Microstructure of Martensite: Why it forms and how it gives rise to the shape–memory effect

Kaushik Bhattacharya, Oxford University Press, 2004, pp. 1–208.

A review for *Contemporary Physics*,Vol. 45, 2004, pp. 528–529

It is just over fifty years since the *crystallographic theory* of martensite was proposed by Bowles, MacKenzie, Wechsler, Lieberman and Read. The profound impact that it has had on the subject is attributed to the vast array of contradictory observations that it reconciled; the theory also made predictions which were subsequently verified.

The theory applies ideally to an elastically accommodated plate of martensite, one which is not perturbed by others in its vicinity. By contrast, shape memory alloys rely on elastically accommodated *groups* of plates. It is the choreography of intervariant transformations that is the essence of many types of shape memory behaviour.

Bhattacharya's book does not profess to cover the whole field of martensite. Instead, it is a rigorous treatment of martensite from the point of view of the shape memory effect. By microstructure, he means the arrangement and symmetry of plates in clusters, the substructures within the plates and the junctions between plates and with the parent phase.

There is a really nice preface and introduction which I believe would motivate even undergraduates to read further. We are gently led into the essentials of notation and continuum mechanics. The introduction to crystallography does take some liberties; for example, lattices are said to be arrangements of atoms rather than lattice points.

Martensite proper begins in Chapter 4, with an emphasis on the Bain correspondence. As in conventional theory, the correspondence (which is not unique) is assumed, mostly it seems by intuition.

This is followed by a discussion in terms of free energy densities. In the continuum model used, the free energy is taken to vary continuously between the parent and product phases as a function of some sort of an order parameter. The reason why a single plate of martensite has a microstructure is because its division into fine twins leads to a reduction in the overall energy. In the language of classical theory, the twins permit the macroscopic deformation to be an invariant–plane strain rather than the invariant–line strain that changes the parent into the product lattice. However, the emphasis on energy density in the continuum model means that it does not require *a priori* assumptions about the mode of twinning.

It is the mixture of twins and/or variants which reduces the long–range strains and allows the material to minimise energy. The process is of course subject to constraints given that there has to be sufficient compatibility at interfaces in order to maintain the diffusionless character of the transformation. The energy decreases as the microstructure becomes finer, but there is a cost due to the interfaces created in the process. Bhattacharya admits that the prediction of length scales in the microstructure, based on interfacial energy, is an open problem.

The discussion of self–accommodating arrays of martensite plates in Chapter 9 is uncompromising. The conditions for self–accommodating arrays are very restrictive, including a zero volume change on transformation. As far as I am aware, a zero dilatation condition is almost never satisfied so it is with some relief that in later discussion he talks of "very small volume change". It is also demonstrated here that the existence of self–accommodating groups is not a sufficient condition for a shape memory effect. In later work, Bhattacharya and co–workers have explained the existence of the reversibility of martensite in terms of the symmetry groups of the parent and product phases (Nature, 2004).

Many constraints are relaxed when it comes to transformations in two–dimensions, for example in thin films. There is a fascinating discussion in the book of devices which can be designed using the crystallographic theory.

Many of the concepts about martensite which Bhattacharya would like to convey are covered in the first ten chapters of the book. The next two chapters seem to me to fall into the category of mathematical technique. But the final chapter is particularly important in that it deals with the case where the parent phase is polycrystalline. Most engineering materials are polycrystalline so this makes the book complete.

The book is extremely well written, is logical and reflects the enthusiasm of the author. It is a work of tremendous scholarship. It is suggested in the preface that the book is a modern version of Wayman's *Introduction to the Crystallography of Martensite*. However, Bhattacharya's book is much more specialised in that it deals with the narrow field of shape memory martensite. It requires a considerable knowledge of mechanics to implement the theory. Bhattacharya's book nevertheless is a fascinating read and I would strongly recommend it to anyone working on displacive phase transformations.