Answers to Question Sheet 4, Solid–State Transformations

1. Mechanical twinning is a deformation which involves the coordinated movement of atoms that leads to a reorientation of a part of the crystal. Annealing twins grow by a reconstructive mechanism from a deformed microstructure in much the same way as conventional grain growth. They do not lead to any deformation. Mechanical twins are lenticular in shape with sharp tips in order minimise strain energy. The shape of annealing twins is governed by the minimisation of interfacial energy. They are facetted on coherent interfaces with no sharp tips. Optical microscopy can also be used to study displacements at the free surface. Surface relief will only be observed with mechanical twinning.

   Twinning involves a shift of each of the close packed planes by a distance $\frac{a}{6} < 1\ 1\ \overline{2} > \equiv (a/\sqrt{6})$ where a is the lattice parameter. The spacing of the $\{1\ 1\ 1\}$ planes is $a/\sqrt{3}$. The twinning shear is the ratio of these two numbers, *i.e.* $1/\sqrt{2}$.

   Four different traces (multiplicity of $\{1\ 1\ 1\}$) planes.

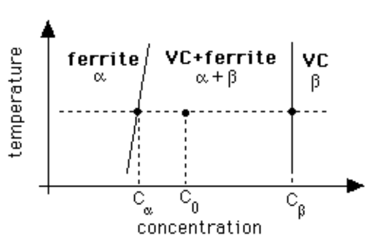
2. Secondary hardening steels are tempered at very high temperatures (500–700 °C) in order to precipitate alloy carbides. Not only does this give the steel an extremely stable microstructure, but because the alloy carbides tend to be very fine and well–dispersed. All power stations (fossil, nuclear) throughout the world are made using secondary hardening steels. The steam temperature in the power plant can reach 600 °C and the plant has to survive for nearly 50 years. The stability of the microstructure is therefore vital, and secondary hardened steels also resist high–temperature deformation (creep) because of the fine carbides. Other applications include gun barrels for tanks and aircraft components.

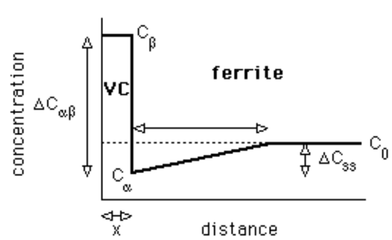
   We note first that $\Delta C_{SS} = C_0 - C_\alpha = 2\,\text{wt\%}$ and $\Delta C_{\alpha\beta} = 81 - 0 = 81\,\text{wt\%}$, From the Data book,

$$x = \frac{2\Delta C_{SS}}{\Delta C_{\alpha\beta}}\sqrt{Dt}$$

$$\text{so that} \qquad x = \frac{2 \times 2}{81}\sqrt{4 \times 10^{-19} \quad \times 3600} \simeq 1.9\,\text{nm}$$

   This considers diffusion on one side of the plate so the actual plate thickness is about 3.8 nm. This value emphasizes the sluggish diffusion of substitutional solutes in steel and also the fine size of the carbide particles (essential if they are to contribute significantly to strength).





Key assumptions include the neglect of soft–impingement, neglect of nucleation, neglect of the fact that cementite precipitates before VC and hence the supply of solutes for the formation of the more stable VC will depend on the dissolution of VC. The effect of interface curvature and of particle shape is also ignored in this one–dimensional treatment.

3. (a) Both metals and ceramics undergo martensitic transformation in which the shape deformation has a large shear and dilatational component. Polish a sample and then transform to martensite. Displacements will be visible at the free surface. The deflection of scratches on the surface can be studied, or the upheavals can be examined using interference light microscopy or atomic force microscopy. For an atomic force microscope image of displacements associated with the formation of bainite see http://www.msm.cam.ac.uk/Teaching/online.html. (b) Ceramics such as barium titanate also undergo displacive transformations in which the shape deformation is minute, a distortion of the cell from cubic to tetragonal. These small distortions can be measured using X–ray diffraction. The difference between (a) and (b) is that the strain energy associated with (a) is very large so that martensite is in the form of thin plates.

4. The shape memory effect is not perfectly reversible in that a few defects are created on each cycle. This means that the defect density increases with the number of cycles, so much so that the interfaces are eventually prevented from reversible motion.

   When a shape memory element is deformed, the strain is accomplished by the growth of certain martensite orientations relative to others. Recoverable strain is exhausted when the element is converted entirely into one set of orientations. Any further deformation is ordinary plastic yielding and will damage the effect.

   Rings for joining, stents to keep arteries open, unbreakable spectacle frames . . .

H. K. D. H. Bhadeshia