Materials Engineering Department
General Materials Branch

Casting Technology I

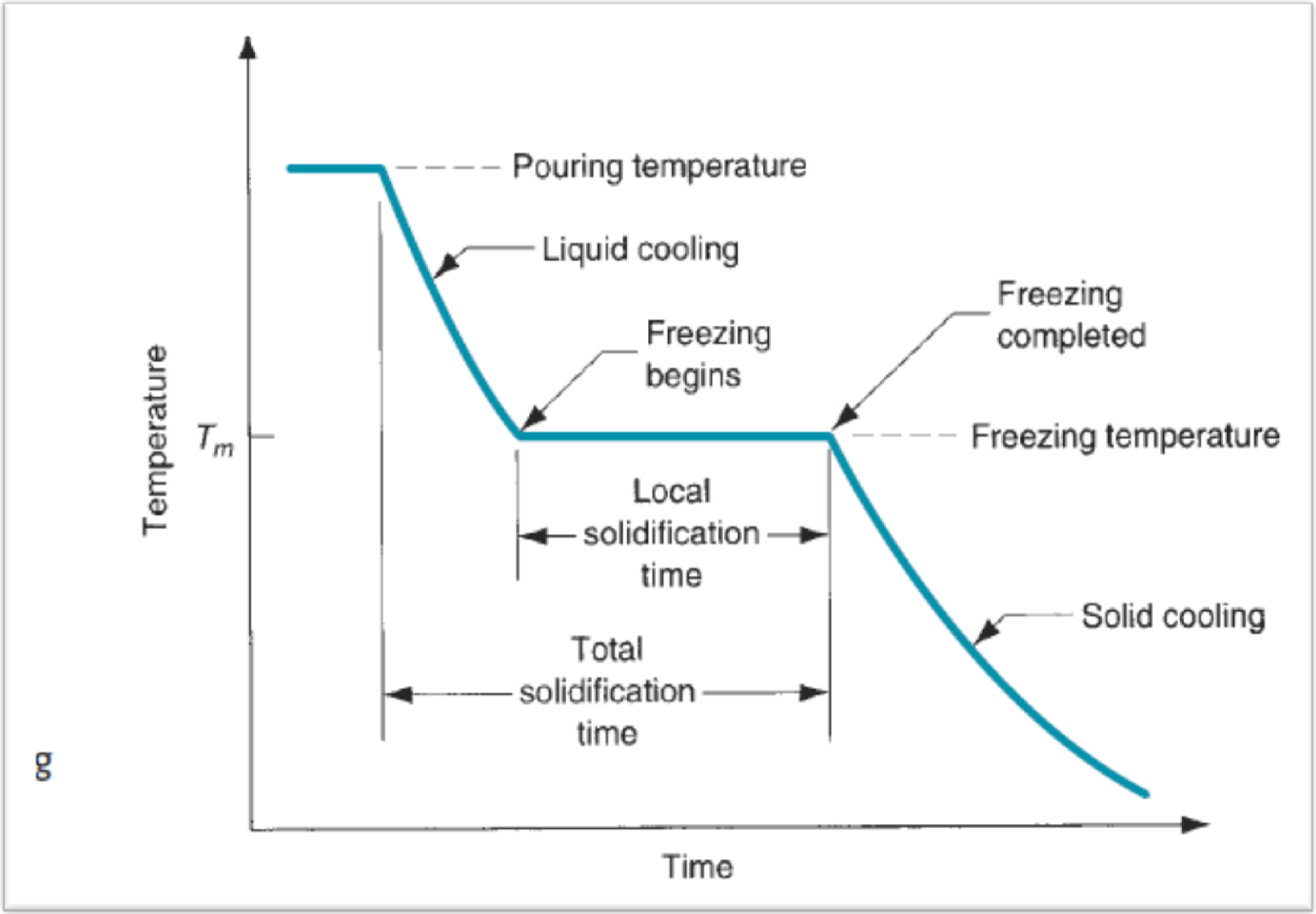
Fourth Class

Lecture Three: Solidification

SOLIDIFICATION OF METALS

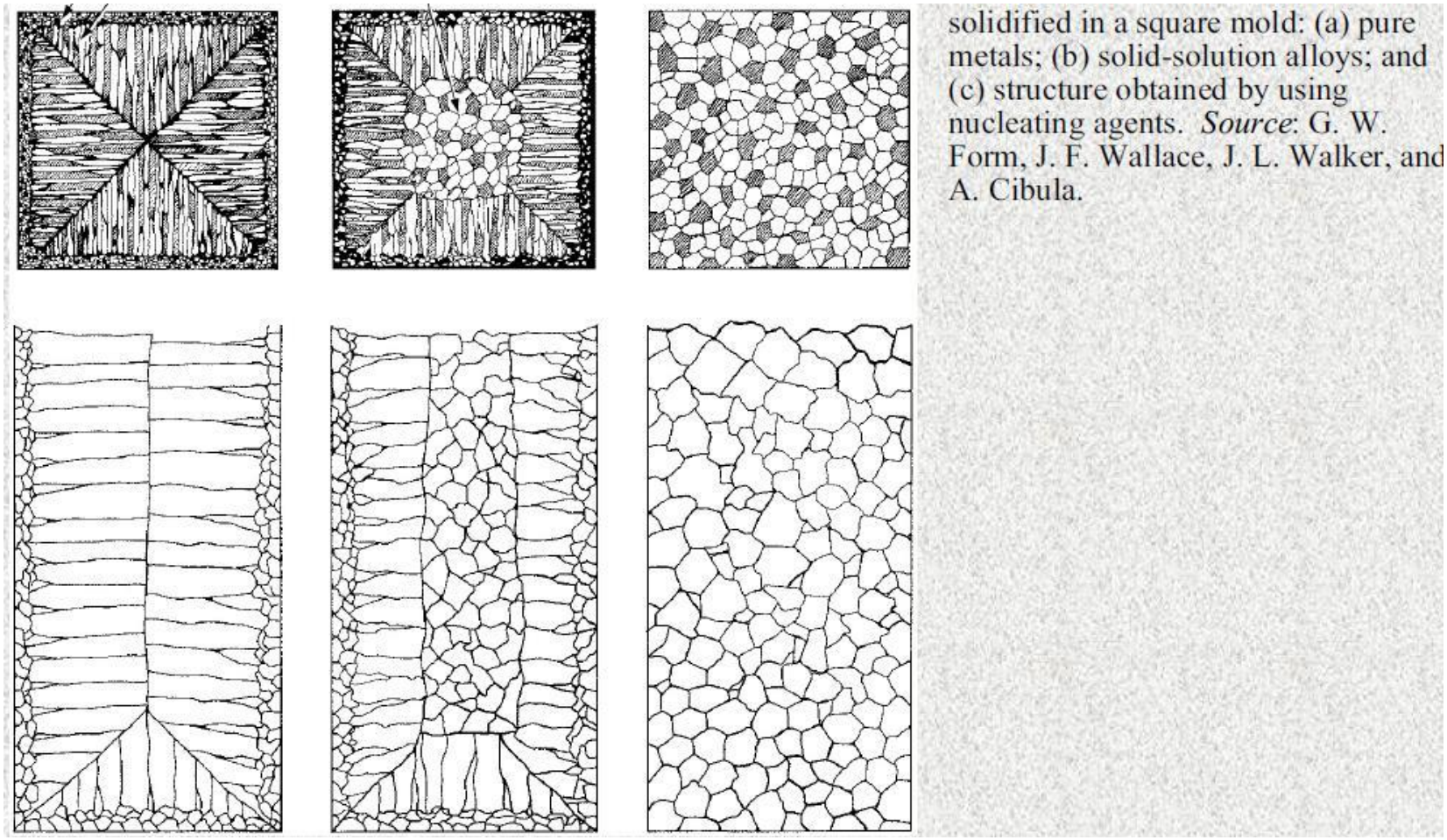
- Solidification involves the transformation of the molten metal back into the solid state. The solidification process differs depending on whether the metal is a pure element or an alloy.

Pure Metals Freezing



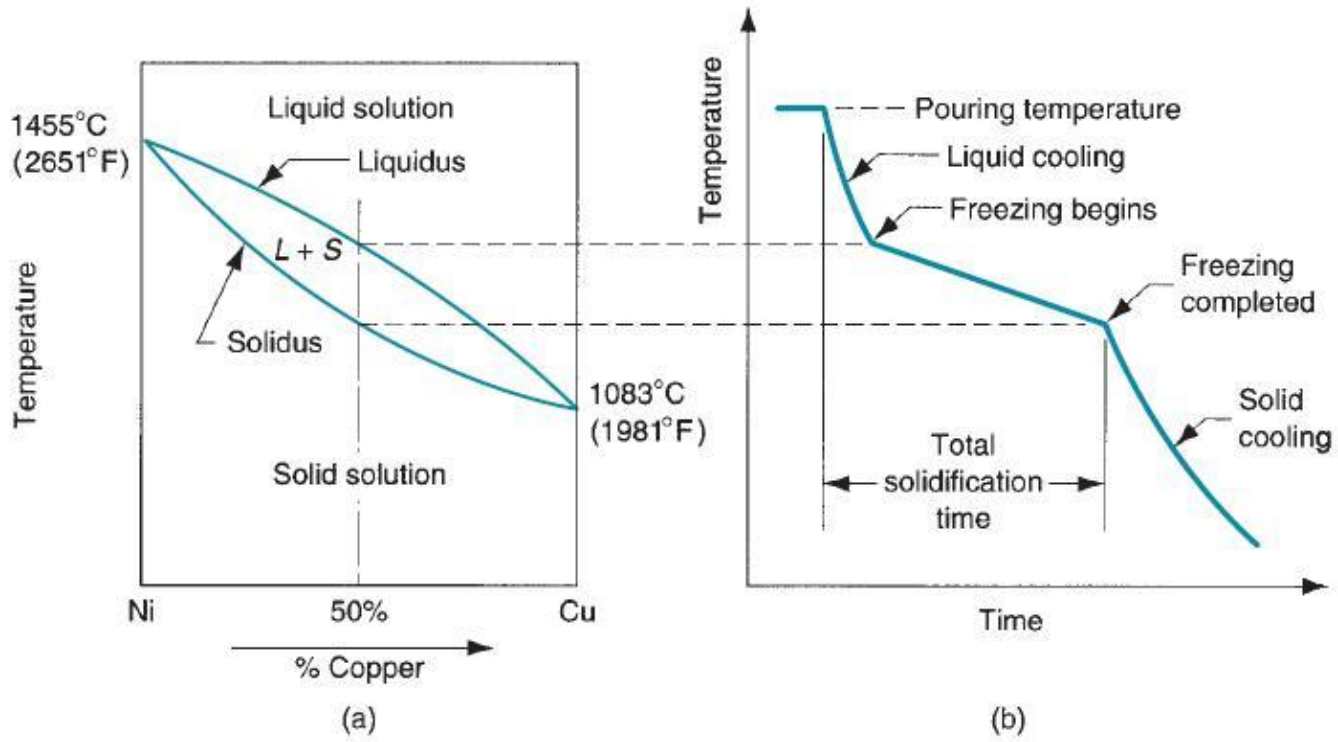
g

Pure Metal

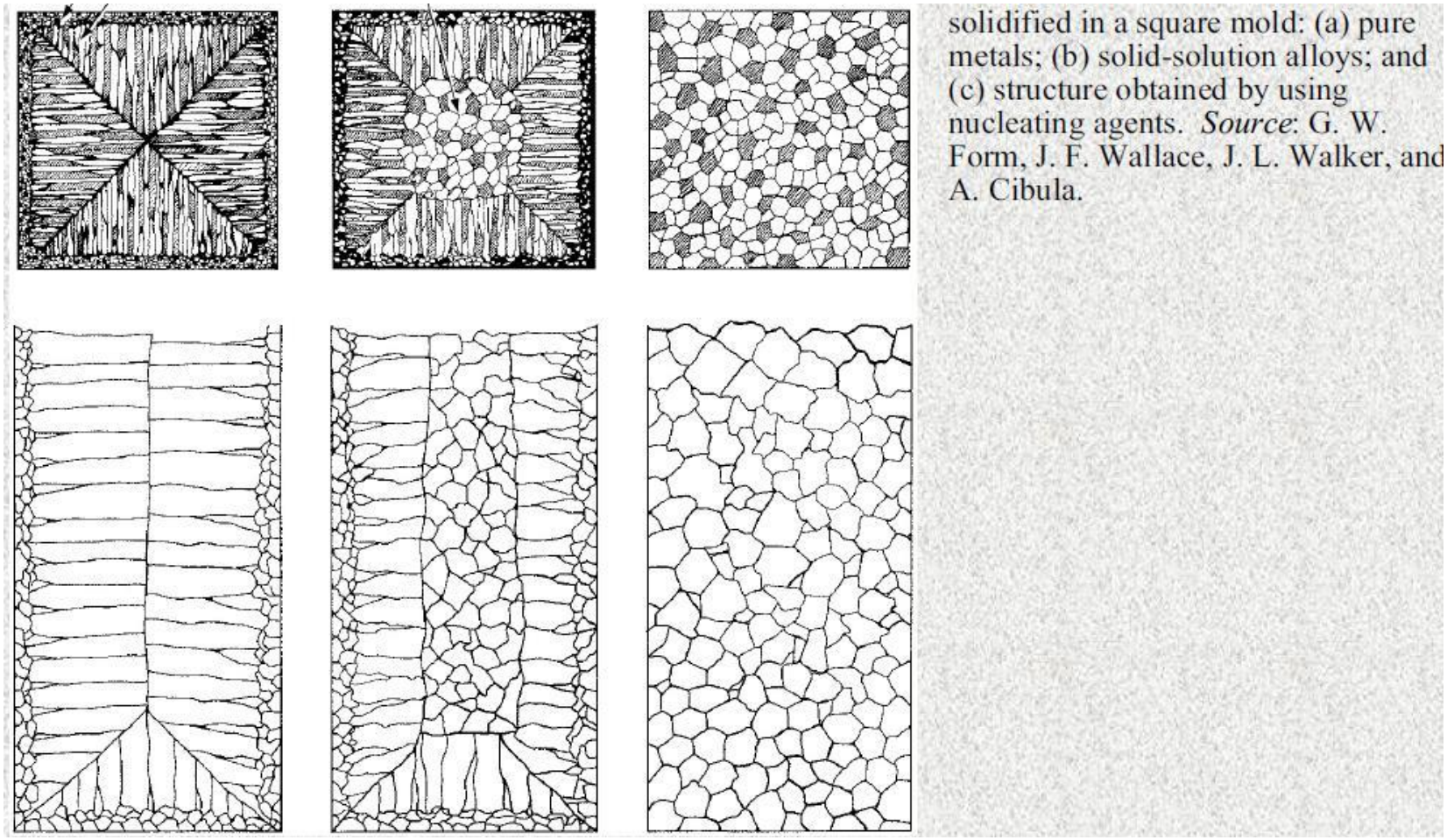


solidified in a square mold: (a) pure metals; (b) solid-solution alloys; and (c) structure obtained by using nucleating agents. *Source*: G. W. Form, J. F. Wallace, J. L. Walker, and A. Cibula.

Alloy Metal


1455°C
(2651°F)
Liquid solution
Liquidus
L + S
Solidus
Solid solution
1083°C
(1981°F)
Temperature
Ni
50%
Cu
% Copper
(a)
Temperature
Pouring temperature
Liquid cooling
Freezing begins
Freezing
completed
Solid
cooling
Total
solidification
time
Time
(b)

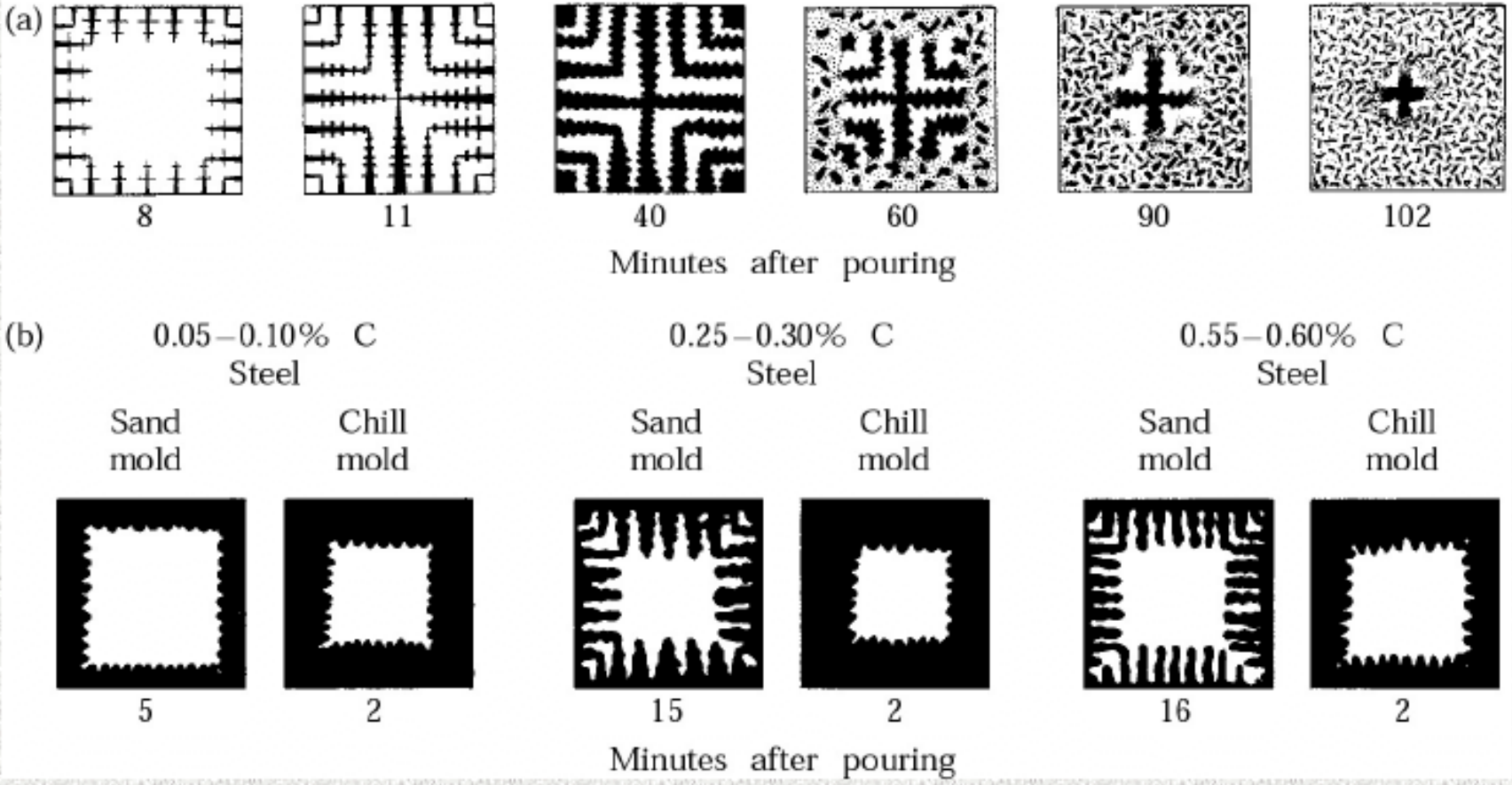
Alloy Metal



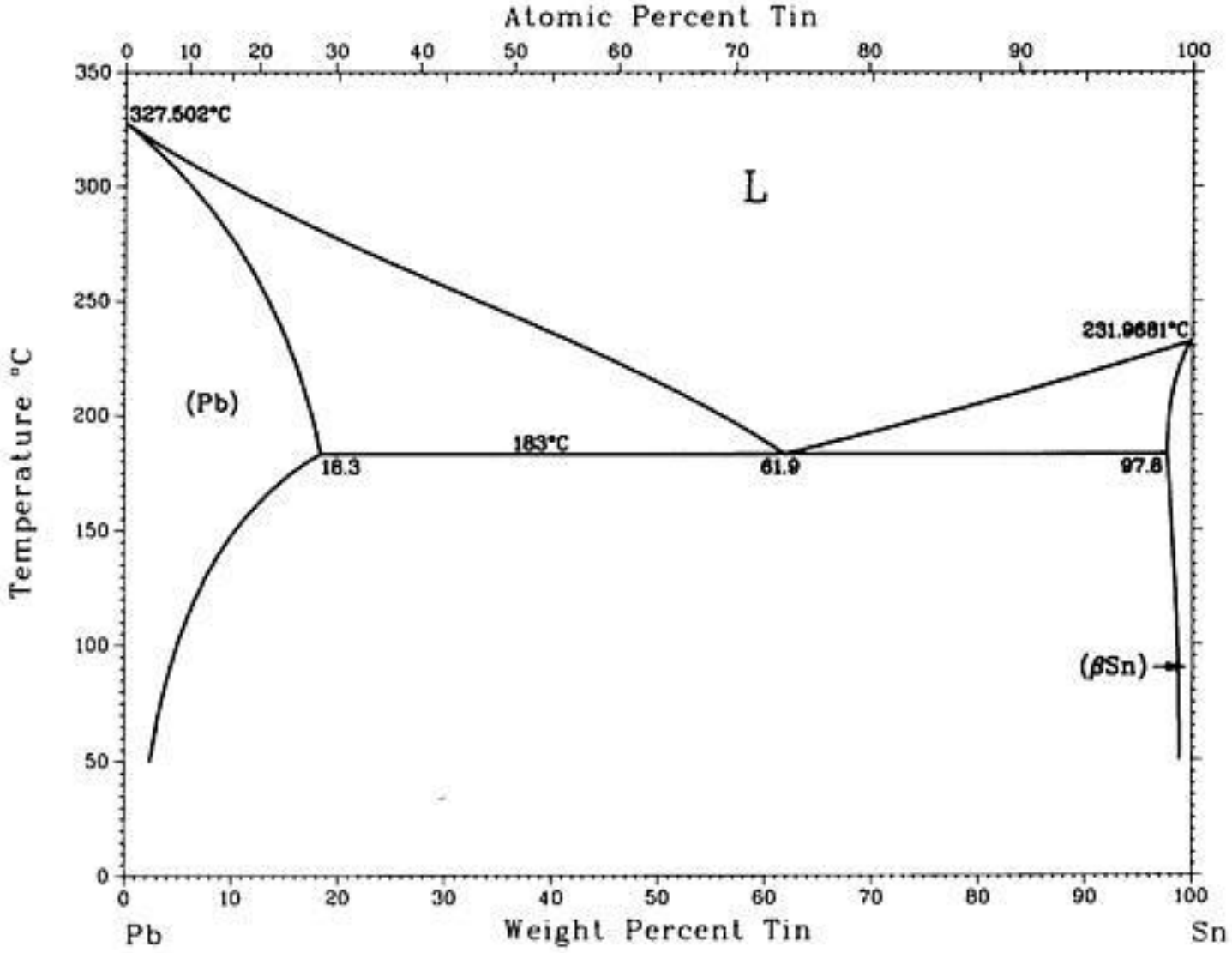
solidified in a square mold: (a) pure metals; (b) solid-solution alloys; and (c) structure obtained by using nucleating agents. *Source*: G. W. Form, J. F. Wallace, J. L. Walker, and A. Cibula.

Solidification Patterns

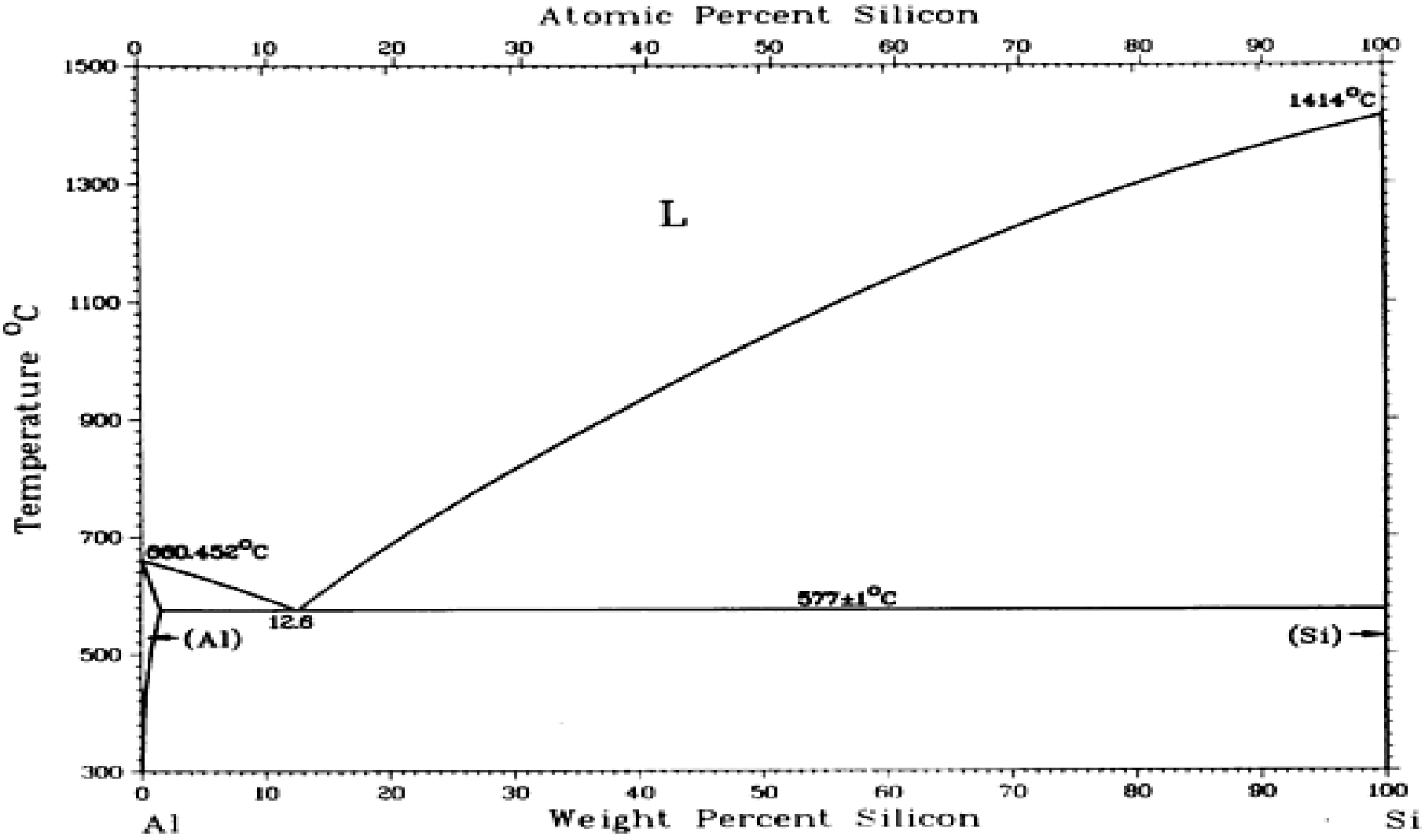
Figure 10.4 (a) Solidification patterns for gray cast iron in a 180-mm (7-in.) square casting. Note that after 11 min. of cooling, dendrites reach each other, but the casting is still mushy throughout. It takes about two hours for this casting to solidify completely. (b) Solidification of carbon steels 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.



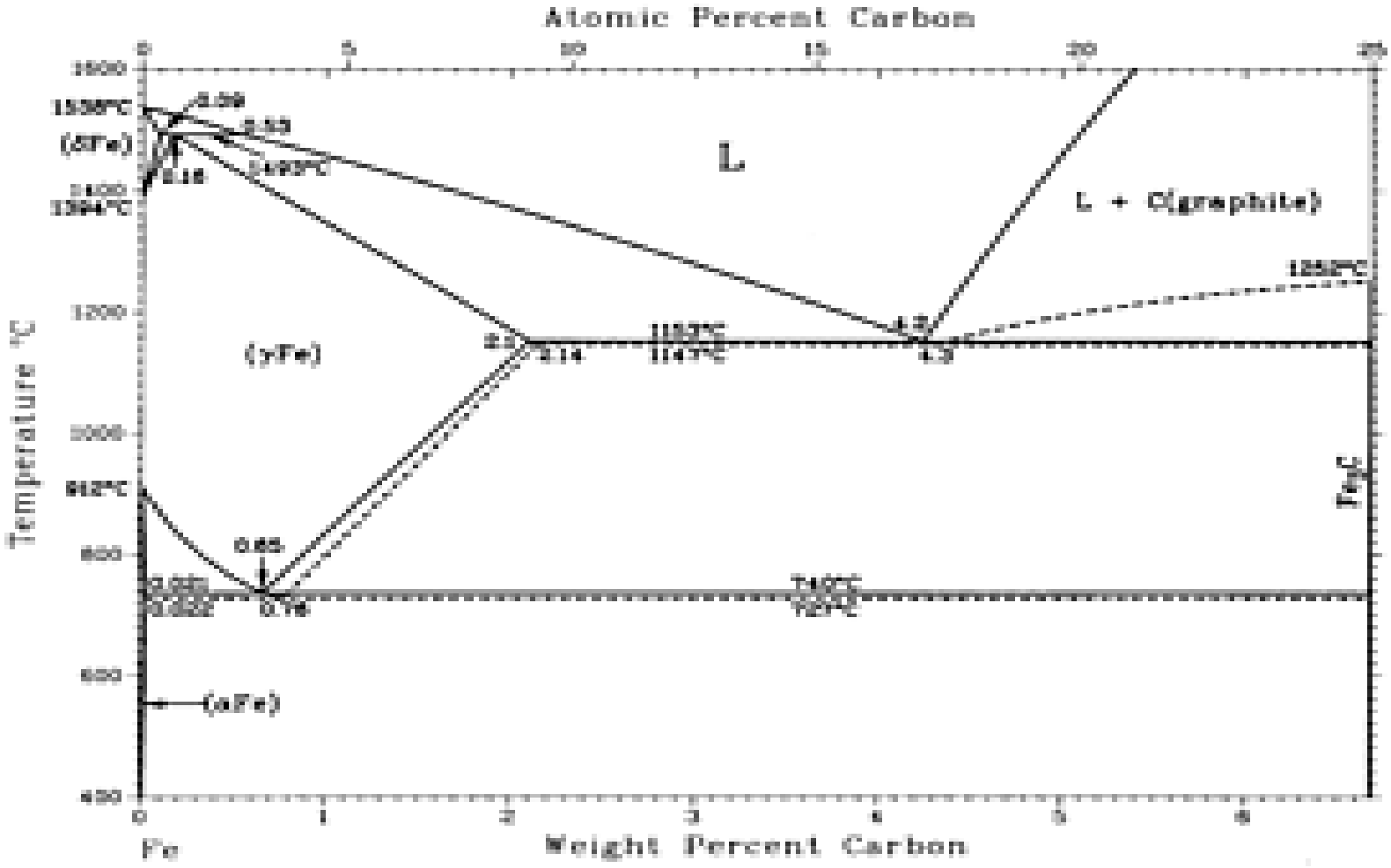
Eutectic Alloys



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

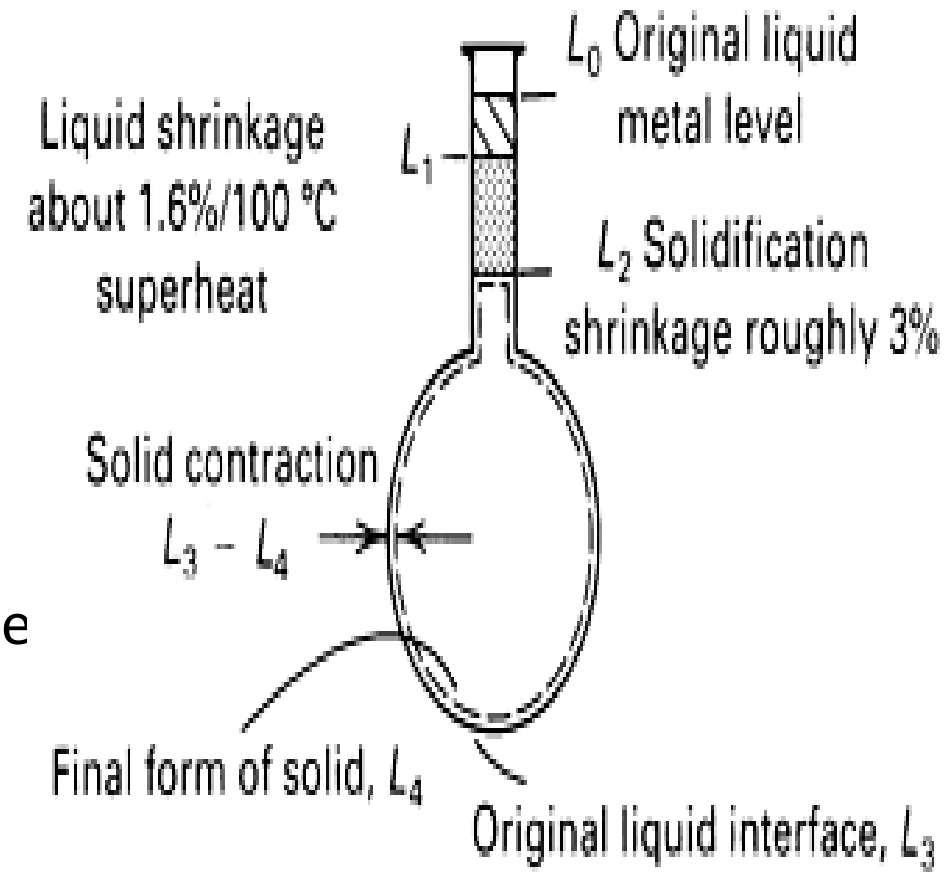
$$B = \left[\frac{\rho_m L}{(T_m - T_o)}\right]^2 \left[\frac{\pi}{4k\rho c}\right] \left[1 + \left(\frac{c_m \Delta T_s}{L}\right)^2\right]$$

- 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 $[J \cdot kg^{-1} \cdot K^{-1}]$)

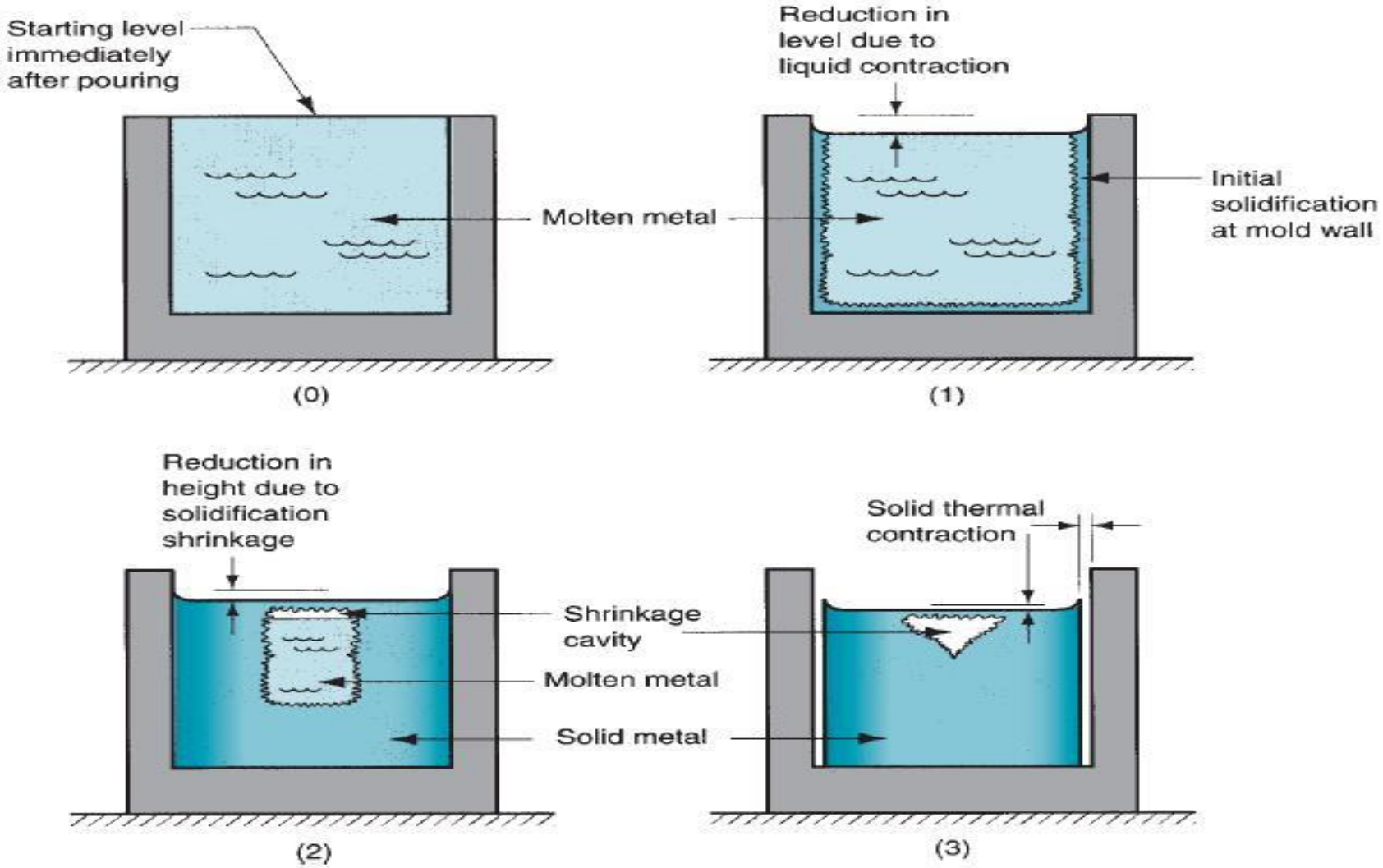
SHRINKAGE

- Shrinkage occurs in three steps:

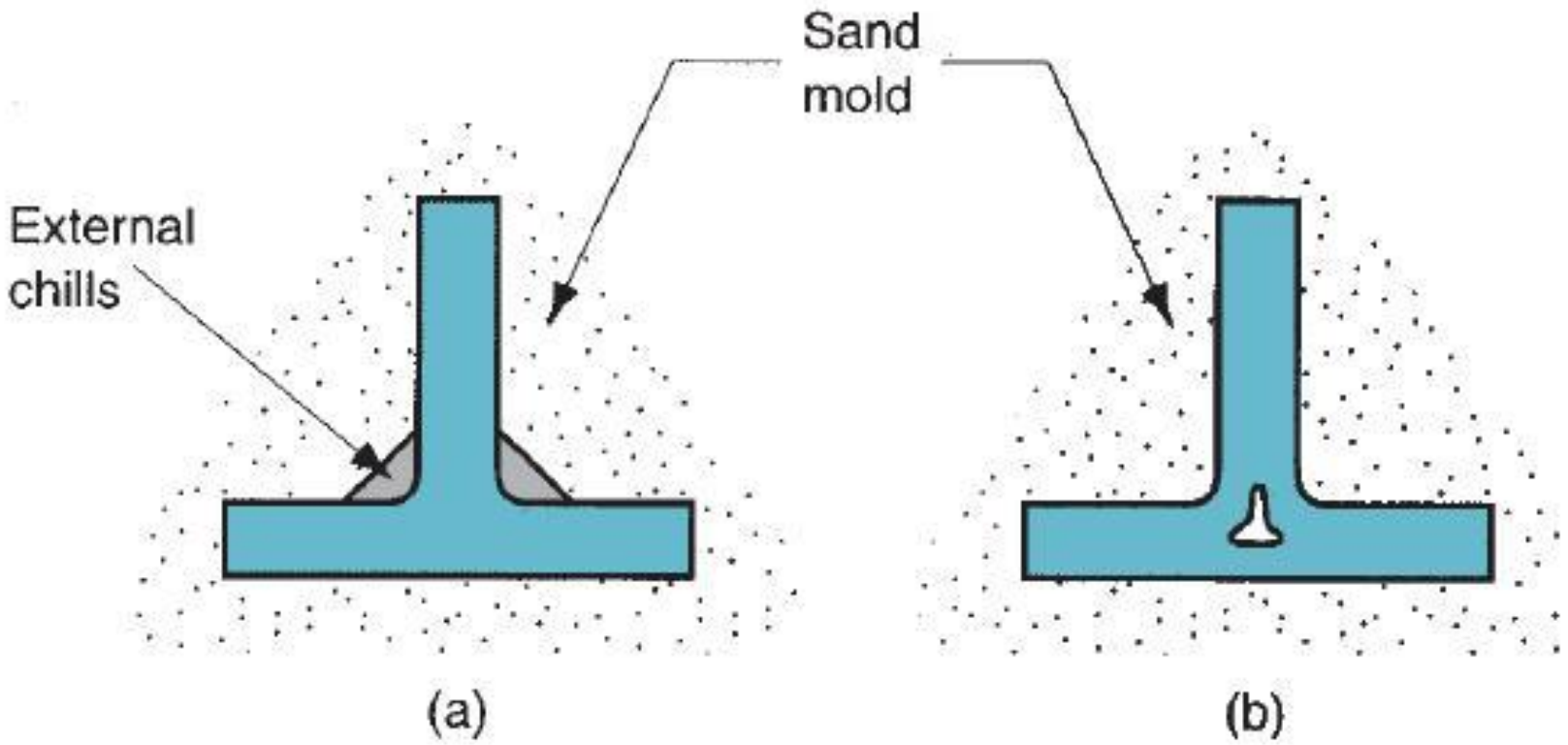
1. Liquid contraction during cooling prior to solidification;
2. Contraction during the phase change from liquid to solid, called solidification shrinkage;
3. Thermal contraction of the solidified casting during cooling to room temperature



SHRINKAGE


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

DIRECTIONAL SOLIDIFICATION



Tutorials

- Determine the shrink rule to be used by pattern makers for white cast iron. Using the shrinkage value in Table 10.1, express your answer in terms of decimal fraction inches of elongation per foot of length compared to a standard 1-foot scale.

Tutorials

- Determine the shrink rule to be used by mold makers for die casting of zinc. Using the shrinkage value in Table 10.1, express your answer in terms of decimal m of elongation per 300mm of length compared to a standard 300-mm scale.

Tutorials

- A flat plate is to be cast in an open mold whose bottom has a square shape that is 200mm × 200mm. The mold is 40mm deep.A total of 1,000,000mm^3 of molten aluminum is poured into the mold. Solidification shrinkage is known to be 6.0%. Table 10.1 lists the linear shrinkage due to thermal contraction after solidification to be 1.3%. If the availability of molten metal in the mold allows the square shape of the cast plate to maintain its 200 mm × 200 mm dimensions until solidification is completed, determine the final dimensions of the plate