SHAPE MEMORY ALLOYS

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ABSTRACT

The aim of this seminar is an introduction to shape memory alloys, the materials that change shape on applying heat. This paper contains a brief history, description of general characteristics of the shape memory alloys and their advantages and limitations. At the end are mentioned groups of most widely used commercial applications.

CONTENTS

1. INTRODUCTION

Metals are characterized by physical qualities as tensile strength, malleability and conductivity. In the case of shape memory alloys, we can add the anthropomorphic qualities of memory and trainability. Shape memory alloys exhibit what is called the shape memory effect. If such alloys are plastically deformed at one temperature, they will completely recover their original shape on being raised to a higher temperature. In recovering their shape the alloys can produce a displacement or a force as a function of temperature. In many alloys combination of both is possible. We can make metals change shape, change position, pull, compress, expand, bend or turn, with heat as the only activator.

Shape memory alloys have found use in everything from space missions (pathfinder and many more) to floral arrangement (animated butterflies, dragon flies and fairies), from bio-medical applications, to actuators for miniature robots and cell phone antennas and even eyeglasses use SMA wires for their extreme flexibility.

2. HISTORY

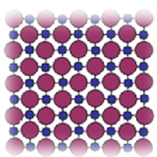
First observations of shape memory behaviour were in 1932 by Olander in his study of "rubber like effect" in samples of gold–cadmium and in 1938 by Greninger and Mooradian in their study of brass alloys (copper–zinc). Many years later (1951) Chang and Read first reported the term "shape recovery". They were also working on gold–cadmium alloys. In 1962 William J. Buehler and his co–workers at the Naval Ordnance Laboratory discovered shape memory effect in an alloy of nickel and titanium. He named it NiTiNOL (for Nickel–Titanium Naval Ordnance Laboratory).

3. DEFINITION OF A SHAPE MEMORY ALLOY

Shape memory alloys are a unique class of metal alloys that can recover apparent permanent strains when they are heated above a certain temperature. The shape memory alloys have two stable phases - the high–temperature phase, austenite and the low–temperature phase, martensite.

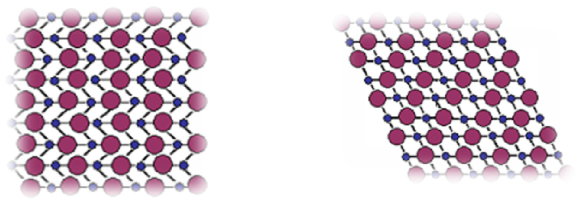
Austenite

- High temperature phase
- Cubic crystal structure



Martensite

- Low temperature phase
- Monoclinic Crystal Structure



Twinned Martensite   Detwinned Martensite

Figure 1: Different phases of a shape memory alloy

The key characteristic of all shape memory alloys is the occurrence of a martensitic phase transformation which is a phase change between two solid phases and involves rearrangement of atoms within the crystal lattice. The martensitic transformation is associated with an inelastic deformation of the crystal lattice with no diffusive process involved. The phase transformation results from a co operative and collective motion of atoms on distances smaller than the lattice parameters. When a shape memory alloy undergoes a martensitic phase transformation, it transforms from its high–symmetry (usually cubic) austenitic phase to a low symmetry martensitic phase (highly twinned mono clinic structure).

Upon cooling without applied load the material transforms from austenite into twinned martensite. With heating twinned martensite, a reverse martensitic transformation takes place and the material transforms to austenite.

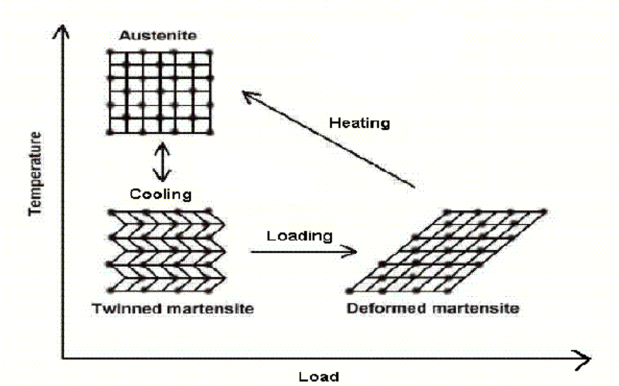


Figure 2: Shape Memory Effect

4. TYPES OF SHAPE MEMORY EFFECTS

4.1 ONE WAY MEMORY EFFECT

If an alloy, which is in a state of self–accommodated martensite, is deformed by applying mechanical load and then unloaded, remains deformed. If the alloy is then reheated to a temperature above the austenite finish temperature, it recovers original macroscopic shape. This is so called one–way memory effect. During the one–way memory effect internal structural changes take place. When we apply load to the self–accommodated martensite, this structure becomes deformed through variant rearrangement, resulting in a net macroscopic shape change. If the alloy is now reheated to a temperature above the martensitic transformation range the original parent phase microstructure and macroscopic geometry is restored. This is possible because no matter what the post deformation distribution of martensite variants, there is only one reversion pathway to parent phase for each variant. If the alloy is cooled again under martensitic finish temperature, a self–accommodated martensite microstructure is formed and the original shape before deformation is retained. Thus one–way shape memory is achieved.

4.2 TWO WAY MEMORY EFFECT

In one–way memory effect there is only one shape "remembered" by the alloy. That is the parent phase shape (so-called hot shape). Shape memory alloys can be processed to remember both hot and cold shapes. They can be cycled between two different shapes without the need of external stress. Two–way shape memory changes rely entirely on micro-structural changes during martensitic transformation which occur under the influence of internal stress. Self–accommodation of the martensite microstructure is lost in the two-way effect due to the presence of these internal stresses. Internal stress may be introduced in a number of ways. Usually we talk about "training" of shape memory alloy. Internal stress is usually a result of irreversible defects which can be introduced through cyclic deformation between hot and cold shapes at a temperature above austenite finish temperature.

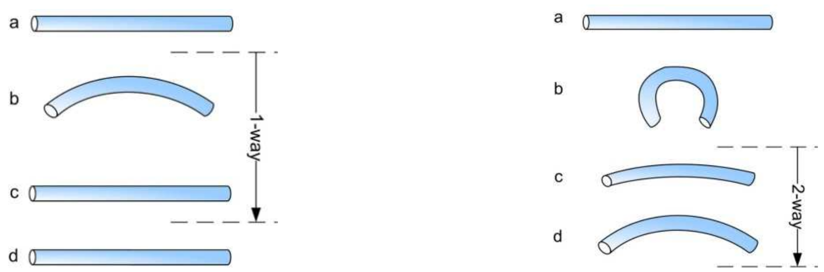


Figure 3: Starting from martensite (a), adding a reversible deformation for the one-way effect or severe deformation with an irreversible amount for the two-way (b), heating the sample (c) and cooling it again (d).

5. PSEUDOELASTICITY OR SUPERELASTIC EFFECT

One of the commercial uses of shape-memory alloy exploits the pseudo-elastic properties of the metal during the high-temperature (austenitic) phase. The frames of reading glasses have been made of shape-memory alloy as they can undergo large deformations in their high-temperature state and then instantly revert back to their original shape when the stress is removed. This is the result of pseudo-elasticity; the martensitic phase is generated by stressing the metal in the austenitic state and this martensite phase is capable of large strains. With the removal of the load, the martensite transforms back into the austenite phase and resumes its original shape.

This allows the metal to be bent, twisted and pulled, before reforming its shape when released. This means the frames of shape-memory alloy glasses are claimed to be "nearly indestructible" because it appears that no amount of bending applied on it results in permanent plastic deformation.

6. ADVANTAGES AND DISADVANTAGES

Some of the main advantages of shape memory alloys include:

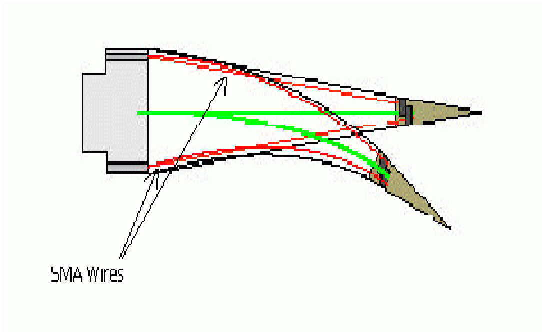
- Bio-compatibility
- Diverse Fields of Application
- Good Mechanical Properties (strong, corrosion resistant)

The use of NiTi as a biomaterial has severable possible advantages. Its shape memory property and super elasticity are unique characteristics and totally new in the medical field. The possibility to make self-locking, self expanding and self- compressing thermally activated implants is fascinating. As far as special properties and good bio compatibility are concerned, it is evident that NiTi has a potential to be a clinical success in several applications in future.

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.

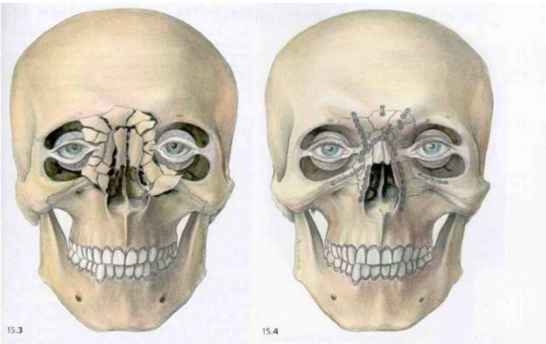
7. APPLICATIONS

- **AIRCRAFT MANEUVERABILITY**

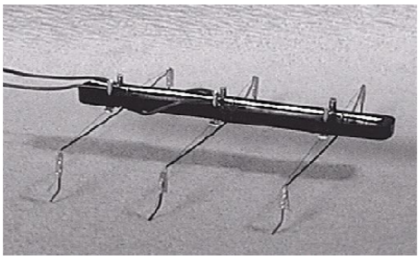


The wire on the bottom of the wing is shortened through the shape memory effect, while the top wire is stretched bending the edge downwards, the opposite occurs when the wing must be bent upwards. The shape memory effect is induced in the wires simply by heating them with an electric current.

- **BONE PLATES**



Bone plates are surgical tools, which are used to assist in the healing of broken and fractured bones. The breaks are first set and then held in place using bone plates in situations where casts cannot be applied to the injured area. Bone plates are often applied to fractures occurring to facial areas such the nose, jaw or eye sockets. Bone plates can be fabricated using shape memory alloys.



- **MINIATURIZED WALKING ROBOT**

The implementation of SMA wires coupled with a simple DC control system can be used to drive small objects without the addition of relatively heavy motors, gears, or drive mechanisms.

- **ROBOTIC MUSCLE**

Shape memory alloys mimic human muscles and tendons very well. SMA's are strong and compact so that large groups of them can be used for creating a life-like movement unavailable in other systems.

8. CONCLUSION

The many uses and applications of shape memory alloys ensure a bright future for these metals. Research is currently carried out at many robotics departments and materials science departments. With the innovative ideas for applications of SMAs and the number of products on the market using SMAs continually growing, advances in the field of shape memory alloys for use in many different fields of study seem very promising.

There are many possible applications for SMAs. Future applications are envisioned to include engines in cars and airplanes and electrical generators utilizing the mechanical energy resulting from the shape transformations. Other possible automotive applications include using SMA springs in engine cooling, carburetor and engine lubrication controls.

9. REFERENCES

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