A

Seminar report

On

Shape Memory Alloys

Submitted in partial fulfillment of the requirement for the award of degree
Of ECE

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Acknowledgement

I would like to thank respected Mr…….. and Mr. ……..for giving me such a wonderful opportunity to expand my knowledge for my own branch and giving me guidelines to present a seminar report. It helped me a lot to realize of what we study for.

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Preface

I have made this report file on the topic **Shape Memory Alloys**; I have tried my best to elucidate all the relevant detail to the topic to be included in the report. While in the beginning I have tried to give a general view about this topic.

My efforts and wholehearted co-corporation of each and everyone has ended on a successful note. I express my sincere gratitude to ……..who assisting me throughout the preparation of this topic. I thank him for providing me the reinforcement, confidence and most importantly the track for the topic whenever I needed it.

Introduction to Shape Memory Alloys

Shape memory alloys (SMAs) are metallic alloys which can recover permanent strains when they are heated above a certain temperature. The key characteristic of all SMAs is the occurrence of a martensitic phase transformation. The martensitic transformation is a shear-dominant diffusionless solid-state phase transformation occurring by nucleation and growth of the martensitic phase from a parent austenitic phase. When an SMA undergoes a martensitic phase transformation, it transforms from its high-symmetry, usually cubic, austenitic phase to a low-symmetry martensitic phase, such as the monoclinic variants of the martensitic phase in a NiTi SMA.

The martensitic transformation possesses well-defined characteristics that distinguish it among other solid state transformations:

- It is associated with an inelastic deformation of the crystal lattice with no diffusive process involved. The phase transformation results from a cooperative and collective motion of atoms on distances smaller than the lattice parameters. The absence of diffusion makes the martensitic phase transformation almost instantaneous.
- Parent and product phases coexist during the phase transformation, since it is a first order transition, and as a result there exists an invariant plane, which separates the parent and product phases. The lattice vectors of the two phases possess well defined mutual orientation relationships (the Bain correspondences), which depend on the nature of the alloy.
- Transformation of a unit cell element produces a volumetric and a shear strain along well-defined planes. The shear strain can be many times larger than the elastic distortion of the unit cell. This transformation is crystallographically reversible.
- Since the crystal lattice of the martensitic phase has lower symmetry than that of the parent austenitic phase, several variants of martensite can be formed from the same parent phase crystal.
- Stress and temperature have a large influence on the martensitic transformation. Transformation takes place when the free energy difference between the two phases reaches a critical value.

General Characteristics

The martensitic transformation that occurs in the shape memory alloys yields a thermoelastic martensite and develops from a high-temperature austenite phase with long-range order. The martensite typically occurs as alternately sheared platelets, which are seen as a herringbone structure when viewed metallographically. The transformation, although a first-order phase change, does not occur at a single temperature but over a range of temperatures that varies with each alloy system.

The herringbone structure of athermal martensites essentially consists of twin-related, self-accommodating variants (Fig. 2b). The shape change among the variants tends to cause them to eliminate each other. As a result, little macroscopic strain is generated This process creates a macroscopic strain, which is recoverable as the crystal structure reverts to austenite during reverse transformation.

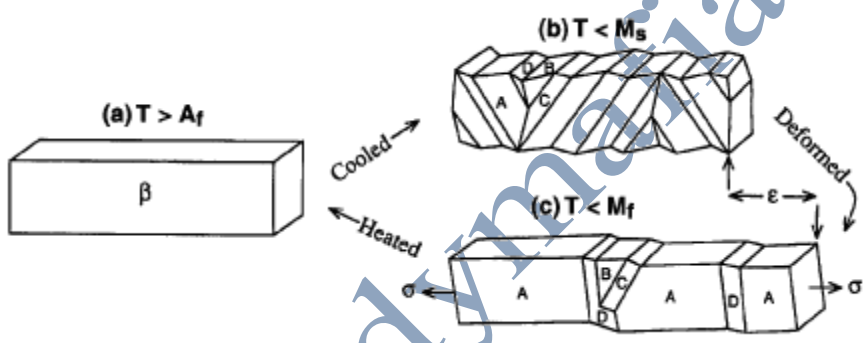


Figure 2: *(a) Beta phase crystal. (b) Self-accommodating twin-related variants, A, B, C, and D, after cooling and transformation to martensite. (c) Variant A becomes dominant when stress is applied. Upon heating, the material reverts to the beta phase and recovers its original shape.*

An interesting feature of the stress-strain behavior is seen in Fig. 3c, where the material is tested slightly above its transformation temperature. At this temperature, martensite can be stress-induced. It then immediately strains and exhibits the increasing strain at constant stress behavior, seen in AB. Upon unloading, though, the material reverts to austenite at a lower stress, as seen in line CD, and shape recovery occurs, not upon the application of heat but upon a reduction of stress. This effect, which causes the material to be extremely elastic, is known as *pseudoelasticity*. Pseudoelasticity is nonlinear. The Young's modulus is therefore difficult to define in this temperature range as it exhibits both temperature and strain dependence.

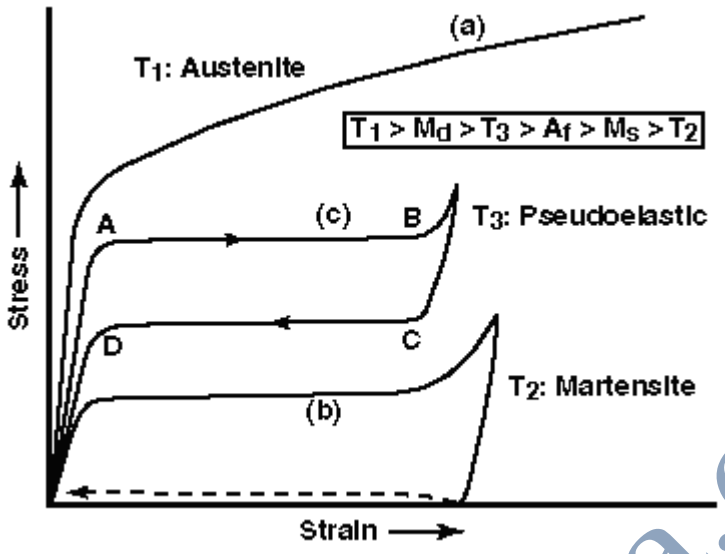


Figure 3: *Typical stress-strain curves at different temperatures relative to the transformation, showing (a) Austenite, (b) Martensite, and (c) Pseudoelastic behavior.*

The amount of this shape change when cooling is always significantly less than obtained when heating , and very little stress can be exerted by the alloy The heating shape change can still exert very high forces, as with the one-way memory.

All rely on the introduction of microstructural stress concentrations which cause the martensite plates to initiate particular directions when they form upon cooling, resulting in an overall net shape change in the desired direction.

Commercial SME Alloys

The only two alloy systems that have achieved any level of commercial exploitation are the NiTi alloys and the copper-base alloys. Properties of the two systems are quite different. The NiTi alloys have greater shape memory strain (up to 8% versus 4 to 5% for the copper-base alloys), tend to be much more thermally stable, have excellent corrosion resistance compared to the copper-base alloys' medium corrosion resistance and susceptibility to stress-corrosion cracking, and have much higher ductility. On the other hand, the copper-base alloys are much less expensive, can be melted and extruded in air with ease, and have a wider range of potential transformation temperatures. The two alloy systems thus have advantages and disadvantages that must be considered in a particular application.

Nickel-Titanium Alloys. The basis of the nickel-titanium system of alloy is the binary, equiatomic intermetallic compound of NiTi. The intermetallic compound is extraordinary because it has a moderate solubility range for excess nickel or titanium, as well as most other metallic elements, and it also exhibits a ductility comparable to most ordinary alloys. This solubility allows alloying with many of the elements to modify both the mechanical properties and the transformation properties of the system. Excess nickel, in amounts up to about 1%, is the most common alloying addition.

Excess nickel strongly depresses the transformation temperature and increases the yield strength of the austenite.

Other frequently used elements are iron and chromium (to lower the transformation temperature), and copper (to decrease the hysteresis and lower the deformation stress of the martensite). Because common contaminants such as oxygen and carbon can also shift the transformation temperature and degrade the mechanical properties, it is also desirable to minimize the amount of these elements.

work hardening, and proper heat treatment can greatly improve the ease with which the martensite is deformed, give an austenite with much greater strength, and create material that spontaneously moves itself both on heating and on cooling (two-way shape memory).

Machining by turning or milling is very difficult except with special tools and practices. Welding, brazing, or soldering the alloys is generally difficult. The materials do respond well to abrasive removal, such as grinding, and shearing or punching can be done if thicknesses are kept small.

Heat treating to impart the desired memory shape is often done at 500 to 800 deg.C, The restrained in the desired memory shape during the heat treatment

Commercial copper-base shape memory alloys are available in ternary CuZnAl and CuAlNi alloys, or in their quaternary modifications containing manganese. Elements such

as boron, cerium, cobalt, iron, titanium, vanadium, and zirconium are also added for grain refinement.

Manganese depresses transformation temperatures of both CuZnAl and CuAlNi alloys and shifts the eutectoid to higher aluminum content (Ref. 10). It often replaces aluminum for better ductility.

Applications

Free recovery

blood-clot filter The NiTi wire is shaped to anchor itself in a vein and catch passing clots. The part is chilled so it can be collapsed and inserted into the vein, then body heat is sufficient to turn the part to its functional shape.

Constrained Recovery

Cryofit hydraulic These fittings are manufactured as cylindrical sleeves slightly smaller than the metal tubing they are to join. Their diameters are then expanded while martensitic, and, upon warming to austenite, they shrink in diameter and strongly hold the tube ends. The tubes prevent the coupling from fully recovering its manufactured shape, and the stresses created

Force Actuators.

exert force over a considerable range of motion, often for many cycles.

circuit-board edge In this electrical connector system, the SMA component is used to force open a spring when the connector is heated. This allows force-free insertion or withdrawal of a circuit board in the connector. Upon cooling, the NiTi actuator becomes weaker and the spring easily deforms the actuator while it closes tightly on the circuit board and forms the connections.

Superelastic Applications.

pseudoelastic (or *superelastic*

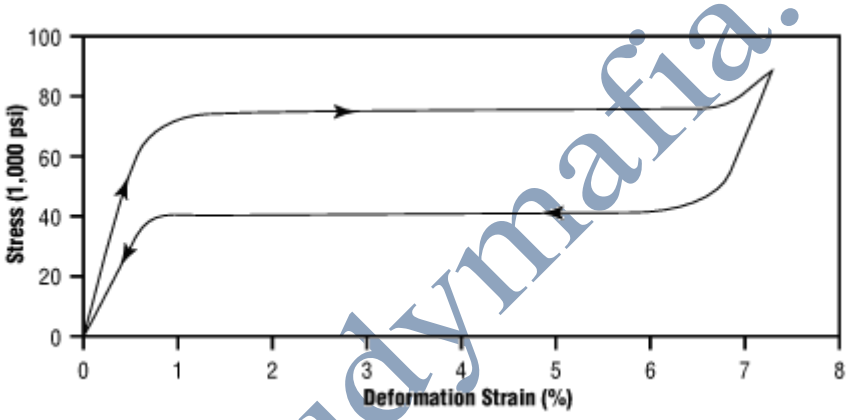
Eyeglass frames that use superelastic NiTi to absorb large deformations without damaging the frames are now marketed,.

biomedical applications. extremely corrosion resistant, demonstrates excellent biocompatibility, can be fabricated into the very small sizes often required, and has properties of elasticity and force delivery.

Future Prospects

The medical industry excellent biocompatibility and large pseudoelasticity
small wire that is stable, is easily heated by a small electrical current, and gives a large repeatable stroke should lead to a new family of **actuator devices** These devices can be inexpensive, are reliable for thousands of cycles

Darel E. Hodgson, *Shape Memory Applications, Inc.*, Ming H. Wu, *Memry Technologies*, and Robert J. Biermann, *Harrison Alloys, Inc.*



Typical Loading and Unloading Behavior of Superelastic NiTi

The ability of shape memory alloys to recover a preset shape upon heating above its transformation temperatures and return to an alternate shape upon cooling is known as *two-way memory*. Two-way memory is unique in that the material "remembers" different high temperature and low temperature shapes.

design to make use of one-way memory with a biasing force acting against the shape memory element to return it upon cooling. inherent temperature hysteresis, which remains. Two-way actuators using one-way shape memory elements acting against bias forces have demonstrated large strains, high forces in both heating and cooling directions, and excellent long-term stability up to millions of cycles. For further information, please consult the references below.

.upon heating or cooling, NiTi alloys do not completely undergo their phase transformation at one particular temperature. Instead, the transformation begins at one temperature (known as the *start temperature*) and is completed at another temperature (known as the *finish temperature*). Further, there is a difference in the transformation

temperatures upon heating from martensite to austenite and cooling from austenite to martensite, resulting in a delay or "lag" in the transformation. This difference, known as the *transformation temperature hysteresis,* is generally defined as the difference between the temperatures at which the material is 50% transformed to austenite upon heating and 50% transformed to martensite upon cooling. This value can be approximated by the difference between A_p and M_p on a DSC curve. Typical values for binary NiTi alloys are about 25 to 50 deg.C.

In addition to the hysteresis, the overall span of the transformation may be important. If the device being designed requires complete transformation upon both heating and cooling, then the difference between A_f and M_f (the finish temperatures of the transformations to austenite and martensite, respectively) must be considered. Typical values for the overall transformation temperature span are about 40 to 70 deg.C.

Copper additions have been shown to reduce the hysteresis to about 10 to 15 deg.C and Niobium (Columbium) additions can expand the hysteresis to over 100 deg.C.

designing a device to activate at boiling water temperature (100 deg.C) that also must be fully retransformed to martensite at room temperature (20 to 25 deg.C), there is a narrow set of binary alloys which meet the criteria. From the above table, one can estimate that one should consider alloys with A_s of approximately 60 to 80 deg.C to satisfy both criteria. Similarly, an alloy designed to be completely transformed by body temperature upon heating (A_f < 37 deg.C) would require cooling to about -10 deg.C to fully retransform to martensite.

Shape setting (or *training*) is accomplished by constraining the NiTi element on a mandrel or fixture of the desired shape and applying an appropriate heat treatment. The heat treatment methods used to set shapes in both shape memory and superelastic forms of NiTi are similar.

The heat treatment parameters, generally one uses a temperature closer to 500 deg.C and times over 5 minutes. Rapid cooling of some form is preferred via a water quench or rapid air .

Aircraft maneuverability depends heavily on the movement of flaps found at the rear or trailing edge of the wings. The efficiency and reliability of operating these flaps is of critical importance.

Most aircraft in the air today operate these flaps using extensive hydraulic systems. These hydraulic systems utilize large centralized pumps to maintain pressure, and hydraulic lines to distribute the pressure to the flap actuators. In order to maintain reliability of operation, multiple hydraulic lines must be run to each set of flaps. This complex system of pumps and lines is often relatively difficult and costly to maintain.

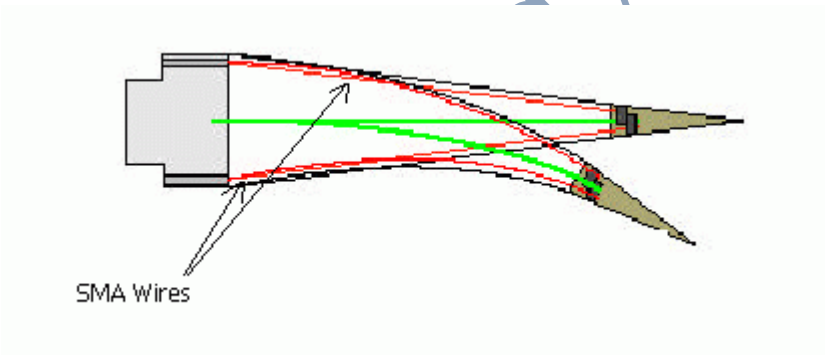
Many alternatives to the hydraulic systems are being explored by the aerospace industry. Among the most promising alternatives are piezoelectric fibers, electrostrictive ceramics, and shape memory alloys.

USAF Aircraft Pictures - http://sun.vmi.edu/hall/afpics.htm

"Smart" wings, which incorporate shape memory alloys, are typically like the wing shown in Figure 3, this system is much more compact and efficient, in that the shape memory wires only require an electric current for movement.

2: Electromechanical Actuator

Figure 3: Hinge less shape memory alloy Flap



The shape memory wire is used to manipulate a flexible wing surface. The wire on the bottom of the wing is shortened through the shape memory effect, while the top wire is stretched bending the edge downwards, the opposite occurs when the wing must be bent upwards. The shape memory effect is induced in the wires simply by heating them with an electric current, which is easily supplied through electrical wiring, eliminating the need for large hydraulic lines. By removing the hydraulic system, aircraft weight, maintenance costs, and repair time are all reduced. The smart wing system is currently being developed cooperatively through the Defense Advanced Researched Project

Agency (DARPA, a branch of the United States Department of Defense), and Boeing.

"Per unit volume, nitinol is the most powerful actuator available today

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.

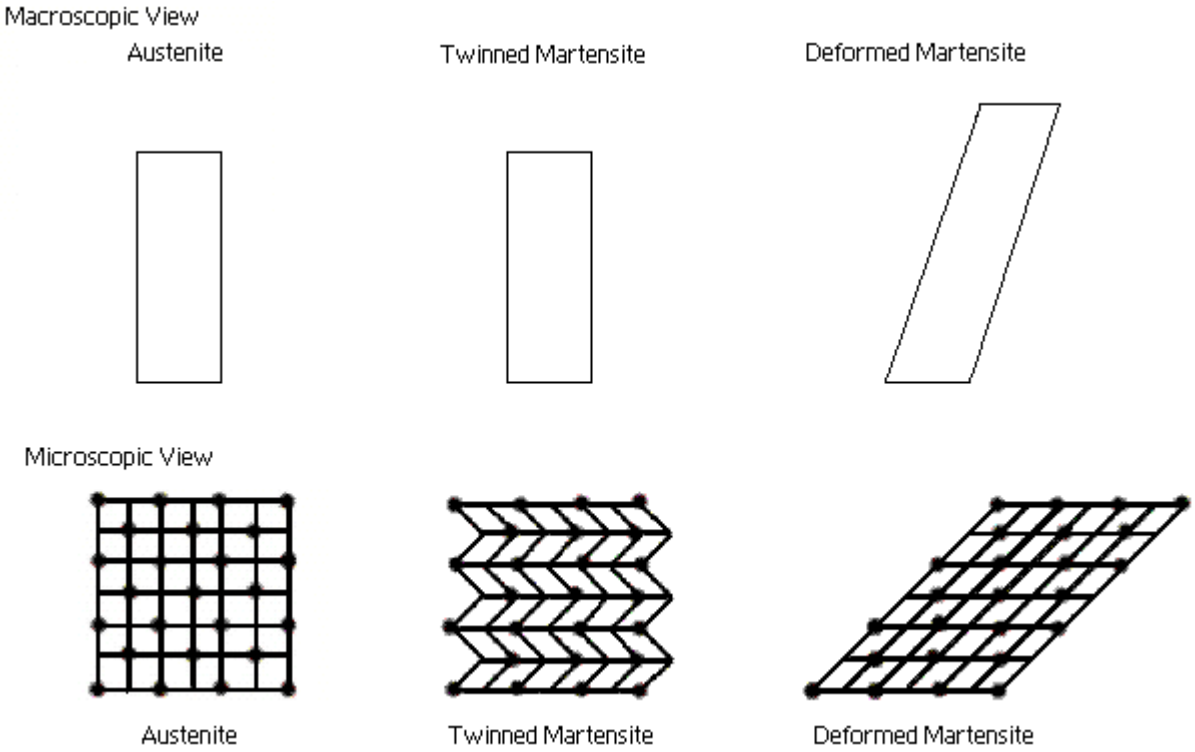
III. How Shape Memory Alloys Work

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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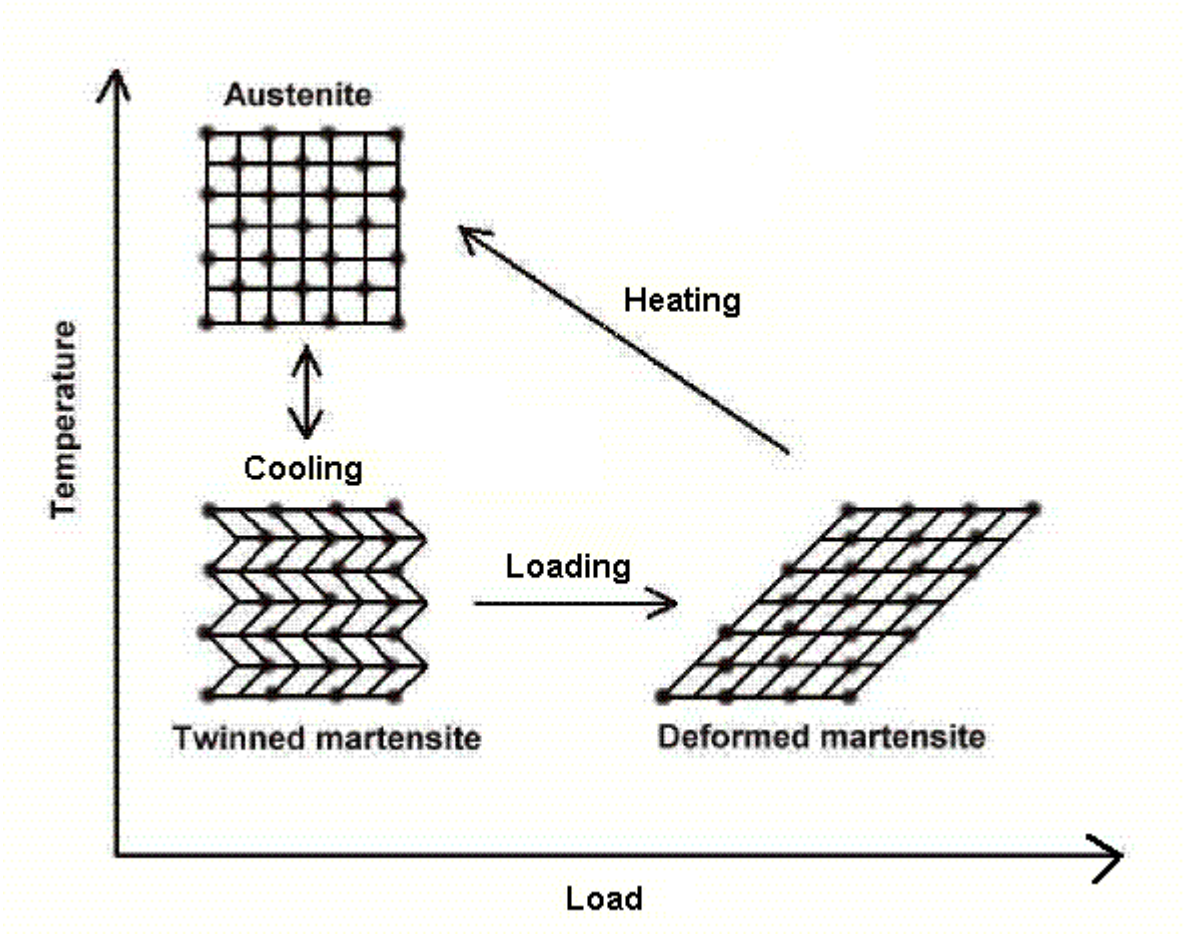

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- Eyeglass Frames
- Bra Underwires
- Medical Tools
- Cellular Phone Antennae
- Orthodontic Arches

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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