Course M21: Examples Class

H. K. D. H. Bhadeshia

1. Explain why:

   (a) martensite, Widmanstätten ferrite and bainite all occur in the form of thin plates;

   (b) Widmanstätten ferrite grows at a rate which is much smaller than the speed of sound in the metal;

   (c) an Fe–30Ni wt% martensite is weak compared with martensite in Fe–0.2C wt% alloy;

   (d) alloying elements have a much greater effect on the kinetics of a reconstructive transformation when compared with the corresponding effect on displacive transformations.

2. A particular austenitic steel undergoes martensitic transformation in which the shape deformation is defined by a shear strain parallel to the habit plane of 0.1 and dilatational strain normal to that plane of -0.05. The steel is subjected to a tensile load. Calculate the angle between the habit plane normal and the tensile axis which would lead to the maximum mechanical driving force for martensitic transformation. You may assume that the tensile axis, habit plane normal and displacement direction lie in the same plane.

   How does the angle change if the stress is uniaxial and compressive.

3. One of the conditions for the diffusion–controlled growth of α from γ is that

$$(c^{\alpha\gamma} - c^{\gamma\alpha})\frac{\partial z^*}{\partial t} = D\frac{\partial c}{\partial z}\bigg|_{z=z^*} \qquad (1)$$

   where D is the diffusivity of solute in the matrix, t is time and z is a coordinate normal to the interface. z^* represents the position of the interface, where the concentration gradient is evaluated.

   Explain the origin of equation 1 and derive the relationship between z^* and t. Identify any approximations or assumptions that you make in your derivation.

   Explain how this equation might be adapted when dealing with at ternary Fe-C-X steel in which 'X' represents a substitutional solute, assuming that both solutes diffuse as the α grows.

4. Pearlite evolves by the simultaneous, diffusion–controlled growth of ferrite and cementite at a common transformation front with the austenite. Explain qualitatively why it is not possible to assign a unique growth rate by considering only the diffusion problem.

Answers

1. **(a)** all of these transformations cause a shape deformation which is an invariant–plane strain. The resulting strain energy is minimised if the transformation product adopts a thin plate shape.

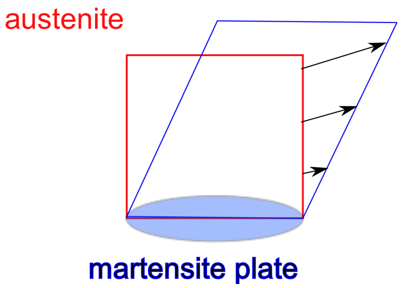

Figure 1: The displacements increase with vertical distance from the habit plane, although the strain (displacement divided by height) is constant. Therefore, a thin plate is associated with smallest strain energy per unit volume since the displacement scales with the thickness. This also explains why the plate tapers to a tip since the displacement at the tip is zero.

   (b) Widmanstätten ferrite growth occurs with paraequilibrium at the transformation front, and hence is controlled by the rate at which carbon diffuses in the austenite ahead of the interface.

   (c) Carbon causes a tetragonal distortion in the irregular–octahedral interstices of martensite in steels. This can interact strongly with both the dilatational and shear components of dislocation strain fields. In contrast, a substitutional solute leads only to hydrostatic strain and hence a weak interaction with dislocations.

   (d) All solutes influence the thermodynamics of the $\gamma \rightarrow \alpha$ transformation, but will partition between phases during reconstructive transformation, thus additionally restricting growth rates.

2. Given that $s = 0.1$ and $\delta = -0.05$, for an applied tensile stress σ

$$U = \frac{1}{2}\sigma \sin 2\theta \times 0.1 + \frac{1}{2}\sigma[1 + \cos 2\theta] \times -0.05$$

$$\frac{\partial U}{\partial \theta} = 0.1\sigma \cos 2\theta + 0.05\sigma \sin 2\theta$$

   The maximum interaction energy is obtained therefore when $\tan 2\theta = -2$ or $\theta = -32°$. The answer is the same when σ is negative.

3. The derivation is given in the lecture notes. For a ternary system we would require two equations of the type given in the question, one for each solute, which must be solved simultaneously in order to satisfy local equilibrium at the transformation front.

4. α/θ interface is created during the growth of a pearlite colony, so that the velocity is obtained as a function of the interlamellar spacing. A further criterion, such as the maximum growth rate hypothesis, has to be implemented in order to obtain a unique velocity.