# Lecture 9: Twins & Martensite

We have so far considered transformations which involve the diffusion of atoms, *i.e.* reconstructive transformations. In displacive transformations, there is by contrast, a coordinated motion of atoms. The parent structure is deformed into that of the product in a process which does not require diffusion.

Mechanical twinning involves a shear of a specific magnitude which re-orients a part of the parent into a mirror orientation (Fig. 46).

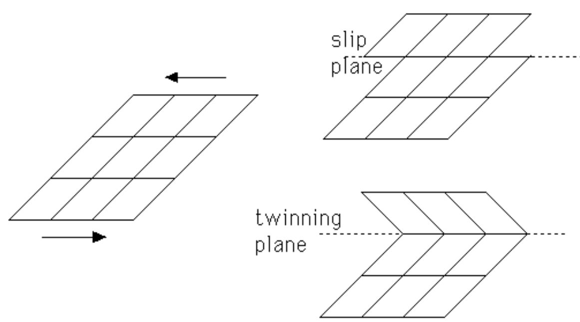


Fig. 46: Slip and Mechanical Twinning

Each atom moves only a small distance relative to its neighbours but the macroscopic effect is quite large (Fig. 47). Note that a twin system is described by a *twin plane* and a *twin direction*. The former is not affected by the twinning deformation and the latter lies in the twin plane.

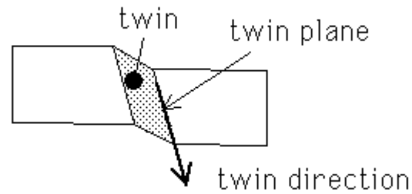


Fig. 47: Macroscopic shape deformation

In a c.c.p. metal, the twinning system is $\{1\ 1\ 1\} < 1\ 1\ \overline{2} >$. The twin–plane is invariant. The twinning displacement occurs on each close–packed plane through a distance $\frac{a}{6} < 1\ 1\ \overline{2} >$ where $a$ is the lattice parameter (Fig. 48). Therefore, the twinning shear $s$ is given by

$$\frac{\frac{a}{6} < 1\ 1\ \overline{2} >}{d_{111}} = \frac{a/\sqrt{6}}{a/\sqrt{3}} = \frac{1}{\sqrt{2}}$$

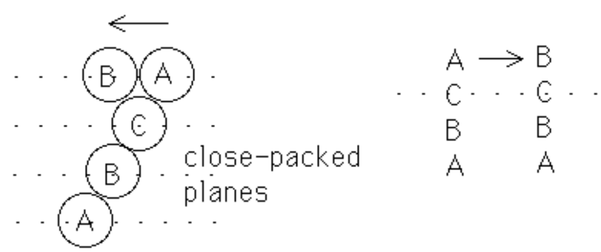


Fig. 48: Twinning in c.c.p.

In situations where a twinning deformation is constrained, for example when the twin is surrounded by matrix, the twin adopts the shape of a thin, sharply pointed plate because this minimises the elastic strain energy (Fig. 49).

Sometimes, during recrystallisation, adjacent grains happen to be in a twin orientation relationship; such grains are known as *annealing twins.* These have a shape (Fig. 49) which is consistent with the minimisation

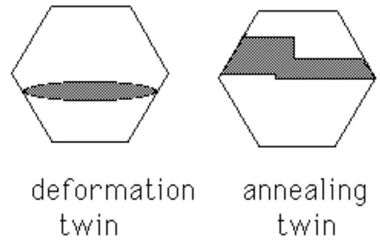


Fig. 49: Deformation & annealing twins

of surface energy. Annealing twins are not associated with any deformation, whereas mechanical twins cause a change in shape.

Deformation twinning is favoured as a deformation mode, when compared with slip, when:

1. There are few slip systems available, *i.e.* low symmetry crystal structure *e.g.* tin (tetragonal), zinc (h.c.p.).
2. High strain rates because twinning can occur at the speed of sound in the metal (tin and indium cry).

## Martensitic Transformation

Martensitic transformations are diffusionless, the change in crystal structure being achieved by a deformation of the parent phase. As in mechanical twinning, there is an invariant–plane on which there is a shear; the transformation may also involve a volume change which occurs normal to the invariant plane.

*c.c.p.→h.c.p. e.g. cobalt*

To transform a c.c.p. structure into h.c.p. requires a displacement of $\frac{a}{6} < 1\ 1\ \overline{2} >$ on every second $\{1\ 1\ 1\}_{ccp} \equiv (0\ 0\ 0\ 1)_{hcp}$ (Fig. 50). The latter is the invariant plane.

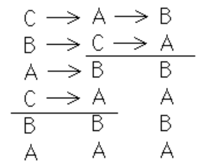


Fig. 50: c.c.p. to h.c.p. transformation

*c.c.p.→b.c.c. e.g. iron*

The deformation necessary to convert the c.c.p. structure into b.c.c. is more complicated (Fig. 51) than the simple shear of the previous example. There is a compression along the $z$ axis and a uniform expansion along the $x$ and $y$ axes.

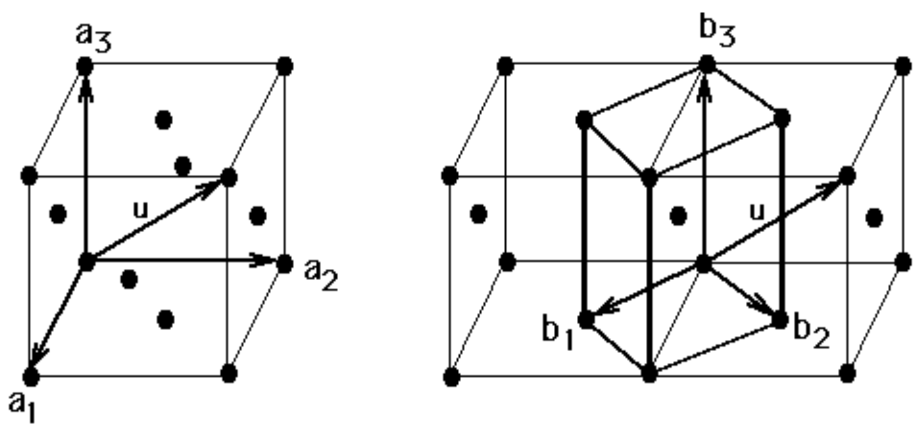


Fig. 51: The Bain strain (not all lattice points illustrated)

Such a deformation causes enormous strains. In order to avoid these intolerable strains, the martensite either slips or undergoes transformation twinning. Thus, although the Bain strain is complicated, the combined effect of the Bain strain and the slip/twinning is to convert the macroscopic strain into a shear.

## Shape Memory Effect

The shape deformation accompanying martensitic transformation can be reversed by transforming back to the parent phase. Suppose a crystal of austenite is cooled to form many variants of martensite, in such a way that they accommodate and hence the overall shape is unaffected by transformation. When a stress is applied, the favoured variant of martensite grows, leading to a shape change. On heating the shape change is reversed, thus regaining the original shape. This is the basis of the shape memory effect.

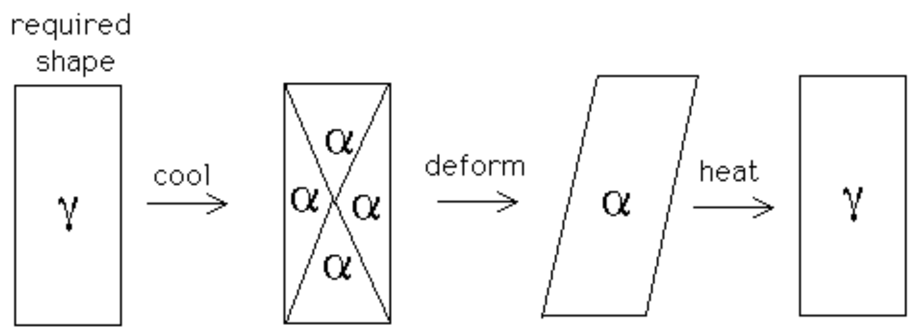


Fig. 51: Shape memory effect

Note that memory can be lost by introducing defects during transformation, *i.e.* by repeated cycling. Also, excessive deformation, beyond that required to produce a single martensite variant, will lead to irreversible strain.

## Additional Resources

1. Martensitic transformations:

   www.msm.cam.ac.uk/phase-trans/2002/martensite.html

2. Annealing twins:

   www.msm.cam.ac.uk/phase-trans/abstracts/annealing.twin.html