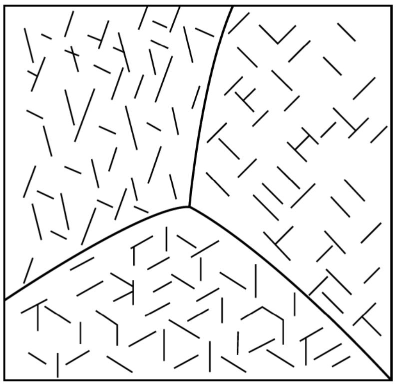


FIG. 16.21 Schematic representation of a Widmanstätten structure. Short, dark lines represent plate-shaped precipitate particles that are aligned on specific crystallographic planes of the crystals of the matrix

PROBLEMS

16.1 Write a computer program based on Eq. 9.15 and obtain the plot in Fig. 16.1. Now consider that a thin sheet specimen of an alloy of iron containing 0.018 percent carbon is heated to 800 K and held there long enough to come to equilibrium before being quenched in iced brine.

(a) Estimate from your figure the amount of carbon in solid solution just after the quench.

(b) If the specimen is maintained in the iced brine for a very long time, would you expect the amount of carbon in solid solution to remain the same as that existing just after the quench?

16.2 The solubility of the interstitials oxygen and nitrogen in the refractory metals vanadium, niobium, and tantalum is of considerable interest because they can seriously affect the mechanical properties of these metals. According to Bunn, P. and Wert, C., *TMS-AIME*, **230** 936 (1964), the solubility of nitrogen in tantalum is given, in weight percent, by the following equation:

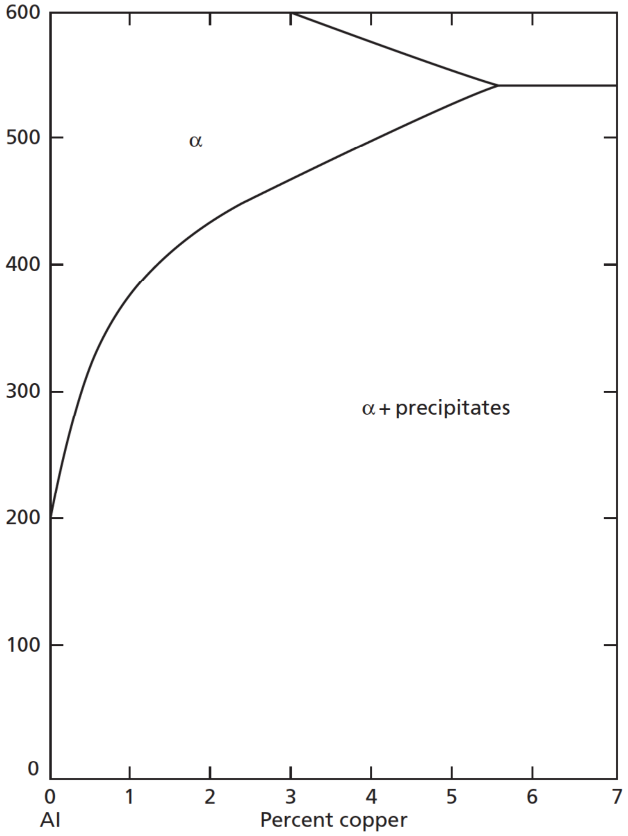
$$C_w = 2.71 \exp(-22{,}600/RT)$$

(a) Plot the solubility curve for N in Ta within the limits $T = 300$ K and $T = 2000$ K.

(b) From a comparison of this curve with that for carbon in iron, deduced in Prob. 16.1, compare the solubility of carbon in iron with that of nitrogen in tantalum at 1000 K.

16.3 A thin sheet specimen of an iron-carbon alloy with 0.016 weight percent carbon is heated to 1000 K, where it is allowed to come to equilibrium. Following this, it is slow cooled to 850 K. It is then quenched in iced brine and aged at 313 K for 100 hours. Describe the resulting microstructure.

16.4 Consider the aluminum end of the aluminum-copper phase diagram in the figure accompanying this problem.



The aluminum-rich end of the copper-aluminum phase diagram that is of interest with respect to precipitation hardening

(a) Outline the complete program for obtaining a maximum hardness in an alloy of aluminum with 4 percent copper if the aging temperature is 403 K.

(b) When the maximum hardness is obtained, what would be the nature of the precipitate? Explain.

16.5 Assume that a spherical precipitate particle forms in an age hardening alloy and that the volume free-energy change associated with the formation of the particle is 60 MJ/m^3. The energy of the interface between the particle and the matrix is 0.40 J/m^2. With the aid of Eq. 15.3 plot the free energy of a particle as a function of its radius from $r = 0$ to $r = 3 \times 10^{-8}$ m. With the aid of this diagram determine r_0 and ΔG_{r_0} for the conditions of this problem.

16.6 Assume that the precipitate in Prob. 16.5 has a total volume fraction of 1.5 percent and that the particles are all of the same size, with a radius equal to twice the critical radius.

(a) Compute the number of particles per cubic meter.

(b) Compute the total change in free energy due to the formation of all the precipitate particles in a cubic meter.

16.7 The Orowan mechanism, which explains the hardening effect of precipitate particles when the precipitates have grown to a size where they are no longer coherent with the matrix, is shown in Fig. 16.18. The strengthening arises from the fact that the dislocations must bow out between two neighboring precipitate particles. This bowing out is opposed by the line tension of the dislocations. Ashby has deduced an equation giving the stress needed to move dislocations under conditions conforming to the Orowan model. An equation giving this stress, which assumes that the precipitate particles are spherical and that the system involves iron containing carbon, may be found in Leslie, W. C., *The Physical Metallurgy of Steels*, McGraw Hill Book Company, New York, 1980, p. 198. It is:

$$\sigma(\text{MPa}) = 5.9 f^{1/2}/X \cdot \ln(X/b)$$

where σ(MPa) is the stress, f is the volume fraction of the precipitate, X is the mean linear intercept diameter of the precipitate particles and b is the Burgers vector. In the case of iron, $b = 2.5 \times 10^{-4}$ μm. In this equation X is expressed in μm units. Plot a curve showing the dependence of the stress on the particle diameter, X, for the case of a constant volume fraction of precipitate, $f = 0.001$. Let X vary from 0.001 to 0.100 μm.

16.8 In Prob. 16.7 the volume fraction of the precipitate was taken to be 0.001.

(a) Assuming that the precipitate consists of cementite and that the densities of cementite and ferrite are nearly equal, estimate the carbon concentration in the iron.

(b) Would it be possible to get this much carbon in solution at 1000 K? In other words, could one reasonably expect to obtain a 0.001 volume fraction of cementite precipitate on aging just above 300 K after a rapid quench from 1000 K?

16.9 According to Leslie in the reference cited in Prob. 16.7, the particles formed during interphase precipitation in a microalloyed HSLA steel have a diameter of about 5 nm. Assume that the microalloying element is vanadium and that the interphase precipitate is vanadium carbide, VC.

(a) What value of f, the volume fraction of these precipitates, would give an increase in strength of 200 MPa?

(b) Estimate the weight percent of the vanadium incorporated in the precipitate.

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