

10.2 (a) This problem first asks that we rewrite the expression for the total free energy change for nucleation (analogous to Equation 10.1) for the case of a cubic nucleus of edge length a . The volume of such a cubic nucleus is a^3 , whereas the total surface area is $6a^2$ (since there are six faces each of which has an area of a^2). Thus, the expression for ΔG is as follows:

$$\Delta G = a^3 \Delta G_v + 6a^2 \gamma$$

Differentiation of this expression with respect to a is as

$$\begin{aligned} \frac{d \Delta G}{da} &= \frac{d(a^3 \Delta G_v)}{da} + \frac{d(6a^2 \gamma)}{da} \\ &= 3a^2 \Delta G_v + 12a \gamma \end{aligned}$$

If we set this expression equal to zero as

$$3a^2 \Delta G_v + 12a \gamma = 0$$

and then solve for a ($= a^*$), we have

$$a^* = -\frac{4\gamma}{\Delta G_v}$$

Substitution of this expression for a in the above expression for ΔG yields an equation for ΔG^* as

$$\begin{aligned} \Delta G^* &= (a^*)^3 \Delta G_v + 6(a^*)^2 \gamma \\ &= \left(-\frac{4\gamma}{\Delta G_v}\right)^3 \Delta G_v + 6\gamma \left(-\frac{4\gamma}{\Delta G_v}\right)^2 \\ &= \frac{32\gamma^3}{(\Delta G_v)^2} \end{aligned}$$

(b) ΔG_v for a cube—i.e., $(32) \left[\frac{\gamma^3}{(\Delta G_v)^2} \right]$ —is greater than for a sphere—i.e., $\left(\frac{16\pi}{3} \right) \left[\frac{\gamma^3}{(\Delta G_v)^2} \right] =$

(16.8) $\left[\frac{\gamma^3}{(\Delta G_v)^2} \right]$. The reason for this is that surface-to-volume ratio of a cube is greater than for a sphere.

10.20 We are asked to determine which microconstituents are present in a 1.13 wt% C iron-carbon alloy that has been subjected to various isothermal heat treatments. These microconstituents are as follows:

- (a) Martensite
- (b) Proeutectoid cementite and martensite
- (c) Bainite
- (d) Spheroidite
- (e) Cementite, medium pearlite, bainite, and martensite
- (f) Bainite and martensite
- (g) Proeutectoid cementite, pearlite, and martensite
- (h) Proeutectoid cementite and fine pearlite

10.27 This problem asks for the microstructural products that form when specimens of a 4340 steel are continuously cooled to room temperature at several rates. Figure 10.28 is used for these determinations.

- (a) At a cooling rate of 0.005°C/s , proeutectoid ferrite and pearlite form.
- (b) At a cooling rate of 0.05°C/s , martensite, ferrite, and bainite form.
- (c) At a cooling rate of 0.5°C/s , martensite and bainite form.
- (d) At a cooling rate of 5°C/s , martensite and bainite form.

Mechanical Behavior of Iron-Carbon Alloys

Tempered Martensite

10.30 The hardness and strength of iron-carbon alloys that have microstructures consisting of α -ferrite and cementite phases depend on the boundary area between the two phases. The greater this area, the harder and stronger the alloy inasmuch as (1) these boundaries impede the motion of dislocations, and (2) the cementite phase restricts the deformation of the ferrite phase in regions adjacent to the phase boundaries. Fine pearlite is harder and stronger than coarse pearlite because the alternating ferrite-cementite layers are thinner for fine, and therefore, there is more phase boundary area. The phase boundary area between the sphere-like cementite particles and the ferrite matrix is less in spheroidite than for the alternating layered microstructure found in coarse pearlite.

10.D5 We are to consider the tempering of an oil-quenched 4340 steel. From Figure 10.34, for a minimum tensile strength of 1515 MPa (220,000 psi) a tempering temperature of less than 400°C (750°F) is required. Also, for a minimum ductility of 40%AR, tempering must be carried out at a temperature greater than about 320°C (610°F). Therefore, tempering must occur at between 320 and 400°C (610 and 750°F) for 1 h.

Miscellaneous Techniques

11.17 This problem asks that we specify and compare the microstructures and mechanical properties in the heat-affected weld zones for 1080 and 4340 alloys assuming that the average cooling rate is 10°C/s . Figure 10.27 shows the continuous cooling transformation diagram for an iron-carbon alloy of eutectoid composition (1080), and, in addition, cooling curves that delineate changes in microstructure. For a cooling rate of 10°C/s (which is less than 35°C/s) the resulting microstructure will be totally pearlite--probably a reasonably fine pearlite. On the other hand, in Figure 10.28 is shown the CCT diagram for a 4340 steel. From this diagram it may be noted that a cooling rate of 10°C/s produces a totally martensitic structure. Pearlite is softer and more ductile than martensite, and, therefore, is most likely more desirable.

11.D15 We are asked to specify a practical heat treatment for a 2014 aluminum alloy that will produce a minimum yield strength of 345 MPa (50,000 psi), and a minimum ductility of 12%EL. From Figure 11.27(a), the following heat treating temperatures and time ranges are possible to give the required yield strength.

<u>Temperature (°C)</u>	<u>Time Range (h)</u>
260	not possible
204	0.3-15
149	10-700
121	300-?

With regard to temperatures and times to give the desired ductility [Figure 11.27(b)]:

<u>Temperature (°C)</u>	<u>Time Range (h)</u>
260	<0.02, >10
204	<0.4, >350
149	<20
121	<1000

From these tabulations, the following may be concluded:

It is not possible to heat treat this alloy at 260°C so as to produce the desired set of properties—attainment of a yield strength of 345 MPa is not possible at this temperature.

At 204°C, the heat treating time would need to be about 0.4 h, which is practical.

At 149°C, the time range is between 10 and 20 h, which is a little on the long side.

Finally, at 121°C, the time range is unpractically long (300 to 1000 h).