Widmanstätten Ferrite

Morphology

Primary Widmanstätten ferrite either directly grows from the austenite grain surfaces, whereas secondary Widmanstätten ferrite develops from any allotriomorphic ferrite that may be present in the microstructure (Fig. 1). Widmanstätten ferrite can form at temperatures close to the Ae_3 temperature and hence can occur at very low driving forces; the undercooling needed amounts to a free energy change of only $50\,\mathrm{J\,mol^{-1}}$. This is much less than required to sustain diffusionless transformation.

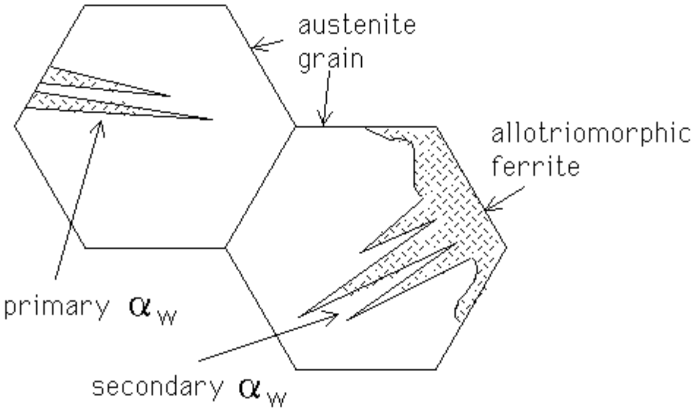

Fig. 1: Morphology of primary and secondary Widmanstätten ferrite

Shape Change

The growth of a single plate of martensite is accompanied by an invariant–plane strain of the type illustrated in Fig. 2a. However, at the high temperatures (low undercoolings) at which Widmanstätten ferrite grows, the driving force is not sufficient to support the strain energy associated with a single plate. Widmanstätten ferrite formation therefore involves the simultaneous and adjacent cooperative growth of two plates, which are crystallographic variants such that their shape deformations mutually accommodate (Fig. 2b). This has the effect of cancelling much of the strain energy.

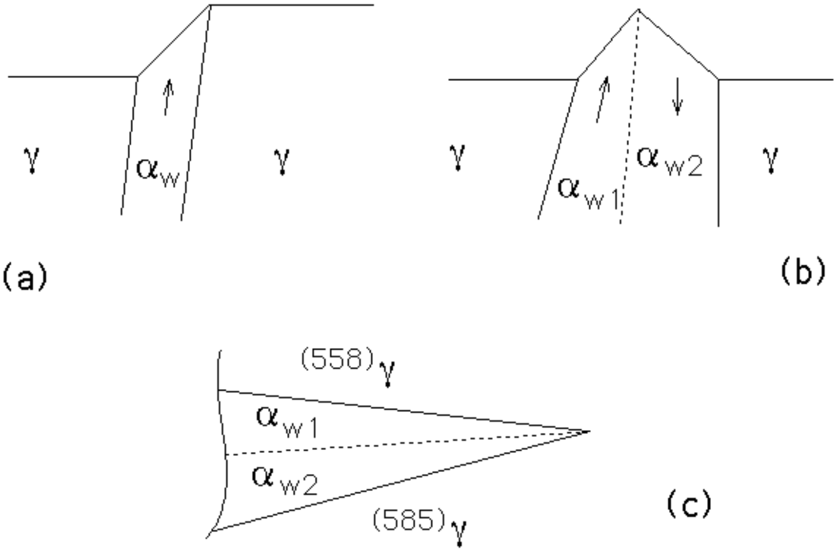

Fig. 2: (a) A single invariant–plane strain shape deformation. (b) The combined effect of two mutually accommodating, back–to–back IPS deformations. (c) The morphology of two plates, with different habit plane variants, growing together in a mutually accommodating manner.

It follows that what is seen as a single plate in an optical microscope is actually a combination of two variants, usually separated by a low–misorientation boundary (Fig. 2c). Widmanstätten ferrite has a habit plane which is close to $\{5\ 5\ 8\}_{\gamma}$. Hence, the two plates α_{w1} and α_{w2} which have different variants of this habit with the austenite, together form the thin–wedge shaped plate which is characteristic of Widmanstätten ferrite.

Because Widmanstätten ferrite forms at low undercoolings (and above the T_0 temperature), it is thermodynamically required that the carbon is redistributed during growth. α_w therefore always has an paraequilibrium carbon content and grows at a rate which is controlled by the diffusion of carbon in the austenite ahead of the plate–tip. For plates, diffusion–controlled growth can occur at a constant rate because solute is partitioned to the sides of the plate, whereas the growing tip can advance into fresh austenite. Since the transformation is nevertheless, displacive, substitutional atoms do not partition and an atomic correspondence is maintained between the parent and product lattices.

Summary

(a) An atomic correspondence is maintained for substitutional solutes, consistent with a displacive transformation mechanism.

(b) Ferrite has a paraequilibrium carbon content during growth which occurs at a constant rate, controlled by the diffusion of carbon in the austenite ahead of the plate tip.

(c) Growth involves the simultaneous and cooperative formation of a pair of adjacent, self–accommodating plates of Widmanstätten ferrite.