Full annealing is a term applied to ferrous alloys. The steel is heated to above A_1 or A_3 (Fig. 4.21) and the cooling takes place slowly [typically at 10°C per hour], in a furnace, after which it is turned off. The structure obtained through full annealing is coarse pearlite, which is soft and ductile and has small, uniform grains.

To avoid excessive softness from annealing of steels, the cooling cycle may be done completely in still air. This process is called **normalizing**, to indicate that

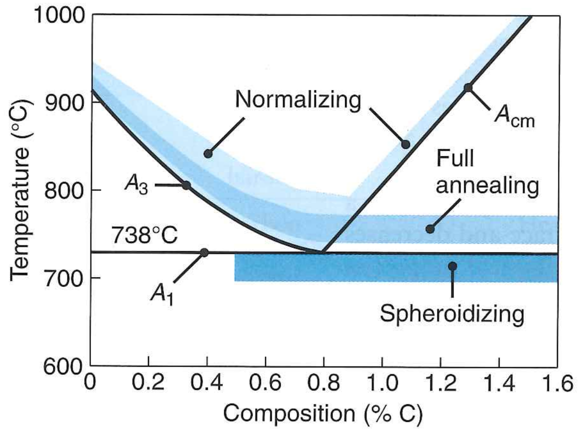

FIGURE 4.21 Heat-treating temperature ranges for plain-carbon steels, as indicated on the iron–iron carbide phase diagram.

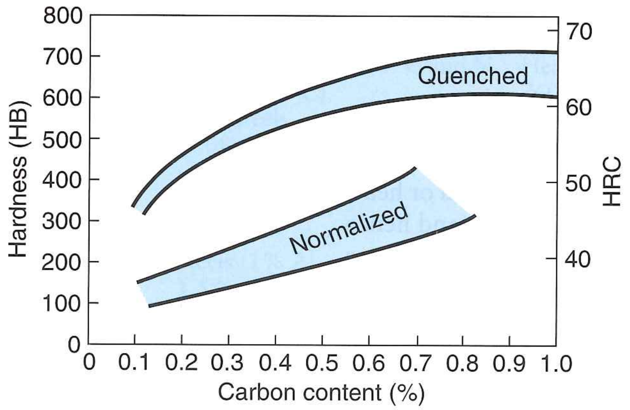

FIGURE 4.22 Hardness of steels in the quenched and normalized conditions as a function of carbon content.

the part is heated to a temperature above A_3 or A_{cm} in order to transform the structure to austenite. Normalizing results in somewhat higher strength and hardness, and lower ductility, than does full annealing (Fig. 4.22). The structure obtained is fine pearlite, with small, uniform grains. Normalizing is generally carried out to refine the grain structure, obtain uniform structure (homogenization), decrease residual stresses, and improve machinability.

The structure of spheroidites and the procedure for obtaining it are described in Section 4.7 and shown in Figs. 4.12 and 4.21. *Spheroidizing annealing* improves the cold workability (Section 14.5) and the machinability of steels (Section 21.7).

Stress-relief Annealing. To reduce or eliminate residual stresses, a workpiece is generally subjected to *stress-relief annealing*, or **stress relieving**. The temperature and time required for this process depend on the material and on the magnitude of the residual stresses present. The residual stresses may have been induced during forming, machining, or caused by volume changes during phase transformations.