University of Technology
Materials Engineering Department

Casting Technology
Fourth Class
Lecture No 3:Heating & Solidification

Class Code :ofp4npn

Heating and Pouring

Heating furnaces of various kinds are used to heat the metal to a molten temperature sufficient for casting. The 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,
3. The heat to raise the molten metal to the desired temperature for pouring.

This can be expressed:

$$H= \rho V\{Cs[T_m -T_o]+ H_f+ C_l(Tp-Tm)\}$$

Where

1. H= total heat required to raise the temperature of the metal to the pouring temperature, J
2. ρ=Density g/cm^3
3. V= Volume of metal Heated cm^3
4. H_f= Heat of Fusion J/g
5. Cs= weight specific heat for the solid metal, J/g°C
6. Cl= weight specific heat of the liquid metal, J/g°C
7. Tp= Pouring Temperature °C
8. Tm=Melting Temperature of metal °C
9. T_o= starting temperature-usually ambient-°C

Heating and Pouring

$$H= \rho V\{Cs[T_m -T_o]+ H_f+ C_l(Tp-Tm)\}$$

The above equation is of conceptual value, but its computational value is limited, not withstanding our example calculation.

The Use of Eq. (1) is complicated by the following factors:

Heating and Pouring

1. Specific heat and other thermal properties of a solid metal vary with temperature, especially if the metal undergoes a change of phase during heating.
2. A metal’s specific heat may be different in the solid and liquid states.
3. Most casting metals are alloys, and most alloys melt over a temperature range between a solidus and liquidus rather than at a single melting point; thus, the heat of fusion cannot be applied so simply as indicated above.

Heading and Pouring

4. The property values required in the equation for a particular alloy are not readily available inmost cases.
5. There are significant heat losses to the environment during heating.

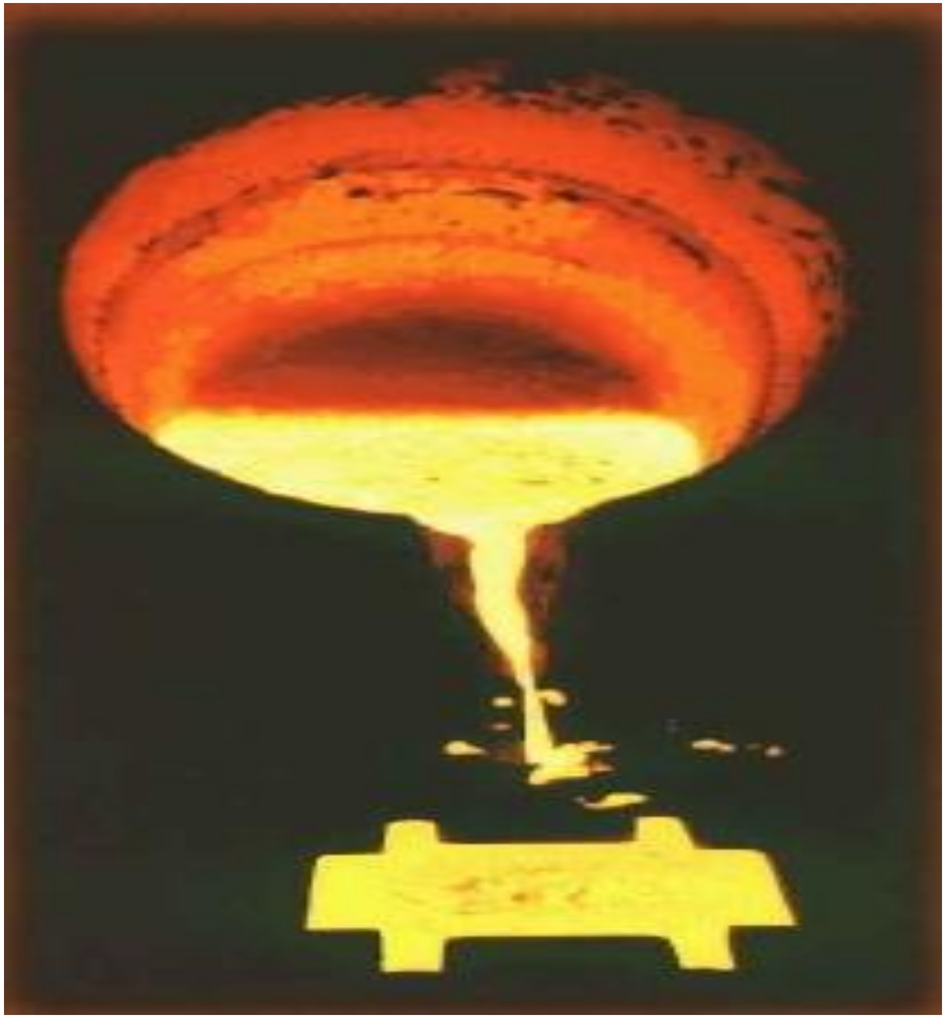
Example

- *EX1* 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?

- **Sol:**
- $H = \{7.5(10^6)\}(0:33)(800- 25)+ 160+(\ \ 0.29(100))$
- $=3335(10^6)$ J

POURING THE MOLTEN METAL

1. ***The Pouring Temperature***
2. ***Superheat***.
3. ***Pouring rate***
4. ***Turbulence***
5. ***Mold Erosion***



FLUIDITY

- **Fluidity**, The capability of molten metal to fill mold cavities is called fluidity, which consists of two basic factors:

1. Characteristics of the molten metal
2. Casting parameters.

- Fluidity is the inverse of viscosity as viscosity increases, fluidity decreases.

Factors Affecting Fluidity

The following characteristics of molten metal influence fluidity

1. **Viscosity.**
2. **Surface Tension**
3. **Inclusions.**
4. **Solidification Pattern of the Alloy.**

Factors Affecting Fluidity

The following casting parameters influence fluidity and also influence the fluid flow and thermal characteristics of the system:

1. **Mold Design**
2. **Mold Material and its Surface Characteristics**
3. **Degree of Superheat**
4. **Rate of Pouring**
5. **Heat Transfer**

Fluidity Test

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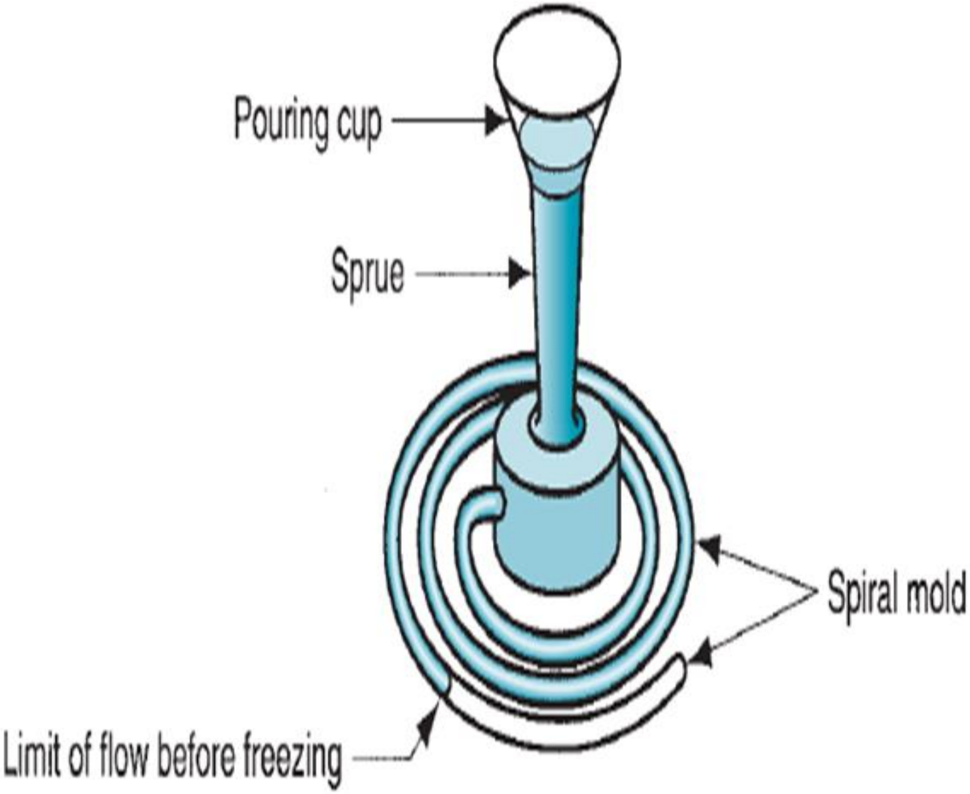
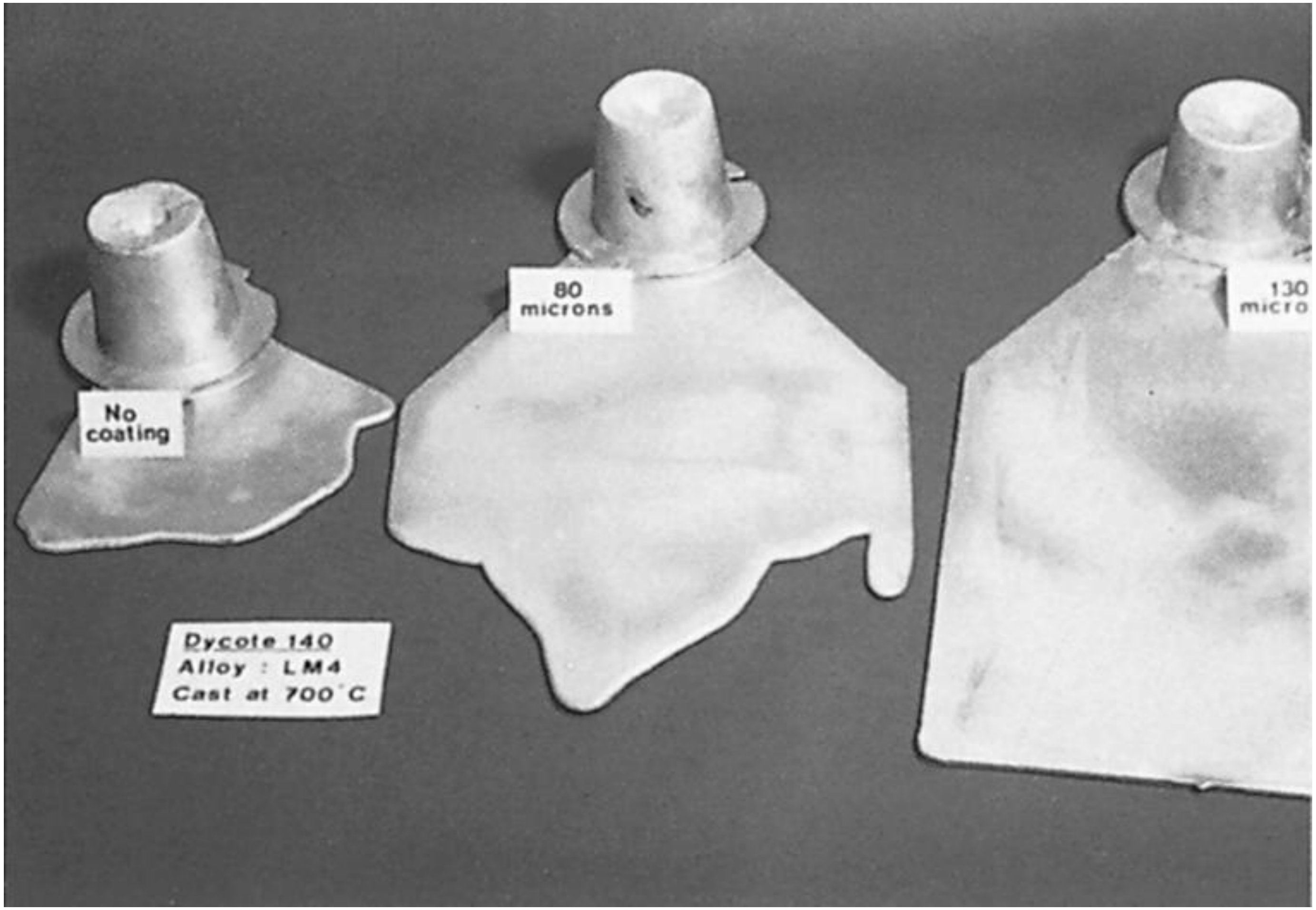


Fluidity Test



Example 2

- *A mold sprue is 20 cm long, and the cross-sectional area at its base is 2.5 cm*^{2}*. The sprue feeds a horizontal runner leading into a mold cavity whose volume is 1560 cm*^{3}.
- Determine:-
- Velocity of the molten metal at the base of the sprue
- Volume rate of flow
- Time to fill the mold.

Solution

- (a)The velocity of the flowing metal at the base of the Sprue is given by Eq. (4):

$$V = \sqrt[2]{2 \ * 981 * 20}$$

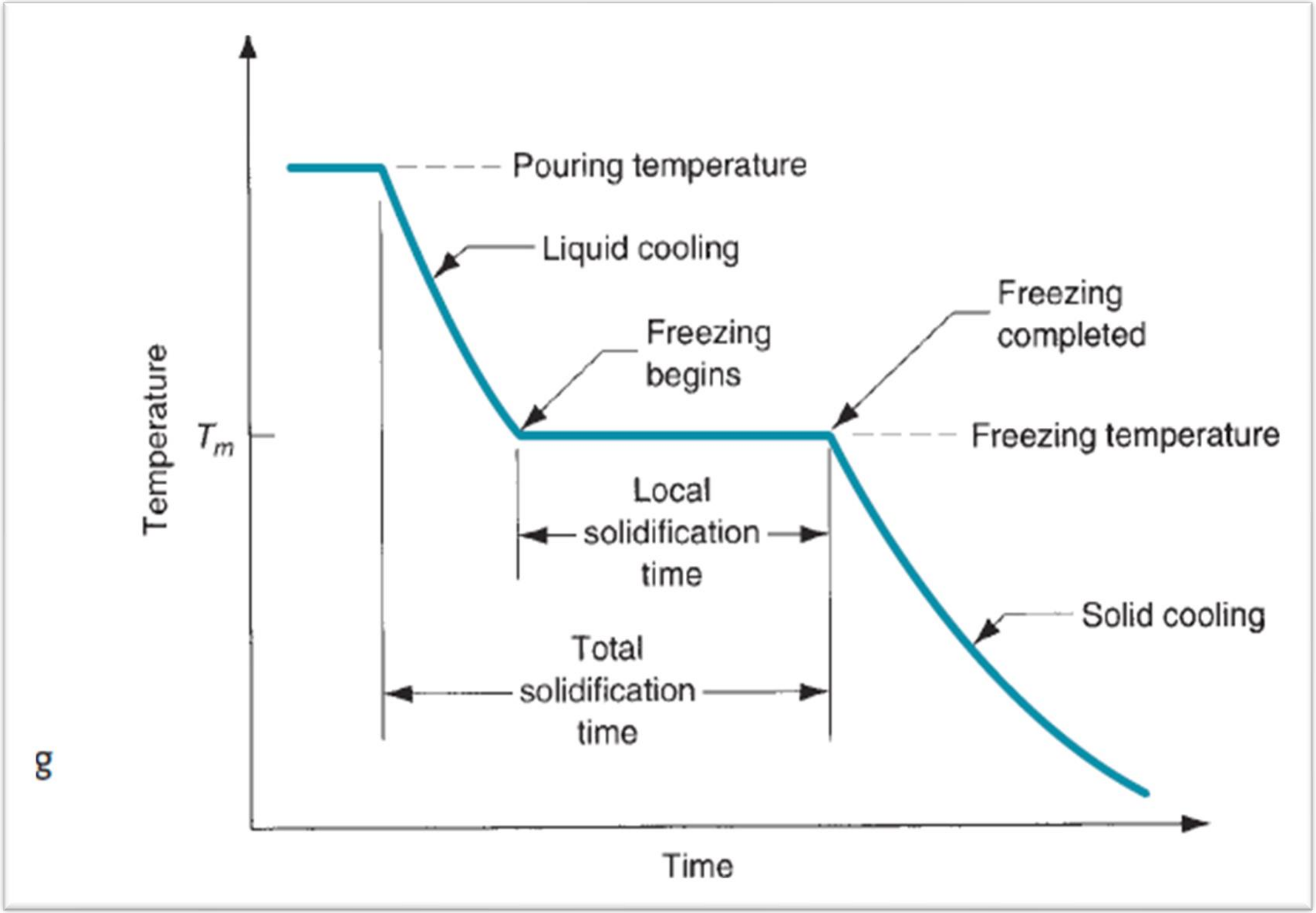
V= 198.1 cm/s

- (b) The volumetric flow rate is
  - Q =(2.5 cm^2)(198.1 cm/s)= 495 cm^2/s
- (c) Time required to fill a mold cavity of 100 in^3 at this flow rate is
  - TMF = 1560/495 = 3.2s

SOLIDIFICATION OF METALS

- **Solidification** involves the transformation of the molten metal back into the solid state. The solidification process differs depending on whether the metal is a pure element or an alloy.

Pure Metals Freezing



Alloy Metal

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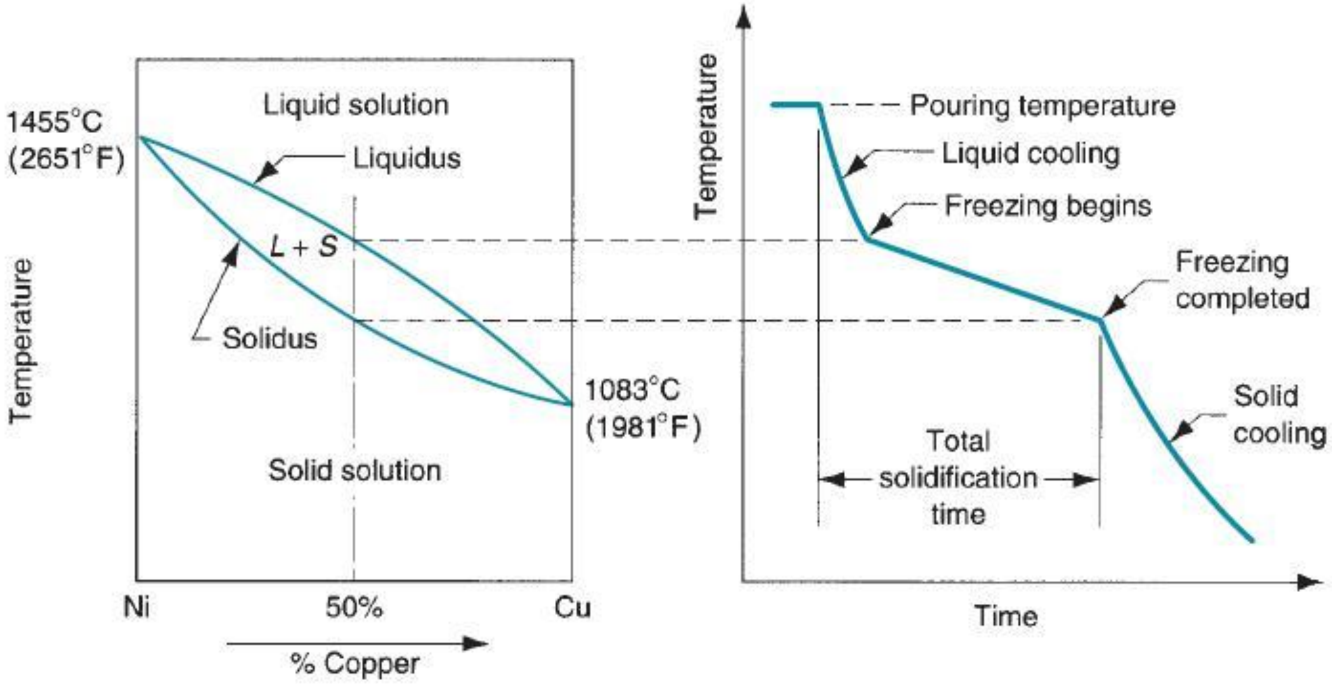
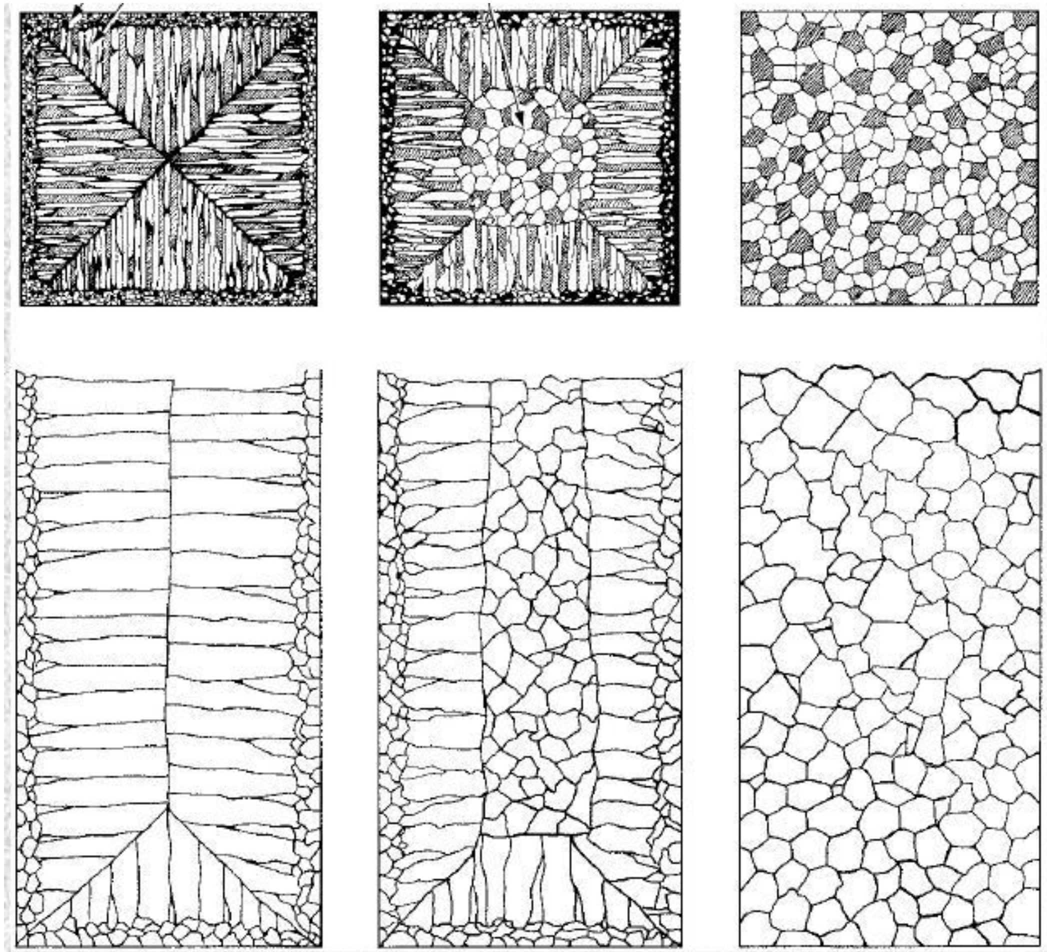


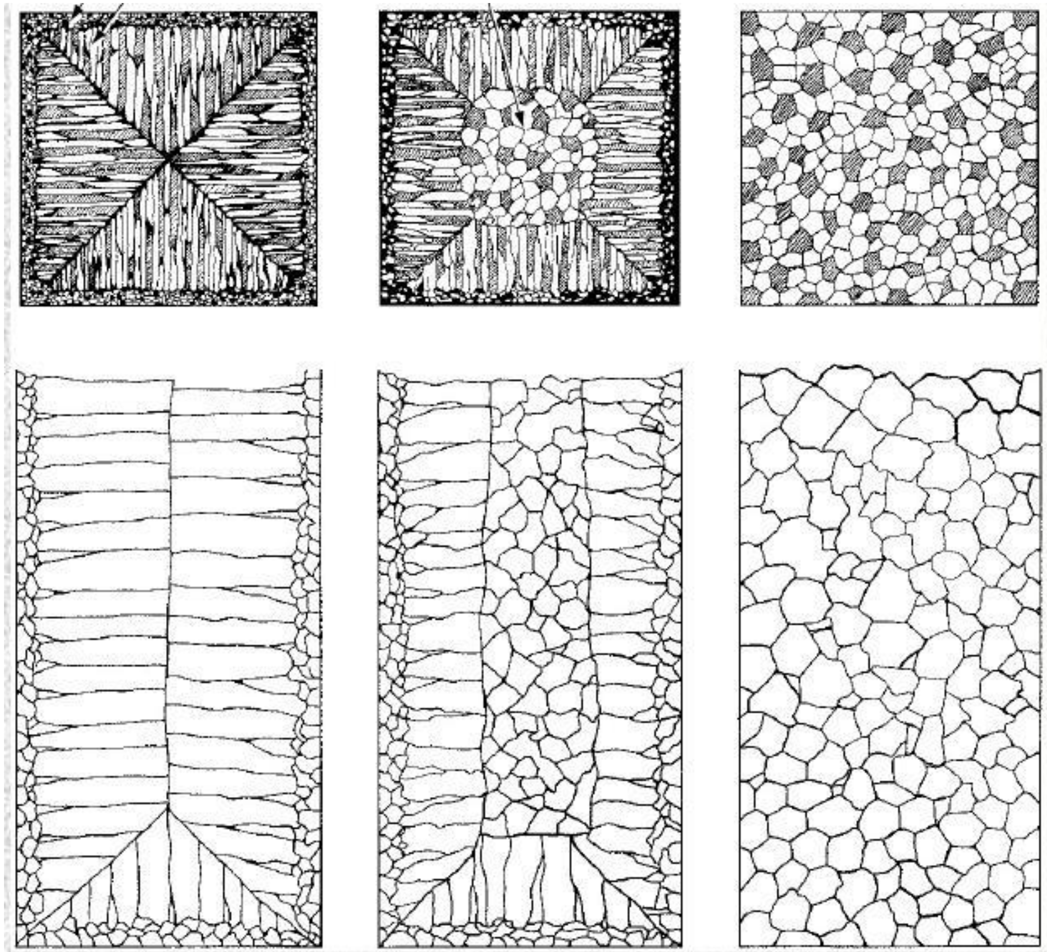
(a) (b)

Pure Metal



solidified in a square mold: (a) pure metals; (b) solid-solution alloys; and (c) structure obtained by using nucleating agents. *Source*: G. W. Form, J. F. Wallace, J. L. Walker, and A. Cibula.

Alloy Metal



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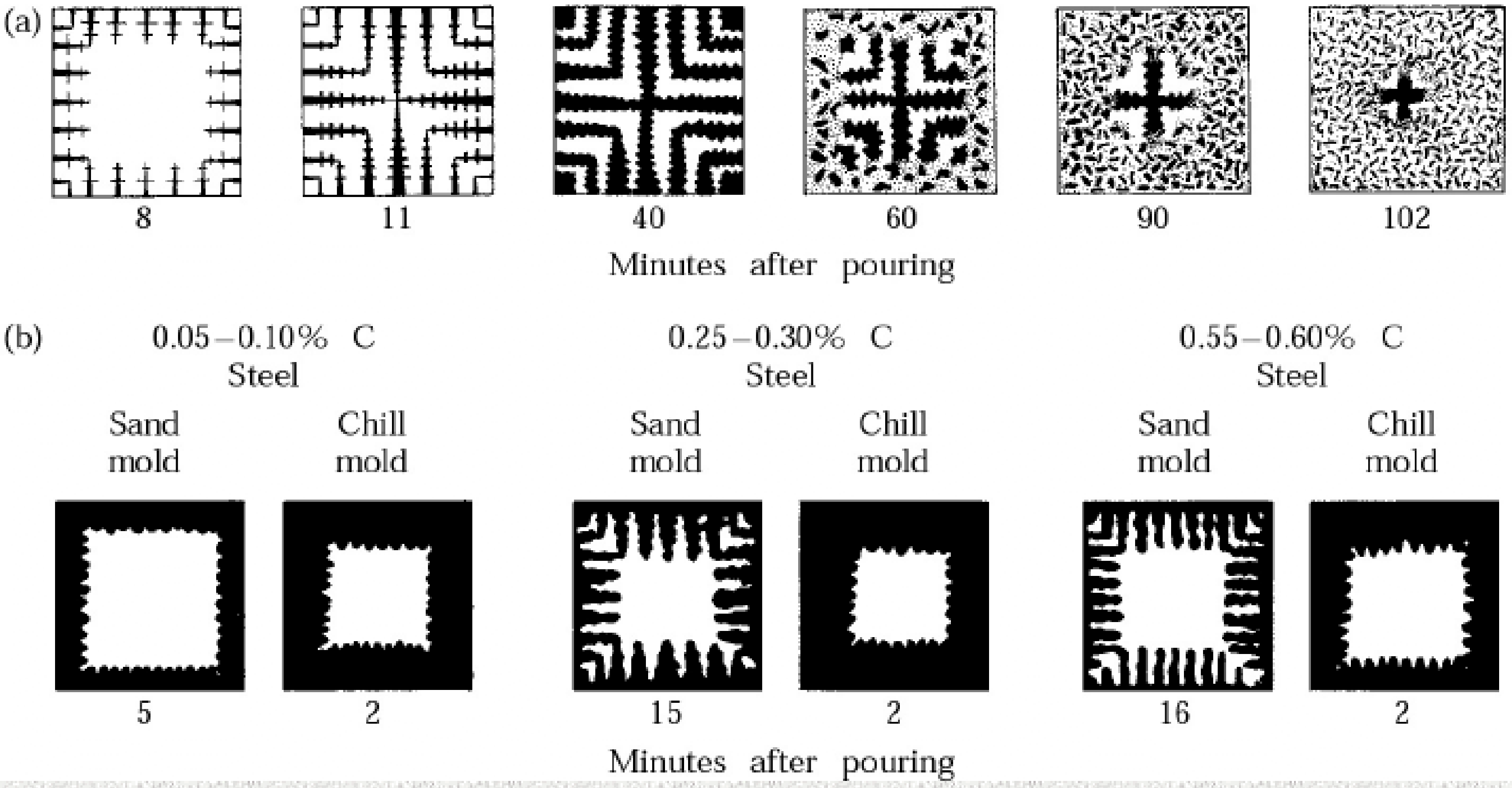
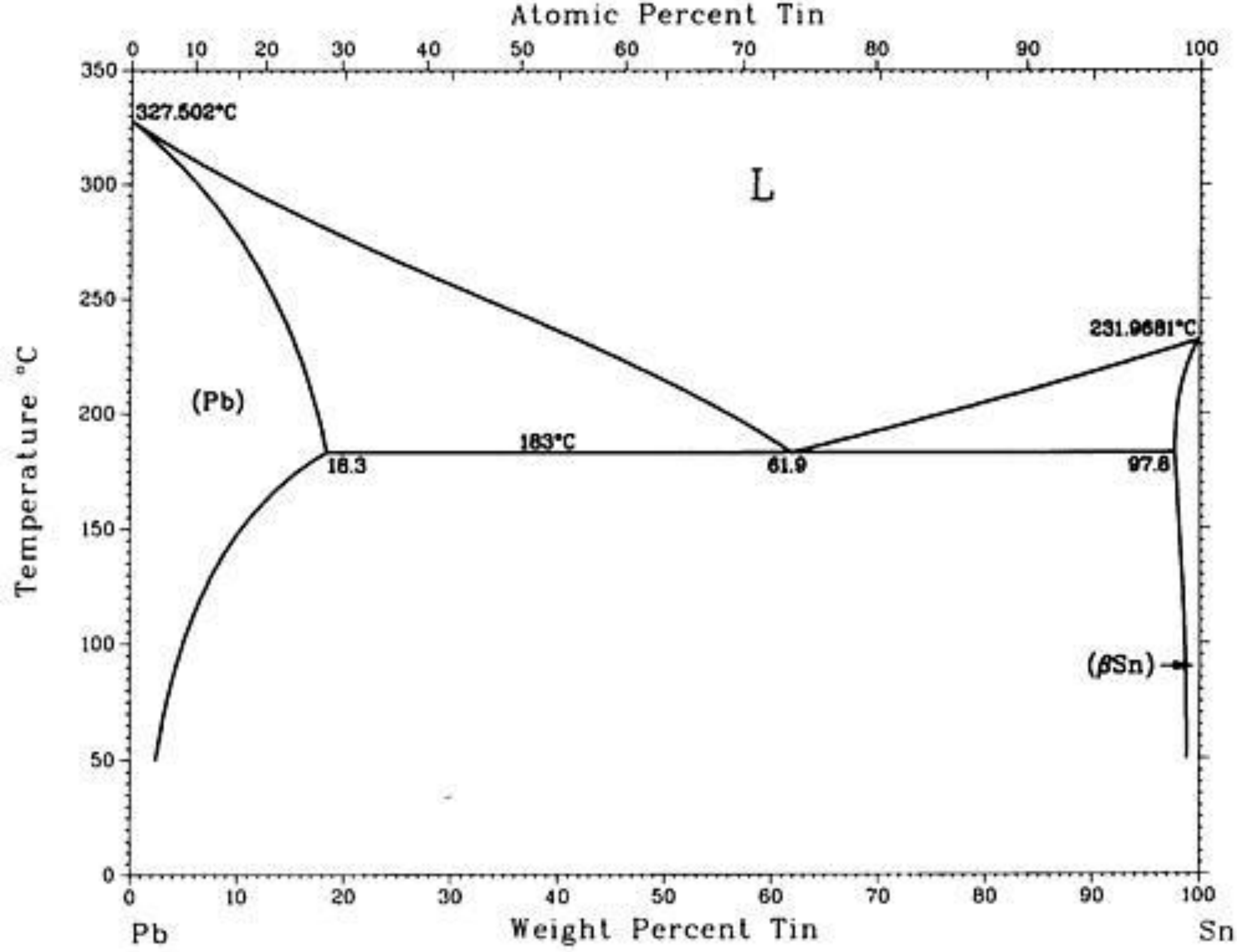
Solidification Patterns

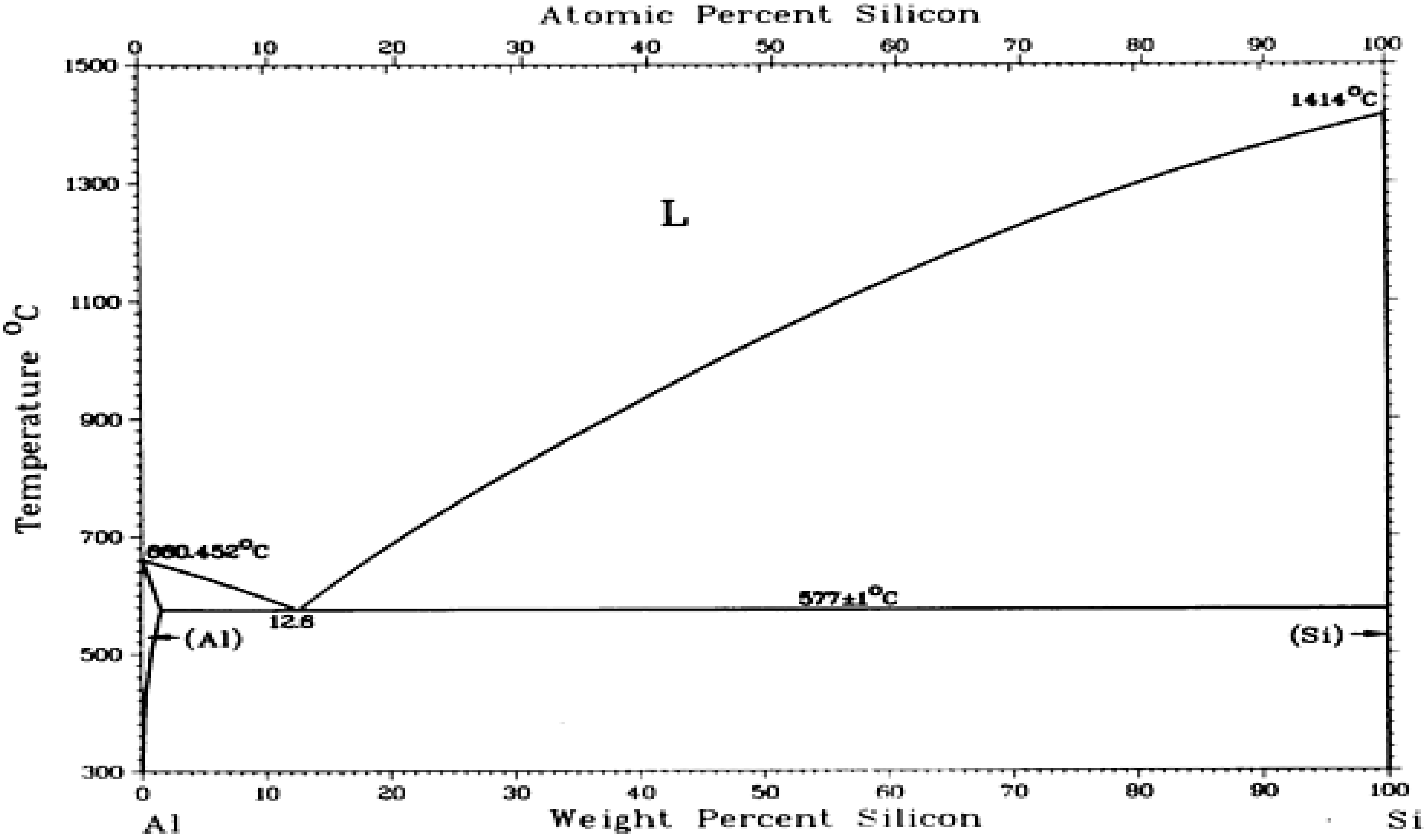
Figure 10.4 (a) Solidification patterns for gray cast iron in a 180-mm (7-in.) square casting. Note that after 11 min. of cooling, dendrites reach each other, but the casting is still mushy throughout. It takes about two hours for this casting to solidify completely. (b) Solidification of carbon steels in sand and chill (metal) molds. Note the difference in solidification patterns as the carbon content increases. *Source*: H. F. Bishop and W. S. Pellini.



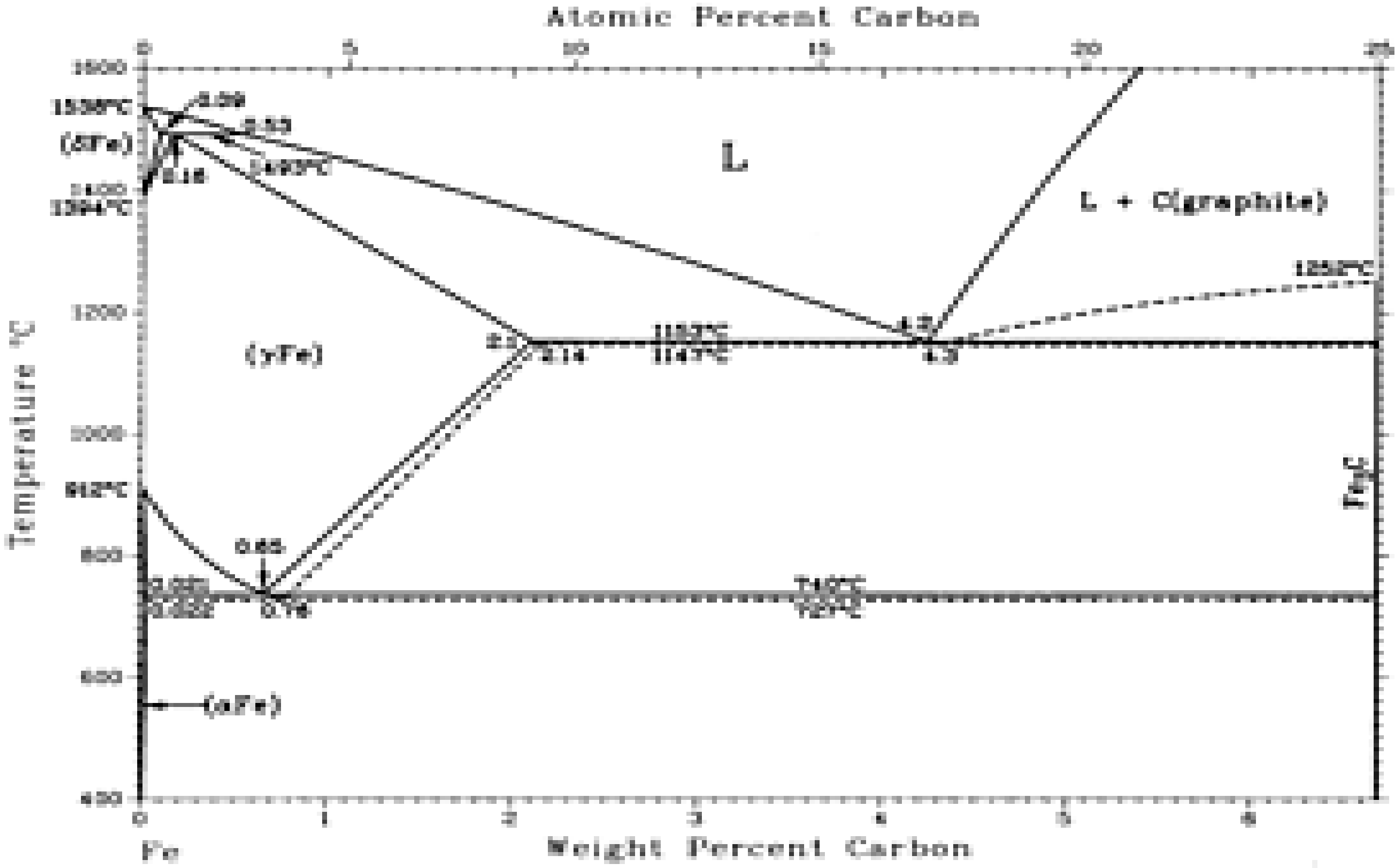
Eutectic Alloys



Eutectic Alloys



Eutectic Alloys



SOLIDIFICATION TIME

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

- Where
- TTS=total solidification time, min;
- V=volume of the casting, cm^3 (in^3);
- A=surface area of the casting, cm^2 (in^2);
- n=is an exponent usually taken to have a value= 2;
- Cm is the mold constant. Given that n= 2,
- the units of Cm are min/cm^2 (min/in^2)

Chvorinov's rule Constant

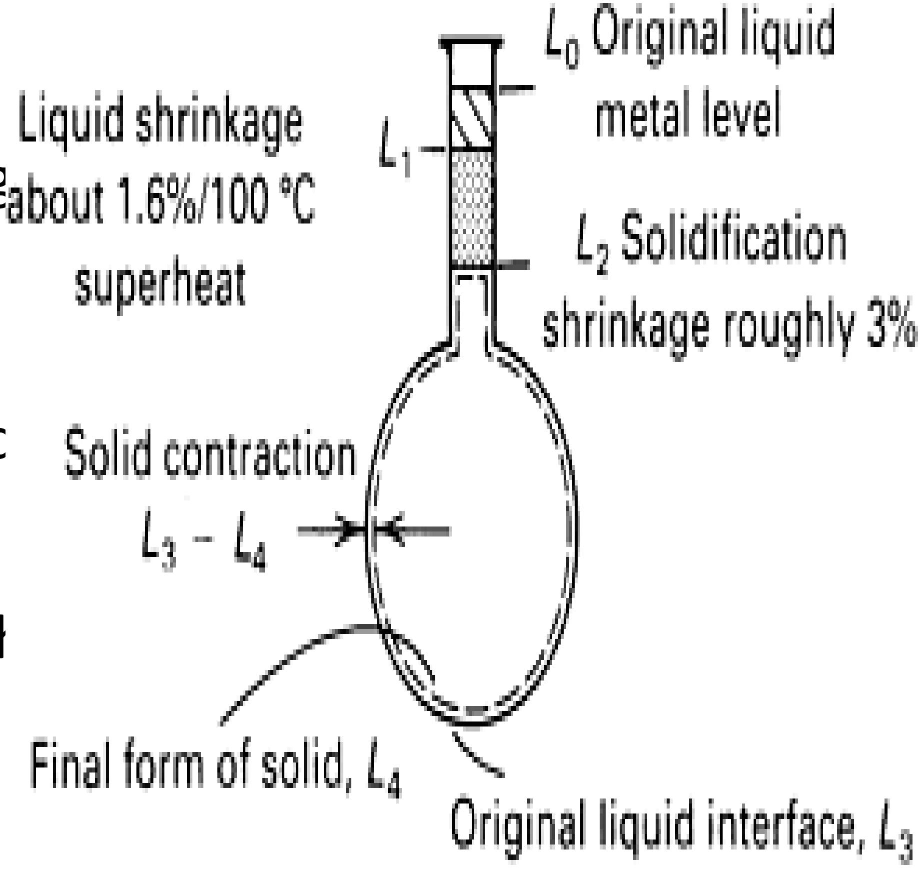
$$B = \left[\frac{\rho_m L}{(T_m - T_o)}\right]^2 \left[\frac{\pi}{4k\rho c}\right] \left[1 + \left(\frac{c_m \Delta T_s}{L}\right)^2\right]$$

- Where
- T_m = melting or freezing temperature of the liquid (in Kelvin)
- T_o = initial temperature of the mold (in Kelvin)
- $\Delta T_s = T_{pour} - T_m$ = superheat (in Kelvin)
- L = latent heat of fusion (in $[J \cdot kg^{-1}]$)
- k = thermal conductivity of the mold (in $[W \cdot m^{-1} \cdot K^{-1}$)])
- ρ = density of the mold (in $[kg \cdot m^{-3}]$)
- c = specific heat of the mold (in $[J \cdot kg^{-1} \cdot K^{-1}]$)
- ρ_m = density of the metal (in $[kg \cdot m^{-3}]$)
- c_m = specific heat of the metal (in $[J \cdot kg^{-1} \cdot K^{-1}]$)

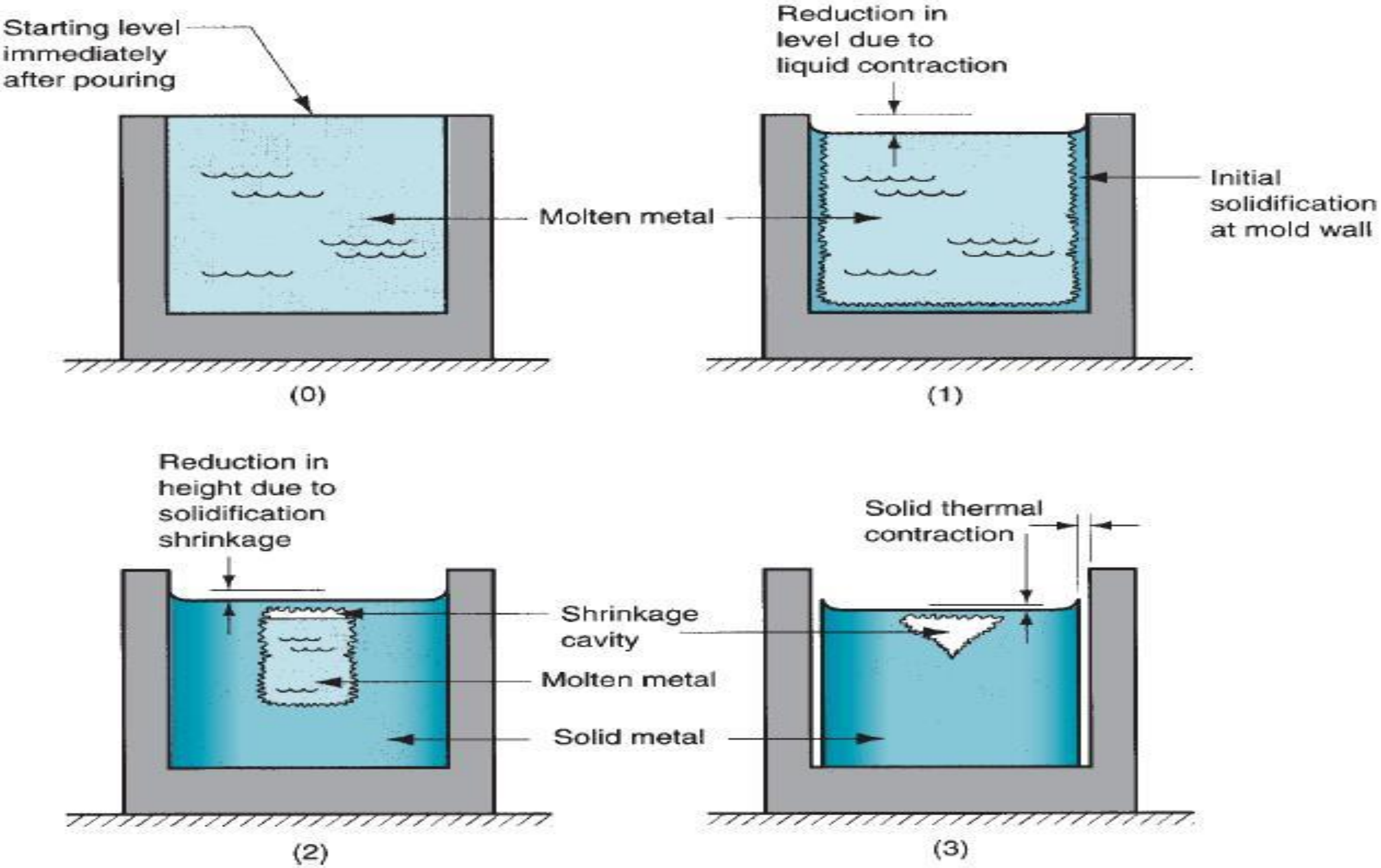
SHRINKAGE

- Shrinkage occurs in three steps:

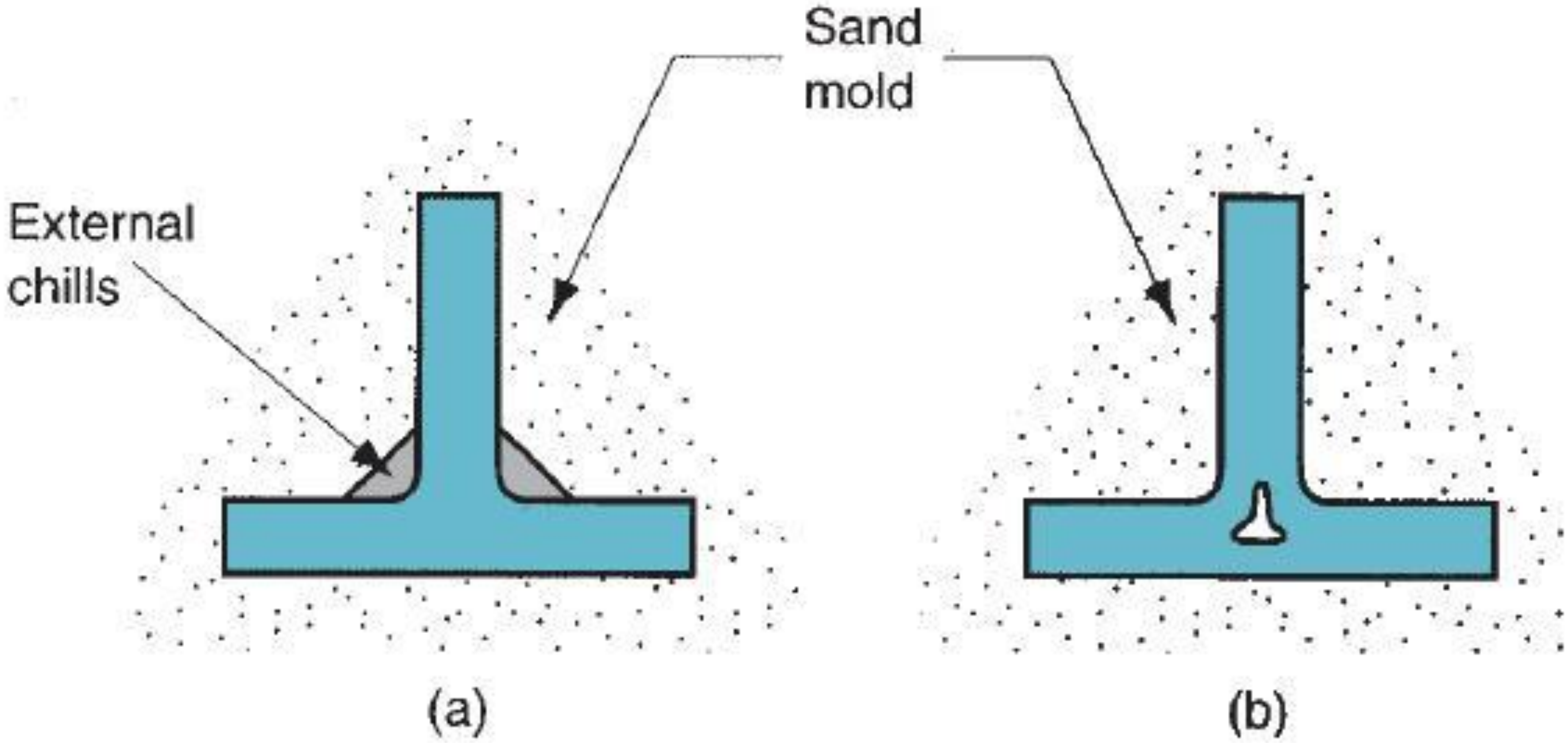
1. Liquid contraction during cooling prior to solidification;
2. Contraction during the phase change from liquid to solid, called solidification shrinkage;
3. Thermal contraction of th solidified casting during cooling to room temperature



SHRINKAGE


Starting level immediately after pouring
Reduction in level due to liquid contraction
Molten metal
Initial solidification at mold wall
(0)
(1)
Reduction in height due to solidification shrinkage
Solid thermal contraction
Shrinkage cavity
Molten metal
Solid metal
(2)
(3)

DIRECTIONAL SOLIDIFICATION



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