Isopleth: constant chemical composition

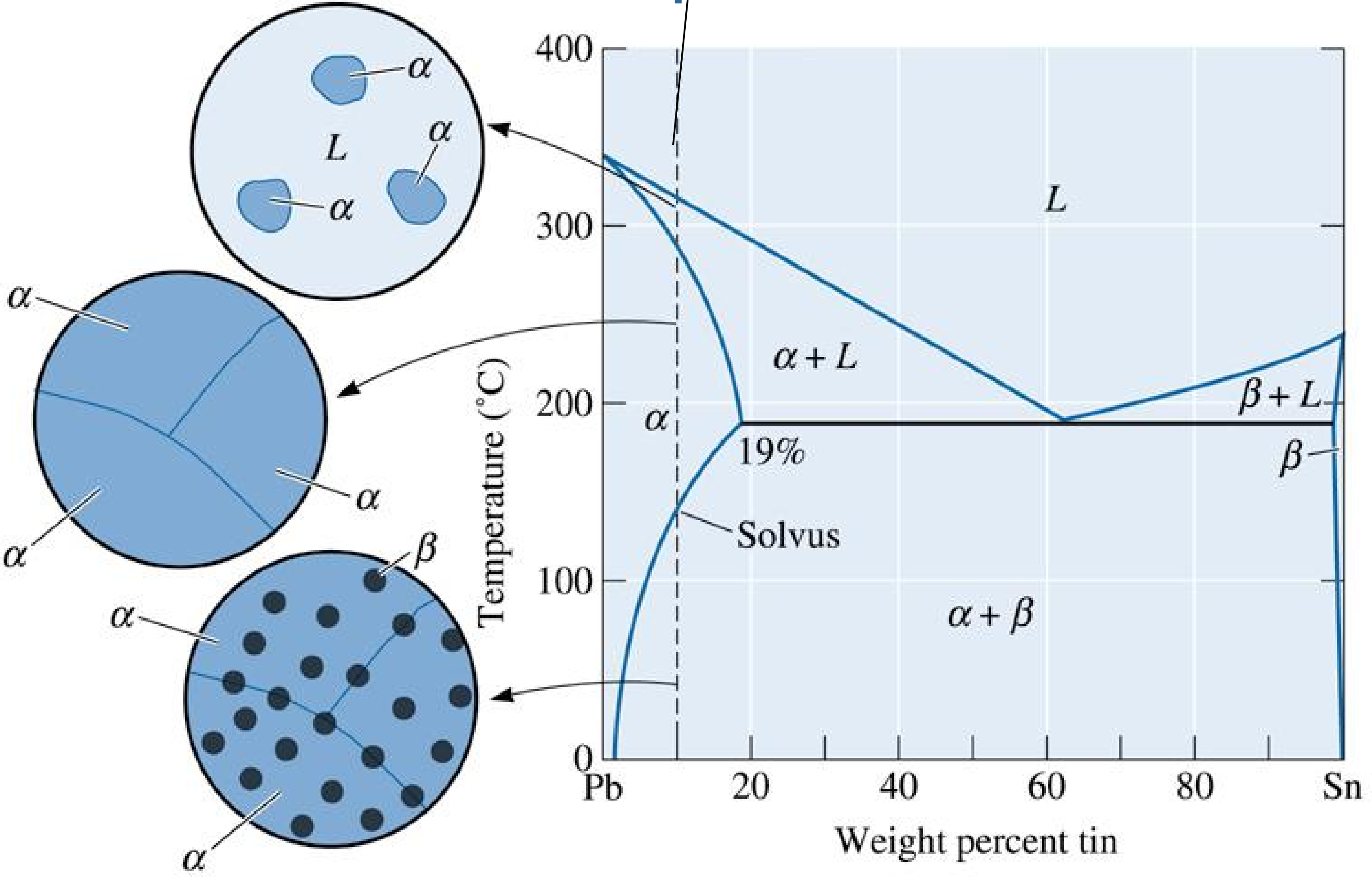

Figure 11.8 Solidification, precipitation, and microstructure of a Pb-10% Sn alloy. Some dispersion strengthening occurs as the *β* solid precipitates.

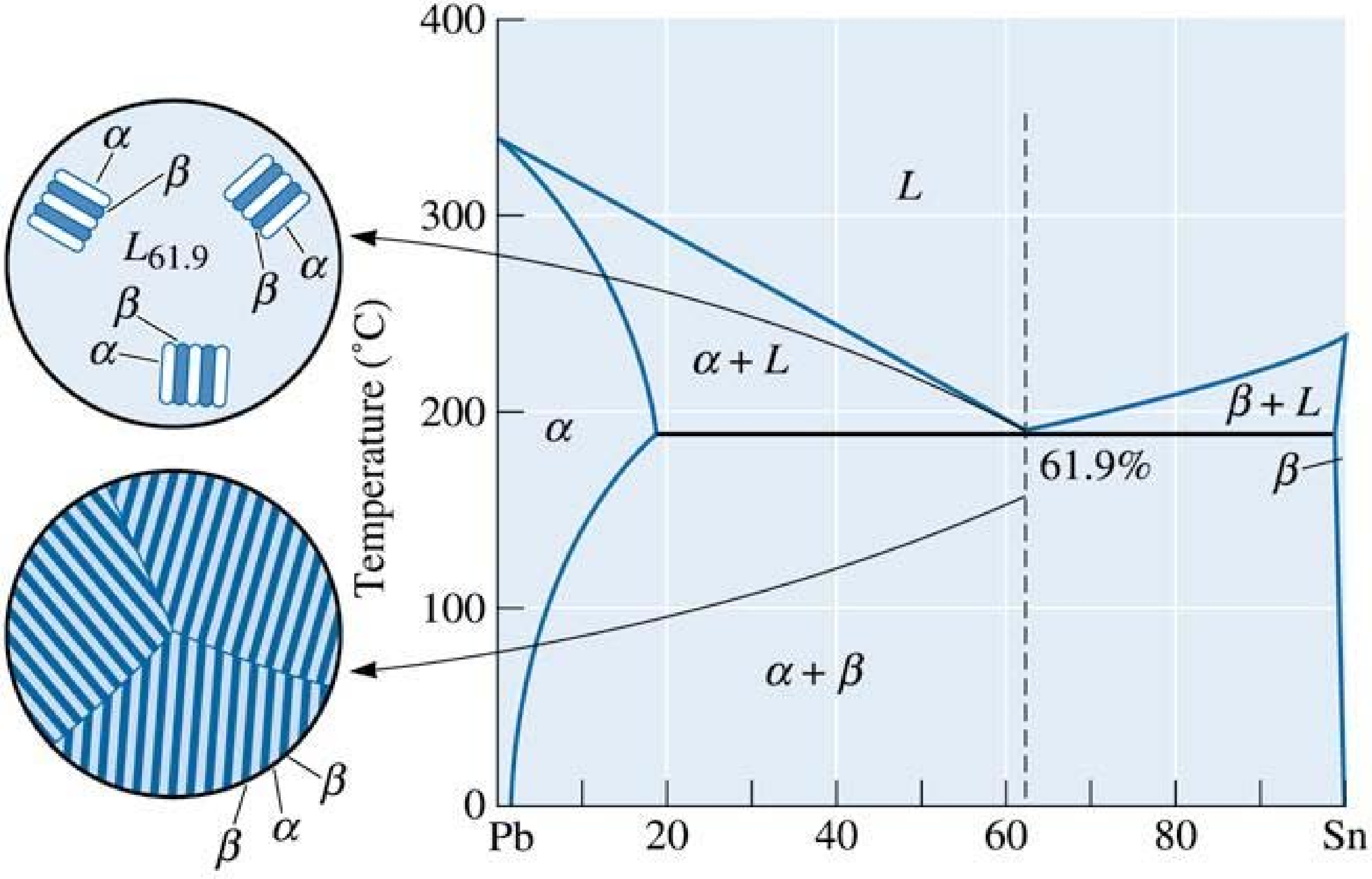

Figure 11-9 Solidification and microstructure of the eutectic alloy Pb-61.9% Sn.

The Science and Engineering of Materials, 5th ed

Donald R. Askeland – Pradeep P. Phulé

Chapter 12 – Dispersion Strengthening by Phase Transformations and Heat Treatment

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Section 11.1

Nucleation and Growth in Solid-State Reactions

- Strain energy - The energy required to permit a precipitate to fit into the surrounding matrix during nucleation and growth of the precipitate.
- Avrami relationship - Describes the fraction of a transformation that occurs as a function of time. This describes most solid-state transformations that involve diffusion, thus martensitic transformations are not described.

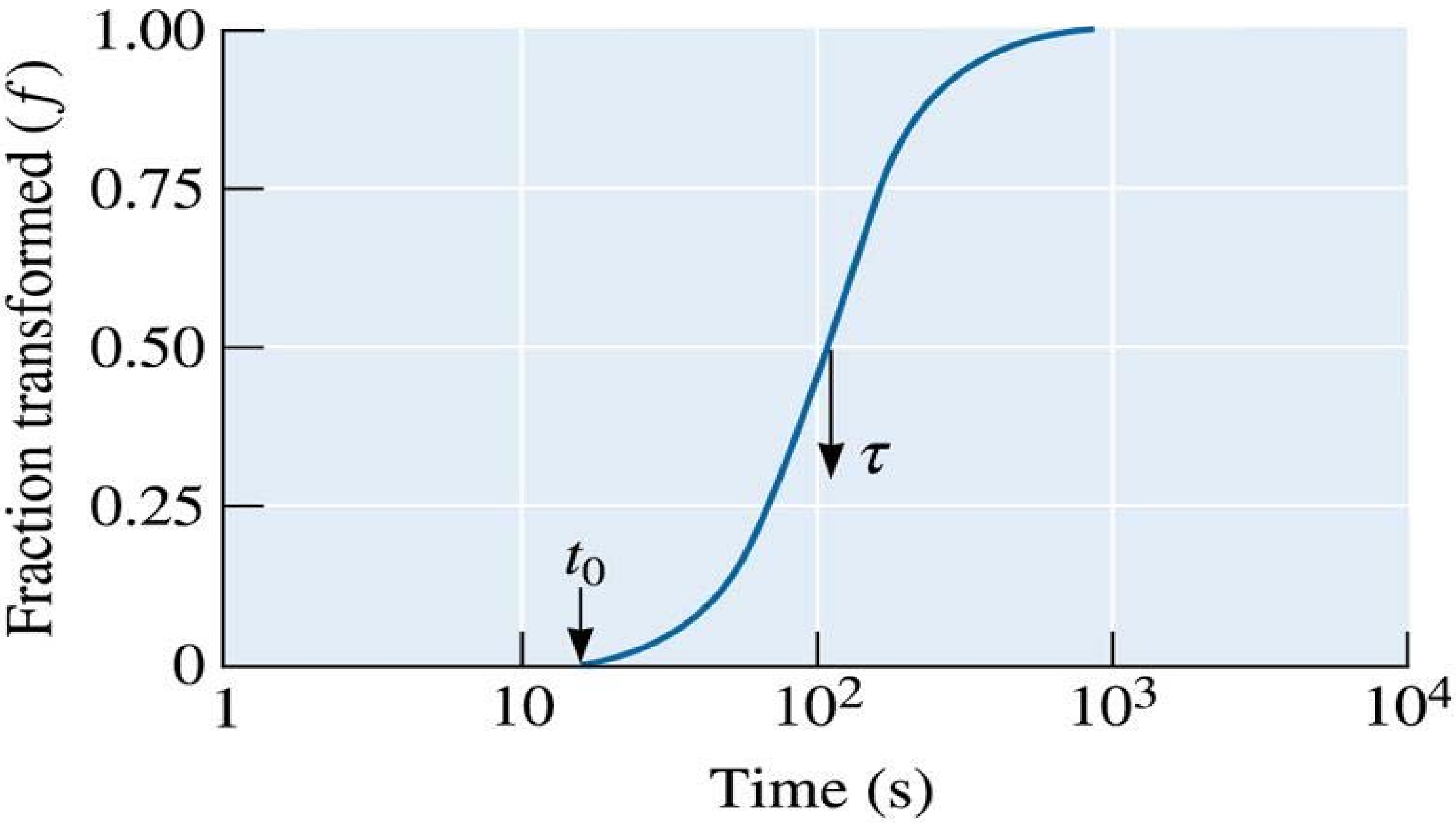


Figure 12.1 Sigmoidal curve showing the rate of transformation of FCC iron at a constant temperature. The incubation time t_0 and the time τ for the 50% transformation are also shown.

Avrami equation: $f = 1-\exp(-ct^n)$; Rate $= 1/\tau$

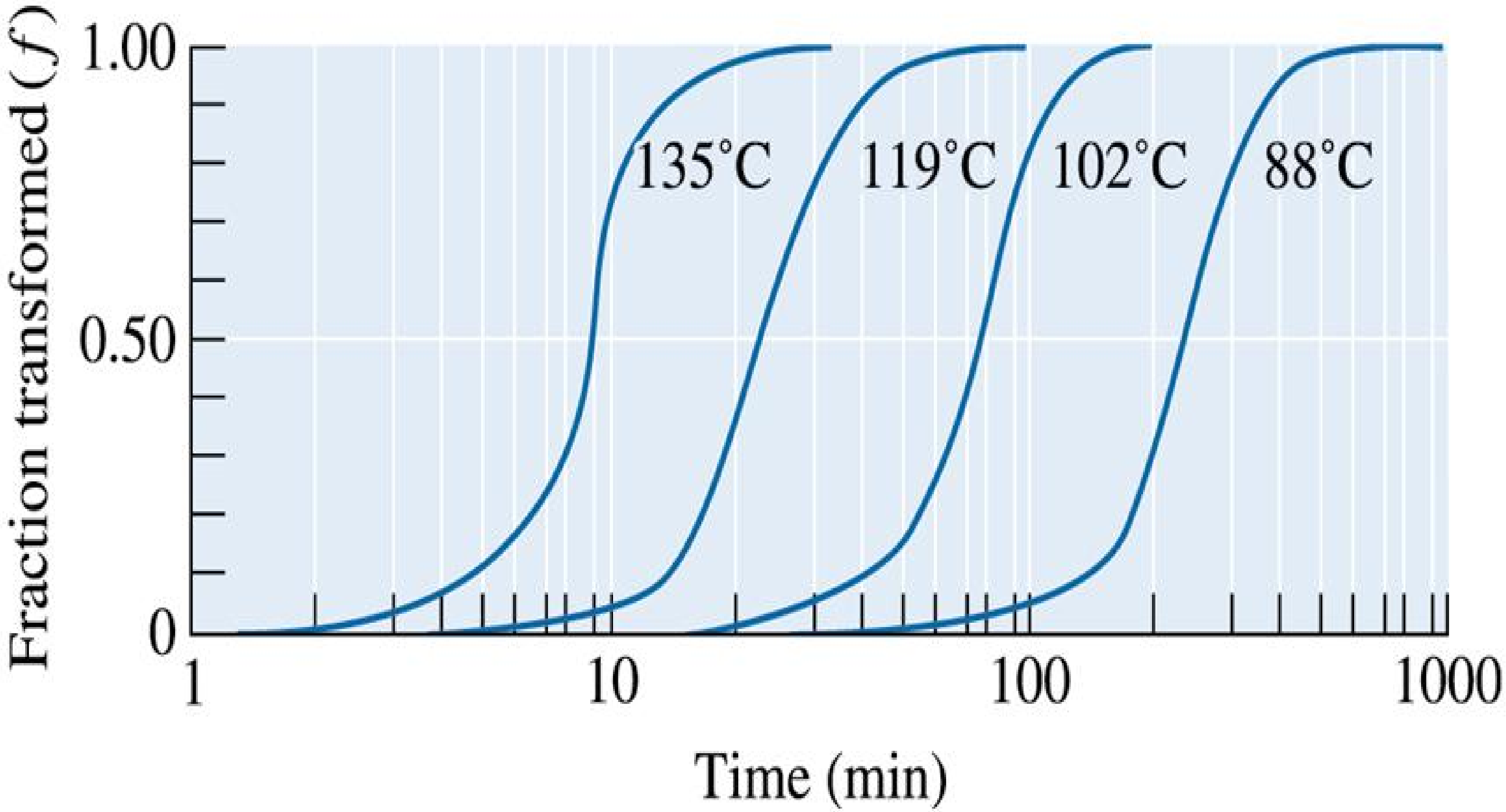
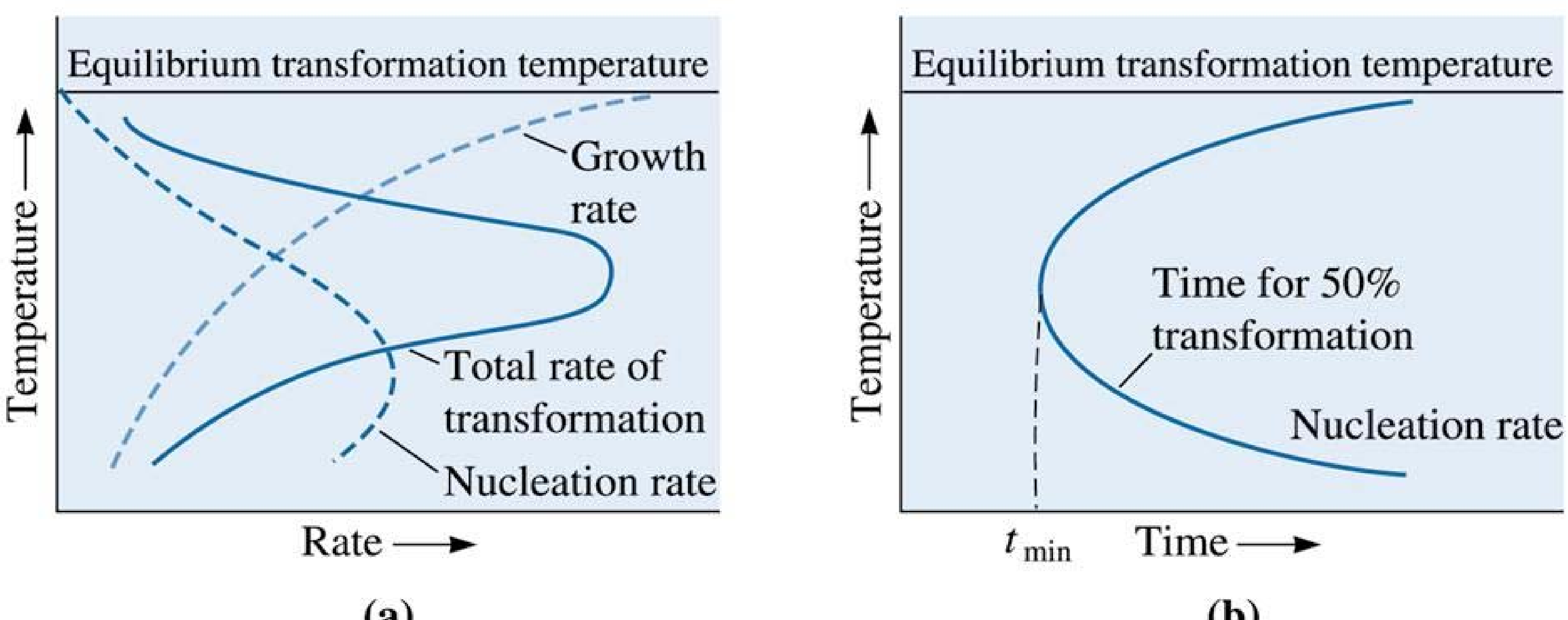


Figure 12.2 The effect of temperature on recrystallization of cold-worked copper.

Growth rate is high at max temp and drops off as temp is reduced: Growth rate = A exp (-Q/RT)



(a) (b)

Figure 11.3 (a) Temperatures lower than equilibrium temp is a type of undercooling. Nucleation rate increases to a max rate that drops off due to diffusion limitations.

Growth rate is high at max temp and drops off as temp is reduced: Growth rate = A exp (-Q/RT)

The effect of temperature on the rate of a phase transformation is the product of the growth rate and nucleation rate contributions, giving a maximum transformation rate at a critical temperature.

Section 11.2 Alloys Strengthened by Exceeding the Solubility Limit

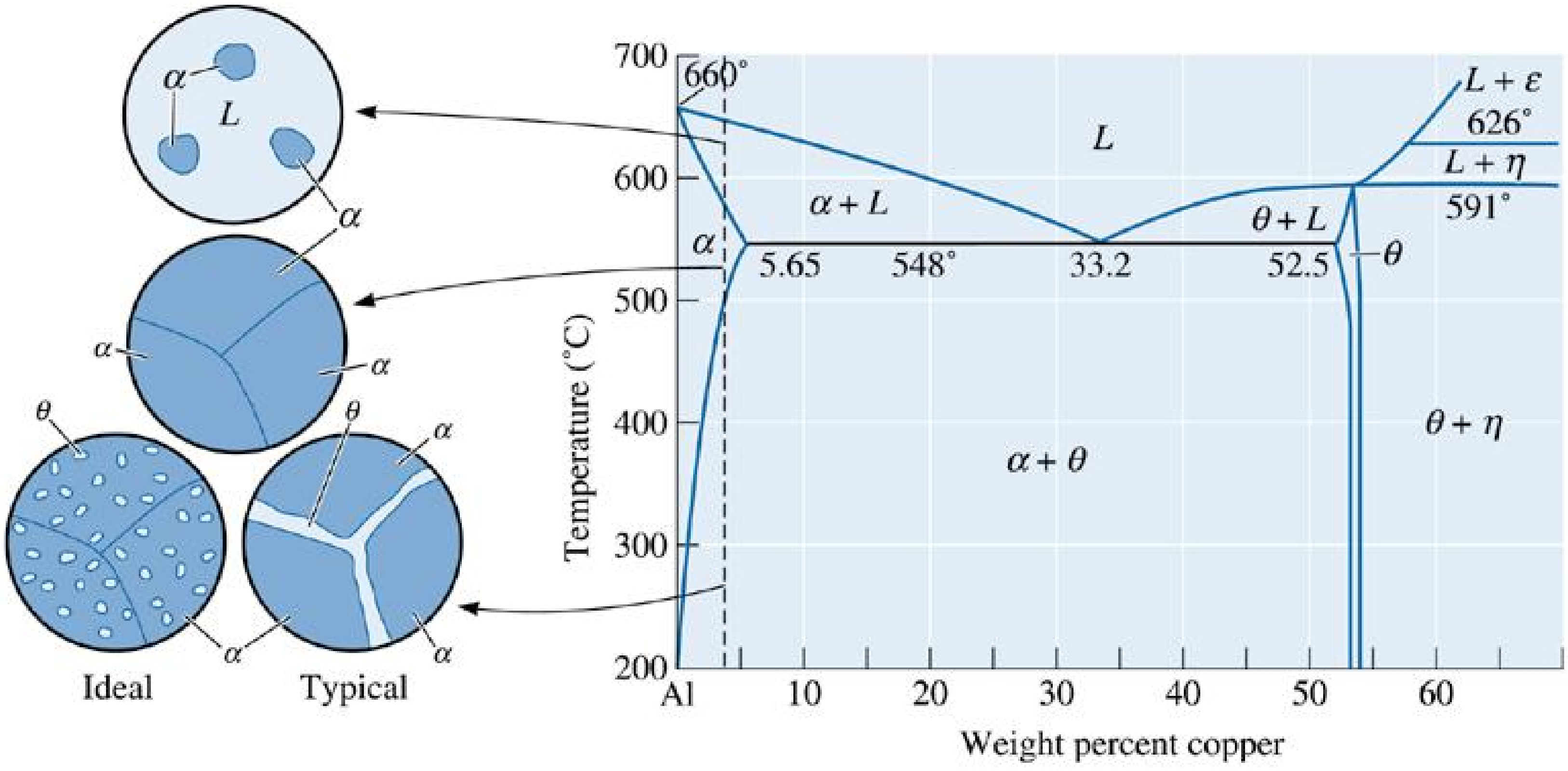


Figure 12.5 The aluminum-copper phase diagram and the microstructures that may develop curing cooling of an Al-4% Cu alloy.

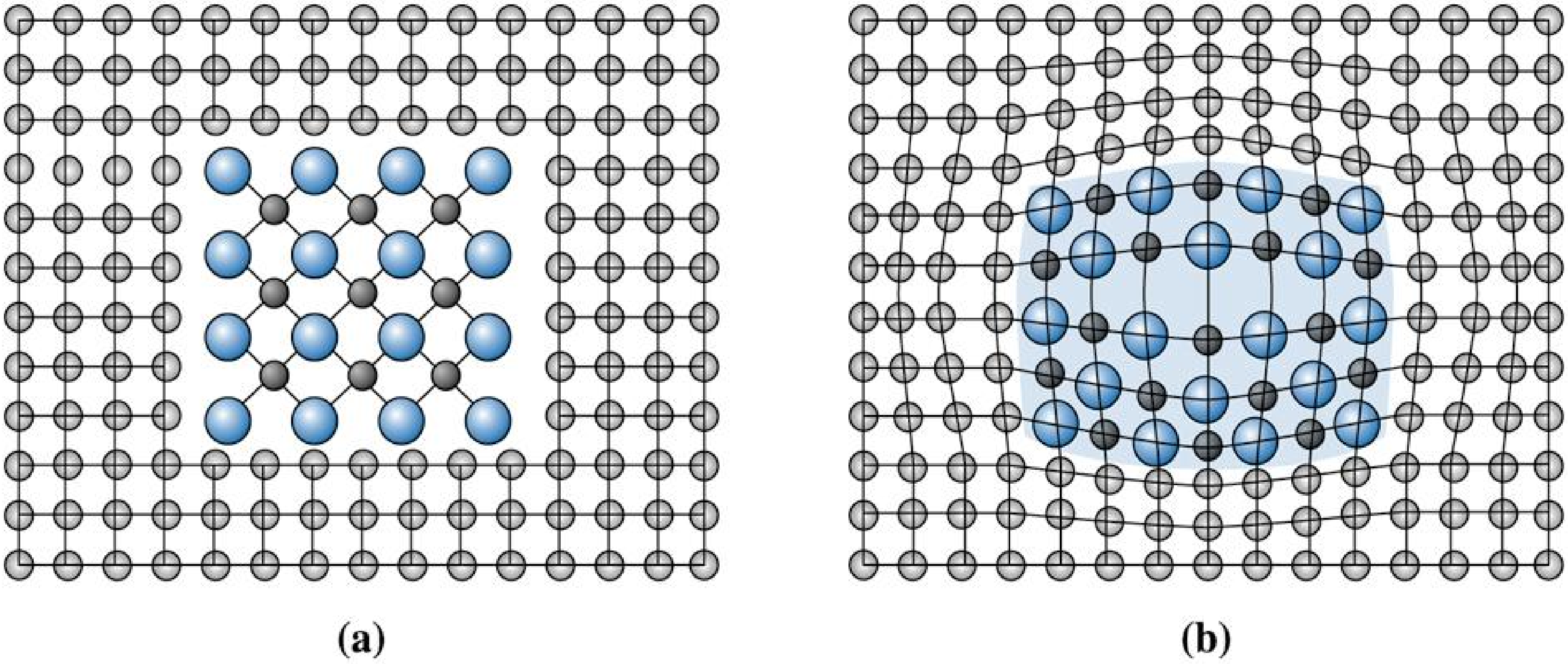
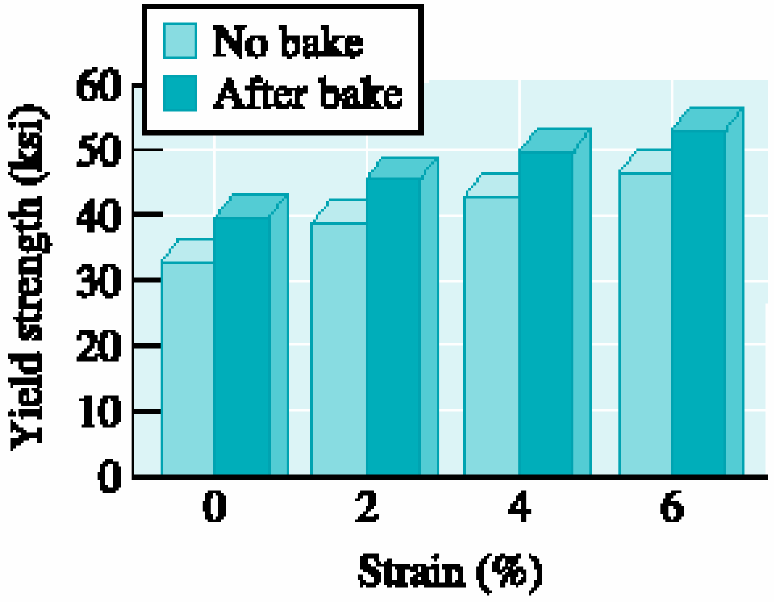
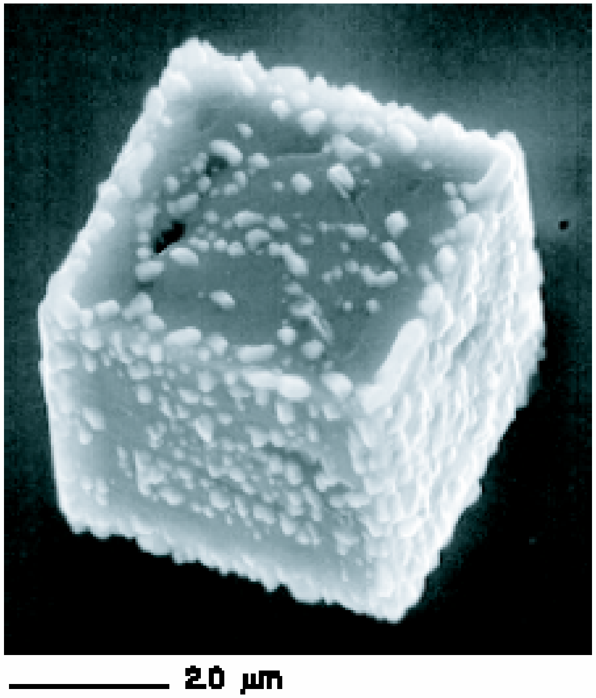


Figure 12.8 (a) noncoherent precipitate (b) A coherent precipitate

Section 11.3 Age (Precipitation) Hardening

Form of Dispersion Strengthening (Chapter 11)





A graph showing the increase in the yield strength of a bake hardenable steel (*Source: Bethlehem Steel, PA*.)

An SEM micrograph of a steel containing niobium (Nb) and manganese (Mn). The niobium react with carbon (C) and forms NbC precipitates that lead to strengthening. (*Courtesy of Dr. A.J. Deardo, Dr. I. Garcia, Dr. M. Hua, University of Pittsburgh*.)

Section 11.5

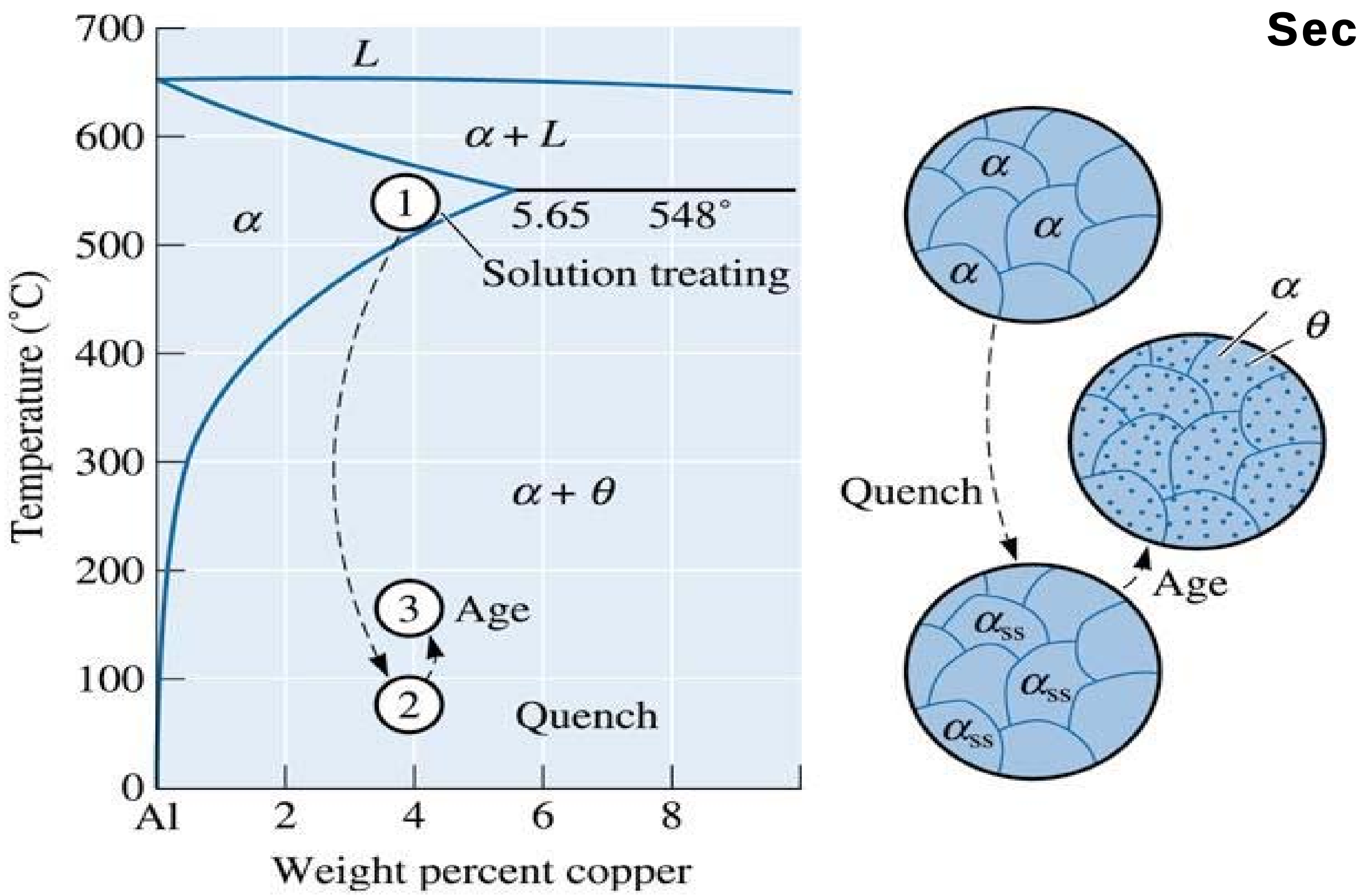


Figure 12-9

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Step 1: Solution treat to produce α solid solution (dissolves all θ)

Step 2: Quench – creates super saturated solid solution – no time for atoms to diffuse and create θ phase)

Step 3: Age; heat to temp below solvus. α is metastable. Copper diffuses, nucleates and grows θ phase over time.

Example 12.3
Design of an Age-Hardening Treatment

The magnesium-aluminum phase diagram is shown in Figure 11.11. Suppose a Mg-8% Al alloy is responsive to an age-hardening heat treatment. Design a heat treatment for the alloy.

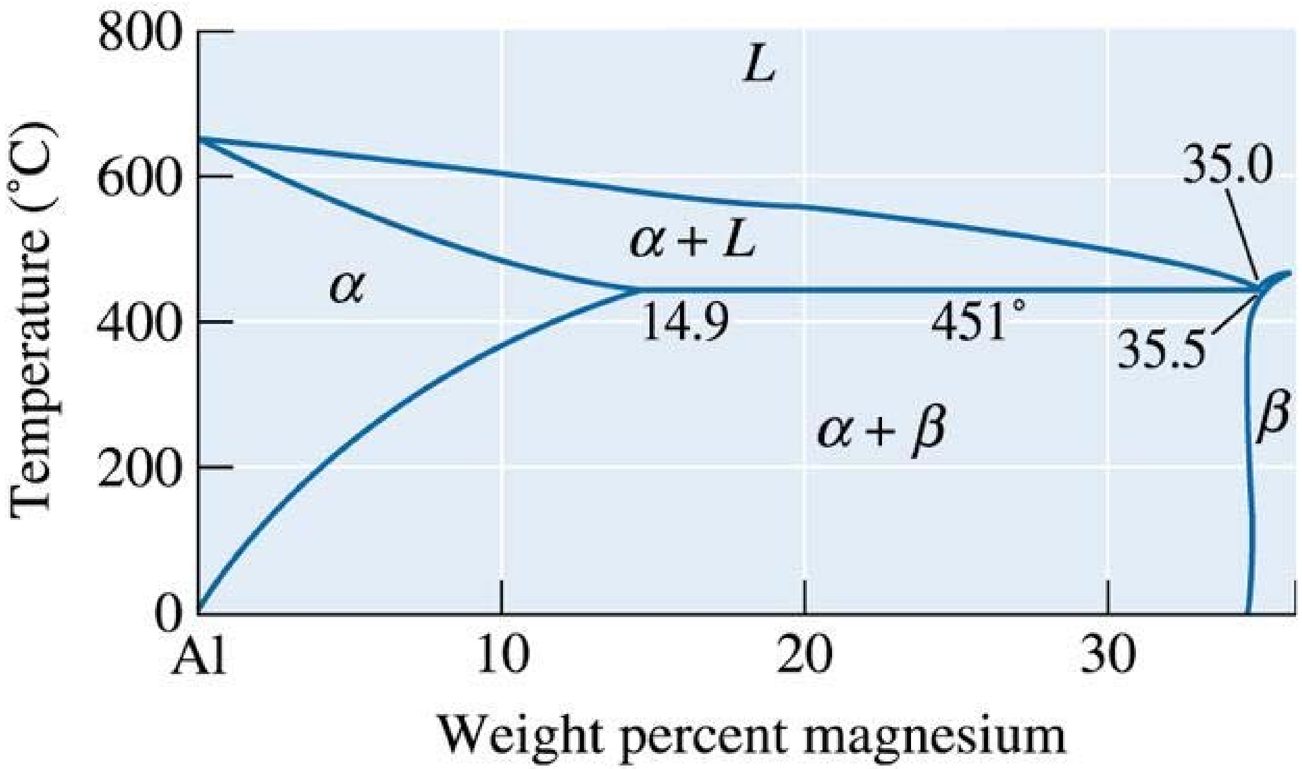


Figure 12.10 Portion of the aluminum-magnesium phase diagram.

Requirements for Age Hardening

- The alloy system must display decreasing solid solubility with decreasing temperature. Only a single phase can exist above the solvus temp.
- The matrix should be relatively soft and ductile, and the precipitate should be hard and brittle. Otherwise the properties might get worse!
- The alloy must be quenchable. This means we can cool fast enough so that the second phase does not have time to form (could be difficult for some materials). Other consideration is fast cooling causes warpage and residual stress that may not be acceptable for application.
- A coherent precipitate must form to maximize interaction with dislocations

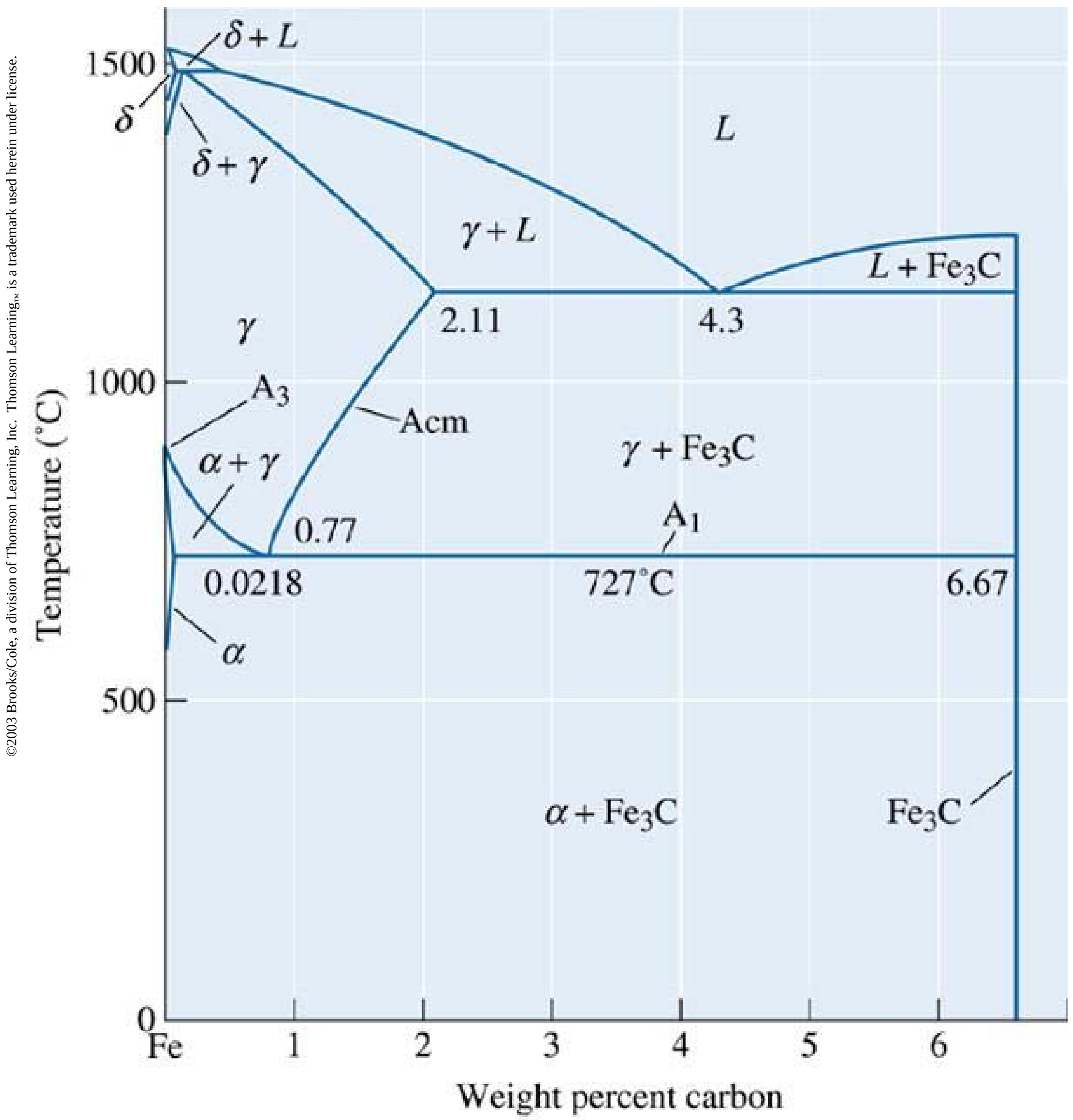
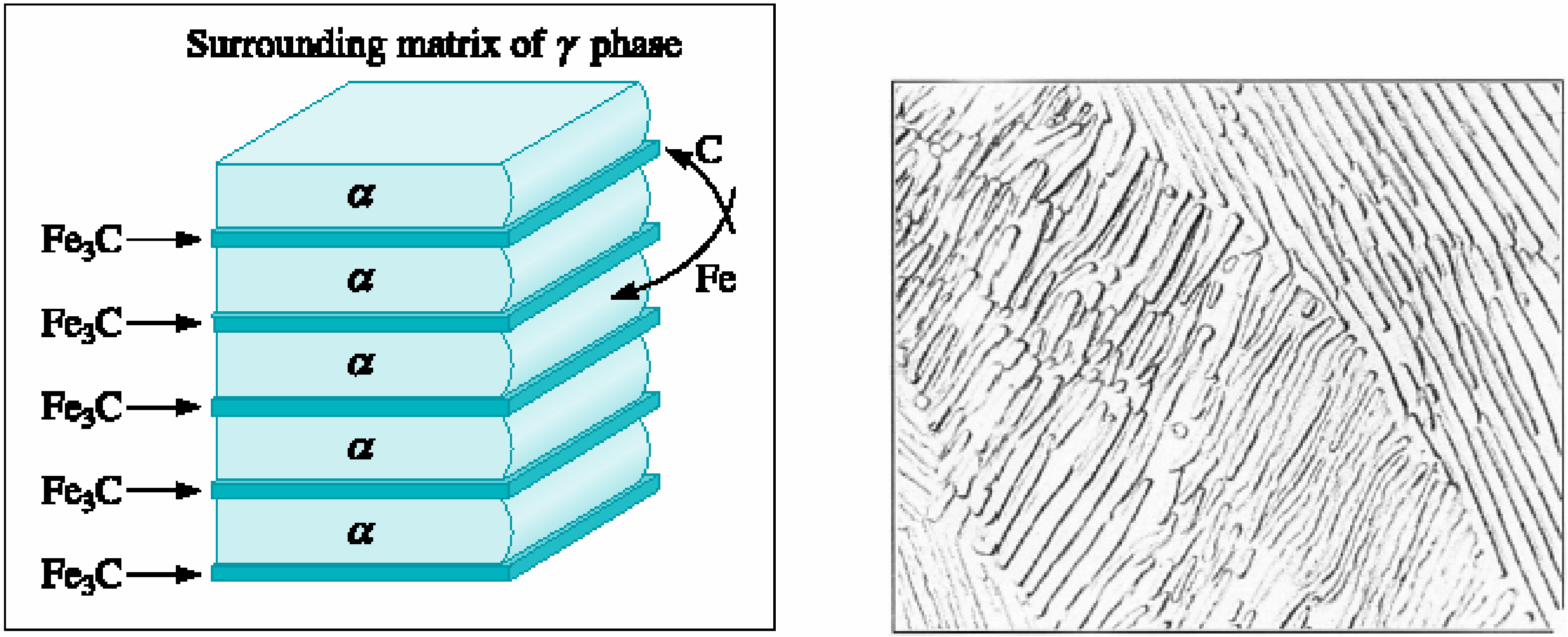

δ + L
1500
δ
δ + γ
L
γ + L
L + Fe$_3$C
2.11
4.3
γ
1000
A$_3$
Acm
γ + Fe$_3$C
α + γ
A$_1$
0.77
0.0218
727°C
6.67
α
500
α + Fe$_3$C
Fe$_3$C
0
Fe
1
2
3
4
5
6
Weight percent carbon
Temperature (°C)

Figure 12.14



(a) (b)

Figure 12.15 Growth and structure of pearlite: (a) redistribution of carbon and iron, and (b) photomicrograph of the pearlite lamellae – much finer spacing than lead-tin example.

Pearlite is the eutectoid reaction

γ (0.77%C) transforms α (0.0218%C) + Fe_3C (6.67%C)

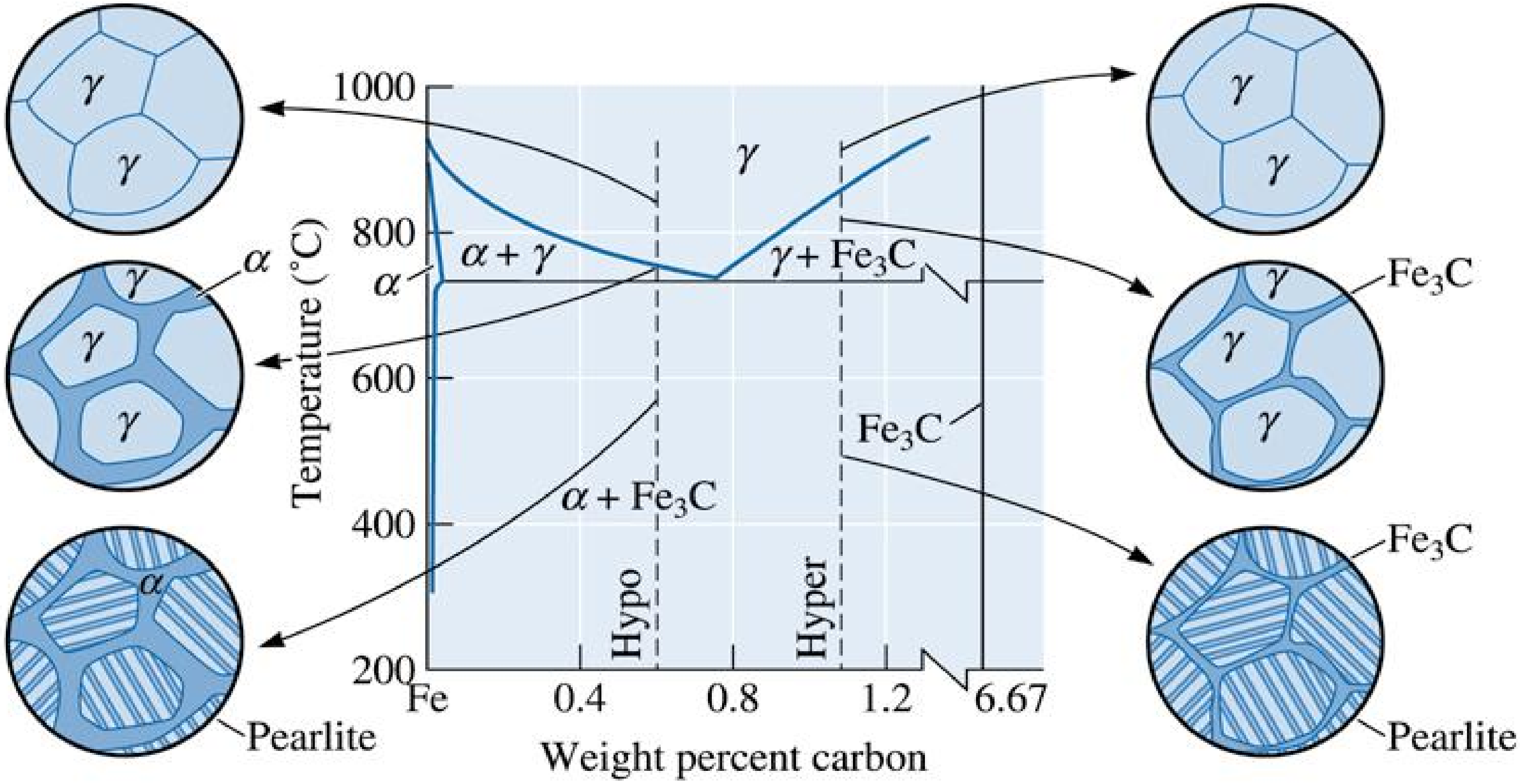


Figure 11.17 The evolution of the microstructure of hypoeutectoid (less) and hypereutectoid (more) steels during cooling. In relationship to the Fe-Fe_3C phase diagram. Pearlite particles in ductile α phase is best for dispersion strengthening.

TABLE 11-1 ■ *The effect of carbon on the strength of steels*

	Slow Cooling (Coarse Pearlite)			Fast Cooling (Fine Pearlite)		
Carbon %	Yield Strength (psi)	Tensile Strength (psi)	% Elongation	Yield Strength (psi)	Tensile Strength (psi)	% Elongation
0.20	42,750	57,200	36.5	50,250	64,000	36.0
0.40	51,250	75,250	30.0	54,250	85,500	28.0
0.60	54,000	90,750	23.0	61,000	112,500	18.0
0.80	54,500	89,250	25.0	76,000	146,500	11.0
0.95	55,000	95,250	13.0	72,500	147,000	9.5

After Metals Progress Materials and Processing Databook, *1981.*

Section 11.11
The Martensitic Reaction and Tempering

- **Martensite** - A metastable phase formed in steel and other materials by a diffusionless, athermal transformation.
- **Displacive transformation** - A phase transformation that occurs via small displacements of atoms or ions and without diffusion. Same as athermal or martensitic transformation.
- **Tempering** - A low-temperature heat treatment used to reduce the hardness of martensite by permitting the martensite to begin to decompose to the equilibrium phases.

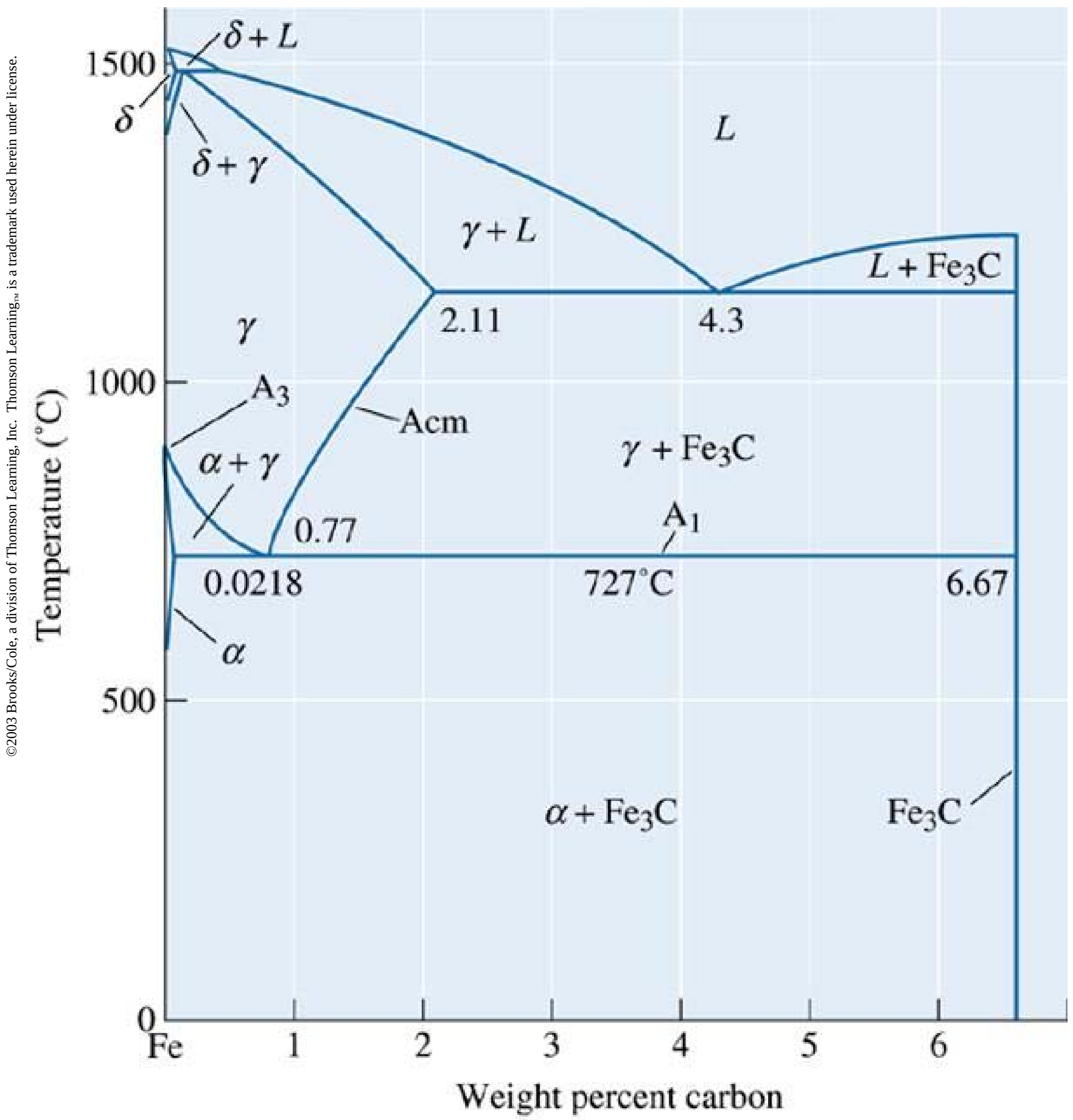

δ + L
1500
δ
δ + γ
L
γ + L
L + Fe₃C
2.11
4.3
γ
1000
A₃
Acm
γ + Fe₃C
α + γ
0.77
A₁
0.0218
727°C
6.67
α
500
α + Fe₃C
Fe₃C
0
Fe
1
2
3
4
5
6
Weight percent carbon
Temperature (°C)

Figure 12.14

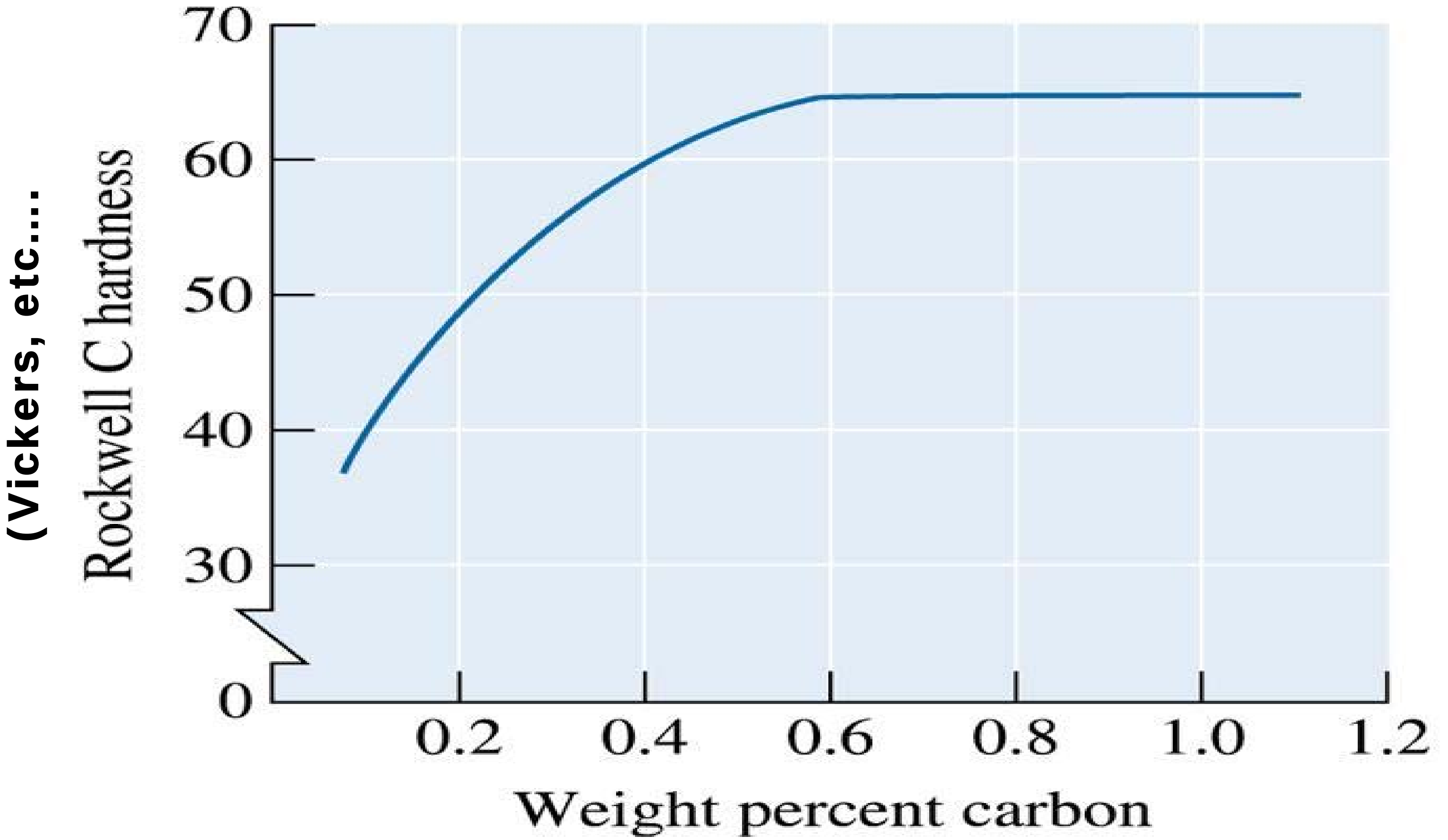


Figure 11.26 The effect of carbon content on the hardness of martensite in steels.

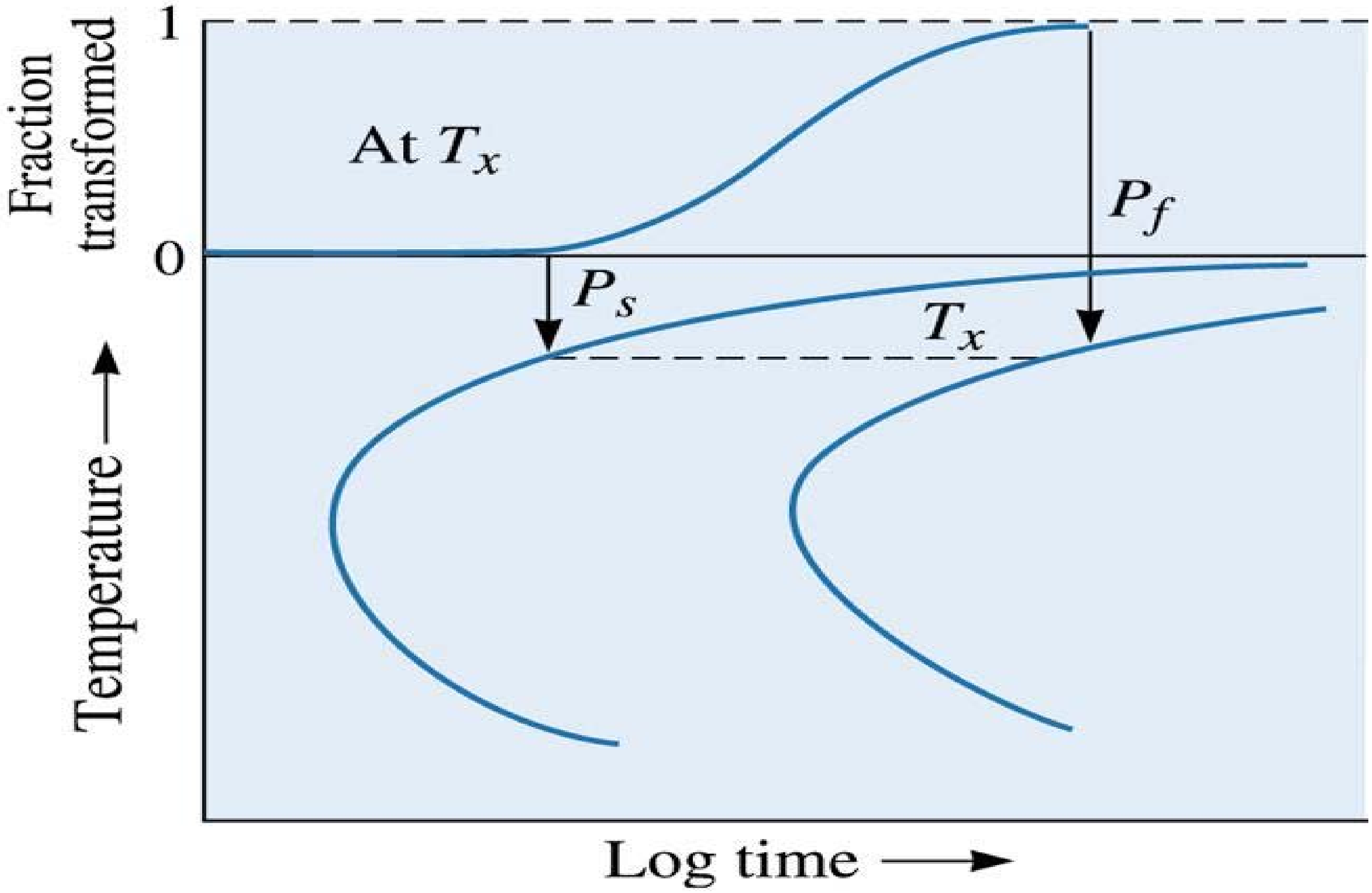


Figure 11.22 The sigmoidal curve is related to the start and finish times on the TTT diagram for steel. In this case, austenite is transforming to pearlite (Different for different alloy compositions)

Section 11.12

The Shape-Memory Alloys (SMAs)

- Shape-memory effect -The ability of certain materials to develop microstructures that, after being deformed, can return the material to its initial shape when heated (e.g. Ni-Ti alloys).
- Smart materials - Materials that can sense an external stimulus (e.g., stress, pressure, temperature change, magnetic field, etc.) and initiate a response. Passively smart materials can sense external stimulus, actively smart materials have sensing and actuation capabilities.

Example 11.11
Design of a Coupling for Tubing

At times, you need to join titanium tubing in the field. Design a method for doing this quickly.

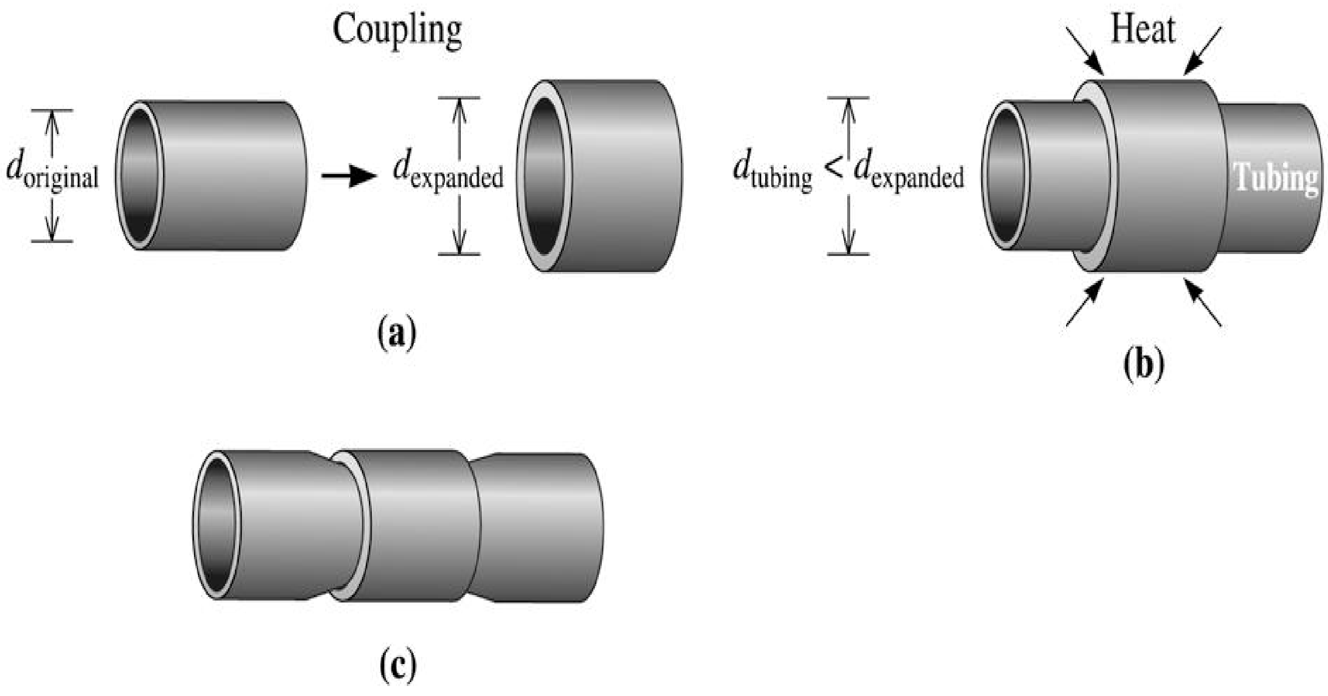


Figure 11.30 Use of memory alloys for coupling tubing: A memory alloy coupling is expanded (a) so it fits over the tubing (b). When the coupling is reheated, it shrinks back to its original diameter (c), squeezing the tubing for a tight fit (for Example 11.11).