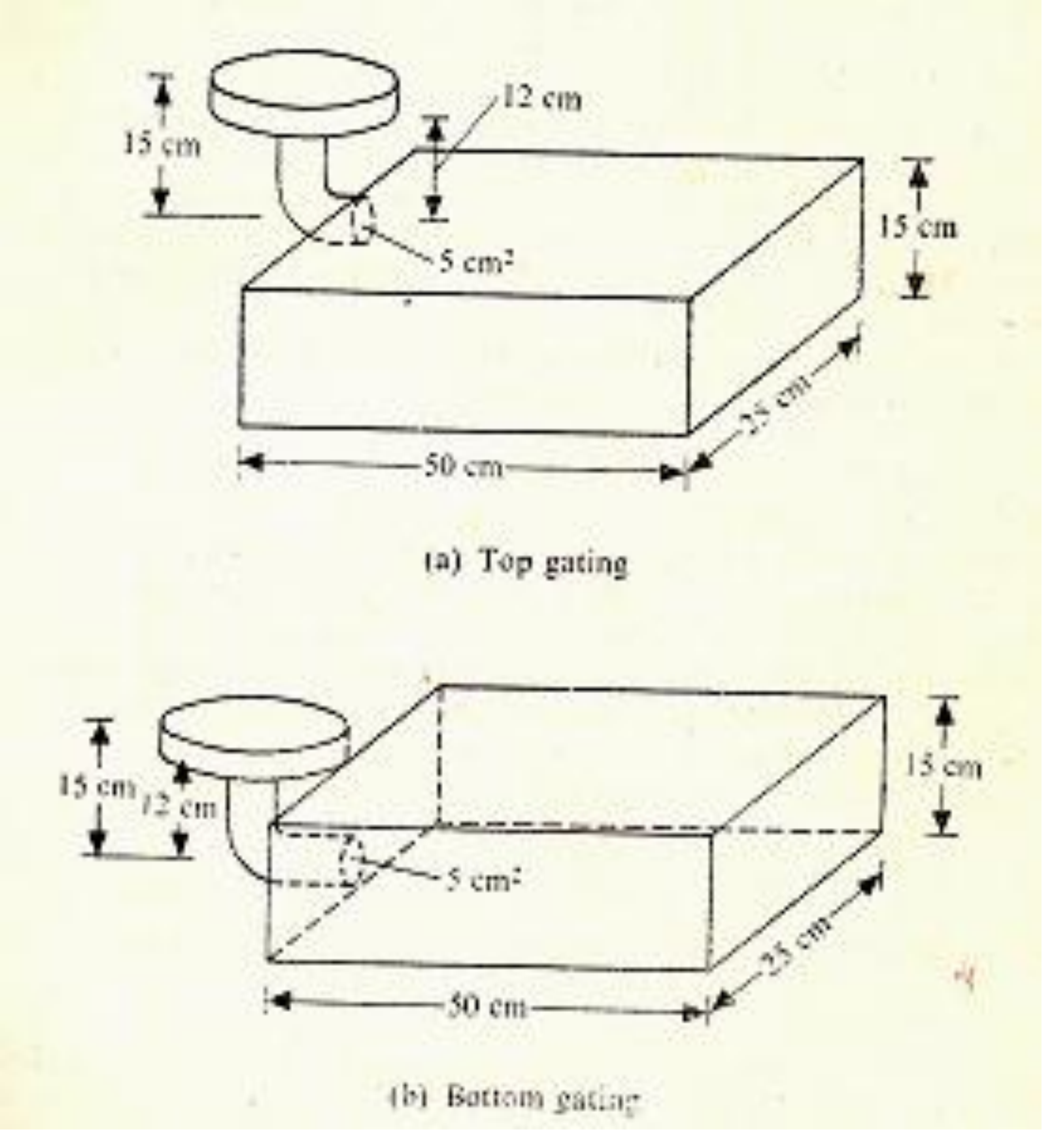

(a) Top gating

(b) Bottom gating

Answer:

t_f = 21.86 sec; 43.71 sec.

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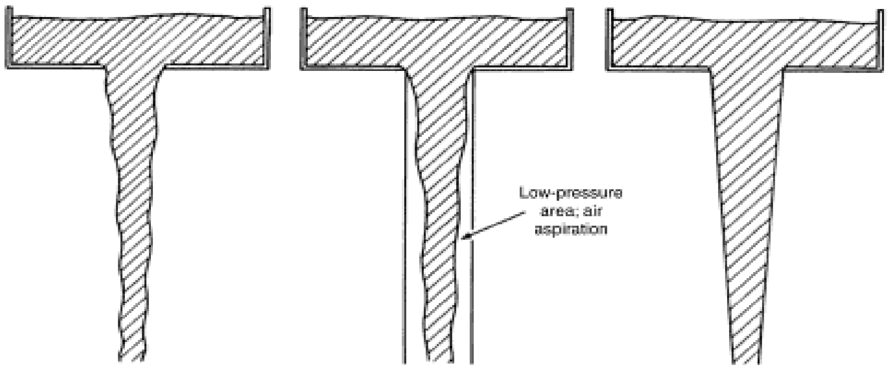
Aspiration effect

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



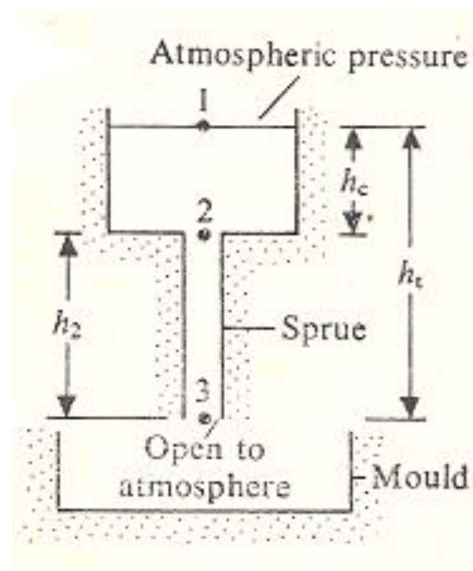
Free falling liquid

Metal flow with aspiration effect

A tapered sprue without aspiration effect

Case 1: straight Vs tapered sprue

Pressure anywhere in the liquid stream should not become negative.

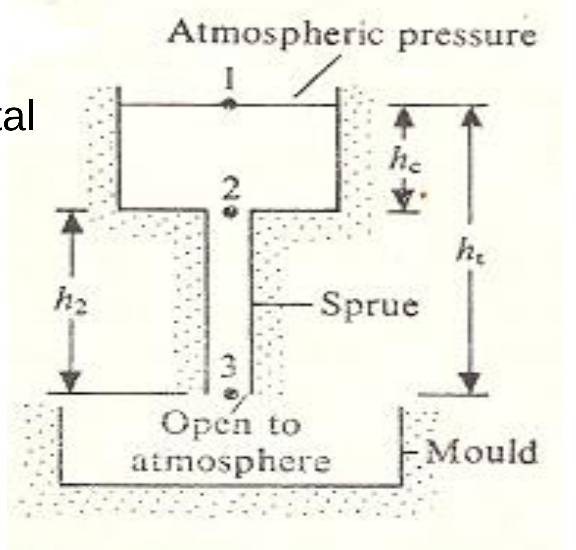


(a) Simple vertical gating

Points 2 & 3

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

ρ_m = density of molten metal



(a) Simple vertical gating

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

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

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

Combining above two eqns., $\frac{v_3^2}{2g} = h_2 + \frac{R^2 v_3^2}{2g}$ $\boxed{R^2 = 1 - \frac{2gh_2}{v_3^2}}$

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

Put this in R^2 eqn, we get, $R^2 = 1 - \frac{h_2}{h_t} = \frac{h_c}{h_t}$ $\boxed{R = \frac{A_3}{A_2} = \sqrt{\frac{h_c}{h_t}}}$

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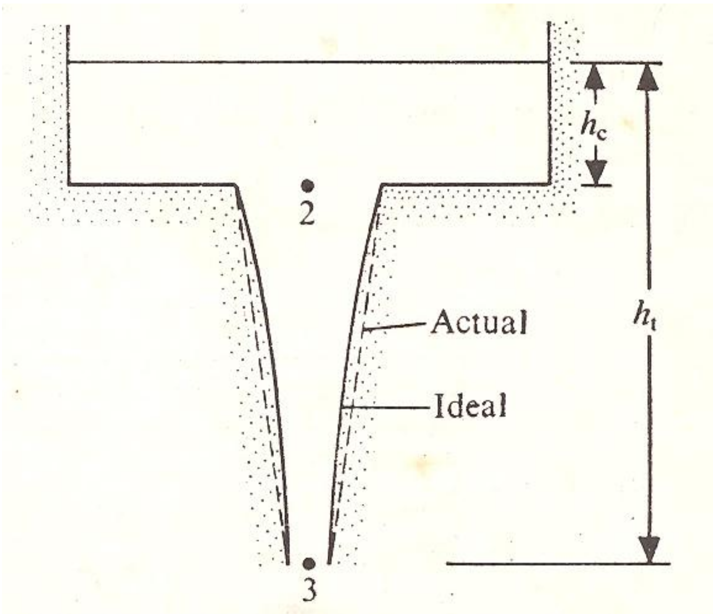
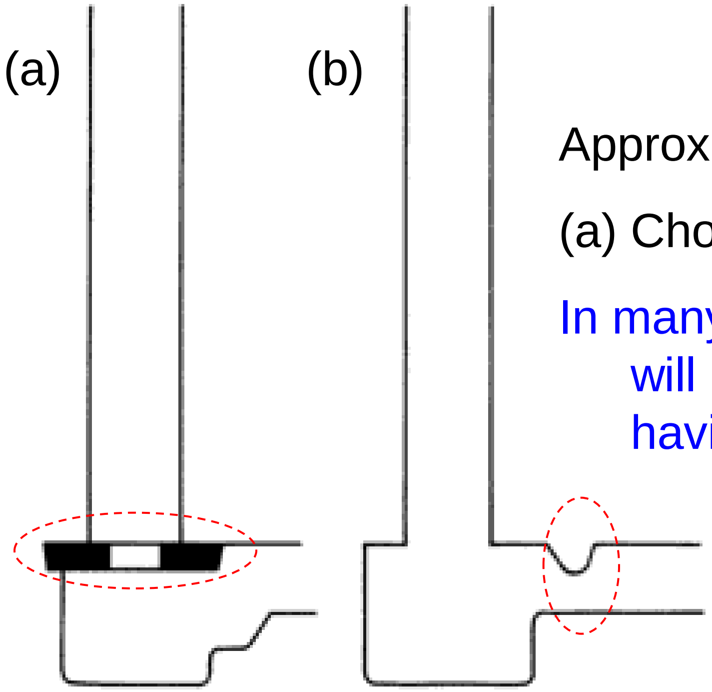
Ideal and actual profiles of sprue



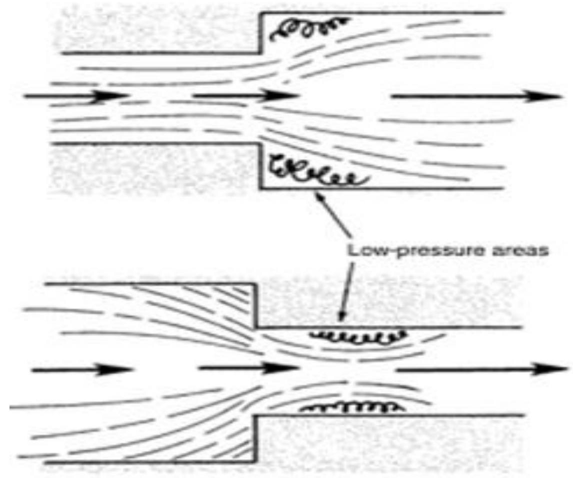


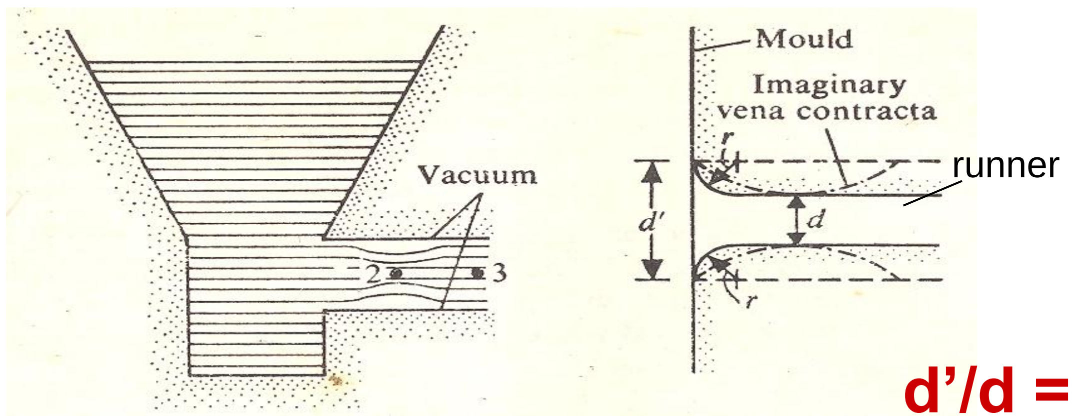
Approximating tapered spure using choke mechanism

(a) Choke core, (b) Runner choke

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

Case 2: sudden change in flow direction





d'/d = 1.3

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

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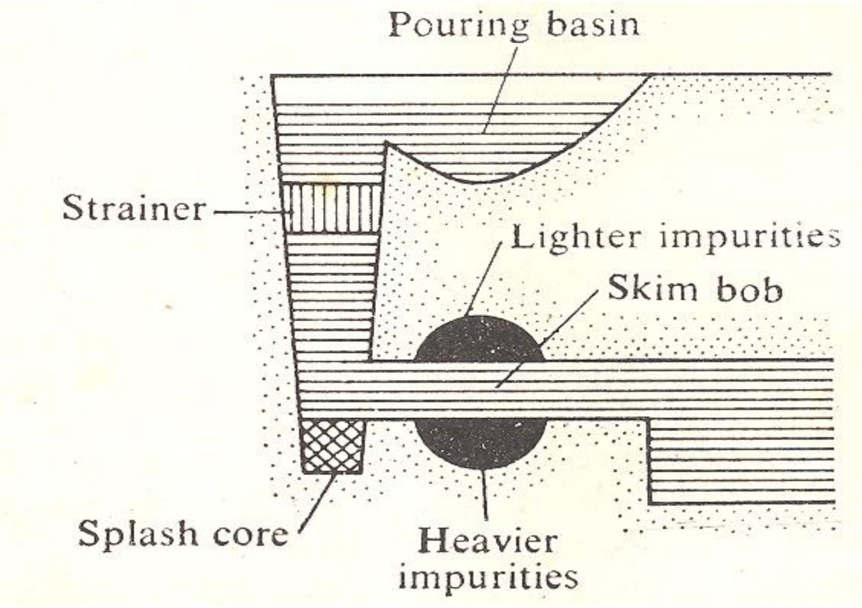
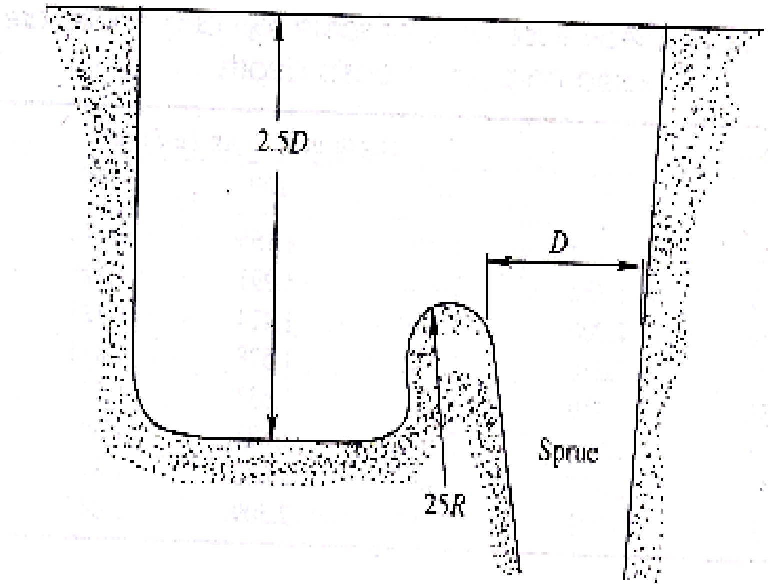
Preventing impurities and turbulence in casting

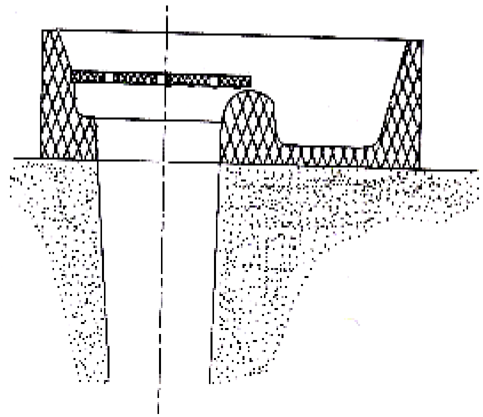


The items provided in the gating system to avoid impurities and turbulence are:

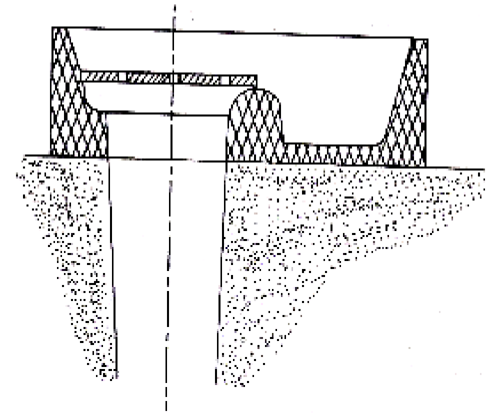
Pouring basin:

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.





Strainer core



Delay screen

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

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

Gating ratios used in practice

Aluminium	1 : 2 : 1
	1 : 1.2 : 2
	1 : 2 : 4
	1 : 3 : 3
	1 : 4 : 4
	1 : 6 : 6
Aluminium bronze	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
	2 : 1 : 4.9
Steels	1 : 1 : 7
	1 : 2 : 1
	1 : 2 : 1.5
	1 : 2 : 2
	1 : 3 : 3
	1.6 : 1.3 : 1

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

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 mm^2 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 mm^2

- convert Q in lit/sec to mm^3/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 cm^3/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 = $\sqrt{4A/\pi}$

M.P. Groover, *Fundamental of modern manufacturing Materials, Processes and systems*, 4ed

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 in^3/sec; (b) 99 in^3; (c) 33 in^3/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

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

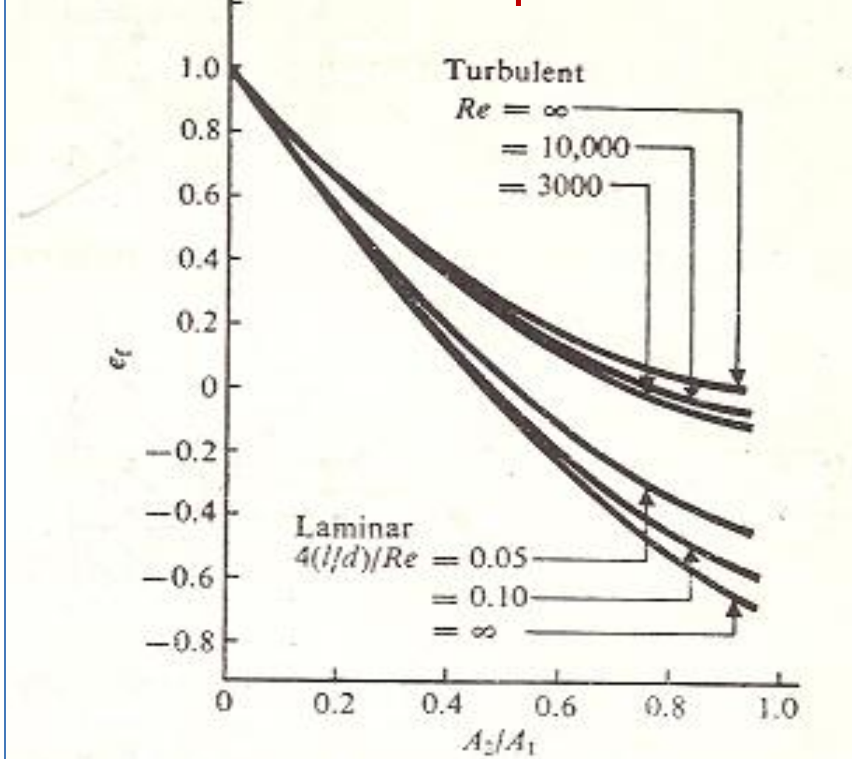
$$f = 0.079(R_e)^{-0.25}$$ for the range 2100 < Re < 10^5 (simplified from above eqn.)

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.

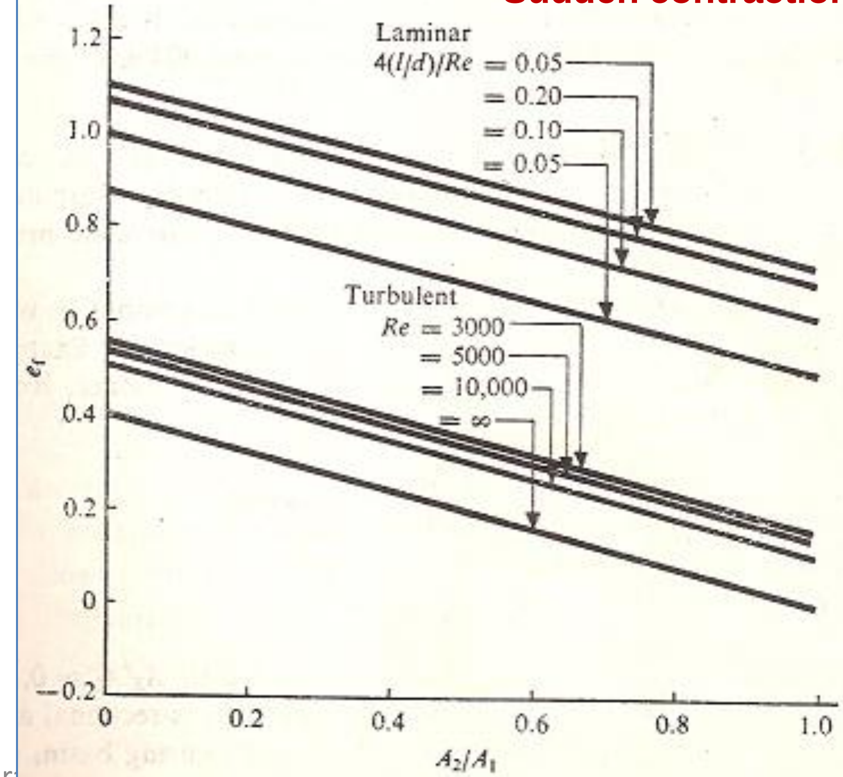
The energy loss due to sudden contraction and enlargement of flow area (per unit mass),

$E_{f2} = \frac{\bar{v}^2}{2} e_f$. Here $\bar{v}$ 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 R_e . In this e_f depends on sudden expansion or sudden contraction as shown in figure.

Sudden expansion



Sudden contraction



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

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 $E_{f1} = \frac{4fl\bar{v}^2}{2d}$ and $E_{f2} = \frac{\bar{v}^2}{2} e_f$, *we get*

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

C_D = discharge coefficient

If the sprue has got a bend or fitting,

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

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

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Cooling and Solidification

Solidification of pure metals

- Change of molten metal to solid state

- Solidification of pure metals and alloys are different

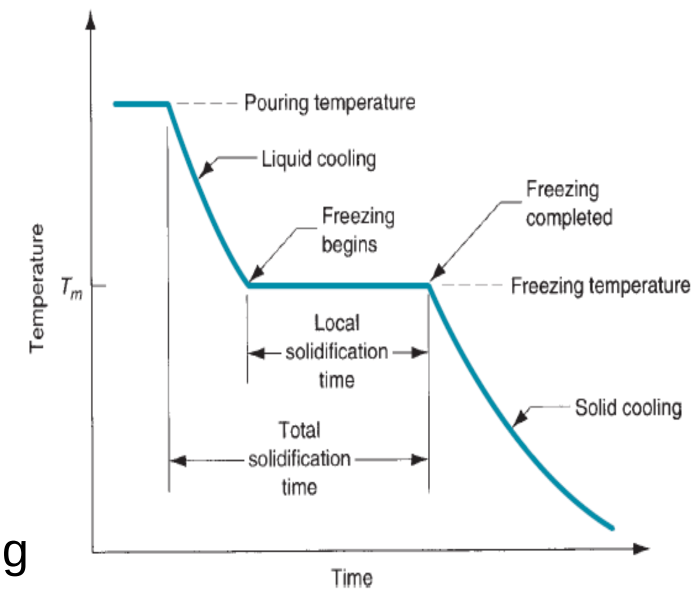
- The cooling curve of pure metals is shown in figure. Here solidification occurs at constant temperature equal to its freezing point.

-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.



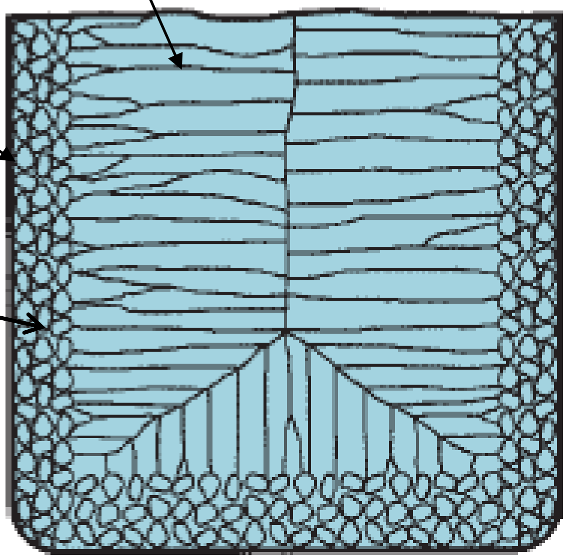
M.P. Groover, *Fundamental of modern manufacturing Materials, Processes and systems*, 4ed

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.

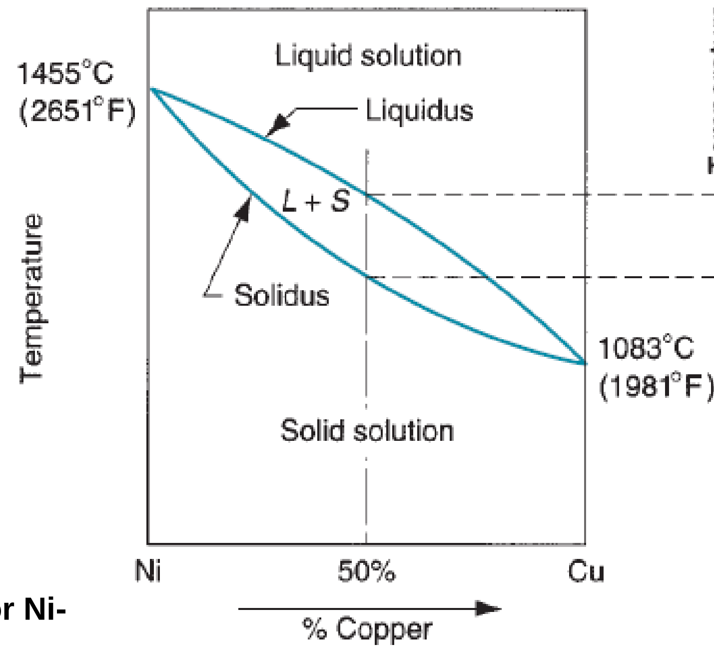
The initial skin formed near the mold wall has gone through fast removal of heat and hence fine, equiaxed and randomly oriented grains are formed.



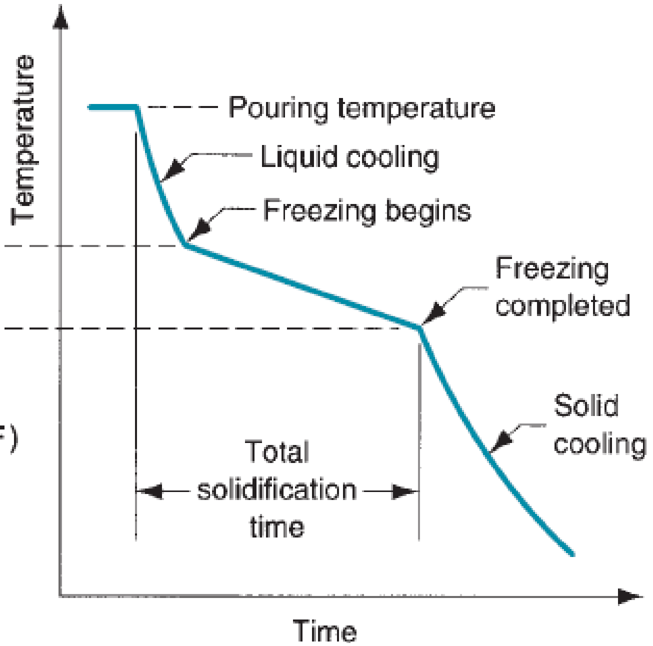
Grain structure in casting of pure metals

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, <u>an imbalance in composition between the solidified metal and the remaining molten metal will develop</u>. This composition imbalance will finally result in the segregation of the elements.

- Segregation of elements can be microscopic and macroscopic. <u>At microscopic level</u>, 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.

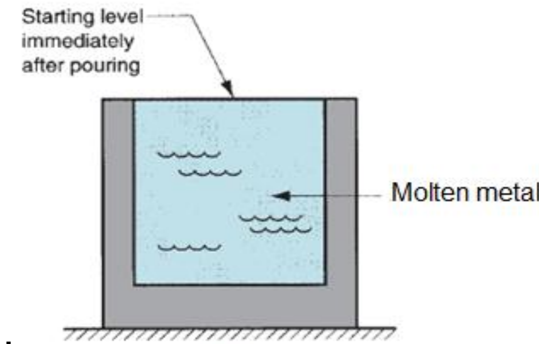
Example:

(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)

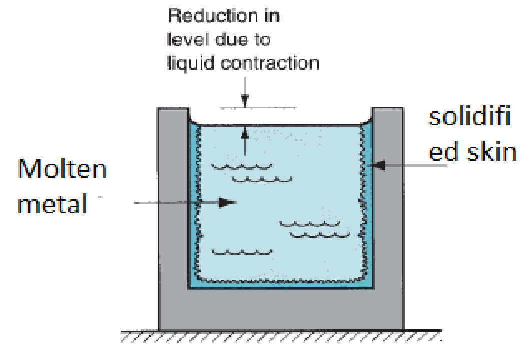
Solidification shrinkage

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

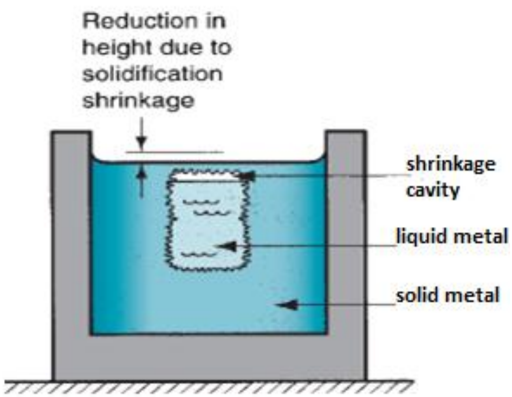
Stage 1: The level of poured molten metal is shown in a mold container.



stage 2

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.



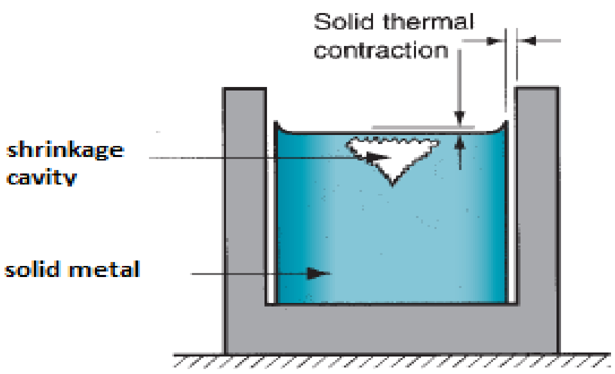
stage 3

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.**



stage 4

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

M.P. Groover, *Fundamental of modern manufacturing Materials, Processes and systems*, 4ed

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.

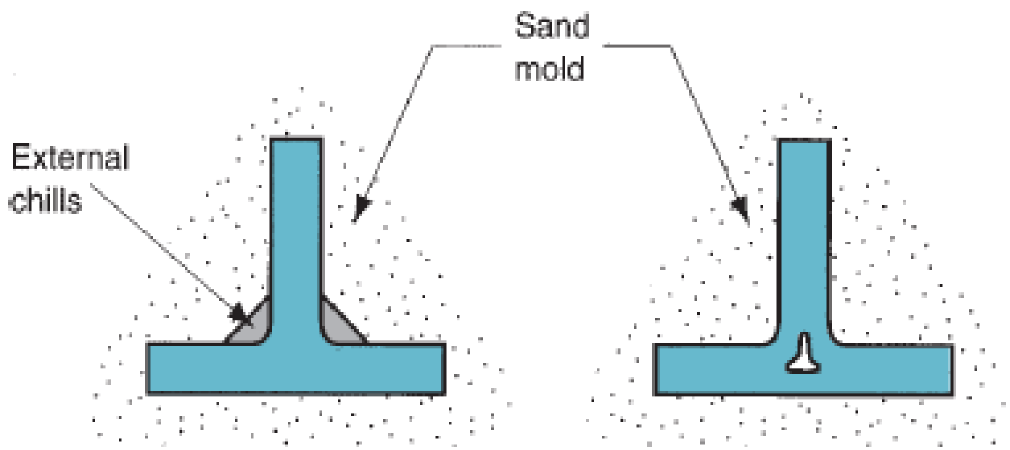
For example, the regions of the cast with lower V/A ratios should be placed far away from the riser location. Solidification will start from these locations and it will progress towards the riser location where bulkier sections of the cast are present. Hence the bulkier sections will continually received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

Method 2: Providing chills:

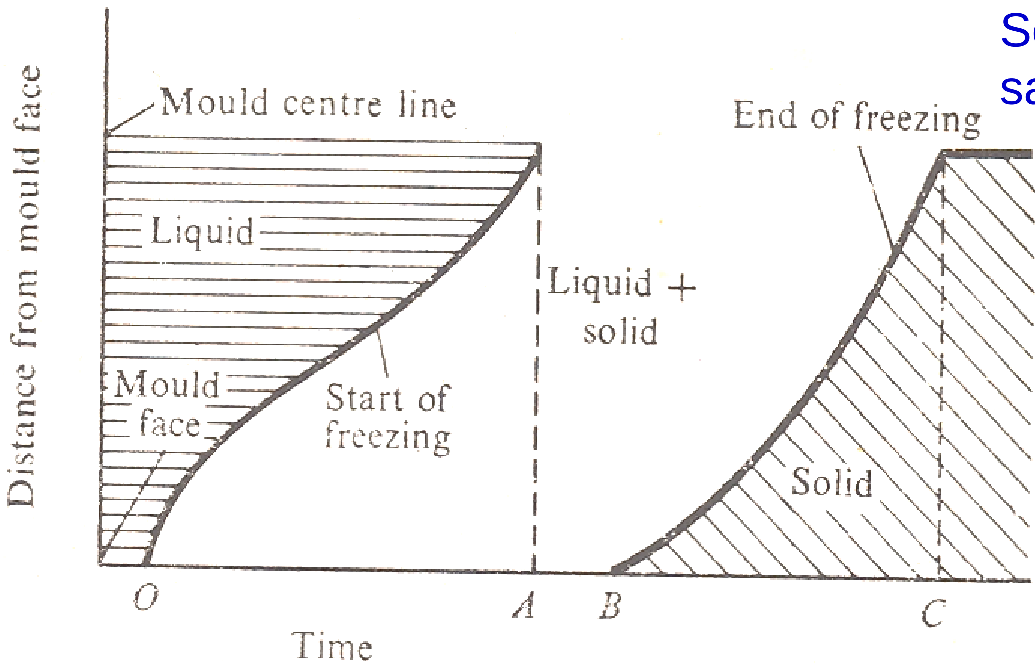
Chills can be provided at appropriate locations in order to have rapid solidification at those points. Internal and external chills can be provided.

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.

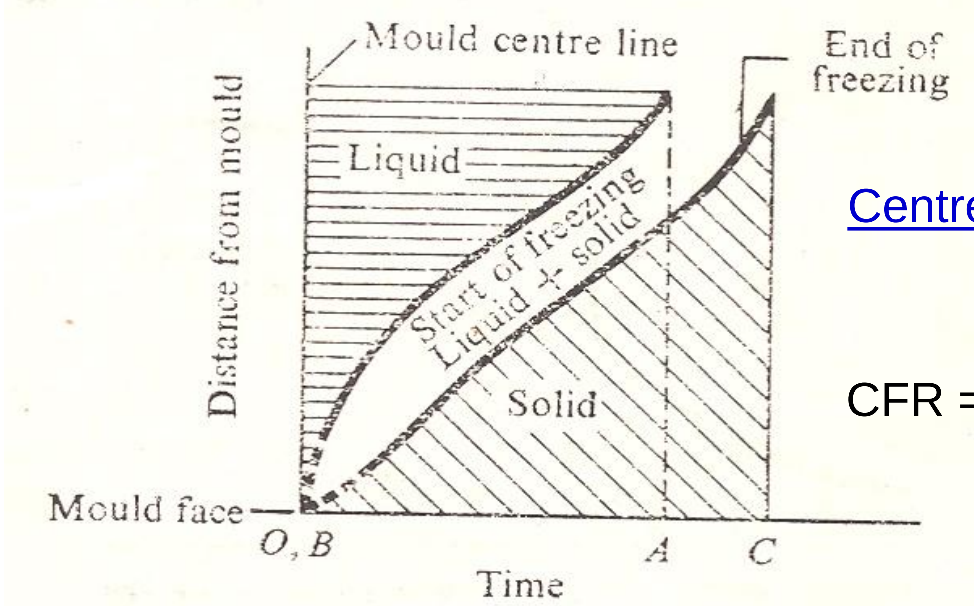
External chills: They are metal inserts kept in mould walls that can extract heat from the molten metal more rapidly than the surrounding sand in order to promote localized solidification. They are mainly used in sections of the casting that are difficult to supply with molten metal.



With external chill Without external chill



Solidification diagram for ordinary sand mould



Solidification diagram for chilled mould

Centre-line feeding resistance (CFR)

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

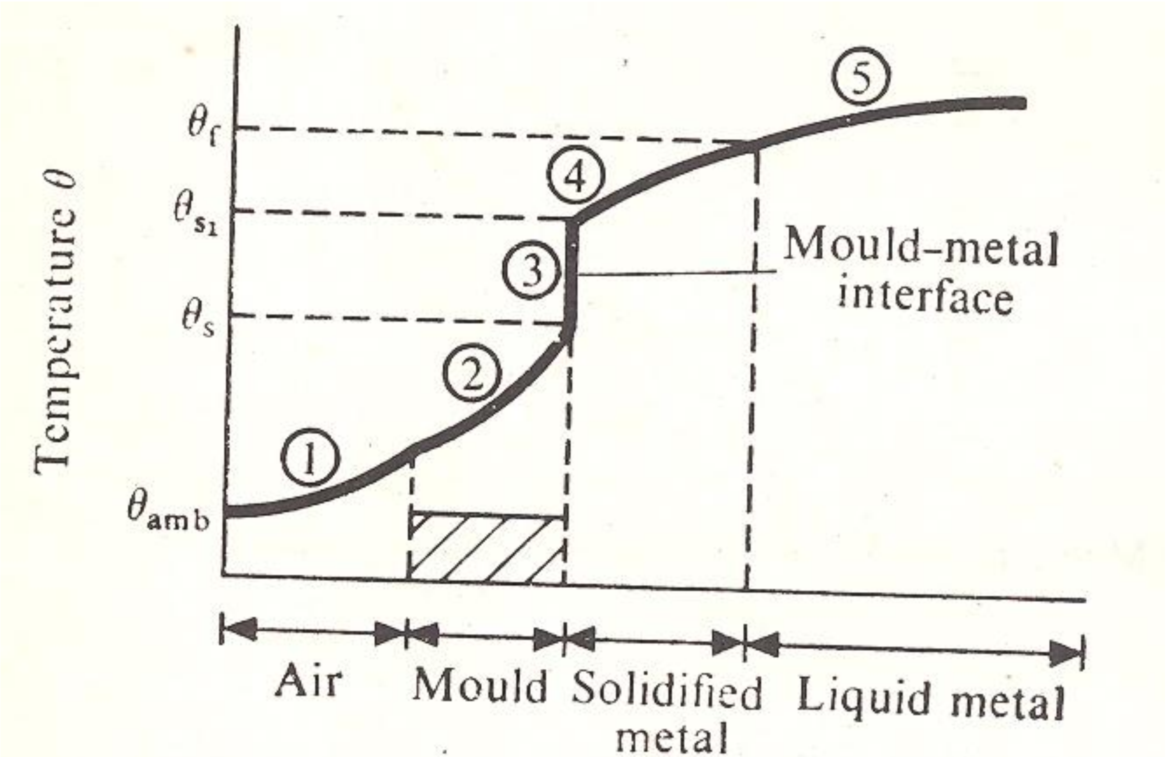
CFR > 70% : FEEDING IS CONSIDERED TO BE DIFFICULT

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.

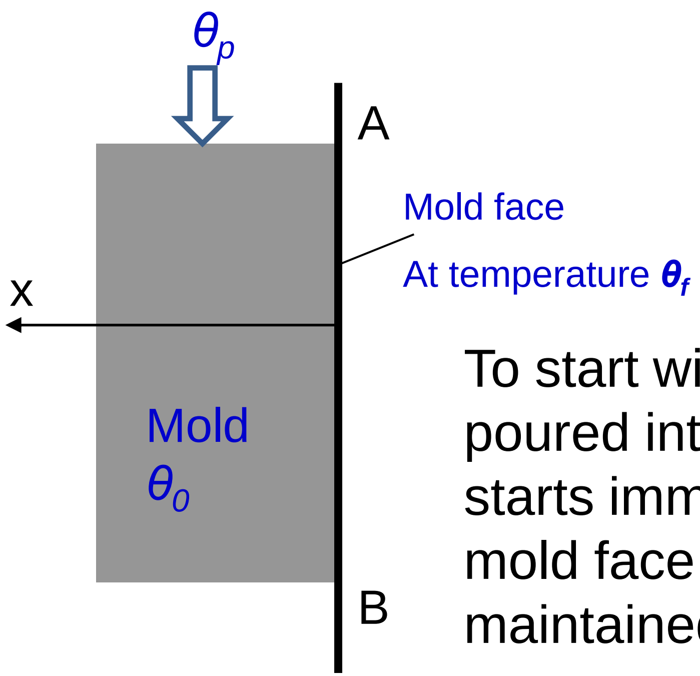
The temperature distribution in these layers is shown in figure.



A Ghosh and A K Mallik, *Manufacturing Science*

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 θp 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 $\dot{Q} = -kA\dfrac{\partial \theta_x}{\partial x}$

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

$$Q_{t0} = \int_0^{t_0} \dot{Q} dt = \frac{2kA(\theta_f - \theta_0)}{\sqrt{\pi\alpha}} \sqrt{t_0}$$

$\left\{ t_0 => t_s;\ Q_{t0} => Q_{ts} \right\}$

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.,

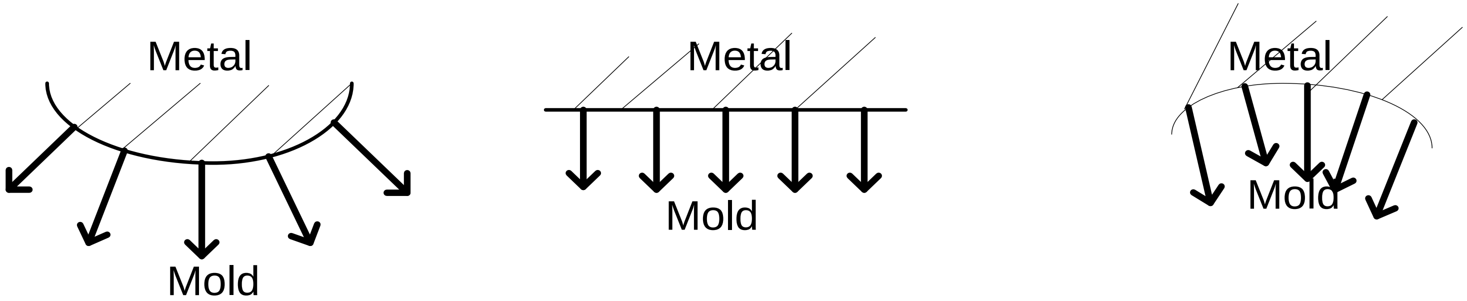
$Q_{ts} = Q_R$

Chvorinov's rule

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

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

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

A Ghosh and A K Mallik, *Manufacturing Science*

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 kJ/kg; density = 7850 kg/m^3

Sand: c = 1.17 kJ/kg-K; k = 0.865 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 x12.5 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:

V/A ratio = (7.5 x 12.5 x 2) / 2(7.5x12.5 + 12.5x2 + 7.5x2)

= 187.5 / 267.5 = 0.7

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

M.P. Groover, *Fundamental of modern manufacturing Materials, Processes and systems*, 4ed

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

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.