Casting of Metals

Principles and Classification

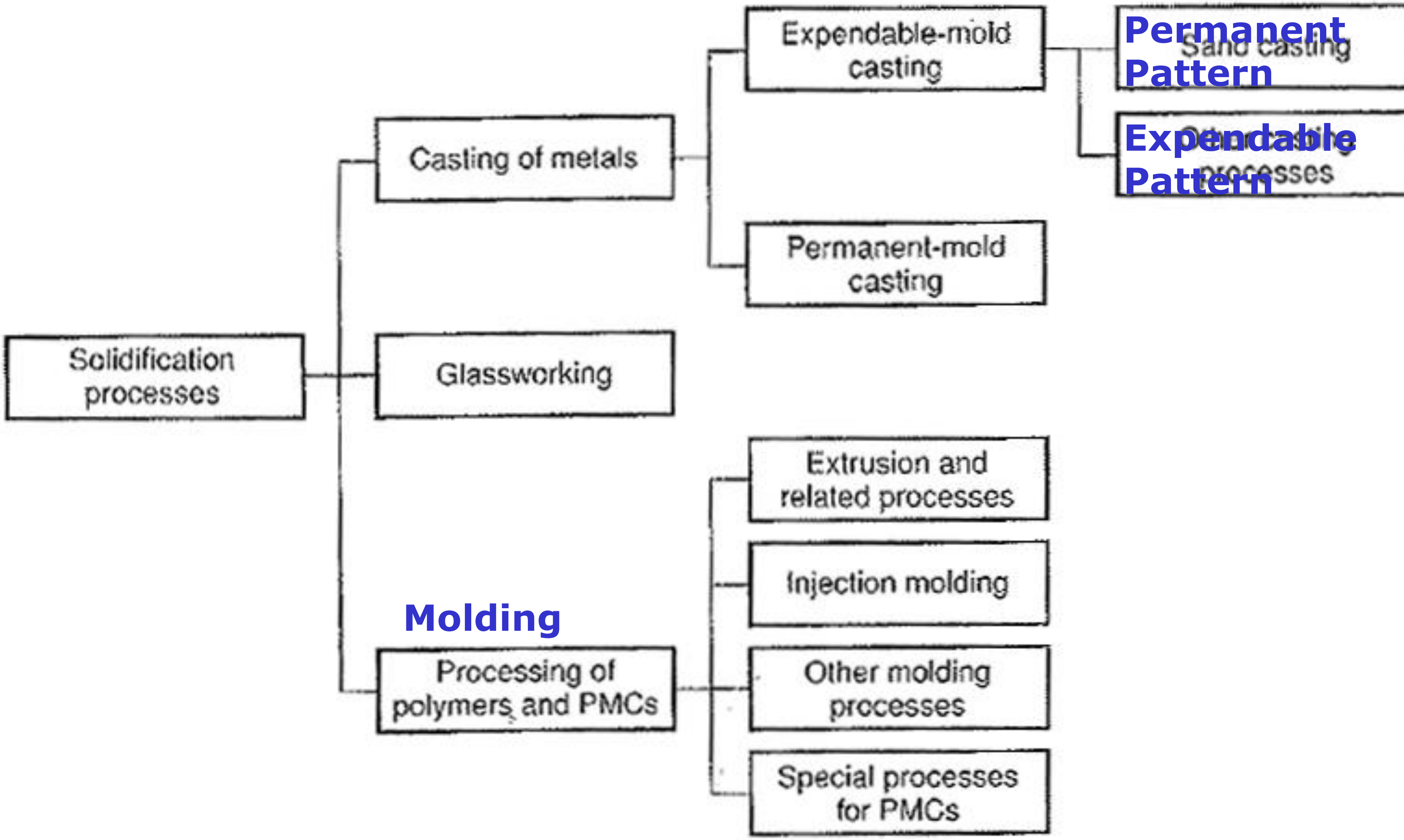
Solidification Process and Time

Mold and Pattern Design

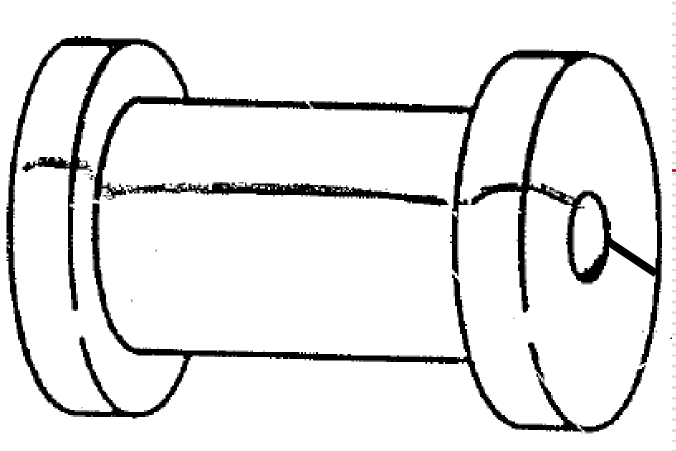
Basic Principle

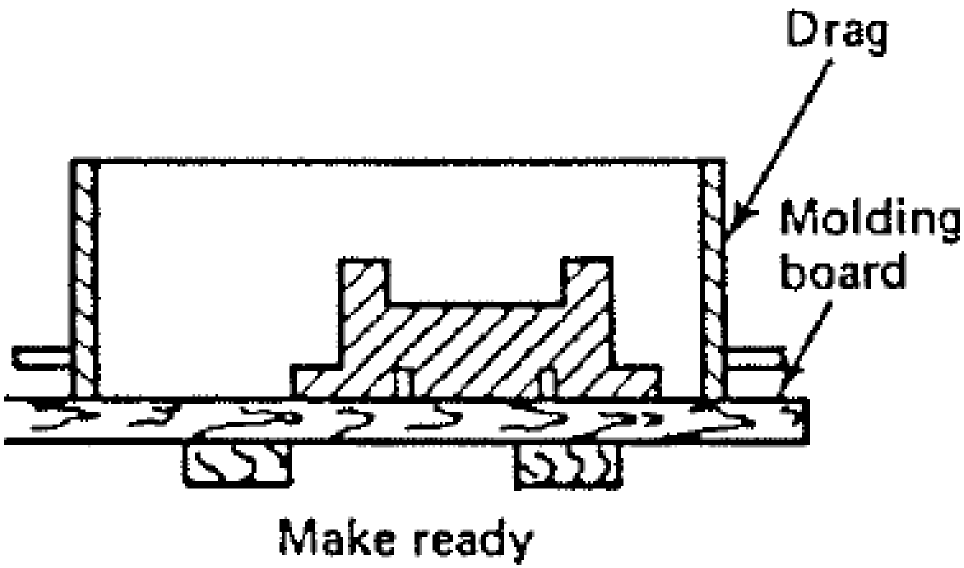
A cavity with a shape that bears some resemblance to the desired part is cut into a mold. A metal is heated to a temperature above the melting point and the molten metal is poured into the cavity. The molten metal solidifies and it is removed from the mold and allowed to cool down.

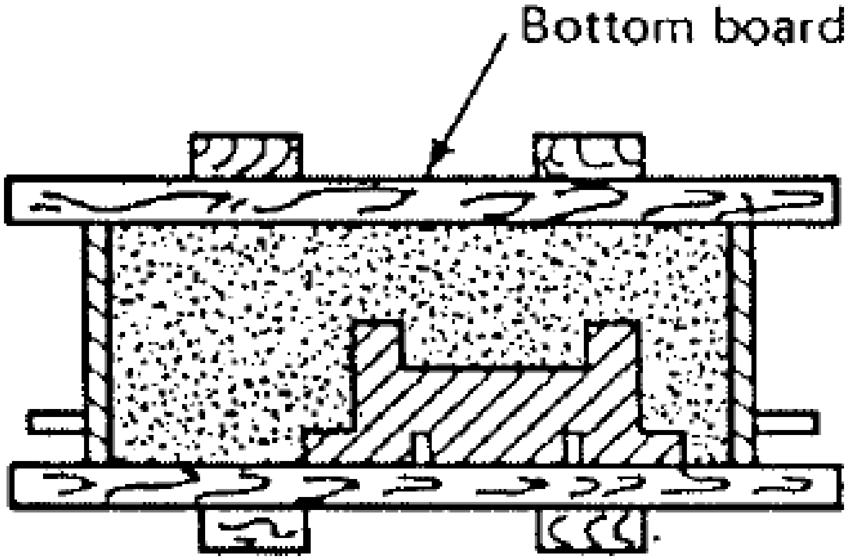
Classification of Solidification Process



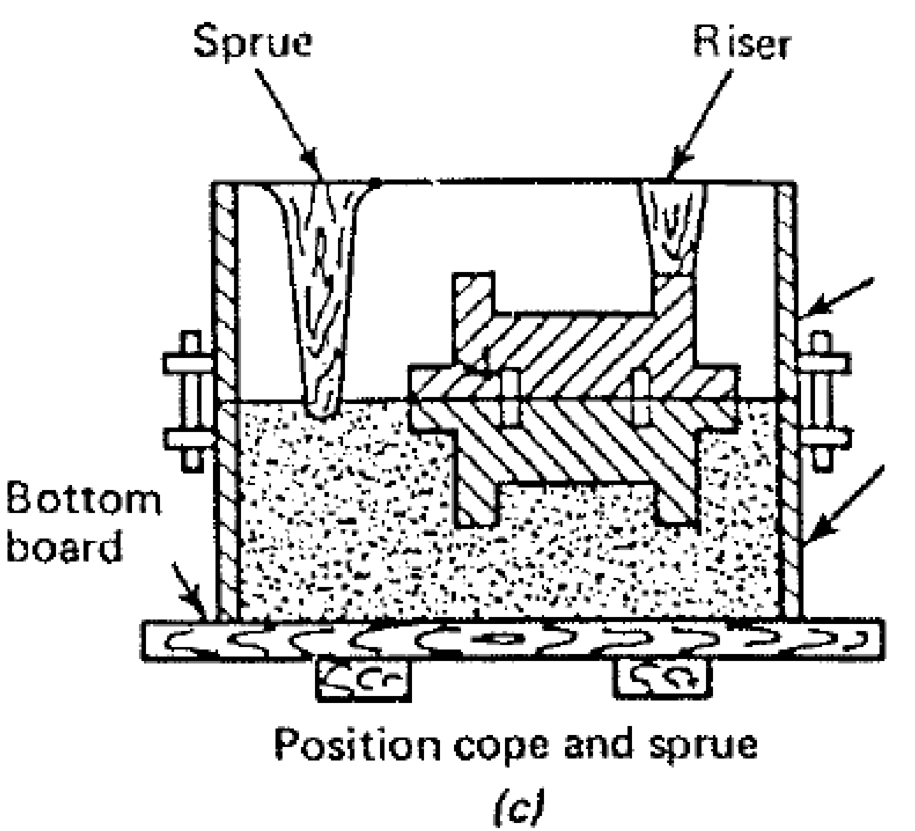
Sand Molding Preparation

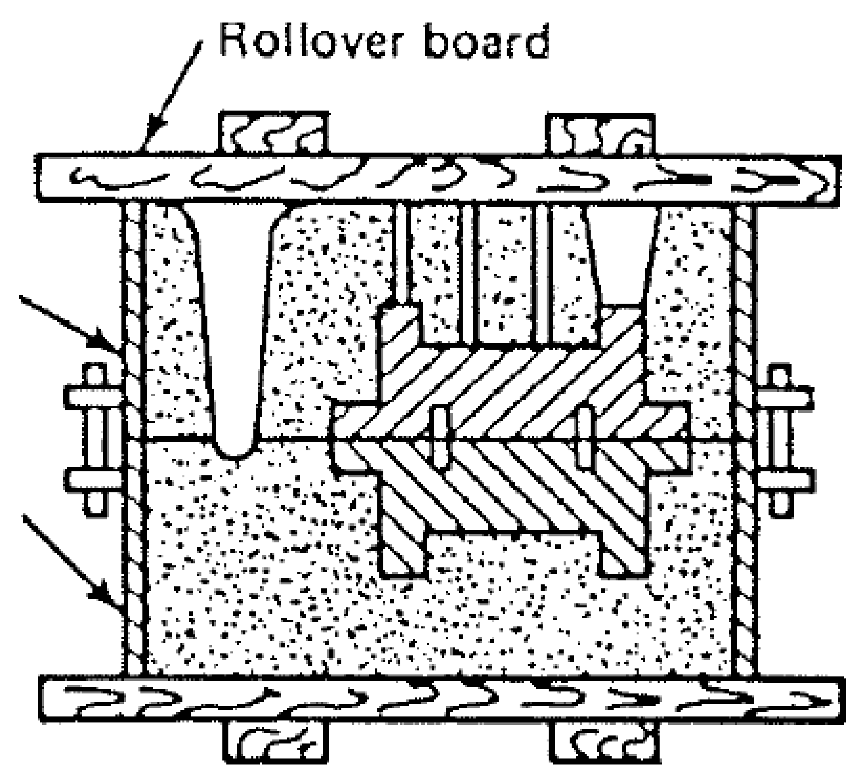




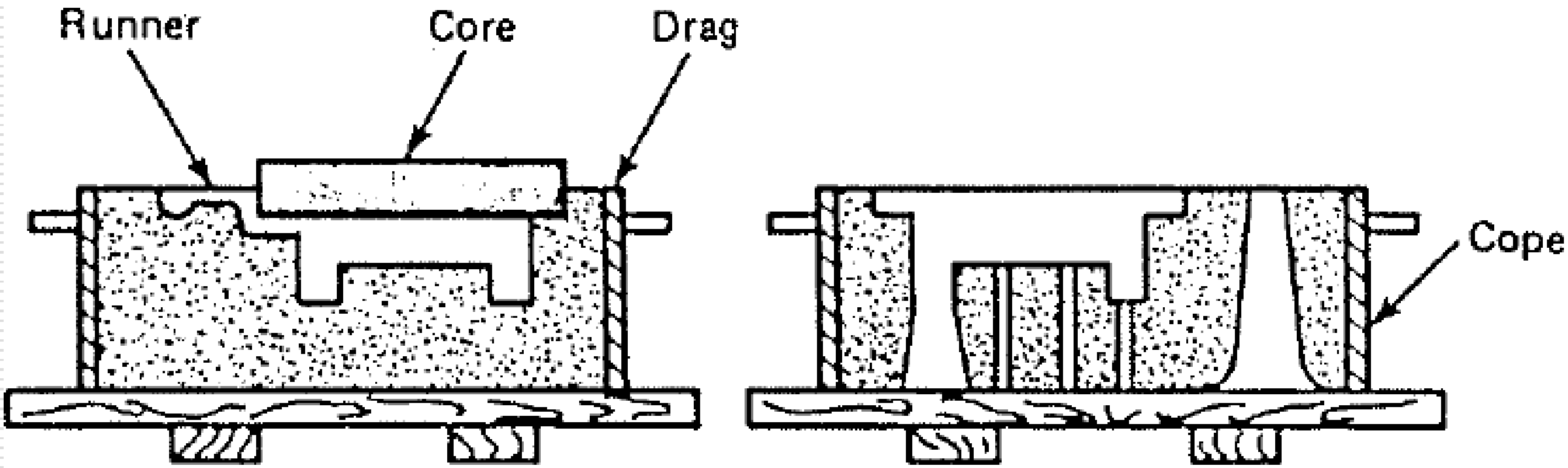


Sand Molding Preparation Cont'd





Sand Molding Preparation Cont'd

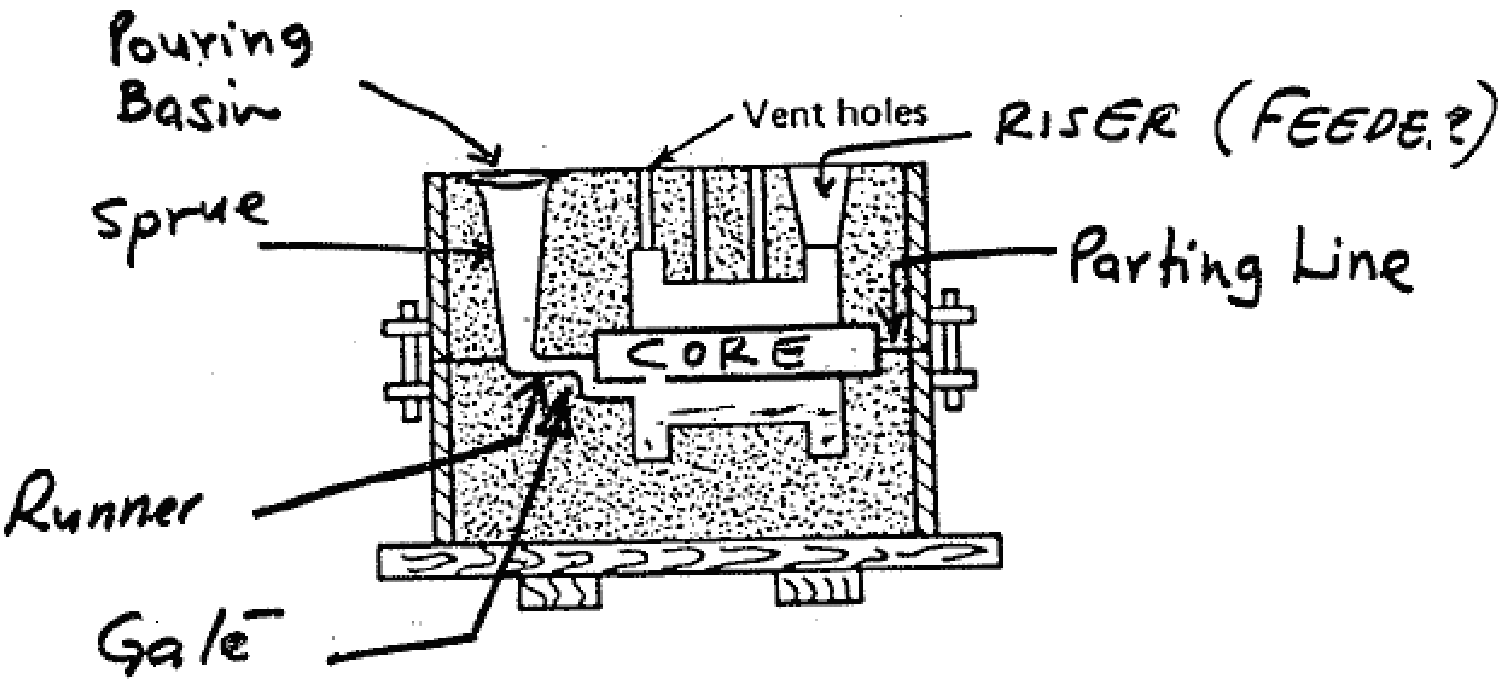


Open flask, place core, cut runner

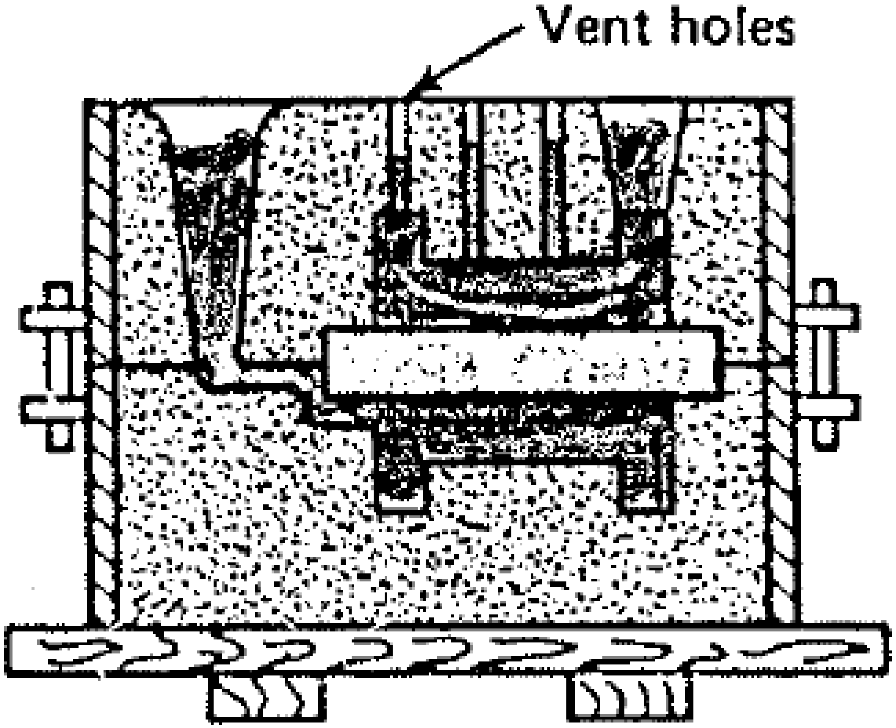
(e)

Core → Hot molten metal flows around it to creates internal geometry
Made of sand and industrial sugar. Converted to brittle material which easily broken up and removed.

Parts of Sand Mold

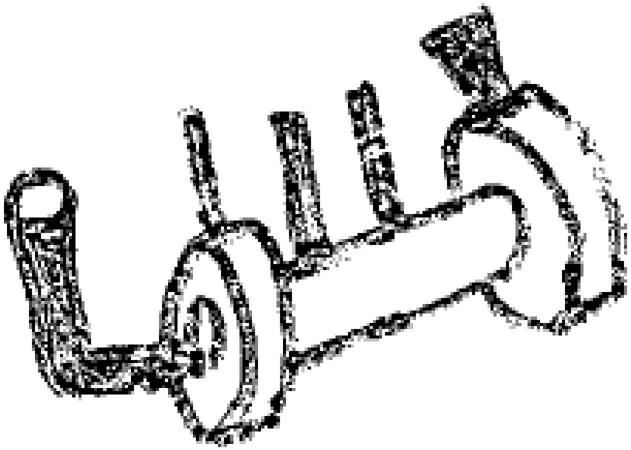


Sand Molding with Molten Part



Assemble, ready for pouring

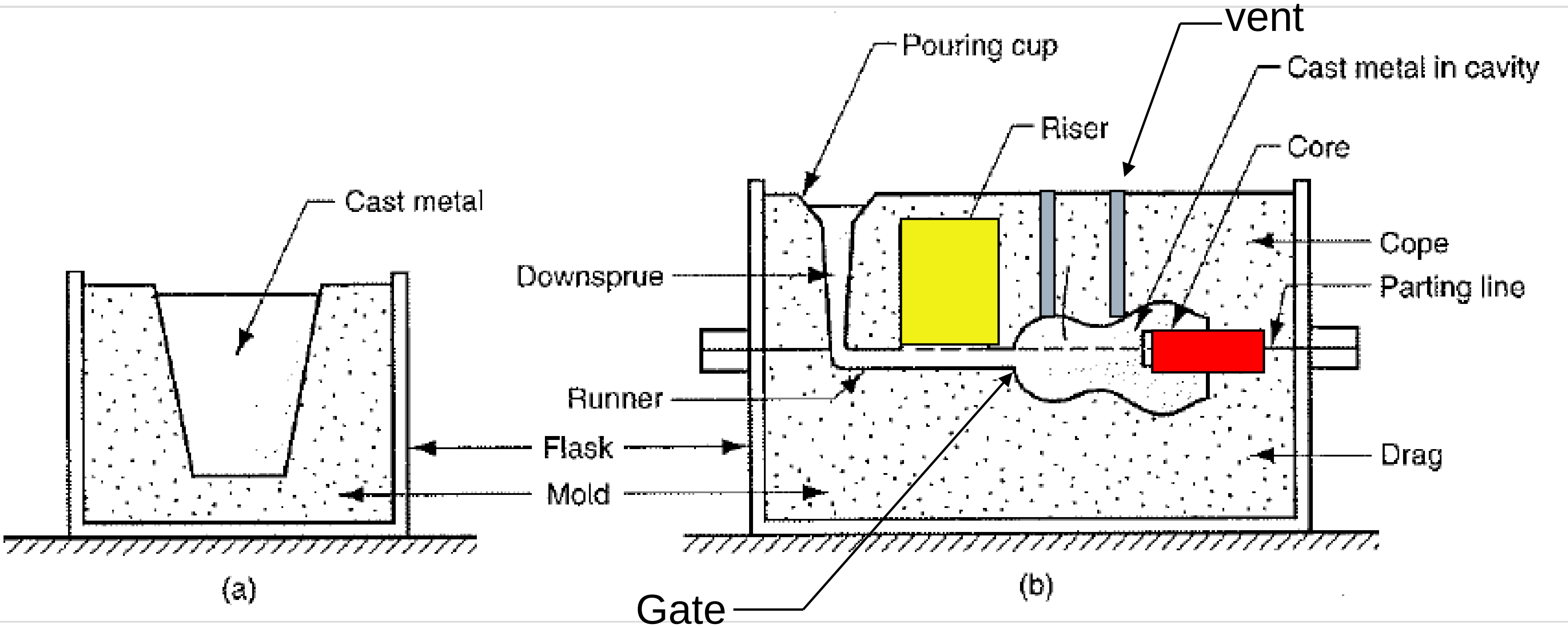
(f)



Solidified Cast Part

Parts of a Sand Mold

(a) Open Mold **(b) Closed Mold**



Foundry Terminology

- Cope
- Drag
- Pattern
- Core
- Sprue
- Runner
- Gate
- Pouring Basin
- Vent
- Riser (Reservior)
- Parting Line
- Flask
- Green Sand
- Dry Sand
- Cheek

Technical Issues in Casting

A. Heating / Pouring / Solidification

Solid :	Heat / Energy Required
↓	
Liquid :	Pouring Temperature (Degree of Superheat)
↓	
Molding :	Sprue Design
↓	
Pouring :	Pouring Rate, Mold Fill Time
↓	
Solidification :	Solidification Time, Riser Design

B. Process Selection

(i) Performance Index / Rating

(ii) Cost per Part Analysis

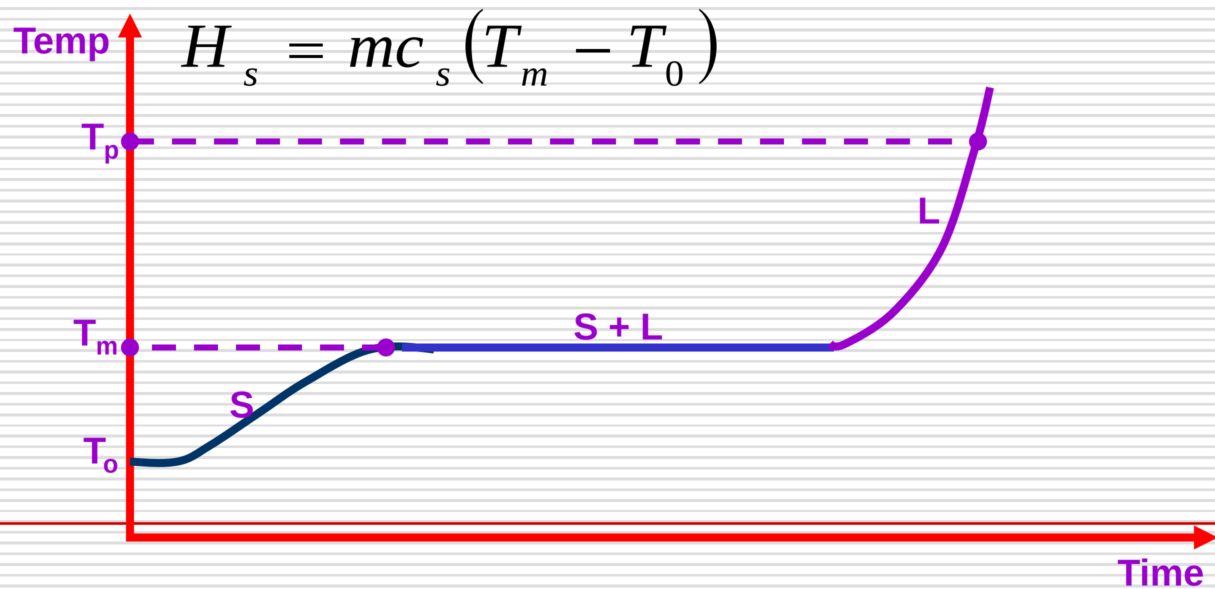
Heat Required

a. **Solid (Room Temperature) $\longrightarrow$ Solid (Melting Point)**

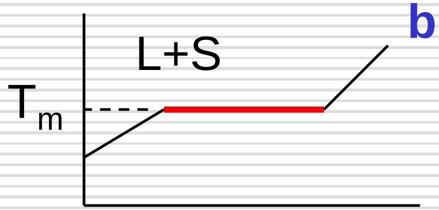
$$Heat,\ H_s = Mass \times Specific\ Heat \times Temperature\ Change$$

$$H_s = mc_s \Delta T$$

$$H_s = mc_s \left(T_m - T_0\right)$$



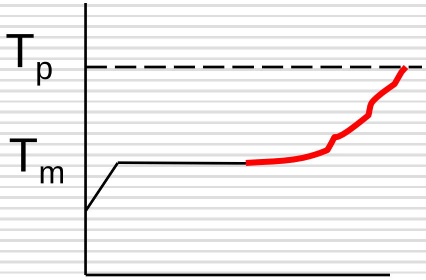
Heat Required Continued



b. Solid (Melting Point) → Liquid (Melting Point)

$$Latent\ \ Heat\ ,H_f = mh_f$$

h_f → Latent heat of Fusion per unit mass.



c. Liquid (Melting Point) → Liquid (Pouring Temp.)

$$H_l = mc_l \Delta T$$

$$H_l = mc_l (T_p - T_m)$$

d. Total Heat Required (H)

$$H = H_s + H_f + H_l$$

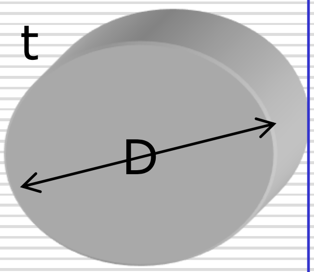
$$note\ : mass\ ,m = \rho \times V$$

Example 1- Heating

10.1 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. Other properties can be obtained from Tables 4.1 and 4.2 in this text. Assume the specific heat has the same value for solid and molten aluminum.

Note: 1 cal = 4.2 J

Solution



Disc, D = 40 cm   Thickness, t = 5 cm
Pure Aluminum; Latent heat, h_f = 389.3 J/kg
Specific Heat, C_s = 0.21 Cal/g-°C
C_l = 0.21 Cal/g-oC
Density ρ = 2.70 g/cm³
Temperatures: T_o = 25 C T_m = 660 C T_p = 800 C

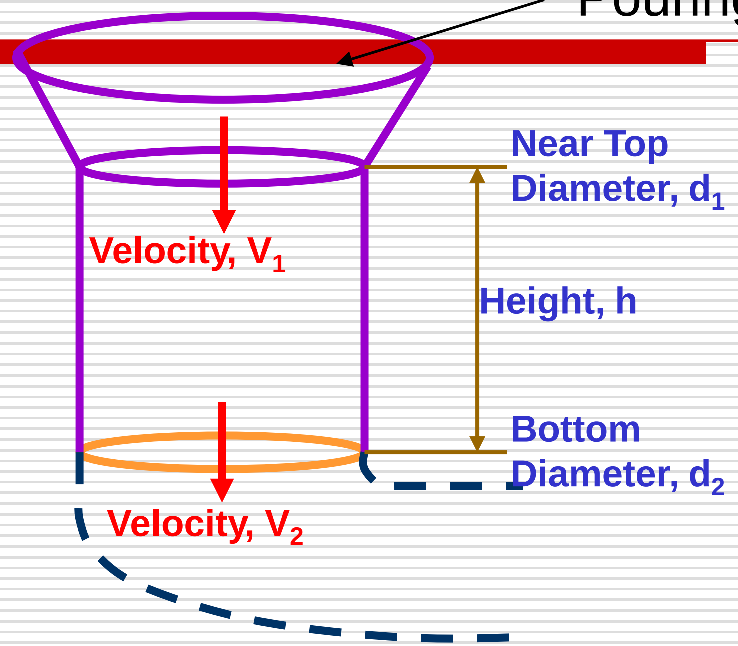
Volume of Casting, V = $(\pi D^2/4)t = (\pi * 40^2/2) * 5 = 6283$ cm³
Heated Volume, $V_H = 1.05V = 6597$ cm³

Heated Mass,   m = ρV = 2.70 x 6597 = 17,812 g

Heat Required = $Ht(T_o \text{ to } T_m) + Ht(\text{Fusion}) + Ht(T_m \text{ to } T_p)$
$= mC_s(T_m - T_0) + mh_f + mC_l(T_p - T_m)$
= 9.95 MJ + 6.93 MJ + 2.19 MJ
= 19.07 MJ

Pouring (Sprue Design)

Sprue Diameter



Let Q = Pour Rate (volume/unit time) or (in^3/sec or liter/s)

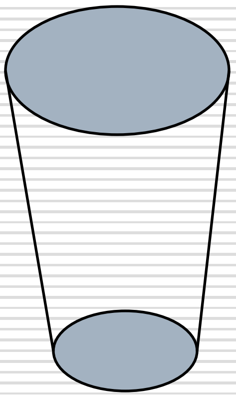
Q = Flow Area * Velocity

Q = A*V

Near Top, $Q = A_1 V_1$ Bottom, $Q = A_2 V_2$

Sprue Diameters

Design Concept: To avoid gas entrapment or Aspiration



FLOW Continuity → constant flow rate

$$A_1 V_1 = A_2 V_2$$

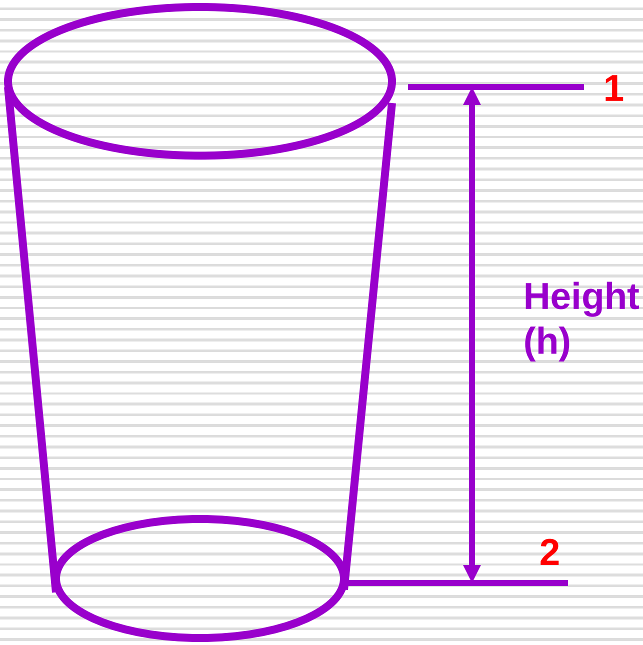
$$\frac{\pi d_1^2}{4} V_1 = \frac{\pi d_2^2}{4} V_2 \longrightarrow d_1^2 V_1 = d_2^2 V_2$$

$$d_2 = \sqrt{\frac{V_1}{V_2}} \times d_1$$

NOTE: $V_2 > V_1$ so $d_2 < d_1$

Thus diameter decreases from top to bottom

Sprue Height



At 1, Total Energy, E_1

$$E_1 = PE + KE$$

$$E_1 = mgh + \frac{1}{2} m v_1^2$$

$$v_1 \approx 0$$ **(pouring) – In the basin**

Thus $$E_1 = mgh$$

At bottom

$$E_2 = mgh + \frac{1}{2} m v_2^2 \qquad h \approx 0$$

$$E_2 = \frac{1}{2} m v_2^2$$

Conservation of Energy

$$E_1 = E_2$$

$$mgh = \frac{1}{2} m v_2^2$$

$$v_2 = \sqrt{2gh}$$

h **can be calculated if v_2 is known**

Desired Area at Base of Sprue

$$A_b = \frac{Q}{V_2}$$

OR

$$A_b = \frac{Q}{\sqrt{2gh}}$$

Desired Sprue Height for a given Flow Rate

$$h = \frac{1}{2g}\left(\frac{Q}{A_b}\right)^2$$

Mold Fill Time (MFT)

$$MFT = \frac{Volume \quad Poured}{Q}$$

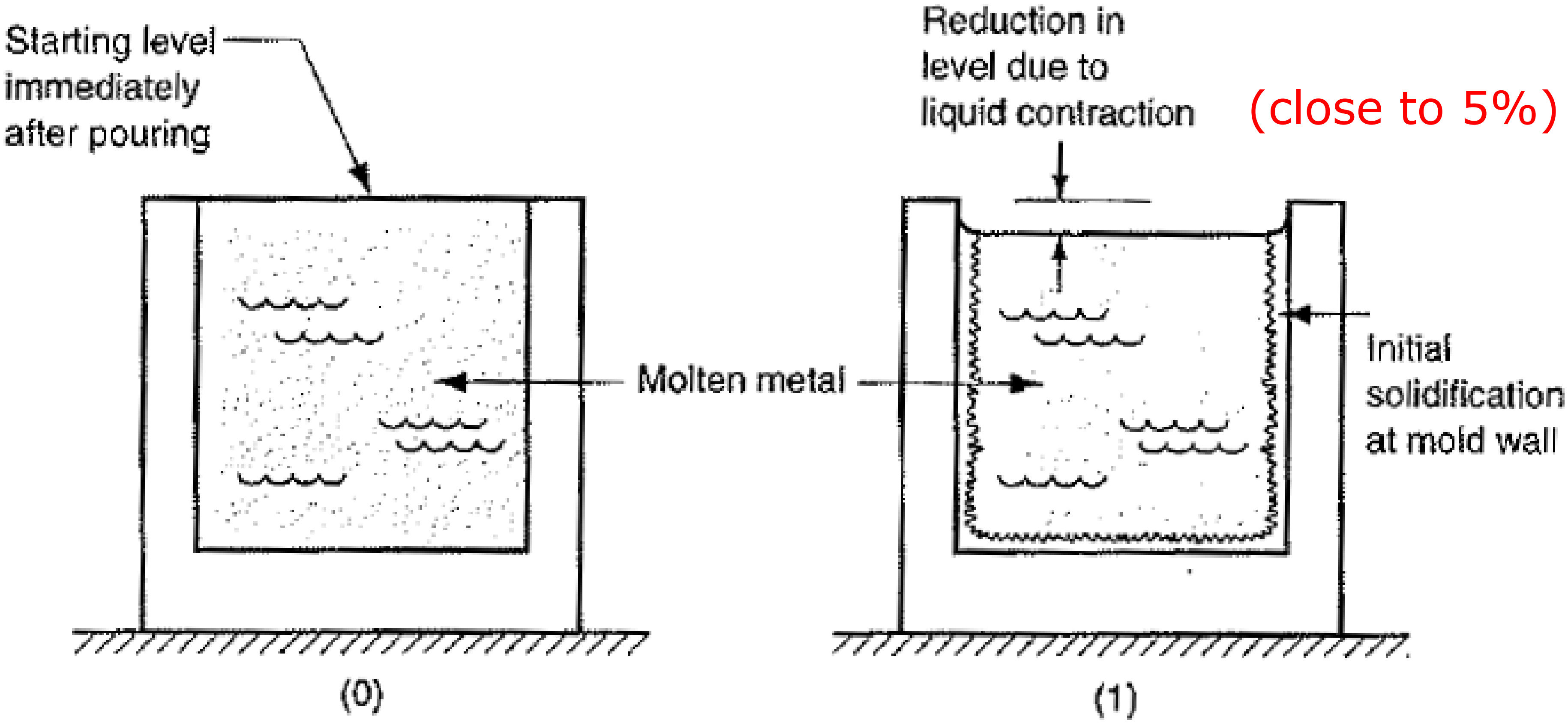
Example – Flow Analysis

10.3 The downsprue leading into the runner of a certain mold has a length = 175 mm. The cross-sectional area at the base of the sprue is 400 mm^2. The mold cavity has a volume = 0.001 m^3. Determine: (a) the velocity of the molten metal flowing through the base of the downsprue, (b) the volume rate of flow, and (c) the time required to fill the mold cavity.

Example – Sprue Design

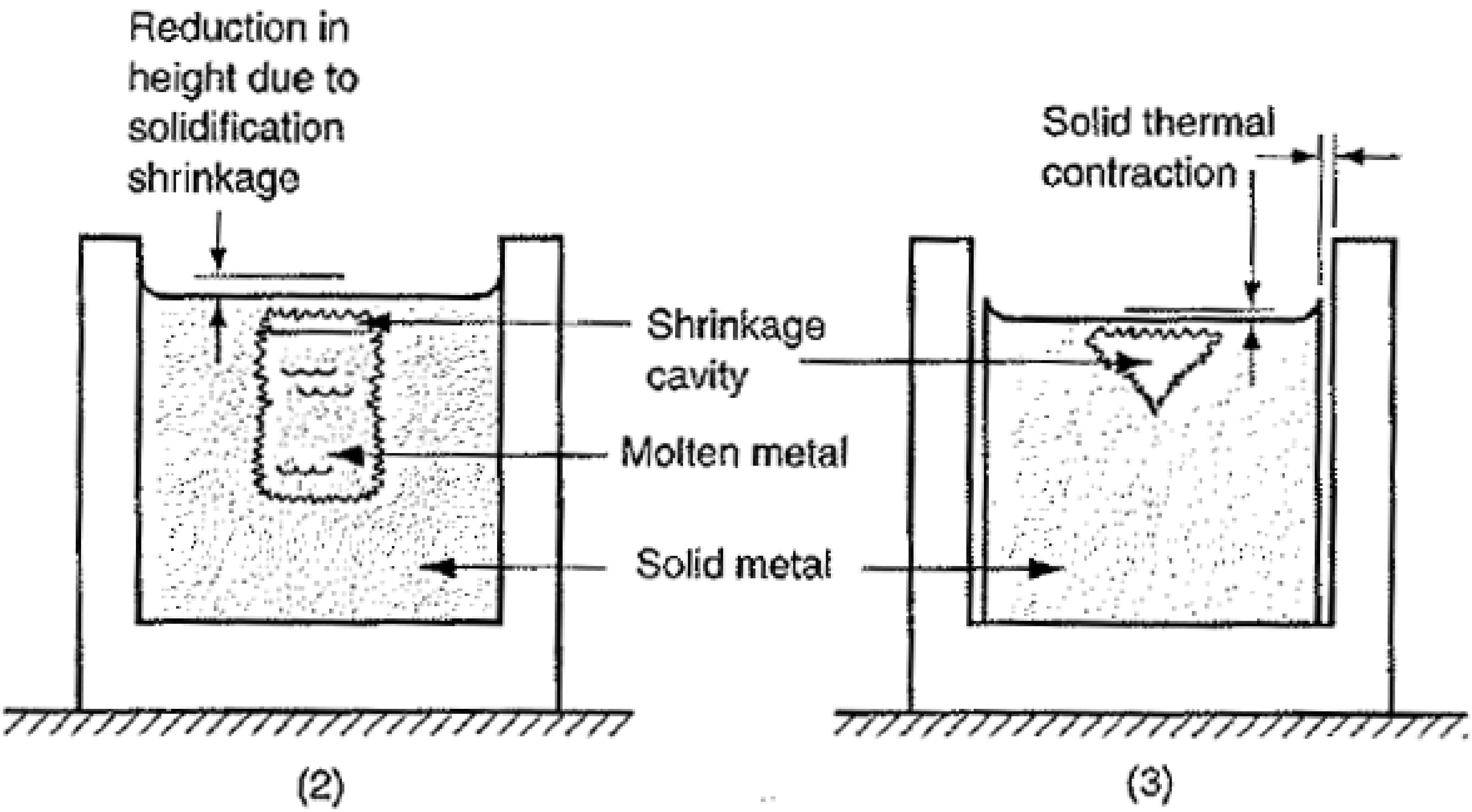
10.5 The flow rate of liquid metal into the downsprue of a mold = 1 liter/sec. The cross-sectional area at the top of the sprue = 800 mm^2 and its length = 175 mm. What area should be used at the base of the sprue to avoid aspiration of the molten metal?

Shrinkage During Solidification and Cooling



(close to 5%)

Shrinkage During Solidification and Cooling Cont'd



Example - Shrinkage

10.10 The cavity of a casting mold has dimensions: $L = 250$ mm, $W = 125$ mm and $H = 20$ mm. Determine the dimensions of the final casting after cooling to room temperature if the cast metal is aluminum. Assume that the mold is full at the start of solidification and that shrinkage occurs uniformly in all directions.

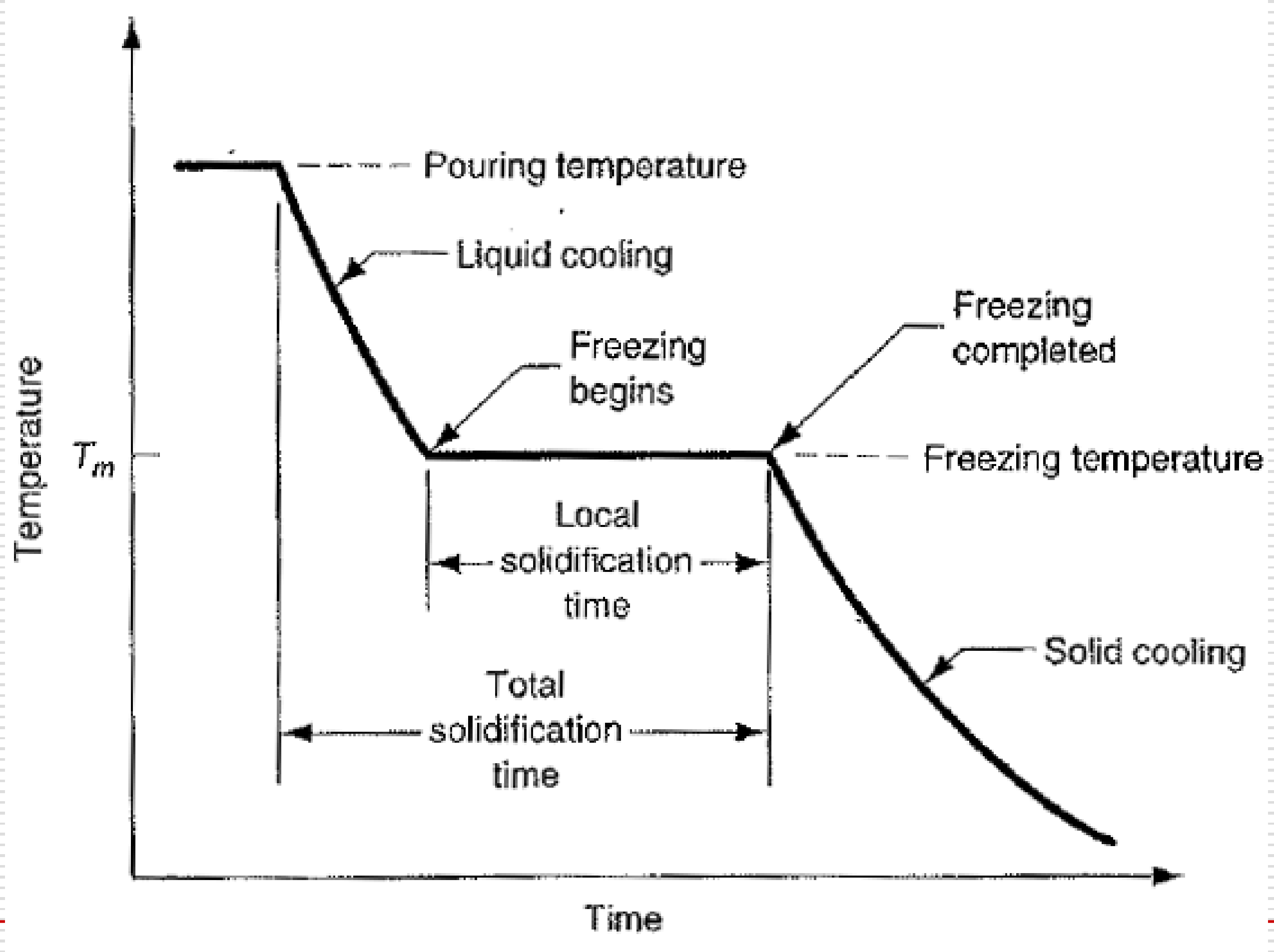
Example - Shrinkage

10.11 Determine the scale of a "shrink rule" that is to be used by pattern-makers for low carbon steel. Express your answer in terms of decimal fraction inches of elongation per foot of length compared to a standard rule.

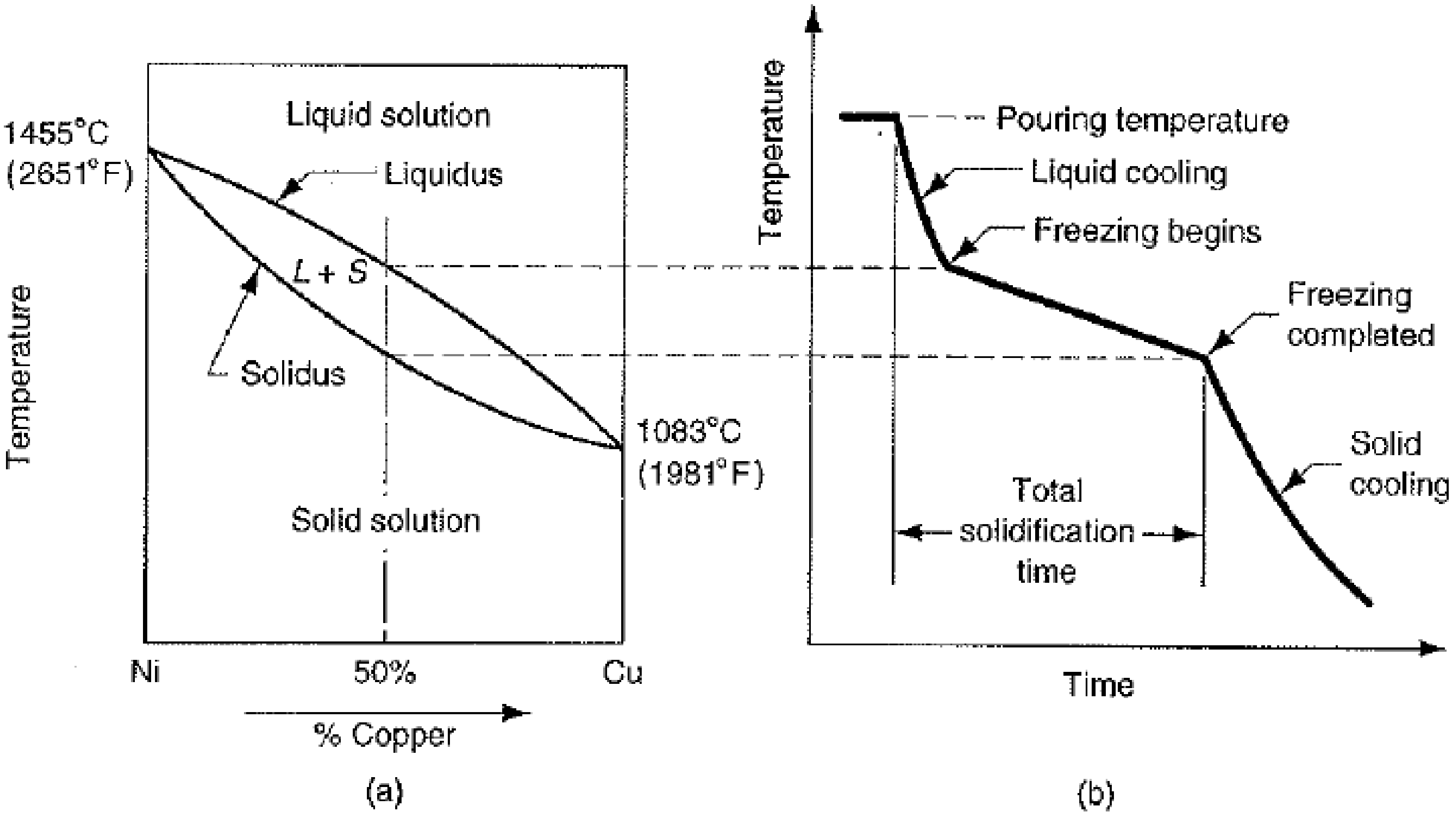
Example - Shrinkage

10.13 Determine the scale of a "shrink rule" that is to be used by pattern-makers for gray cast iron. The gray cast iron has a volumetric contraction of -2.5%, which means it expands during solidification. Express your answer in terms of millimeters of elongation per meter of length compared to a standard rule.

Solidification Curve – Pure Metal



Solidification Curve for Alloys



Total Solidification Time (TST)

Chvorinov's Rule

Total Solidification Time, *TST*,

$$TST = C_m \left(\frac{V}{A} \right)^n$$

Where

V = Volume of Casting

A = Surface Area of Casting exposed to Mold and Cores

n = exponent (n =2 for expendable mold castings)

n = 1 for permanent mold castings

V/A = Casting Modulus

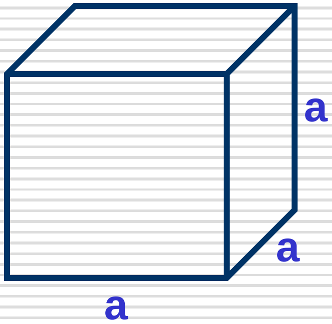
C_m = Mold Constant. This is a function of Mold Material and Cast Material

Mold Material: Specific Heat, Thermal Conductivity, Density

Cast Material: Heat of Fusion, Density, Melting Temperature, Thermal Conductivity

Examples of Casting Modulus (V/A)

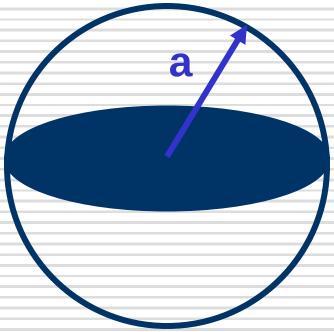
1. Cube



$$V = a^3 \qquad A = 6a^2$$

$$Modulus\ ,\ \frac{V}{A} = \frac{a}{6}$$

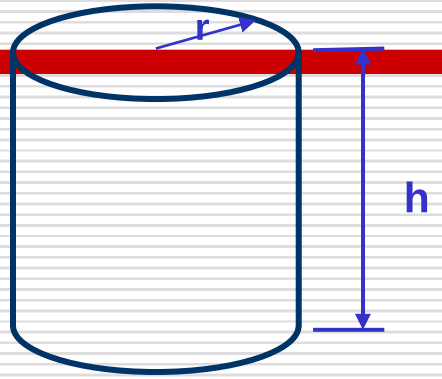
2. Sphere



$$V = \frac{4}{3}\pi a^3 \qquad A = 4\pi a^2$$

$$Modulus\ ,\ \frac{V}{A} = \frac{a}{3}$$

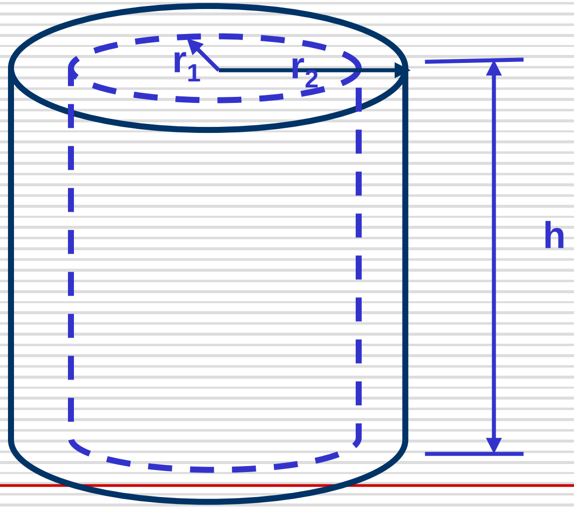
3. Solid Cylinder / Disk



$$V = \pi r^2 h$$

$$A = 2\pi r h + 2\left(\pi r^2\right)$$

4. Hollow Cylinder / Disk



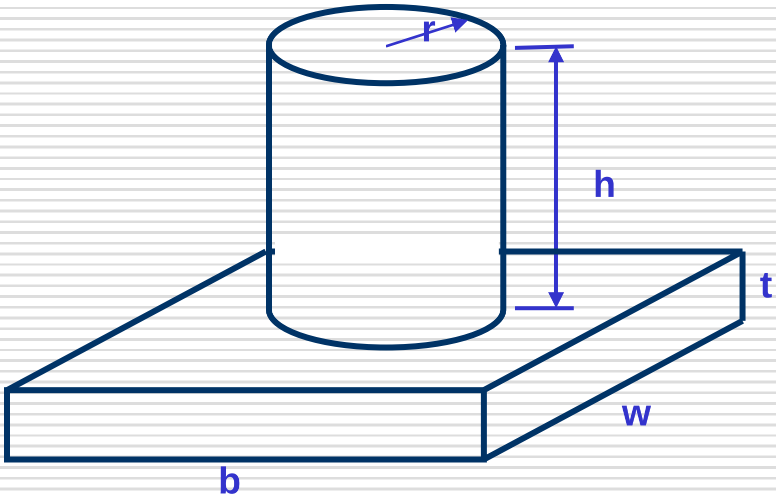
$$V = \left(\pi r_2^2 - \pi r_1^2\right) h$$

A = Exposed Area

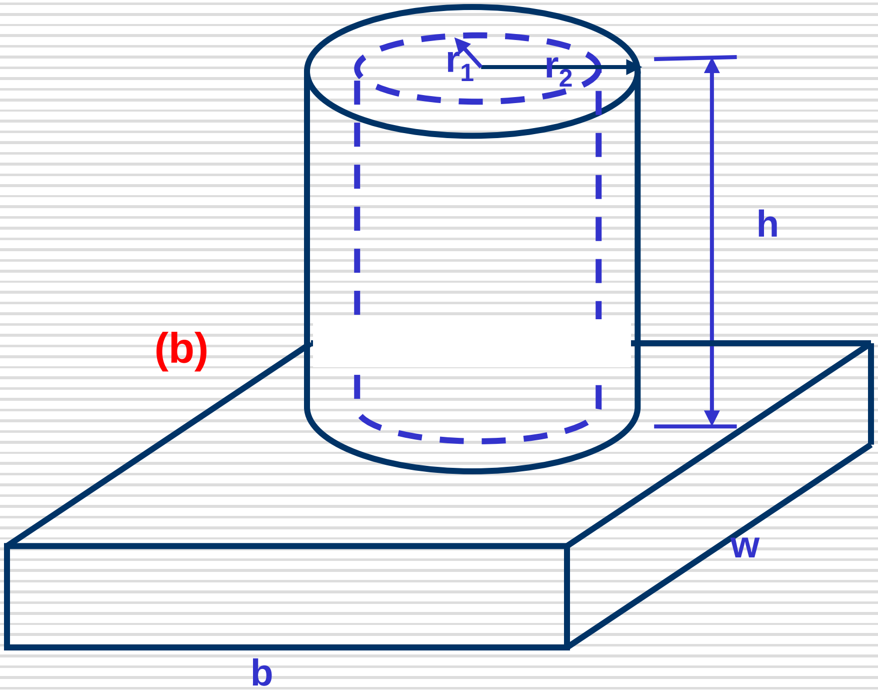
$$A = 2\pi r_2 h + 2\pi r_1 h + 2\pi\left(r_2^2 - r_1^2\right)$$

5. Modulus of Composite Shapes

(a)



(b)



Riser Design

Concept: Riser should be last section to solidify

Steps

1. Calculate TST for the Casting
2. Decide on TST for Riser such that $(TST)_{riser} > (TST)_{casting}$
3. Determine Riser Modulus

$$(TST)_{riser} = C_m \left(\frac{V}{A}\right)^2_{riser}$$

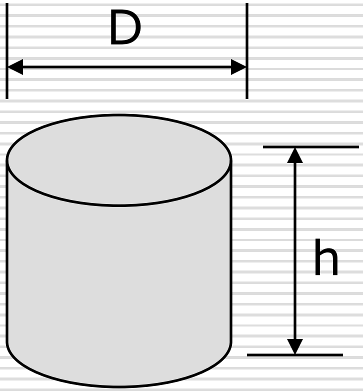
Solve

$$\left(\frac{V}{A}\right)_{riser} = \left(\frac{TST}{C_m}\right)^{\frac{1}{2}}$$

Cylindrical Riser

Modulus of Solid Cylinder:

$$\left(\frac{\left[\pi D^2 / 4 \right] h}{\pi D h + \pi D^2 / 4} \right)_{riser} = \left(\frac{TST}{C_m} \right)^{\frac{1}{2}}$$



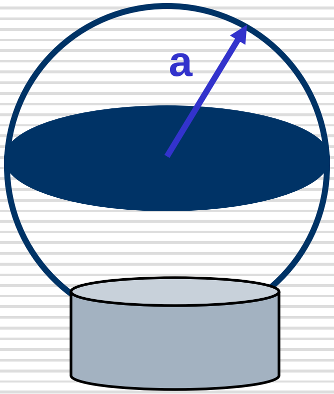
Determine D/h ratio.

- **Put D in terms of h, solve for h**

  OR

- **Using D/h ratio and knowing h, solve for D**

Spherical Riser



$$\frac{a}{3} = \left(\frac{TST}{C_m} \right)^{\frac{1}{2}}$$

Examples – Solidification Time

Examples - Riser Design

Pattern Allowances

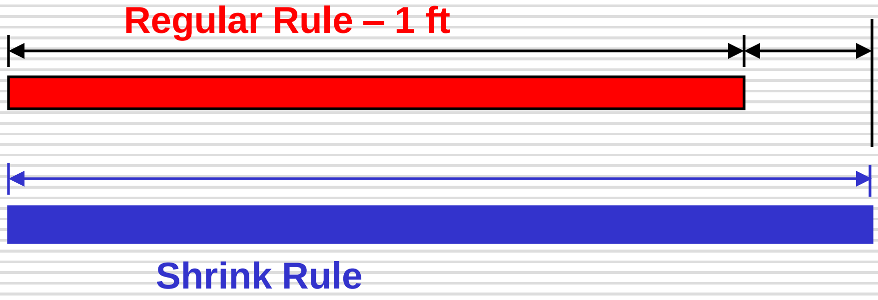
Pattern: A replica of the part to be cast and is used to prepare the mold.

It is made either of wood or metal. Metals: Al, Mg, commonly used.

It is made somewhat larger than the final part for various reasons.

This excess in dimensions is referred to as **"pattern allowance"**.

Shrink Rule: A special ruler with the expansion added to the dimensions



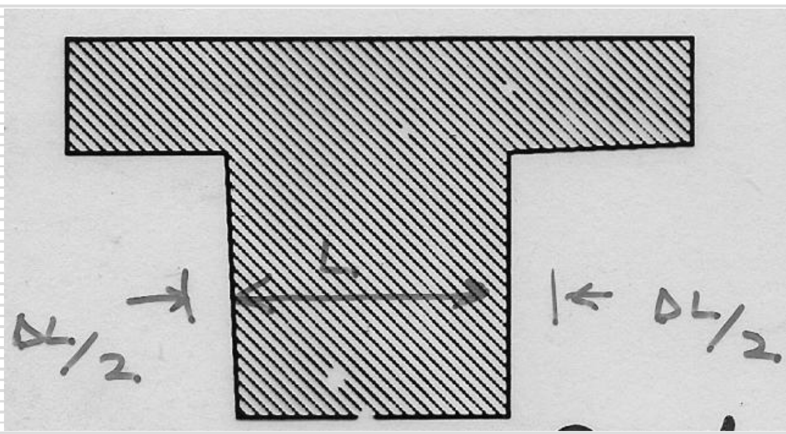
$$\Delta L = \alpha L \Delta T$$

Major Pattern Allowances

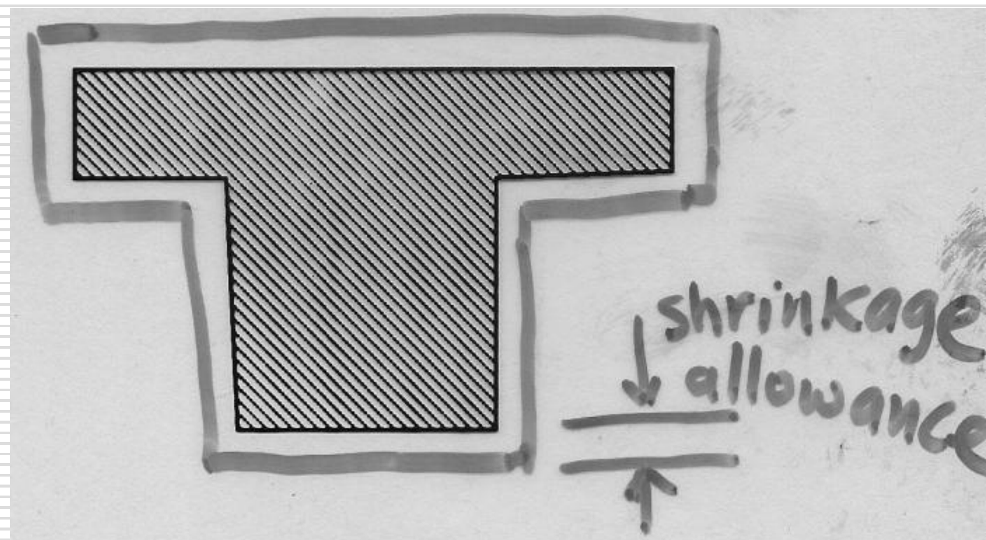
1. **Shrinkage Allowance:**

   A linear allowance added to the dimensions to compensate for contractions of the casting.

Liquid - - - → **Solid (Freezing Temp)** - - - → **Solid (Room Temp)**



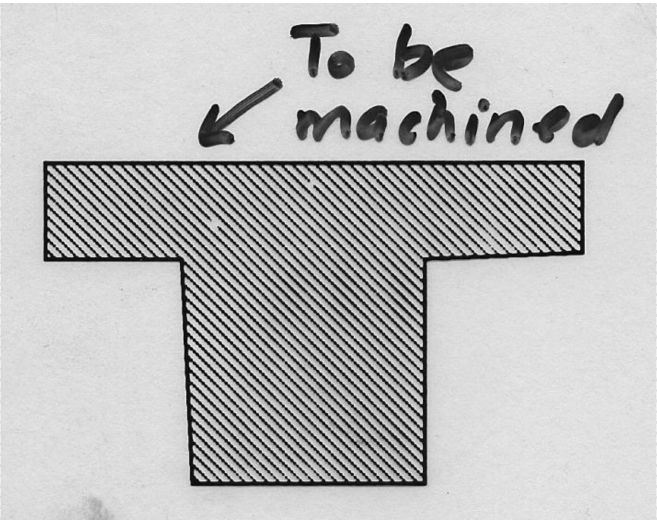
Desired Part

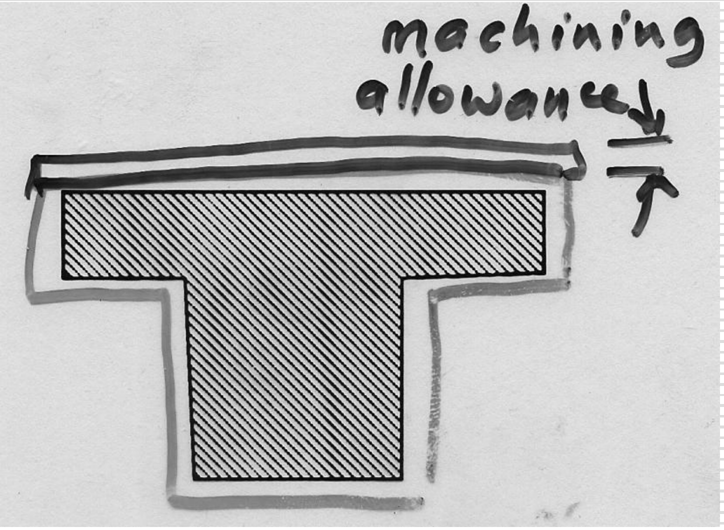


Major Pattern Allowances

2. **Machining Allowance:**

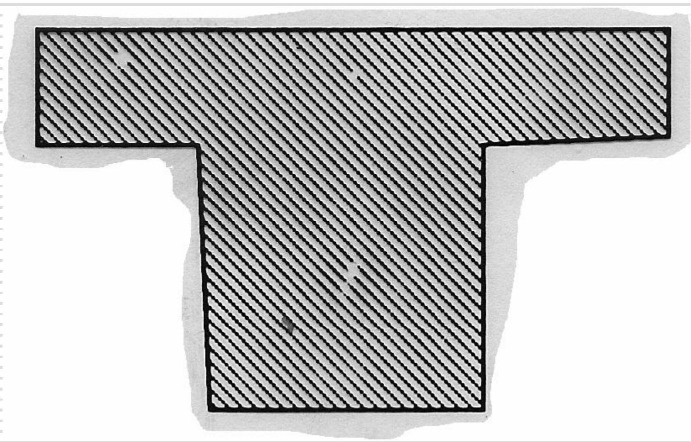
An allowance added to the dimensions so that we may later machine it off to produce better surface finish and tolerance.

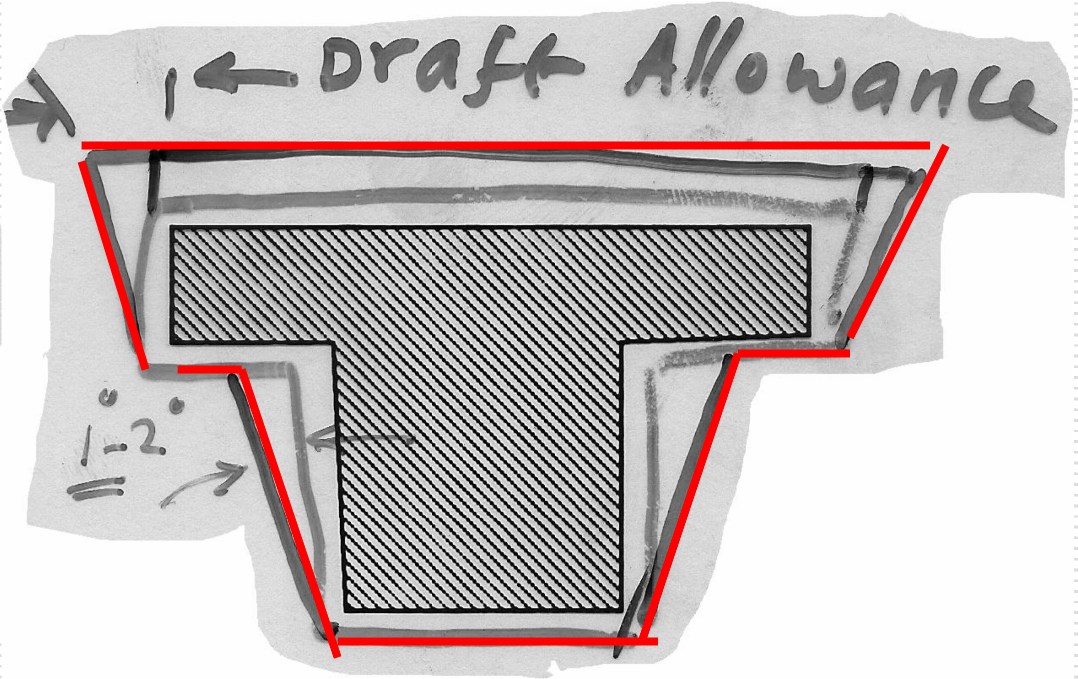




Major Pattern Allowances

3. **Draft Allowance:** An angular allowance placed on the pattern to facilitate its removal from the mold.





4. **Distortion Allowance:** Needed for thin irregular sections.