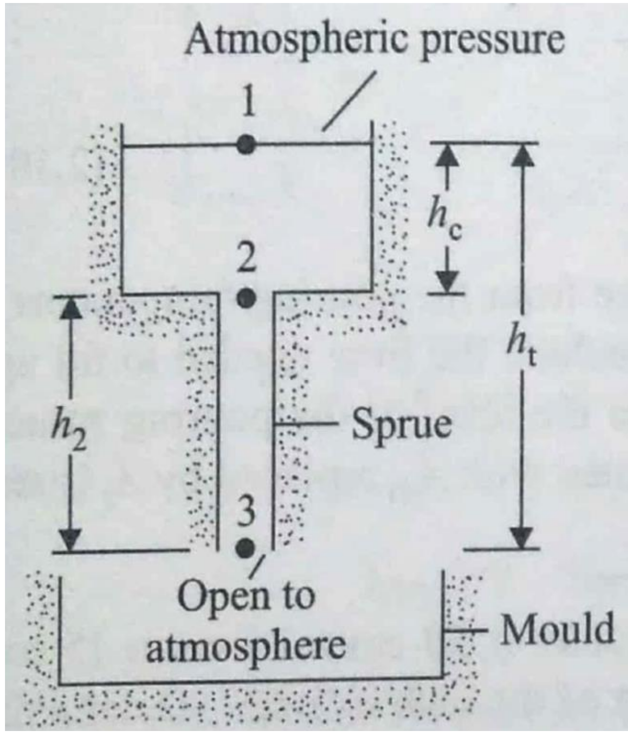
Casting

Gating System Design

- A good gating design ensures distribution of the metal in the mould cavity at a proper rate without excessive temperature loss, turbulence, and entrapping gases and slags.
- Very slow metal flow → solidification starts before complete filling of mould cavity.
- Very fast metal flow → Mould erosion

Pouring time calculation for top gate



$P_1 = p_3 = p_{atm}$; $v_1 = 0$; Frictional losses are ignored

Apply Bernoulli's between points 1 & 3.

$$\frac{p_1}{\rho} + \frac{v_1^2}{2} + gh_t = \frac{p_3}{\rho} + \frac{v_3^2}{2} + 0$$

$$\rightarrow \quad v_3 = \sqrt{2gh_t}$$

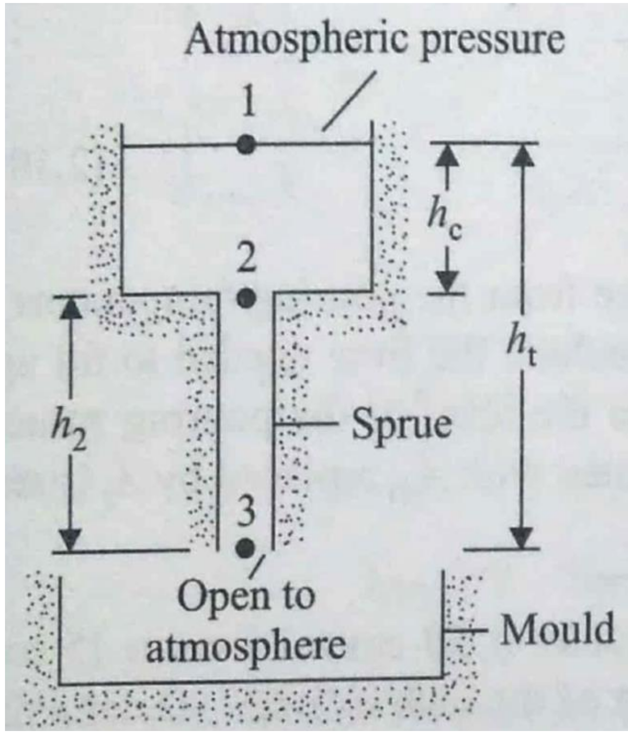
$$Pouring\ time = \frac{V}{A_3 v_3} = \frac{V}{A_g v_g}$$

V = casting volume

$A_g = A_3$ = gate area

$v_g = v_3$ = molten metal velocity at gate

Aspiration effect



Pressure of molten metal should not fall below atmospheric pressure anywhere. Otherwise, air aspiration will occur in the low pressure zones and cause porous casting.

$P_1 = p_3 = p_{atm}$; $v_1 = 0$; Frictional losses are ignored

Apply Bernoulli's between points 2 & 3.

$$\frac{p_2}{\rho} + \frac{v_2^2}{2} + gh_2 = \frac{p_3}{\rho} + \frac{v_3^2}{2} + 0$$

For cylindrical sprue, $v_2 = v_3$; → $P_2 = -\rho g h_2$

Hence, negative pressure is created for cylindrical sprue.

In the limiting case, $P_2 = 0$; → $\frac{v_2^2}{2} + gh_2 = \frac{v_3^2}{2}$

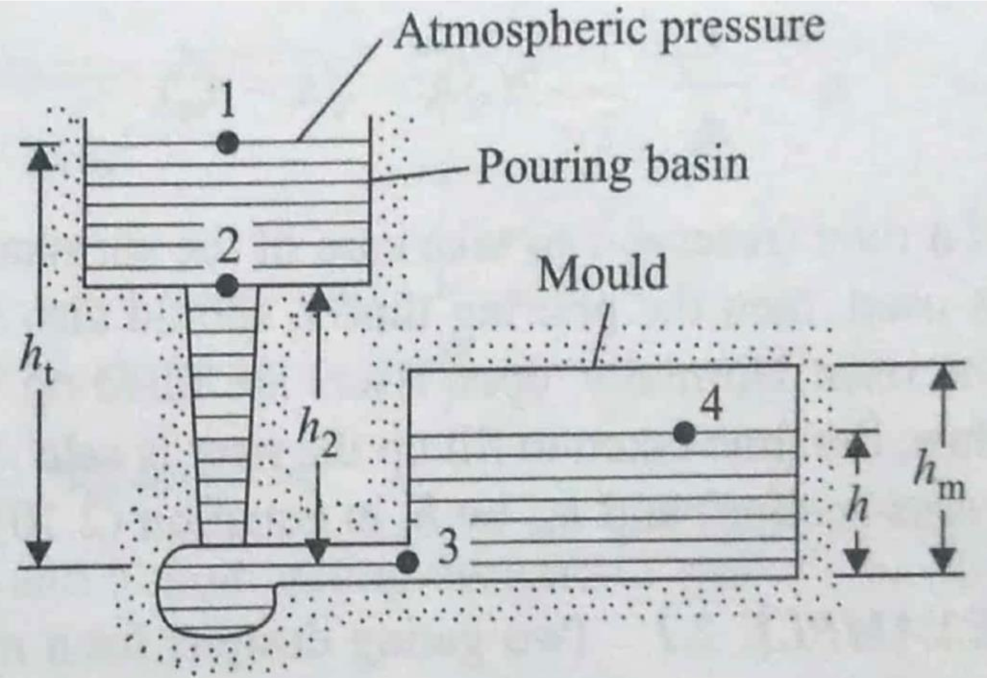
From continuity eq., $A_3 v_3 = A_2 v_2$; → $v_2 = (A_3/A_2)\, v_3 = R v_3$

→ $\frac{R^2 v_3^2}{2} + gh_2 = \frac{v_3^2}{2}$; → $R = \sqrt{1 - \frac{2gh_2}{v_3^3}}$

Now, $v_3 = \sqrt{2gh_t}$; → $R = \frac{A_3}{A_2} = \sqrt{1 - \frac{h_2}{h_t}} = \sqrt{\frac{h_c}{h_t}}$

→ Sprue should be tapered to avoid negative pressure at point 2.

Pouring time calculation for bottom gate



$P_1 = p_4 = p_{atm}$; $v_1 = v_4 = 0$; Frictional losses are ignored

Applying Bernoulli's eq. between points 1 and 3, we get $gh_t = \frac{p_3}{\rho} + \frac{v_3^2}{2}$

Applying Bernoulli's eq. between points 3 and 4, we get $\frac{p_3}{\rho} = gh$

→ $v_3 = v_g = \sqrt{2g(h_t - h)}$

For the instance, let metal level of the mould increase by 'dh' in time 'dt'.

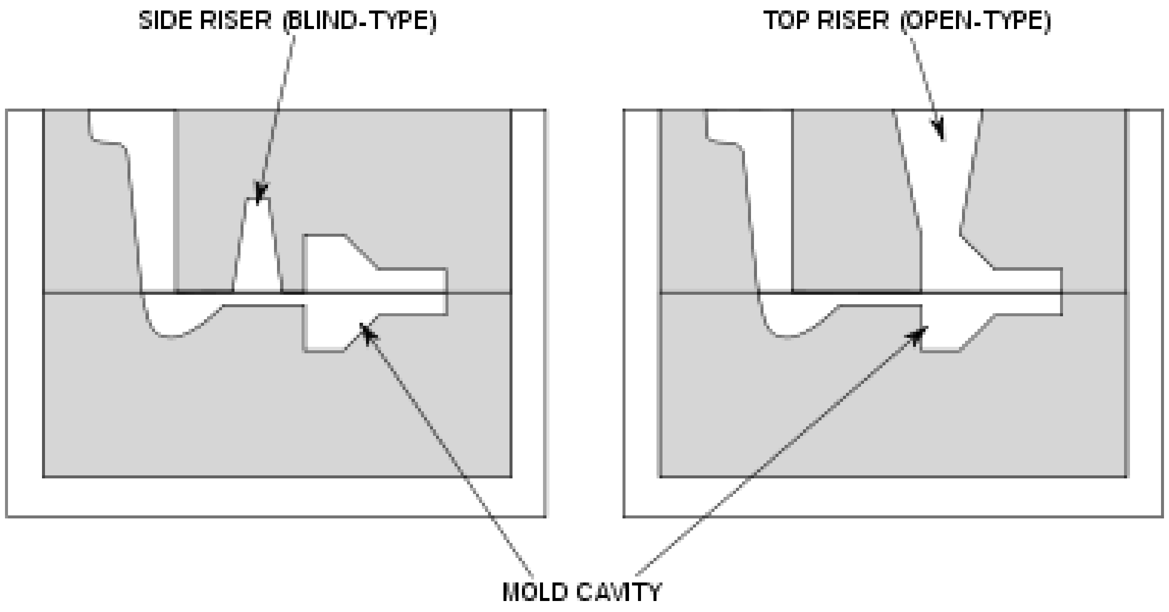
→ $A_m\,dh = A_g\,V_g\,dt$ → $\frac{dh}{v_g} = \frac{A_g}{A_m}dt$ → $\frac{dh}{\sqrt{2g(h_t-h)}} = \frac{A_g}{A_m}dt$

At t = 0, h = 0; At $t = t_f$, $h = h_m$

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

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

Riser: Reservoir of molten metal for supply to the mould cavity to compensate the shrinkage of the molten metal in the mould cavity.



Riser design criteria:

1. Molten metal in riser solidifies after casting
2. Riser volume sufficient to compensate casting shrinkage

Types of riser:

(i) location: (a) **Top riser** (located on top of the casting, takes less space, shorter feeding distance)
(b) **Side riser** (located on the side of the casting)

(ii) openness to atmosphere (a) **Open riser** (Open to atmosphere, faster heat loss due to convection and radiation to atmosphere directly through top of the riser)
(b) **Blind riser** (Completely contained in the mould, slower heat loss, smaller than open riser)

(iii) Filling of riser (a) **Live riser** (riser receives material from the gating system and fills before the mold cavity)
(b) **Dead/Cold riser** (riser fills with material that has already flowed through the mold cavity, larger than live riser)

Riser design

Riser supplies molten metal to the casting to compensate the shrinkage of molten metal during solidification.

Caine's method of riser design

Solidification of casting and riser depends on (V/A) ratio.

Chvorinov rule → Solidification time, $t_s = k(V/A)^2$

k = mould constant, depends on pouring temperature, and thermal characteristics of mould & casting

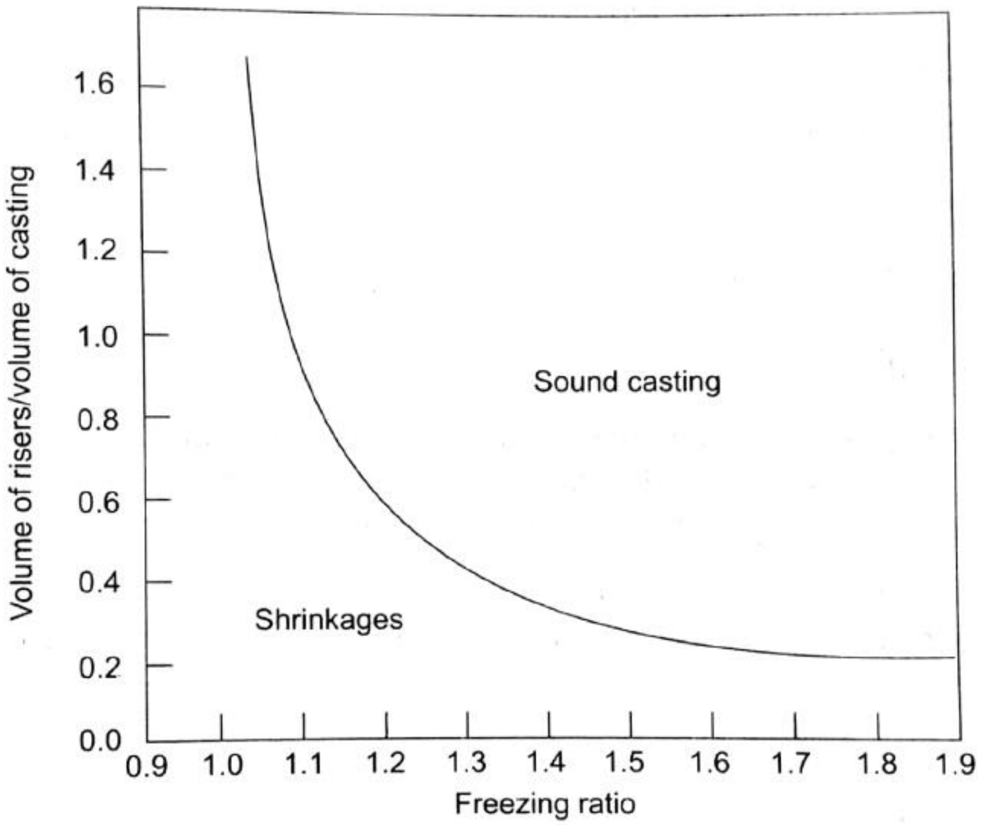
Freezing ratio, $X = \frac{A_{casting}/V_{casting}}{A_{riser}/V_{riser}}$

Riser should solidify at last. → X > 1

Caine's eq.→ $\boldsymbol{X = \frac{a}{Y-b} + c,}$

where $Y = V_{riser}/V_{casting}$, a,b,c are constants

For steel,	a = 0.10,	b = 0.03,	c = 1.00
For aluminium,	a = 0.10,	b = 0.06,	c = 1.08
Cast iron, brass,	a = 0.04,	b = 0.017,	c = 1.00
Grey cast iron	a = 0.33,	b = 0.03,	c = 1.00
Aluminium bronze,	a = 0.24,	b = 0.017,	c = 1.00
Silicon bronze,	a = 0.24,	b = 0.017,	c = 1.00



Problem: Calculate the size of a cylindrical top riser (H = D) necessary to feed a steel slab casting 25 cm x 25 cm x 5 cm.

Solution

$V_{casting}$ = 25 x 25 x 5 cm^3 = 3125 cm^3

$A_{casting}$ = 2 x 25 x 25 + 4 x 25 x 5 cm^2 = 1750 cm^2

$V_{riser} = \pi D^2 H/4 = 0.25\pi D^3$ (Since, H = D)

Ariser = $\pi DH + \pi D^2/4 = \pi D^2 + \pi D^2/4 = 1.25\,\pi D^2$

$$X = \frac{A_c/V_c}{A_r/V_r} = \frac{1750/3125}{1.25\pi D^2/0.25\pi D^3} = 0.112D$$

$$Y = V_r/V_c = 0.25\pi D^3/3125 = 0.000251D^3$$

Caine's eq.→ $X = \frac{a}{Y-b} + c$, where Y = $V_{riser}/V_{casting}$, and a,b,c are constants

For steel, a = 0.10, b = 0.03, c = 1.00

→ $0.112D = \frac{0.10}{0.000251D^3 - 0.03} + 1.0$

→ $D^4 - 8.9286D^3 - 119.52D = 2490$

→ **D = 12 cm**

Modulus method of riser design

Modulus of riser, $M_r = V_r/A_r$

Modulus of casting, $M_c = V_c/A_c$

It is empirically found that if $\mathbf{M_r = 1.2M_C}$, then casting is satisfactory.

If, H = D for riser, then

$$V_r = \frac{\pi D^3}{4} \qquad A_r = \frac{\pi D^2}{4} + \pi D^2 \text{ (top riser)}$$

→ $M_r = V_r/A_r = (\pi D^3/4)/(5\pi D^2/4) = D/5 = 0.2D$

Now, $M_r = 1.2M_c$

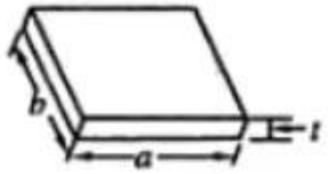
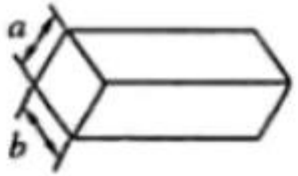
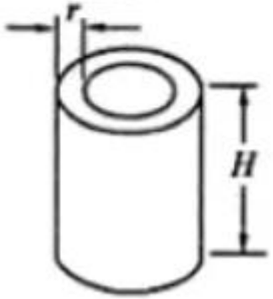
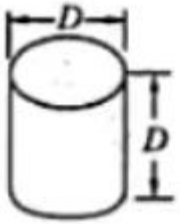
→ $0.2D = 1.2M_c$

→ $D = 6M_c$

For the previous example, $M_c = V_c/A_c = 3125/1750 = 1.7857$

→ $D = 6M_c = 10.71$ cm

Moduli of simple geometric shapes

Shape			Modulus, M_c	Shape		Modulus, M_c
Plate		$a \le 5t$	$0.5t$	Sphere		$\frac{D}{6}$
Disc		$d \le 5t$	$0.5t$	Cylinder		$\frac{DH}{2(D+2H)}$
Long bar			$\frac{a \times b}{2(a+b)}$	Annulus		$\frac{rH}{2(r+H)}$
Cube			$\frac{D}{6}$	Any bar with no cooling ends		$\frac{\text{cross-sectional area}}{\text{perimeter of cross section}}$
Cylinder			$\frac{D}{6}$			

Melting Practices

- The quality of casting depends on the method of melting.
- A furnace is used to melt the metal.
- A furnace contains high temperature zone where the metal to be melted is placed.
- Heat in the furnace is created by combustion of fuel, electric arc etc.
- Different types of furnaces for melting – pit furnace, cupola furnace, electric arc furnace, crucible furnace, induction furnace, reverberatory furnace, etc.

Heat required in a furnace

The heat 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 can be expressed as:

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

H = total heat required to raise the temperature of the metal to the pouring temperature (J)

ρ = density of metal (kg/m^3);

C_s = specific heat for the solid metal (J/kg-C)

T_m = melting temperature of the metal (C)

T_o = ambient temperature (C)

H_f = heat of fusion (J/kg)

C_l = specific heat of the liquid metal (J/kg-C)

T_p = pouring temperature (C)

V = volume of metal being heated (m^3)

One cubic meter of a certain eutectic alloy is heated in a crucible from room temperature to 100°C above its melting point for casting. The alloy's density = 7.5 g/cm³, melting point = 800°C, specific heat = 0.33 J/g°C in the solid state and 0.29 J/g°C in the liquid state; and heat of fusion = 160 J/g. How much heat energy must be added to accomplish the heating, assuming no losses?

Solution: Assume ambient temperature in the foundry = 25°C and that the density of the liquid and solid states of the metal are the same. Noting that one $m^3 = 10^6\ cm^3$, and substituting the property values into Equation (10.1),

$$H = (7.5)(10^6)\{0.33(800 - 25) + 160 + 0.29(100)\} = 3335(10^6)\ J$$

Furnace selection

Furnace selection depends on:

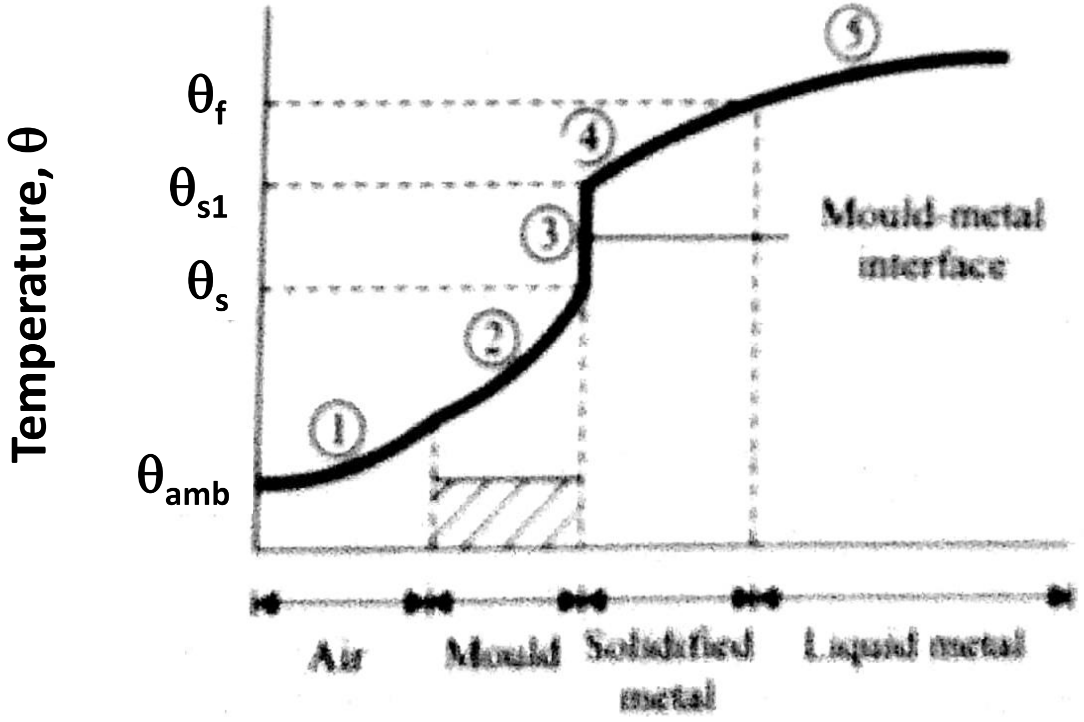
- The type of metal
- The maximum temperature required [Higher value of ($T_{pouring} – T_{melting}$) will increase the fluidity of molten metal. However, fuel cost of the furnace will be higher.]
- Quantity of metal to be melted
- Rate of molten metal delivery
- Cost of the furnace
- Fuel cost/ Cost of operation
- Cost of furnace repair and maintenance

Cooling and Solidification of Casting

- Crystal structure and alloy composition at different parts of casting are decided during solidification.
- Improper solidification results in casting defects.

Rate of Solidification

- Estimate of solidification time of casting helps in design and placement of riser.



Temperature Distribution in Different Layers

Zone 1 → Heat Loss in the Air

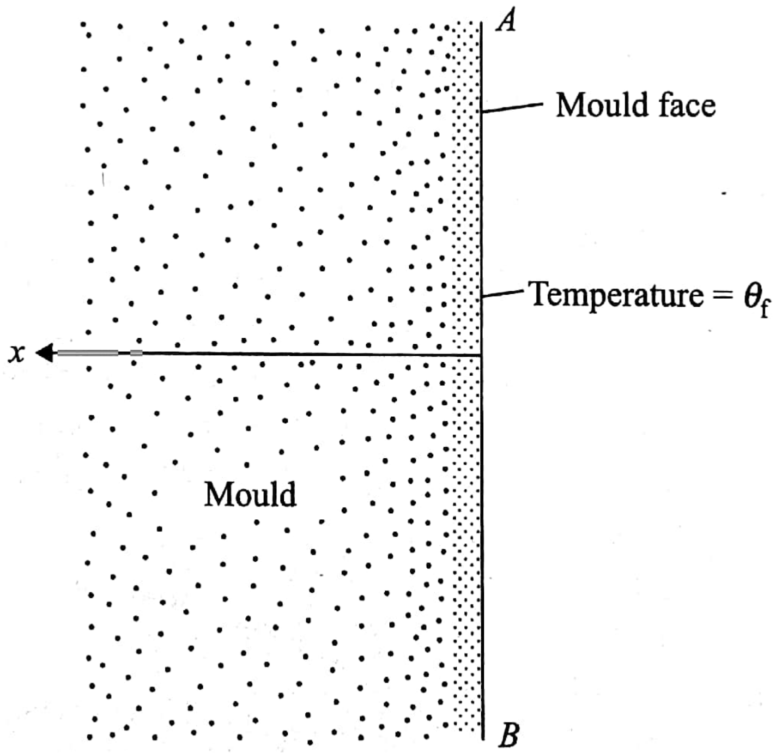
Zone 2 → Heat Loss in the Mould

Zone 3 → Heat Loss in the Mould - Metal Interface

Zone 4 → Heat Loss in the Solidified Metal

Zone 5 → Heat Loss in the Liquid Metal

Solidification of a Large Casting in an Insulating Mould (thermal resistances all zones are negligible w.r.t. **zone2**)



Mould face and coordinate system

- No interfacial thermal resistance → Perfect wetting of mould face by the molten metal.
- Intial temp. of mould → θ_o
- Mould is assumed to be extended up to infinity in x direction.
- Metal just in contact with mould face is assumed to solidify instantaneously. → Mould face temp. is raised to θ_f at t = 0. It is maintained till the completion of solidification.
- Heat conduction through mould is assumed to be 1-D.

Rate of heat transfer through the mould face at any instant *t*

$$\dot{Q} = -kA\left[\frac{\partial \theta_x}{\partial x}\right]_{x=0} = \frac{kA(\theta_f - \theta_0)}{\sqrt{\pi \alpha t}}$$

α = thermal diffusivity of mould material = $k/\rho c$

k = thermal conductivity of mould material

ρ = density of mould material

c = specific heat of mould material

Total quantity of heat flow up to time t_0 is

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

Heat rejected by liquid metal during solidification is

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

where, V = total volume of casting

L = latent heat of solidification of metal

ρ_m = density of metal

c_m = specific heat of metal

$$Q_{t_0} = Q_R$$

$$\rightarrow \frac{2kA\left(\theta_f - \theta_0\right)}{\sqrt{\pi\alpha}}\sqrt{t_0} = \rho_m V\left[L + c_m\left(\theta_p - \theta_f\right)\right]$$

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

Casting Defects

Major types: **(i) Gas defects** **- caused by lower gas passing tendency of mould.**

(ii) Shrinkage cavities **- caused by liquid metal shrinkage during solidification.**

(iii) Moulding material defects **- caused by unsuitable properties of moulding materials**

(iv) Pouring metal defects **- caused by improper pouring of metal into the mould.**

(v) Metallurgical defects **- caused by improper cooling technique.**

Gas defects:

1. Blowholes and open blows: spherical, flattened or elongated cavities on the surface or inside of casting, caused by moisture left in mould and core. Open blows → on casting surface, Blowholes → inside the casting. Main reason is low permeability of mould due to fine sand grains, too much binder, inadequate venting, over ramming of mould.

2. Air inclusion: Air is absorbed in molten metal during melting, in the ladle, or due to faulty gating system. This air is trapped in casting and weakens it. Main reasons are high pouring temp., straight sprue, abrupt bends etc.

3. Pinhole porosity: Cause by H2 gas in the molten metal, which is produced due to dissociation of water in the furnace or mould due to high temperature. Particularly severe in Aluminium alloys.

Moulding material defects:

1. **Cuts and washes:** Areas of rough spot and excess metal in casting caused by mould erosion due to low mould strength and high liquid metal velocity.
2. **Metal penetration:** Metal enters the pores of sand grains causing poor surface finish. Caused due to coarse sand grains, no facing sand/mould wash, higher pouring temp.
3. **Fusion:** Glassy brittle surface of casting due to fusion of sand with metal caused at high pouring temp. of metal. Lower refractoriness of sand may be a reason.
4. **Run out:** Caused due to leakage of molten metal from the mould due to faulty mould making or faulty moulding flask.
5. **Rat tails and buckles:** Caused by compression failure of the skin of the mould at high temp. of molten metal. Buckles are rat tails, which are severe. Improper thermal expansion property of sand, low hot strength of sand are the causes.
6. **Swell:** Under metalostatic forces, mould wall may move back causing a swell in dimension of casting. Proper ramming can solve this problem.
7. **Drop:** Dropping of loose sand or lumps from cope surface into mould cavity causes this problem.

Pouring metal defects:

1. **Misruns and cold shuts:** Misrun is caused when the metal is unable to fill the mould cavity completely.
   Cold shut is caused when two metal streams while meeting in the mould cavity don't fuse together properly.

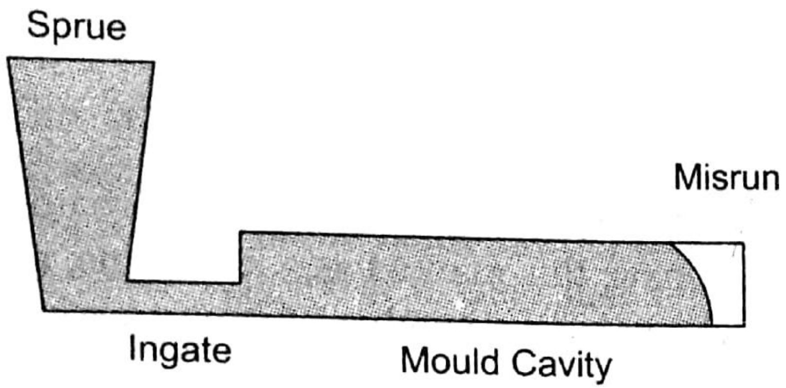


Fig. 5.10 *Misrun*

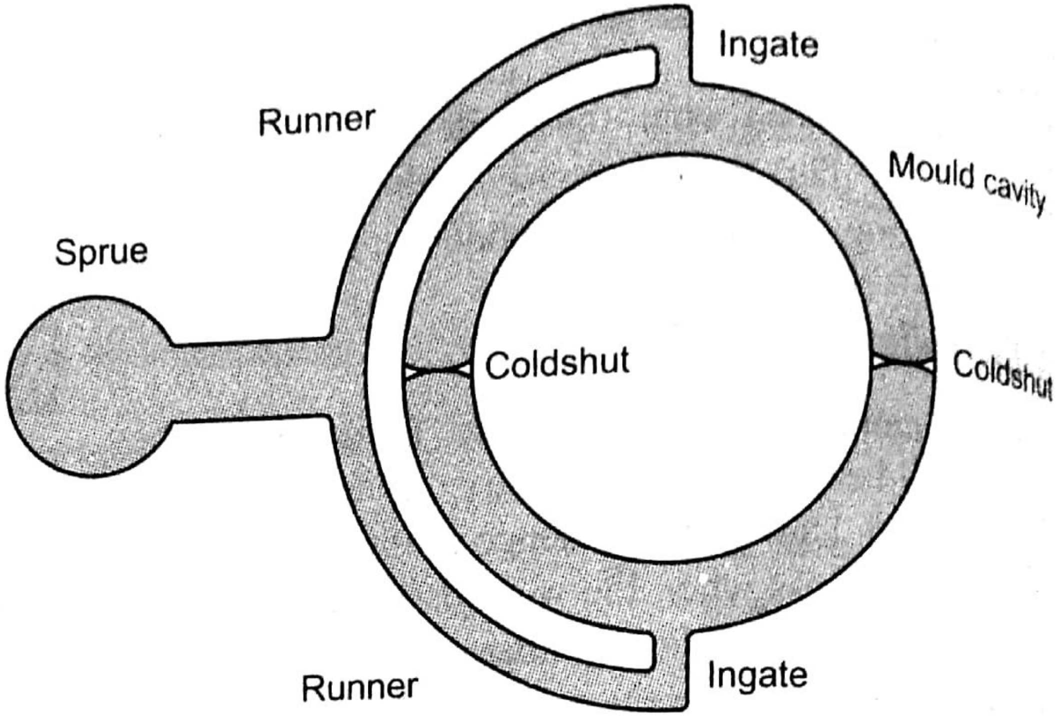


Fig 5.11 *Cold shut*

2. Slag inclusion: Slag should be eliminate from molten metal, otherwise it weakens the casting.

Metallurgical defects:

1. **Hot tears:** Metal strength is low at high temp. Thus, improper cooling may cause high thermal stress, which may lead to rupture of casting.
2. **Hot spot:** These are very hard spots, which are caused by very fast cooling of molten metal.