Teacher's Preparatory Guide

Shape Memory Alloys – Smart Materials

Purpose
Students learn about a class of materials called shape memory alloys. They will explore how these materials work and what applications these materials are used in. They will discuss phase transformations.

Level
Middle to high school

Time required
1 (50 minutes) class period

Background Information

Shape memory alloys are a class of materials also referred to as smart materials. These smart materials can "think" and do amazing things. The one this activity focuses on is a metal called nitinol

In 1932, Swedish researcher Ame Olander observed the shape and recovery ability of a gold-cadmium alloy (Au-Cd) and noted that it actually created motion. In 1950, L.C. Chang and T.A. Read at Columbia University observed this unusual motion at the microscopic level by using x-rays to note the changes in crystal structure of Au-Cd. As a result of Chang and Read, other such alloys were discovered including indium-titanium. In 1963, W.J. Buehler and co-workers at the US Naval Ordinance Laboratory observed the shape memory effect in a nickel and titanium alloy, today known as nitinol ("Night in All"; **N**ickel **T**itanium **N**aval **O**rdinance **L**ab).). Other studies followed and researchers found the shape memory effect in other alloys, including copper-tin, iron-platinum, and nickel-aluminum.

Nickel titanium and copper-zinc-aluminum became the materials of choice because of their low cost, strength, large-shape changing abilities, and ease of fabrication.

Shape memory alloys (SMA) belong to a class of materials which display the shape memory effect (SME). These alloys possess the ability to radically change crystal structure or phase at a distinct temperature. Imagine the ability to change water into ice, or steam into water instantaneously. Unlike most metals, if the alloy is below the "transition temperature," it can be stretched and transformed without permanent damage.

After the alloy has been reshaped or stretched, if it is heated above the transition temperature, the alloy "recovers" and returns to the un-stretched shape. The alloy can remember its original shape – it's smart. The shape of the SMA can be set and reset many times. Simply clamp the wire or

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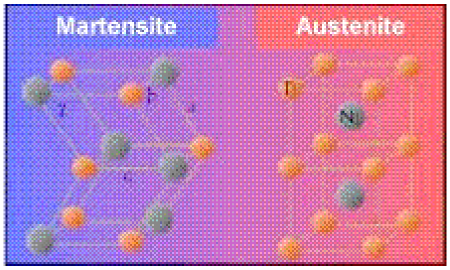
SMA into the desired shape, and heat it above 500-550ºC for 10 to 60 minutes, the SMA will take the new shape once quenched into a water bath. SMAs intended for use at room temperatures typically have transition temperatures near 70ºC.

There are two phases of nitinol

High temperature – austenite with cubic symmetry, hard and rigid

Low temperature – martensite, less symmetric, more flexible



Texas A&M Smart Labe– http://smart.tamu.edu

When pressure is applied at the lower temperature, the atoms change orientation/position to adjust to the pressure. But when nitinol is heated above its transition temperature, where the phase transformation occurs, then the nitinol returns to its original atomic configuration. This is a solid state phase transition. Varying the amounts of nickel and titanium in the wire will change the transition temperature.

In the past twenty years, SMAs (shape memory alloys) have been incorporated into a variety of products. Coffee makers, eyeglass frames, guide wires for arthroscopic surgery, staples for attaching broken bone fragments, and a mechanical coupler are just some applications.

Materials

- Nitinol wire (resource list below)
- Tweezers
- Shallow glass bowls or dishes
- Hot water, heat guns, candles and matches
- Safety glasses are recommended (some students are able to shape their wire such that it flies out of the dish!)

Advance Preparation

- Download PowerPoint presentation on Shape Memory Alloys
- Purchase sufficient quantities of nitinol wire (pre-cut into 3 inch pieces) for one piece per two students (minimum). Sources for materials are included below.
- Prepare hot water and have means for distributing to student dishes. (**note:** water cools quickly and once below the transition temperature for the metal the shape memory effect will not occur).

Directions for the Activity

1. Introduce the students to shape memory alloys via the PowerPoint presentation. Stop the presentation at slide 7 which discusses current uses for the materials
2. Have students obtain their bowls, wire pieces, tweezers and safety glasses.

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3. Discuss phase transformation; solid – liquid – gas. Explain that there are also solid state phase transformations which occur at the atomic level in some materials.
4. Ask them if they think they can twist metal and have it instantly return to the original shape.
5. Demonstrate to the class by twisting a piece of wire. Place it in tweezers and use a lighter to put heat onto the wire until it springs back into the original shape.
6. Direct students to pour hot water into their bowls, twist the wire, and then insert it into the hot water. Use the tweezers to retrieve from the hot water. Alternatively, you may use lighters, candles, or Bunsen burners at the heat source.
7. Next ask the students to set their wire into a specific shape. Simple shapes like a V or S are the easiest to set. Have the students light their candles and using the tweezers to hold their wire on both ends (it will try to return to its original shape once it reaches its transition temperature), insert it into the flame. The wire should set in about a minute. Allow the wire to cool, then put it into a new shape or stretch it out straight. Place in hot water or back into the flame and see that it returns to the new shape set by heating in the candle flame.
8. Have the students discuss what is occurring in the metal. Make sure that they understand that the change is occurring at the atomic/molecular level but the effect is seen at the macroscopic level.
9. Have students brainstorm about possible uses for shape memory alloys. Have groups report out their ideas. Ask them how the product would be a benefit. Tell them that not all SMAs are metal. There is an excellent video on Science Central showing MIT researchers using plastic SMAs that respond to UV light to tie surgical knots: http://www.sciencentral.com/articles/view.php3?article_id=218392685&cat=3_5
10. Complete PowerPoint presentation and direct students to additional web site information.

Safety Information

The only safety precautions involve:

- The possibility of the wire "jumping" from the dish
- Spilling of hot water
- Use of candles/flames

Nitinol sources – specify a diameter of around 0.29" and a transition temp of about 50^{o}C

http://www.teachersource.com
http://www.imagesco.com.nitinol/wire.html
http://www.smallparts.com/products
http://www.robotstore.com

Additional Information on Shape Memory Alloys

http://www.imagesco.com/articles/nitinol/01.html
http://www.cs.ualberta.ca/~database/MEMS.sma_mems.sma.html
http://www.mrsec.wisc.edu/Edetc/supplies/index.html
http://web.ask.com/web?q=shape+memory+alloys&o=0&qsrc=0
http://smart.tamu.edu/overview/smaintro/simple/definition.html
http://smst.org/smstweblinks.html
http://www.memry.com
http://www.nitinol.com

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National Science Education Standards

Middle School Content Standard

- Standard A
  - Abilities necessary to do scientific inquiry
  - Understandings about scientific inquiry
- Standard B
  - Properties and changes of properties in matter
  - Transfer of energy
- Standard E
  - Abilities of technological design
  - Understanding about science and technology
- Standard F
  - Science and technology in society
- Standard G
  - Science as a human endeavor
  - Nature of science

High School Content Standards

- Standard A
  - Identify questions and concepts that guide scientific investigations
  - Understanding about scientific inquiry
- Standard B
  - Structure and properties of matter
  - Interactions of energy and matter
- Standard E
  - Abilities about technological design
  - Understanding about science and technology
- Standard G
  - Science as a human endeavor
  - Nature of scientific inquiry

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