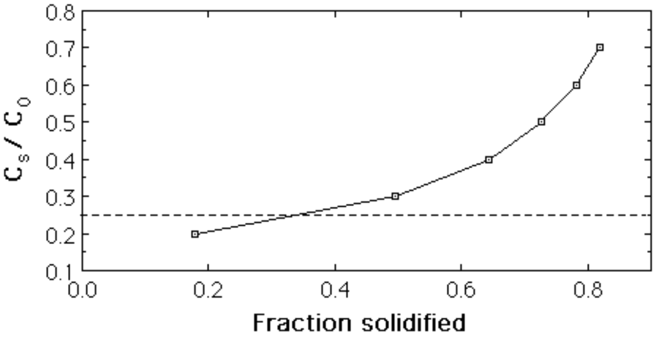
Answers to Question Sheet 2, Solidification

1. Directional solidification is used, for example, in the growth of single crystals of turbine blades for jet engines, and in the growth of crystals for lasers.

   For Al–Cu, the partition coefficient is from the phase diagram $k = 5.7/33 = 0.17$. The concentration in the acceptable solid should be a quarter that in the alloy as a whole, so $C_s/C_0 = 0.25$. When this is substituted into the Scheil equation:

   $$C_s = kC_0(1 - f_s)^{k-1}$$

   where f_s is the fraction of solid, the fraction of acceptable bar is found to be 0.37.



2. Dendrite formation requires an undercooled liquid ahead of the interface. Thermal dendrites are rare indeed, when pure materials solidify with a negative temperature gradient in the liquid ahead of the interface. In constitutional supercooling the undercooling arises because of solute concentration variations ahead of the interface.

   For Al–Si, the partition coefficient is from the phase diagram $k = 1.65/11.7 = 0.14$ and the liquidus gradient $m_L = \frac{660-577}{11.7} = 7.1\,\mathrm{K\,wt\%^{-1}}$.

   For a planar front the interface has to be stable to perturbations *i.e.* the temperature gradient must be larger than the liquidus–temperature gradient. The limiting temperature gradient is therefore

   $$\frac{dT}{dx} = \frac{m_L C_0(1-k)v}{kD_L} = \frac{7.1 \times 0.3 \times 0.86 \times 10^{-5}}{0.14 \times (5 \times 10^{-9})} = 26169\,\mathrm{K\,m^{-1}}$$

   This is a large gradient which is difficult to achieve in practice. Hence most impure alloys tend to solidify by a dendritic mode.

3. $M7$ has large chunks of angular silicon plates which render the alloy brittle because it is easy to fracture silicon. $M8$ has much finer particles of silicon which are less easy to crack.

Small concentrations of solute generally influence the development of microstructure through kinetic effects. They may segregate to grain boundaries thus reducing grain boundary energy and hence making them less effective as heterogeneous nucleation sites for precipitation (*e.g.* parts per million of boron has a large effect on transformations in steel). They may produce minute inclusions which are potent nucleation sites (*e.g.* spheroidal graphite cast iron and Al–Si). Segregation can also influence interface mobility.

The low density of silicon helps compensate for the shrinkage accompanying solidification, thus producing less porosity in the casting. In addition, silicon increases the fluidity of the melt, thus allowing complex castings to be manufactured. Many modern automobile engine blocks are cast from Al–Si alloys.

You can see micrographs and descriptions of specimens $M7$ and $M8$ on

http://www.msm.cam.ac.uk/Department/Teaching/online.html

4. Assume Newtonian conditions with constant cooling rate $\dot{T}$ and zero latent heat (given that we deal here with glass formation). For interfacial heat transfer,

$$q = h\Delta T = c\dot{T}x, \qquad x = \frac{h\Delta T}{c\dot{T}} = \frac{2 \times 10^5(1000 - 300)}{4 \times 10^6 \times 10^6} = 3.5 \times 10^{-5}\,\mathrm{m}$$

You could have calculated the Biot had you been given the thermal conductivity of the alloy, which is $40\,\mathrm{W\,m^{-1}\,K^{-1}}$:

$$\text{Biot number} \qquad Bi = (2 \times 10^5)(35 \times 10^{-6})/40 = 0.17$$

Since this is small, the assumption of Newtonian cooling is justified.

Iron base glasses are magnetically soft because of the absence of microstructure. They can be used in the manufacture of transformers to reduce hysteresis losses. The lack of a microstructure also gives the glasses a high corrosion resistance since there is a lack of sites for the nucleation of corrosion.

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