Magnetic shape memory alloys

Metals that change their shape in a magnetic field have tremendous potential as actuators, sensors and other devices

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Positioning a sample on the 4-circle diffractometer D9

The shape memory effect is the ability of some alloys to remember, and return to, the form which they had at one temperature after being plastically deformed into another shape at a lower temperature. This property can be exploited in many ways, for example, in actuators controlled by heat. Devices based on shape memory alloys are being developed in fields as far apart as astronautics and medicine.

In order for an alloy to have the shape-memory property, it must undergo what is called a martensitic transition. This derives its name from a change in crystal structure when steel is cooled rapidly to form so-called martensite (after its discoverer Adolf Martens), which has a variety of characteristic microstructures. The transition involves small displacements, or slips, between planes of atoms in the crystal at a certain temperature.

The shape memory alloy is first formed at a temperature above that of the transition and then deformed below it. The memory arises because residual stresses in the structure introduced during the forming process, influence which slips then occur in the martensitic transformation, and thus which variants of the martensitic phase are present at the lower temperature.

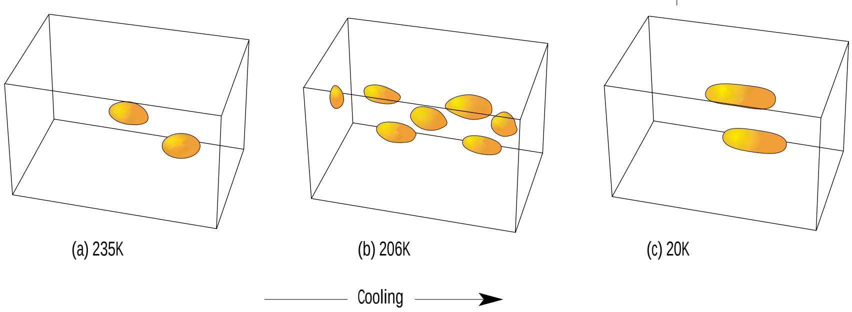
Shape memory alloys scatter neutrons very effectively, so neutrons are an almost ideal probe with which to view the martensitic transformation at a microstructural level. Neutron diffraction can follow the evolution of different martensite variants as the temperature is changed.

Magnetic possibilities

Combining the shape memory property with ferromagnetism, vastly increases the range of applications. Magnetic fields can also influence the martensitic transition, and the possibility of controlling shape memory properties using a magnetic field is currently receiving much attention. An alloy made of nickel, manganese and gallium (Ni_2MnGa) is one of the rare ferromagnetic shape memory alloys. It undergoes a martensitic transition from a cubic structure to a tetragonal variant at a temperature around 200K.

At ILL, we carried out neutron diffraction experiments on single crystals of this alloy using the 4-circle diffractometer (D9). On this instrument a small position-sensitive detector records the scattered neutrons. The figure below shows how the diffraction pattern evolves before, during and after the martensitic transition. At 235K, above the transition, the scattering shows a single compact peak associated with the cubic phase. At 206K, the martensitic transformation is under way, and the original single peak has broken up into seven smaller peaks, each corresponding to a different martensite variant. On further cooling, two of the variants grow at the expense of the others so that at 200K there are just two peaks in the pattern. On reheating the process is reversed and the original cubic single crystal restored.

Experiments of this kind, carried out on crystals which have been subjected to different mechanical treatment, allow the transformation processes that give rise to the shape memory effect to be studied in great detail. ■



A 3D representation of the neutron scattering peaks as the crystal of the ferromagnetic shape memory alloy is cooled through the martensitic transition