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Memory metals

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SMAs are used to make flexible glasses frames

Carol Tear explains how shape memory alloys work, and explores some of their uses

Do you or some of your friends wear glasses, or have retainers or aligners to straighten your teeth? These items often use shape memory alloys (SMAs). SMAs are metals that can be deformed, such as by bending or stretching, but return to their original shape when heated to a certain temperature.

Phases of nitinol

Nitinol is an alloy of nickel and titanium. It is an SMA because of the different phases of its crystal structure. It has a 'hot' state, where the atoms are in an ordered, compact crystalline structure called the austenite structure or phase. In this phase it is a tough, ductile and super-elastic material. It can absorb up to 8% strain before being plastically deformed, which is 10–30 times greater than other metals.

When the alloy cools there is a transition to a different structure called the martensite phase. The atoms rearrange themselves into a 'twinned' martensite structure, which is not so hard and is more flexible. It can be deformed by a large amount by becoming 'detwinned' when stress is applied. Twinned crystals are crystals of the same type that grow together in a symmetrical way, sharing some of the same lattice points at the boundary, but are orientated slightly differently to each other. Detwinning changes the crystals so they both have the same orientation.

When nitinol is heated to a certain temperature, called its transformation temperature, it returns to the austenite structure and its original shape. This process is reversible.

Changing the temperature

The transformation temperature depends on the proportions of nickel and titanium. Let's consider nitinol with a transformation temperature of 110°C. To train the alloy into the original shape, it is heated to a high temperature – about 500°C – and formed into the permanent shape. It is then cooled. Above 110°C, it is strong and super-elastic. When it is cooled below 110°C, it is less stiff and has a lower Young modulus. This means that it is flexible and can be bent or deformed. This alloy is used for making flexible products that may get deformed, but can be restored to their original shape by heating to 110°C.

In contrast, if nitinol has a transformation temperature of below room temperature, such as 15°C, it is in the austenite phase at room temperature. It will be very strong and have super-elastic properties, and when it is bent, it will go back to the original shape as soon as the stress is released.

Uses in health and medicine

SMAs with a transformation temperature of about 110°C are used to make flexible glasses frames. They

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are particularly useful for people whose lifestyle means they often bend or twist the frames, because they are flexible enough not to break and can be heated to return to their original shape.

Using nitinol with a transformation temperature just below body temperature enables its shape memory properties to be used in medical implants. For example, when treating bone fractures, staples of nitinol are manufactured in a closed state, and then cooled below the body temperature to make them flexible. They are deformed into an open position and inserted, after which the body temperature warms the staple, so that it tries to return to the original closed shape. It continues to exert compressive forces, holding the bone together to promote healing and provide structural support. All sorts of implants using this effect are developed for different purposes in the body.

Orthodontic wires are used to provide a small force to pull teeth gently into the correct position as the wires try to straighten. SMAs are stronger and have a lower Young modulus than stainless steel alloys. Higher temperatures tighten the wires and increase the force. When they are first fitted, some wearers are advised that if the tension is uncomfortable, cool drinks or ice will give some relief from the tension by cooling the wires and making them more flexible.

Nitinol is also used to make coronary stents. Coronary stents are short wire mesh tubes that act like a scaffold to keep an artery open. They expand inside the blood vessels to improve blood flow.

Other uses

On a different scale, SMAs have uses that range from reinforcing concrete bridges to protecting heritage buildings and lifting loads. The first SMA bridge reinforcement took place in Michigan in the USA when alloy rods were fixed across a crack and heated to 300°C by passing an electric current through them, causing them to pull the crack closed. Some churches in Italy have had SMAs installed to repair earthquake damage and there is currently interest in designing buildings that will absorb energy during an earthquake by being deformed, allowing them to be repaired rather than demolished.

In the aerospace and automotive industries, SMAs have many uses as actuators and vibration dampers. An actuator is a component that produces a force or displacement by transferring energy. The links in the 'Resources' box show how heating and cooling a nitinol wire can produce movement.

Questions

1 Describe the properties of materials that are:

a tough
b ductile
c elastic
d hard
e stiff
f strong

Answer

a Absorbs shock, difficult to break
b Deforms by bending, twisting or stretching
c Returns to its original shape when the force is removed
d Difficult to scratch or indent
e Difficult to bend
f Withstands compression, tension and shear forces

Resources

Videos about SMAs:

https://tinyurl.com/metal-memory-mars
https://tinyurl.com/metal-SMA
https://tinyurl.com/SMAs-rocks