Memory Metal

memory metal - metal that remembers its shape

examples: NiTi, Cu-Zn-Al, Fe-Mn-Si, Au-Ca, Cu-Al-Ni, Cu-Al, etc.

smart material-responds to a stimulus in a predictable manner

Characteristics of NiTi

1. bent at room temp. but return to linear shape when heated by hot air or water

   -"atomic ballet"

   -some limits

2. can be "trained" to remember new shape by heating in candle flame (500°C)

3. NiTi consists of 2 structures interconverted by changes in temp. or pressure
   -between 0-100°C there are 2 phases
   1. Austenite
      -high temp. phase
      -cubic symmetry
      -hard, rigid
   2. Martensite
      -low temp. phase
      -less symmetrical
      -flexible

Martensite + energy === Austenite
(more dense) (less dense)

Martensite can have 24 varients
-flexibility of martensite due to varients in structure & ability to re-orient these varients = mecahnical flexibility

Nickel-Titanium = Nitinol = Nickel Titanium Naval Ordinance Laboratory
-nitinol discovered in 1965

-contains nearly equal amounts of Ni & Ti atoms

NiTi common composition but relative amounts of Ni & Ti varied to control temp. of the phase change responsible for its smart behavior

Ni_xTi_{1-x}

ex. $Ni_{0.5}Ti_{0.5}$ $Ni_{0.3}Ti_{0.7}$

BB board analogy
-case = solid, BB's = atoms
-groups of atoms (BB's) = small groups with regular internal pattern separated from each other by gaps
-gaps = defects

Nitinol composed of 3-D crystalline regions = grains

- grains have random shapes, sizes, orientations

heat to 500-550°C to fix shape, linear defects are minimized, not eliminated

-defects minimized by atoms moving & reshaping grains
-allows atoms to fit closer together

<u>Crystallography</u>-study of the structure of crystals, including ways of describing the crystal structure, the principles that govern the various structures, & methods of determining a crystal's structure

<u>3 parts to crystallography</u>

1. ways that spheres pack into a 3-D array that can be extended indefinitely in all directions

2. the smallest unit that can be associated with a solid

3. determining planes & directions in crystal structures

<u>unit cell</u>-an imaginary box that can be constructed from arrays of atoms, ions, or molecules-basic unit of a crystal structure

valid unit cells-used to represent the array

See Appendix A or overheads

Note: Each unit cell contains 1 complete circle, & only the shaded portion of the circle lies in the unit cell. If any of the unit cells is moved along its edges the entire pattern is produced.

Simple Cubic | Face-centered cubic | Body-centered cubic

See Figure 2 in Investigation 2 (Notes for the Instructor)

valid unit cell vs. invalid unit cell

coordination number - number of nearest neighbors

Thermochemical equation to represent transition between phases

martensite + energy === austenite

-energy of a few kJ/mol to change from martensite to austenite

Ni & Ti atoms within the grain(crystalline region) in a sample of memory metal in austenite phase are almost perfectly arranged with few imperfections

- -memory from defects in austenite phase & grain boundaries
- -to give metal a new shape, new defects must be created - goes to new set of defects, rather than old
- -new defects obtained by heating metal 500°C while securing shape
- -thermal energy allows atoms to relax into lower energy positions = defects formed
- -if heated too long, memory metal feature of wire destroyed because if atoms around defects have enough energy they relax & a defect free structure results
- -defects created in austenite phase (altered by candle flame) create new memory by forcing groups of atoms to have particular positions relative to one another

<u>Uses and Capabilities</u>

-sense changes in environment & respond to disturbances in a pre-programmed way so used for...

For example:

Artistic medical engineering
eyeglass frames
golf clubs
clamps
practical jokes
See background information for more.

archwire for braces
coffee pot thermostats
electrical connectors
sculptures
medical applications

<u>Austenite</u>	<u>Martensite</u>
1. high temp. phase	1. low temp. phase
2. rigid/hard	2. flexible
3. symmetrical	3. less symmetrical
4. ring	4. thud
5. uniform structure allows sound waves to travel through it easily	5. boundaries between regions with different orientations reduce vibrations & muffle the sound
6. less dense	6. more dense

<u>Hysteresis Effect</u> - the phase changes in the 2 directions do not have the same temperature dependence-phase change from austenite to martensite occurs over a lower temp. range than that from martensite to austenite

Graph of figure 9.9 from Companion

Explanation: one solid phase needs to grow within the region of the other-elastic strain in region around new crystal growth

Overall effect: displacement of heating curve to higher temps.
therefore, whether it was heated or cooled makes a difference

<u>Equilibrium</u> - system in which the rates of forward & reverse processes are equal
-processes can be chemical or physical

-system must be closed

closed vs. steady state

<u>LeChatelier's Principle</u> - when a system at equilibrium is subjected to a stress (change in temperature, pressure, concentration), the equilibrium will shift in the direction that tends to counteract or relieve the stress

Straining material causes NiTi to change from one phase to another

-as rod is bent some atoms compressed & some pulled apart

Figure 9.7 from Companion

-therefore, pressure exerted on atoms
-material favors matensite (more dense phase) formation under high pressure

<u>Transistion temperature (TTR)</u> - temperature at which a phase transformation occurs