IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.67
Volume 5, Issue 6, March 2025

Shape-Memory Alloys for Multiple Applications in the Materials World

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Abstract: *Shape-memory alloys (SMAs) are stimuli-responsive shape-changing polymers. They are of great interest for fundamental research and technological innovation. Traditional shape memory alloys (SMAs) are those capable of memorizing a temporary shape and recovering to the permanent shape upon heating. Although such a basic concept has been known for half a century, recent progresses have challenged the conventional understanding of the polymer shape memory effect and significantly expanded the practical potential of SMAs. In this article, notable recent advances in the field of SMAs are highlighted. Particular emphasis is placed on how the new developments have changed the conventional view of SMAs, what they mean for practical applications, and where the future opportunities are. Shape memory alloys are used in a variety of fields, such as medical or aeronautical. Other fields of knowledge have been researching these materials, attracted by their capacity to dissipate energy through high-strain hysteretic cycles without significant residual strains. Because of these interesting properties for seismic protection, an example of the possible beneficiaries of these materials is civil engineering structures*

Keywords: Shape-memory alloys

I. INTRODUCTION

Different materials are used in various applications. As per the applications materials need to have some desired properties. It is a great advantage if a material has one or more properties that can be significantly changed in a controlled fashion by external stimuli. Smart materials have properties those react to changes in their environment. “Smartness” of a material is characterized by self-adaptability, self-sensing memory and decision making. Smart materials are the materials which respond with shape or other property change upon application of externally applied driving forces (electrical, magnetic and thermal). In other words, smart materials refer to materials which can undergo controlled transformations through physical interactions and are structured with multi-functionality. This means that one of their properties can be changed by an external condition, such as temperature, light, pressure, electricity, voltage, pH, or chemical compounds. This change is reversible and can be repeated many times. There is a wide range of different smart materials. Each offer different properties which can be changed. Some materials are very good indeed and cover a huge range of the scales. One of the smart materials is shape memory alloys (SMAs). Shape memory alloys (SMAs) are metals, which exhibit two very unique properties, pseudo elasticity and the shape memory effect. A shape-memory alloy is an alloy that "remembers" its original shape and that when deformed returns to its pre-deformed shape when heated. This material is a lightweight, solid-state alternative to conventional actuators such as hydraulic, pneumatic, and motor-based systems. Due to their advanced properties as compared to other materials, these Shape Memory Alloys (SMAs) can be used in many applications in material areas like in fabrication, modeling. Potential applications of the SMAs-based materials as medical and biomimetic devices, self-healing systems, self-deployable structures, actuators, sensors, etc. or their direct implementation in the industry are finally outlined [1].

II. HISTORY

First observation of shape memory behaviour was in 1932 by Olander in his study of “rubber-like effect” in samples of gold-cadmium and in 1938 by Greininger and Mooradian in their study of brass alloys (Copper-Zinc). Many years later

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(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) [2].

III. DEFINITION OF SHAPE MEMORY ALLOY AND WORKING PRINCIPLE

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 [1]. 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 in volves 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 cooperative 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) [11].

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.

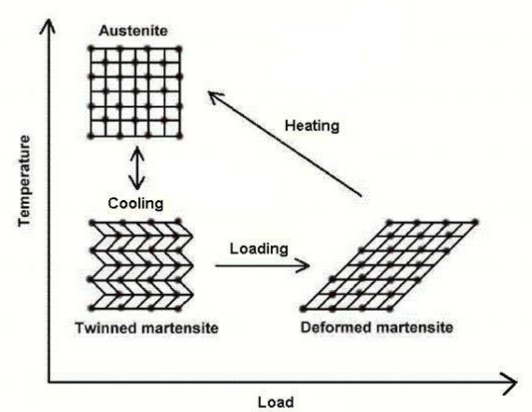

Figure 1: Shape Memory E

IV. WORKING PRINCIPLE

1. A phase transformation which occurs between austenite and martensite phase upon heating/ cooling is the basic for the unique properties of SMAs.
2. The shape change involves a solid-state phase change involving molecular rearrangement between martensite and austenite.
3. Upon cooling in absence of applied load, the material transforms from austenite into twinned martensite (No observable microscopic change occurs).
4. Upon heating the material in the martensitic phase, a reverse phase transformation takes place and as a result the material transforms to austenite.
5. If mechanical load is applied to the material in the state of twinned martensite (at low temperature), it is possible to detwin the martensite.
6. Upon releasing of the load, the material remains deformed. A subsequent heating of the material to a temperature above the austenite finish temperature will results in reverse phase transformation (Martensite to austenite) and will lead to complete shape recovery.
7. SMAs remember the shape when it has austenitic structure.
8. So if we need SMAs to remember and regain/recover certain shape, the shape should be formed when the structure is austenite.
9. Reheating the material will result in complete shape recovery.

V. TYPES OF SHAPE MEMORY EFFECTS

5.1 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 [10].

5.2 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 c old 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.

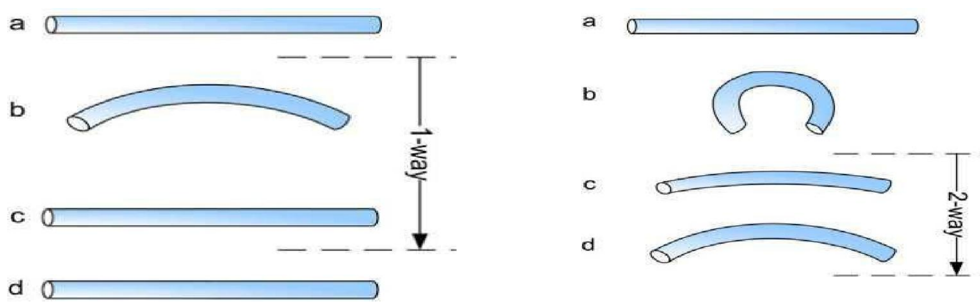

Figure 3: Starting from martensite (a), adding a reversible deformation for the one-way effect or severe deformation with an irreversible amount for the two-way (b), heating the sample (c) and cooling it again (d).

VI. MATERIALS

A variety of alloys exhibit the shape-memory effect. Alloying constituents can be adjusted to control the transformation temperatures of the SMA. Some common systems include the following (by no means an exhaustive list):

- Ag-Cd 44/49 wt.% Cd
- Au-Cd 46.5/50 wt.% Cd
- Co-Ni-Al
- Co-Ni-Ga
- Cu-Al-Ni 14/14.5 wt.% Al, 3/4.5 wt.% Ni
- Cu-Al-Ni-Hf
- Cu-Sn approx. 15 wt.% Sn
- Cu-Zn 38.5/41.5 wt.% Zn
- Cu-Zn-X (X = Si, Al, Sn)
- Fe-Mn-Si

- Fe-Pt approx. 25 wt.% Pt
- Mn-Cu 5/35 wt.% Cu
- Ni-Fe-Ga
- Ni-Ti approx. 55 – 60 wt.% Ni
- Ni-Ti-Hf
- Ni-Ti-Pd
- Ni-Mn-Ga
- Ti-Nb

VII. ADVANTAGES

1. The copper-based and NiTi-based shape-memory alloys are considered to be engineering materials. These compositions can be manufactured to almost any shape and size.
2. The yield strength of shape-memory alloys is lower than that of conventional steel, but some compositions have a higher yield strength than plastic or aluminum. The yield stress for Ni Ti can reach 500 MPa. The high cost of the metal itself and the processing requirements make it difficult and expensive to implement SMAs into a design. As a result, these materials are used in applications where the super elastic properties or the shape-memory effect can be exploited. The most common application is in actuation.
3. One of the advantages to using shape-memory alloys is the high level of recoverable plastic strain that can be induced. The maximum recoverable strain these materials can hold without permanent damage is up to 8% for some alloys. This compares with a maximum strain 0.5% for conventional steels.
4. Light-weight parts.
5. They can acts as solid state alternatives to conventional actuators like hydraulic, pneumatic and motor based systems.
6. Good mechanical properties (Strong, Corrosion resistant).
7. Diverse field of applications due to advanced mechanical properties.

VIII. DISADVANTAGES

1. These alloys are still relatively expensive to manufacture and machine compared to other materials such as steel and aluminum.
2. Most SMA's have poor fatigue properti

IX. APPLICATIONS OF SHAPE MEMORY ALLOYS:

9.1 Aircraft and spacecraft
9.2 Automotive
9.3 Robotics
9.4 Bio-engineered robotic hand
9.5 Civil Structures
9.6 Piping
9.7 Telecommunication
9.8 Medicine
9.9 Optometry
9.10 Orthopedic surgery
9.11 Dentistry
9.12 Essential Tremor
9.13 Engines
9.14 Crafts
9.15 Heating and Cooling

X. 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.

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