Shape Memory Alloys

I. What are Shape Memory Alloys?

Shape memory alloys (SMA's) are metals, which exhibit two very unique properties, pseudo-elasticity, and the shape memory effect. Arne Olander first observed these unusual properties in 1938 (Oksuta and Wayman 1998), but not until the 1960's were any serious research advances made in the field of shape memory alloys. The most effective and widely used alloys include NiTi (Nickel - Titanium), CuZnAl, and CuAlNi.

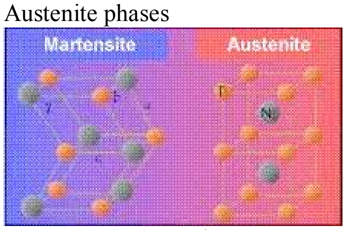
II. Applications of Shape Memory Alloys

The unusual properties mentioned above are being applied to a wide variety of applications in a number of different fields. The buttons below are links to pages about some of the most promising applications of SMAs. Each page contains information about the application as well as videos and interactive applets which allow you to become more familiar with the behavior of SMAs.

[ Aeronautical Applications] [ Surgical Tools] [ Muscle Wires]

III. How Shape Memory Alloys Work

Figure 1: The Martensite and Austenite phases



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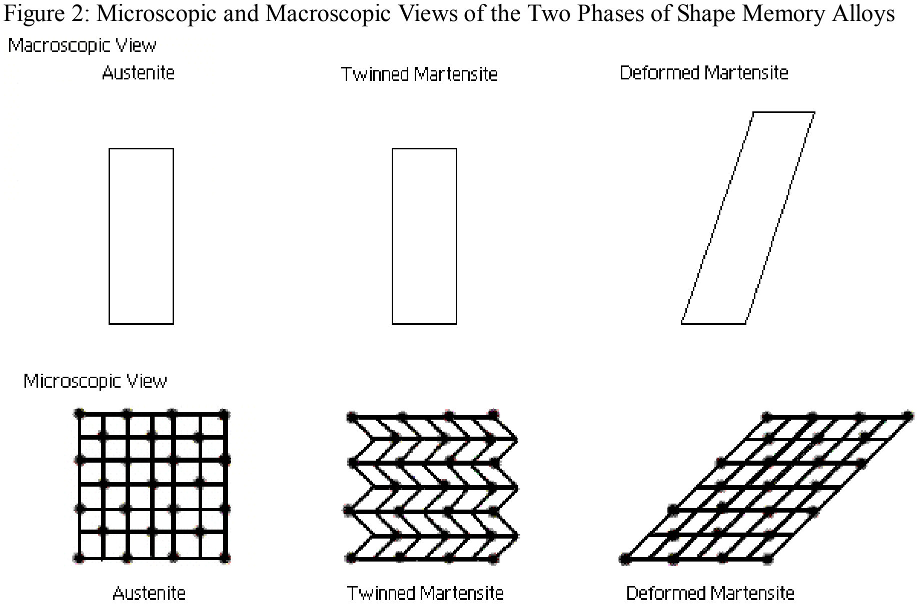
The two unique properties described above are made possible through a solid state phase change, that is a molecular rearrangement, which occurs in the shape memory alloy. Typically when one thinks of a phase change a solid to liquid or liquid to gas change is the first idea that comes to mind. A solid state phase change is similar in that a molecular rearrangement is occurring, but the molecules remain closely packed so that the substance remains a solid. In most shape memory alloys, a temperature change of only about 10�C is necessary to initiate this phase change. The two phases, which occur in shape memory alloys, are Martensite, and Austenite.

Martensite, is the relatively soft and easily deformed phase of shape memory alloys, which exists at lower temperatures. The molecular structure in this phase is twinned which is the configuration shown in the middle of Figure 2. Upon deformation this phase takes on the second form shown in Figure 2, on the right. Austenite, the stronger phase of shape memory alloys, occurs at higher temperatures. The shape of the Austenite structure is cubic, the structure shown on the left side of Figure 2. The un-deformed Martensite phase is the same size and shape as the cubic Austenite phase on a macroscopic scale, so that no change in size or shape is visible in shape memory alloys until the Martensite is deformed.

Figure 2: Microscopic and Macroscopic Views of the Two Phases of Shape Memory Alloys



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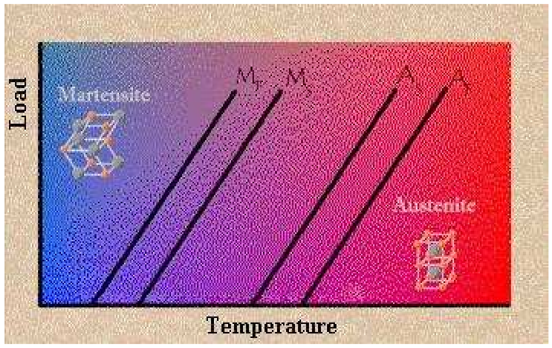
The temperatures at which each of these phases begin and finish forming are represented by the following variables: Ms, Mf, As, Af.

The amount of loading placed on a piece of shape memory alloy increases the values of these four variables as shown in Figure 3. The initial values of these four variables are also dramatically affected by the composition of the wire (i.e. what amounts of each element are present).

Figure 3: The Dependency of Phase Change Temperature on Loading



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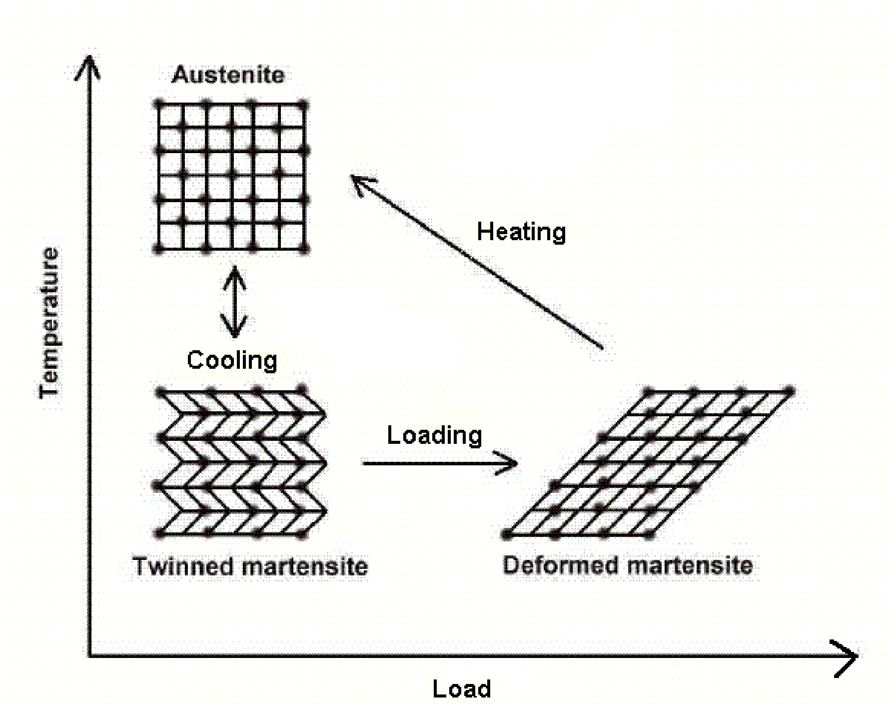
Shape Memory Effect

Figure 4: Microscopic Diagram of the Shape Memory Effect



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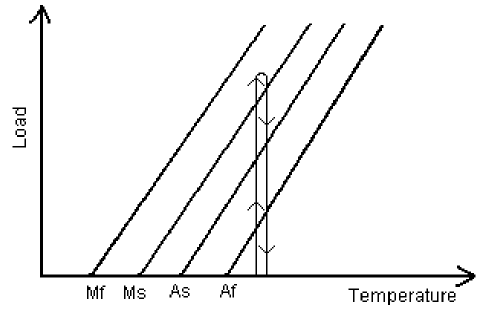
The shape memory effect is observed when the temperature of a piece of shape memory alloy is cooled to below the temperature Mf. At this stage the alloy is completely composed of Martensite which can be easily deformed. After distorting the SMA the original shape can be recovered simply by heating the wire above the temperature Af. The heat transferred to the wire is the power driving the molecular rearrangement of the alloy, similar to heat melting ice into water, but the alloy remains solid. The deformed Martensite is now transformed to the cubic Austenite phase, which is configured in the original shape of the wire.

The Shape memory effect is currently being implemented in:

- Coffepots
- The space shuttle
- Thermostats
- Vascular Stents
- Hydraulic Fittings (for Airplanes)

Pseudo-elasticity

Figure 5: Load Diagram of the pseudo-elastic effect Occurring



Pseudo-elasticity occurs in shape memory alloys when the alloy is completely composed of Austenite (temperature is greater than Af). Unlike the shape memory effect, pseudo-elasticity occurs without a change in temperature. The load on the shape memory alloy is increased until the Austenite becomes transformed into Martensite simply due to the loading; this process is shown in Figure 5. The loading is absorbed by the softer Martensite, but as soon as the loading is decreased the Martensite begins to transform back to Austenite since the temperature of the wire is still above Af, and the wire springs back to its original shape.

Some examples of applications in which pseudo-elasticity is used are:

- Eyeglass Frames
- Bra Underwires
- Medical Tools
- Cellular Phone Antennae
- Orthodontic Arches

IV. Advantages and Disadvantages of Shape Memory Alloys

Some of the main advantages of shape memory alloys include:

- Bio-compatibility
- Diverse Fields of Application
- Good Mechanical Properties (strong, corrosion resistant)

There are still some difficulties with shape memory alloys that must be overcome before they can live up to their full potential. These alloys are still relatively expensive to manufacture and machine compared to other materials such as steel and aluminum. Most SMA's have poor fatigue properties; this means that while under the same loading conditions (i.e. twisting, bending, compressing) a steel component may survive for more than one hundred times more cycles than an SMA element.

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