Question Sheet 2, Solidification

1. Give an example of an industrial application of one–dimensional solidification.

   A bar of aluminium is contaminated with copper at a concentration four times the acceptable limit. It is to be purified by directional freezing, with a planar growth front. Use the Al–Cu phase diagram (Data Book) to estimate the fraction of the bar which will have an acceptable purity.

2. Distinguish between thermal dendrites and those induced by constitutional supercooling.

   Using the Al–Si phase diagram, calculate the solid/liquid solute partitioning coefficient and the gradient of the liquidus curve for the solidification of aluminium–rich alloys.

   For an alloy of composition Al–0.3Si wt%, calculate the thermal gradient needed in the liquid at the solid–liquid interface to ensure a planar front during solidification at $1 \times 10^{-5}\,\mathrm{m\,s^{-1}}$. The diffusivity of Si in liquid Al is $5 \times 10^{-9}\,\mathrm{m^2\,s^{-1}}$.

3. Silicon has the diamond structure with directional bonds. This results in poor mechanical properties. Compare the microstructures of samples $M7$ and $M8$, both of which are Al–Si casting–alloys containing silicon particles which precipitate from the liquid; $M8$ contains also a minute addition of sodium (it is a "sodium–modified" variant). Discuss why one of these alloys is expected to have better mechanical properties.

   There are many examples in metallurgy where minute additions of solute have a major influence on microstructure. Given the very small concentrations involved, the effects are unlikely to be thermodynamic in origin. Comment on possible mechanisms to explain such observations.

   Many castings suffer from shrinkage porosity. The diamond structure of silicon gives it a relatively low density. Explain therefore the popularity of Al–Si alloys for casting applications.

4. Ni–P metallic glass strip is made by planar flow casting on to a rotating copper drum. Given that the interfacial heat transfer coefficient is $2 \times 10^5\,\mathrm{W\,m^{-2}\,K^{-1}}$, estimate the maximum thickness that can be cast. The cooling rate needed for glass formation in $10^6\,\mathrm{K\,s^{-1}}$. The temperature at which vitrification is complete is 1000 K. The specific heat capacity of the alloy is $4 \times 10^6\,\mathrm{J\,m^{-3}\,K}$.

   Give an example of how the lack of a microstructure in metallic glass might be exploited in developing practical applications.

Numerical answers (full answers distributed with AQ4):

(1.) $f_s = 0.37$ (2.) 26169 K $\mathrm{m^{-1}}$ (4.) 3.5×10^{-5} m

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