Smart Memory Alloys
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Abstract - The aim of presenting this paper is an introduction to shape memory alloys (SMAs), the materials that change shape by applying heat. This paper contains a brief history and a description of general characteristics of the shape memory alloys. At the end are described groups of most widely used commercial applications. Adding just a small proportion of carbon to iron produces a material that is much stronger and harder. Mixing nickel and titanium can produce a material that has the extraordinary property of being able to ‘remember’ a shape. From just a few dozen metallic elements, there are an infinite number of alloys that can be created, each with their own characteristic properties. Understanding how the structure of metals and alloys determines their properties has led to advances in the design of alloys with properties suited to their intended applications.

Index Terms - Introduction to Smart Memory Alloy, Definition, History, Types, Applications.

I. 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.

Key features of products that possess this shape memory property include: high force during shape change; large movement with small temperature change; a high permanent strength; simple application, because no special tools are required; many possible shapes and configurations and easy to use - just heat. Because of these properties shape memory alloys are helping to solve a wide variety of problems. In one well-developed application shape memory alloys provide simple and virtually leak proof couplings for pneumatic or hydraulic lines. The alloys have also been exploited in mechanical and electromechanical control systems to provide, for example, a precise mechanical response to small and repeated temperature changes. Shape memory alloys are also used in a wide range of medical and dental applications.

II. DEFINITION

A shape-memory alloy (SMA, smart metal, memory metal, memory alloy, muscle wire, smart alloy) is an alloy that "remembers" its original, cold-forged shape returning the pre-deformed shape by heating. This material is a lightweight, solid-state alternative to conventional actuators such as hydraulic, pneumatic, and motor-based systems. Shape-memory alloys have applications in industries including medical and aerospace. The shape memory alloys have two Stable phases - the high-temperature phase, called austenite (named after English metallurgist William Chandler Austen) and the low-temperature phase, called martensite (named after German metallographer Adolf Martens).

III. BASICS ABOUT SHAPE MEMORY ALLOYS

In 1932, Chang and Read observed a reversible phase transformation in gold–cadmium (Au-Cd), which is the first record of the shape memory transformation. It was after 1962, when Buechler and co-researchers discovered the shape memory effect (SME) in nickel–titanium at Naval Ordnance Laboratory (they named the material Nitinol after their workplace), that both in-depth research and practical applications of shape memory alloys emerged. Up to date, many types of shape memory alloys have been discovered. Among them, Nitinol possesses superior thermo-mechanical and thermo-electrical properties and is the most commonly
used SMA. In this paper, SMAs are referred to as Nitinol SMAs unless another type of SMA is specified. The following reviews two important properties of Nitinol SMAs: the shape memory effect and the super elasticity.

A. One-Way Memory Effect.

When a shape-memory alloy is in its cold state (i.e. below \( A_s \)), the metal can be bent or stretched and will hold those shapes until heated above the transition temperature. Upon heating, the shape changes to its original. When the metal cools again it will remain in the hot shape, until deformed again. With the one-way effect, cooling from high temperatures does not cause a macroscopic shape change. A deformation is necessary to create the low-temperature shape. On heating, transformation starts at \( A_s \) and is completed at \( A_f \) (typically 2 to 20 °C or hotter, depending on the alloy or the loading conditions). \( A_s \) is determined by the alloy type and composition and can vary between “150 °C and 200 °C.

![Fig. 2. One-Way Memory Effect.](image)

B. Two-Way Memory Effect.

The ability of SMA to recover a specific shape upon heating and then return to an alternate shape when cooled (below the transformation temperature) is known as two-way shape memory.

![Fig. 3. Two-Way Memory Effect](image)

However, there are limitations that reduce the usability of the two-way effect, such as smaller strains (2 %), extremely low cooling transformation forces and unknown long-term fatigue and stability. Even slight overheating removes the shape memory effect in two-way devices. Setting shapes in two-way SMAs is a more complex procedure than the one used with one-way SMAs. A shaped, trained object heated beyond a certain point will lose the two-way memory effect; this is known as "amnesia".

C. Super Elasticity

Like the smart alloys described earlier, super elastic alloys also have a ‘memory’. When they are bent or stretched they return to their original shape, though they do not need to be heated to do this. These are the alloys used in some spectacle frames; by making the bridge and sides from super elastic alloy, the frames can be bent or twisted without being permanently deformed. Super elastic alloy is also used in the arch wires in dental braces, which can be stretched, positioned and released, thus exerting a force on the teeth. In medicine, the alloy is widely used for making stents. These are cylinders of wire mesh that are inserted into a hollow structure of the body to keep it open, for example, an artery, vein, urethra or trachea. Super elastic alloys also find applications in bra underwire and mobile phone antennae.

![Fig. 4. Super Elastic Eye-Ware Frame.](image)

IV. MANUFACTURE

Shape-memory alloys [1] are typically made by casting, using vacuum arc melting or induction melting. These are specialist techniques used to keep impurities in the alloy to a minimum and ensure the metals are well mixed. The ingot is then hot rolled into longer sections and then drawn to turn it into wire.

The way in which the alloys are “trained” depends on the properties wanted. The “training” dictates the shape that the alloy will remember when it is heated. This occurs by heating the alloy so that the dislocations re-order into stable positions, but not so hot that the material recrystallizes. They are heated to between 400 °C and 500 °C for 30 minutes. Typical variables for some alloys are 500 °C and for more than 5 minutes. They are then shaped while hot and are cooled rapidly by quenching in water or by cooling with air.
IV. APPLICATIONS

A. Super Elasticity

Among the various principles of SMA application, super elastic devices are the most significant in both material consumption and commercial value. Today, [2] Ni-Ti SMA has achieved a permanent place in high-end eyeglass frames. The use of super elastic SMA[3 -5] components for the nose piece (bridge) and ear pieces (Temples) provide improved wearer comfort as well as great resistance to accidental damage. To achieve the highly kink-resistant super elasticity over a wide range of environmental temperatures, these components are usually highly cold-worked followed by a low temperature heat treatment to impart “work-hardened Pseudo elasticity”. [6]

B. Dental Wires

Used for braces and dental arch wires, memory alloys maintain their shape since they are at a constant temperature, and because of the super elasticity of the memory metal, the wires retain their original shape after stress has been applied and removed.

C. Force Actuators

In some applications, the shape memory component is designed to exert force over a considerable range of motion, often for many cycles. Such an application is a circuit-board edge connector in which the SME 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 nickel-titanium actuator becomes weaker, and the spring easily deforms the actuator while it closes tightly on the circuit board and forms the connections.

Based on the same principle, Cu-Zn-Al shape memory alloys have found several applications in this area. One such example is a fire safety valve, which incorporates a Cu-Zn-Al actuator designed to shut off toxic or flammable gas flow when fire occurs.

D. Constrained Recovery

Some hydraulic couplings 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 as the coupling attempts to do so are great enough to create a joint that, in many ways, is superior to a weld.

E. Bones

Broken bones can be mended with shape memory alloys. The alloy plate has a memory transfer temperature that is close to body temperature, and is attached to both ends of the broken bone. From body heat, the plate wants to contract and retain its original shape, therefore exerting a compression force on the broken bone at the place of fracture. After the bone has healed, the plate continues exerting the compressive force, and aids in strengthening during rehabilitation. Memory metals also apply to hip replacements, considering the high level of super-elasticity.

F. Robotics

There have also been limited studies on using these materials in robotics, for example the hobbyist robot Stiquito (and “Roboterfrau Lara), as they make it possible to create very light robots. Weak points of the technology are energy inefficiency, slow response times, and large hysteresis.

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.

CONCLUSIONS

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.

REFERENCES