Memory Metal

What is memory metal?

Memory metal is an alloy that can be "trained" to take on a predetermined shape in response to a stimulus such as a change in temperature. For example, a linear wire can be twisted and bent, yet will return to its original shape when heated above a characteristic temperature.* Many alloys exhibit this characteristic, although the effects are not always as dramatic. Some examples of shape-memory alloys include copper-zinc-aluminum, iron-manganese-silicon, gold-cadmium, copper-aluminum, copper-aluminum-nickel, and the subject of this module, nickel-titanium (NiTi).

*There are some limits to the distortions that the wire will accommodate; for example, if bent into a knot, the wire typically cannot return to its linear shape.

Nitinol

Nickel-titanium shape memory alloy, Nitinol, was discovered in 1965. Nitinol is an acronym for **Ni**ckel **Ti**tanium **N**aval **O**rdnance **L**aboratory, where the alloy's remarkable properties were discovered. Nitinol is an alloy containing nearly equal numbers of nickel and titanium atoms, leading to its common compositional representation as NiTi. The relative amounts of Ni and Ti can be varied by a few percent in order to control the temperature of the phase change responsible for its "smart" behavior. A more accurate representation of its composition is Ni_xTi_{1-x}.

Nitinol and the BB Board Analogy

Through an analogy to the atomic scale, structural changes that Nitinol undergoes can be shown with a transparent, empty plastic CD case and BB's.

A. B.

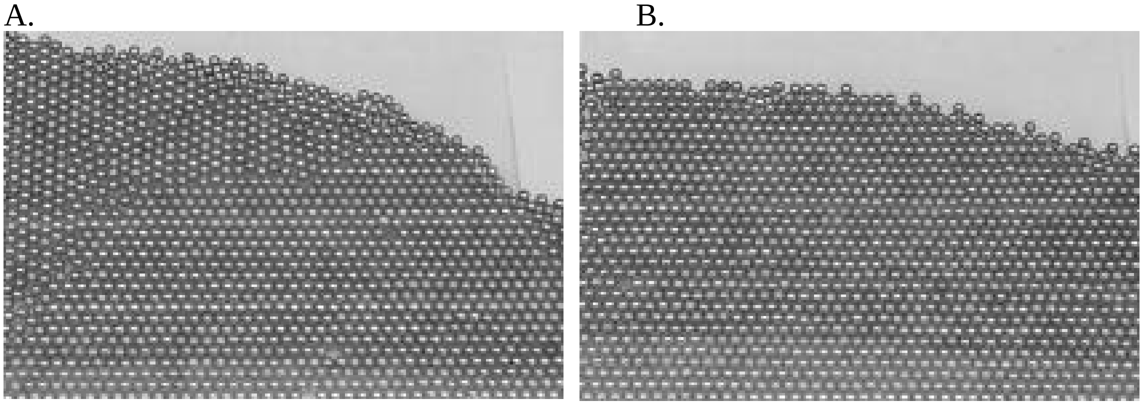

Figure 1. BB board with defects (IDENTIFY SOME WITH ARROWS)(A), and without defects (B).

Fill the case with a single layer of BB's until it is two-thirds full. Observe the pattern of BB's while holding the case almost horizontal. (Using an overhead projector to display this is also a good method of illustrating it to a class.) Several small groups of BB's, each with a regular internal pattern, are separated from each other by gaps. These gaps form defects. Analogous defects in Nitinol are composed of myriad three-dimensional crystalline regions called grains. Similar to the two-dimensional groups of BB's in the CD case, these grains are of random size, shape, and orientation. When Nitinol is heated to 500-550 degrees Celsius to fix the shape, the defects are minimized but not eliminated. Shifting atoms minimizes the defects as the grains are re-shaped. This shifting allows the atoms to fit closer together. You can use the CD case filled with BB's to illustrate how the atoms create this new arrangement. Shaking the CD case gently will add energy to the system (analogous to adding heat), and a new arrangement of BB's results. During heating, Nitinol's grains are restructured into the high-temperature austenite phase.

Uses and Capabilities

Since Nitinol has the capability of remembering its shape, this "smart" material can sense changes in its environment. It can respond to disturbances in a pre-programmed way. This new high-tech solid can consequently be used in a variety of artistic, medical, and engineering applications. These include eyeglass frames, golf clubs, coffee pot thermostats, electrical connectors, aircraft de-icers, solar collectors, clamps, sculptures, and structural damping elements, which are used to lessen the damage caused by earthquakes. For the practical joker, a magic spoon that bends when placed into a hot beverage cup also exists. The biocompatibility of NiTi allows it to be used in medical applications such as vascular stents for holding arteries open, anchors for attaching tendons to bone, medical guidewires, medical guidepins, root canal files, bendable surgical tools, and devices for closing holes in the heart as well as the common archwire for braces. Research that uses memory metal to deploy solar arrays, to create antennae on satellites and to control the balance on helicopter rotor blades is underway. Currently, these as well as many other uses are being developed.