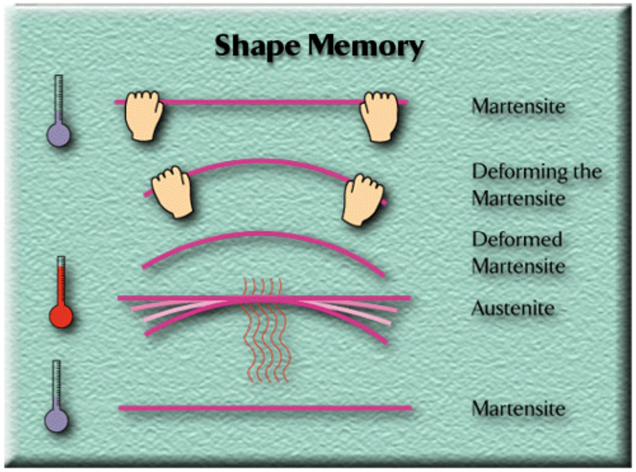
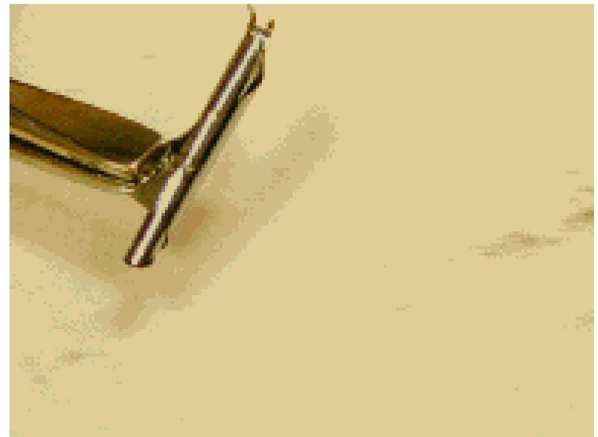
MECHANICAL & INDUSTRIAL ENGINEERING DEPARTMENT
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

Chapter 5. Shape Memory Materials

What's Shaped Memory Alloys





Shape Memory Alloys (SMA's) are novel materials that have the ability to return to a predetermined shape when heated. When a SMA is cold, or below its transformation temperature, it has a very low yield strength and can be deformed quite easily into any new shape-which it will retain. However, when the material is heated above its transformation temperature it undergoes a change in crystal structure, which causes it to return to its original shape.

DID YOU KNOW?

THAT YOU CAN NOW HAVE…

- Eyeglass frames that can be bent totally out of shape and return to their original shape upon warming
- Orthodontic wires that reduce the need to retighten and adjust the wire
- A shirt which moulds to the shape of your body, or shortens and lengthens the sleeves to match the temperature.

EXPERIMENT 1 INVESTIGATING NITINOL

SHAPE MEMORY ALLOY–NITINOL

- **What is it?**

  One type of shape memory alloy is Nitinol, which is short for Nickel Titanium Naval Ordnance Laboratory and which acknowledges the site of its discovery in 1965

- **Where does it get its name?**

  Nitinol is an alloy of about 56 % Nickel and 44 % Titanium. (Hence the name: Ni–Ti–Naval Ordinance Laboratory)

- **What does it do?**

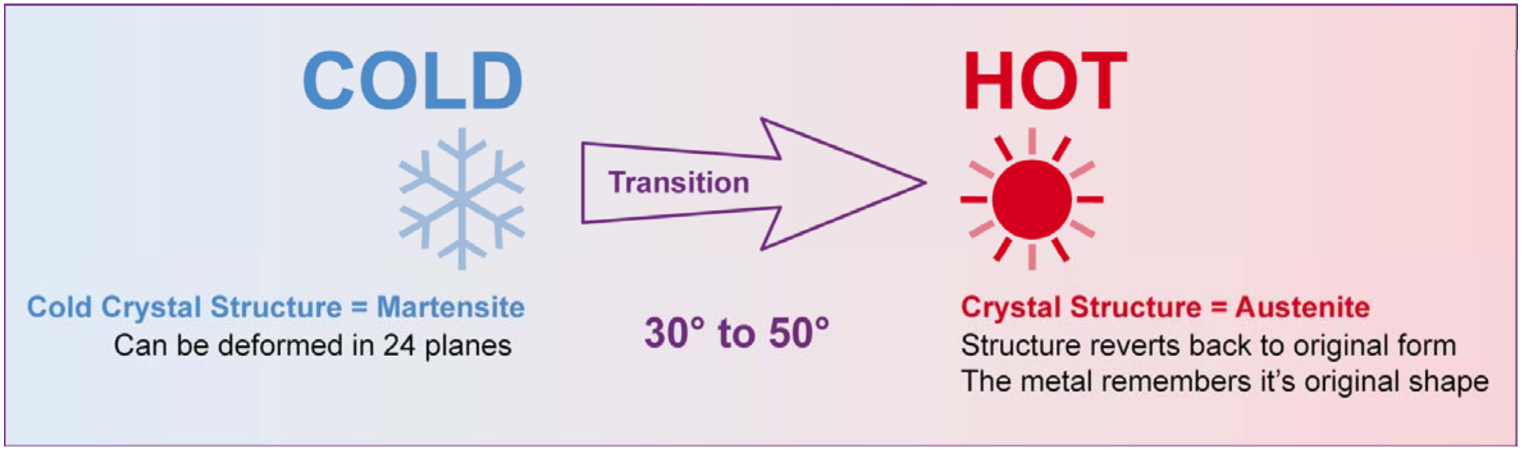
  Nitinol "remembers" its original shape and springs back up to temperatures up to 500 degrees C. Can be strained 8 to 10 times more than spring steel without permanent deformation. Won't kink. Coils easily.

What Is A Shape Memory Alloy?

Nitinol

HOW DOES NITINOL WORK?

- Nitinol is made of Nickel and Titanium
- Most solids have one crystal structure, but Nitinol has two
- The crystal structure is different at cold and hot temperatures
- At cold temps it is soft and easy to bend but at hot temps it is stiff and springy.



WHY IS NITINOL SO VERSATILE?

It has similar properties to human hair and human tendons and is being used in a wide range of applications.

Did You Know?

THAT YOU CAN NOW HAVE…

Nitinol's amazing properties allows surgeons to perform life saving operations

Ninol is used to:

- Seal holes in the heart
- Patch up faulty blood vessels
- Attach tendons to bones.

AMPLATZER® Septal Occluder for heart defect repair utilizes the shape memory of Nitinol

ACTIVITY 1 USES OF NITINOL

Research scientists, innovators and artists are always finding new creative uses for Nitinol.

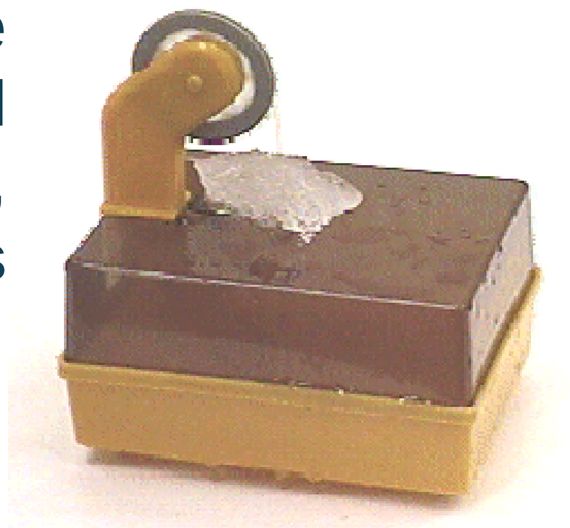
- Knee replacements
- Spectacle frames
- Medical stents
- Repair broken bones
- Replace damaged discs.
- What else?

Search the net to find current uses of Nitinol and add to the list.

Applications of Nitinol

THE ICEMOBILE

A Nitinol heat engine, called the Icemobile has a loop of Nitinol which you immerse in warm water, to make it spin (which then cuts up ice cubes).



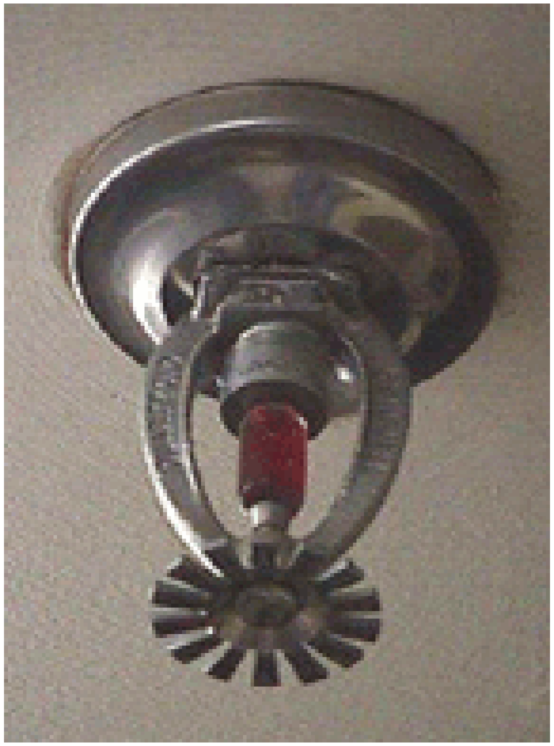
Applications of Nitinol

NO MORE OIL BURNS

A deep fryer that senses the right temperature for when to lower the basket into the oil!

APPLICATIONS OF NITINOL

A DETECTOR FOR FIRE ALARM SPRINKLER SYSTEM.



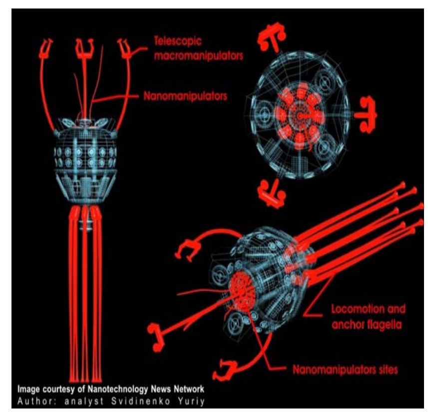
When there is a fire the temperature will affect the electrical circuit and trigger the sprinkler.

APPLICATIONS OF NITINOL

ROBOTICS

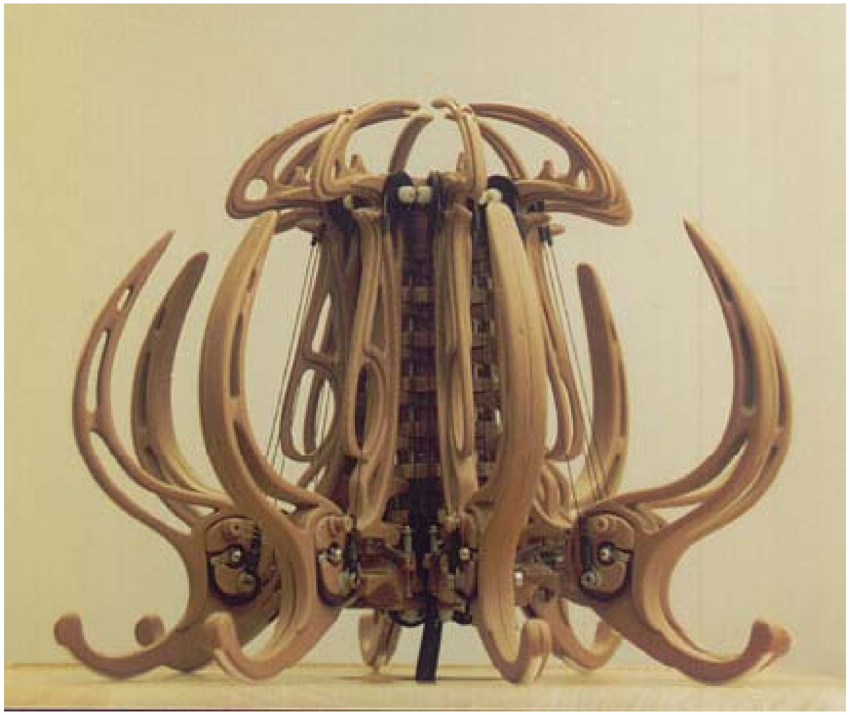
Watch clip of “Inchworm Robot” using SMA wire to make it move.

When there is a fire the temperature will affect the electrical circuit and trigger the sprinkler.



NITINOL IN ART

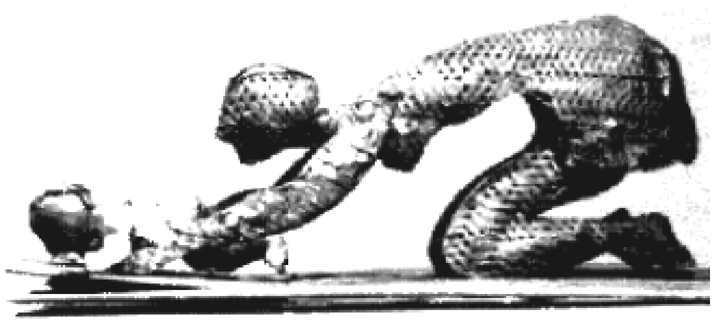
ARTISTS PRODUCE CREATIVE PIECES WITH NITINOL



This sculpture senses its environment and reacts by bending and moving its legs through the use of Nitinol.

NITINOL IN ART

ARTISTS PRODUCE CREATIVE PIECES WITH NITINOL



This famous sculpture "Espoir – Desespoir" by Olivier Deschamps has inspired students at St Helena Secondary College to become creative artists when they designed Kinetic Wire Sculptures.

ACTIVITY 2 NITINOL ART

Design a figurative sculpture or an innovative product which performs a movement with a change in temperature.

ACTIVITY 3 NITINOL ART

DESIGNING WITH NITINOL.

Shaped Memory Effect

At a low temperature, a SMA can be seemingly "plastically" deformed, but this "plastic" strain can be recovered by increasing the temperature. This is called the Shape Memory Effect (SME). At a high temperature, a large deformation can be recovered simply by releasing the applied force. This behavior is known as Superelasticity (SE).

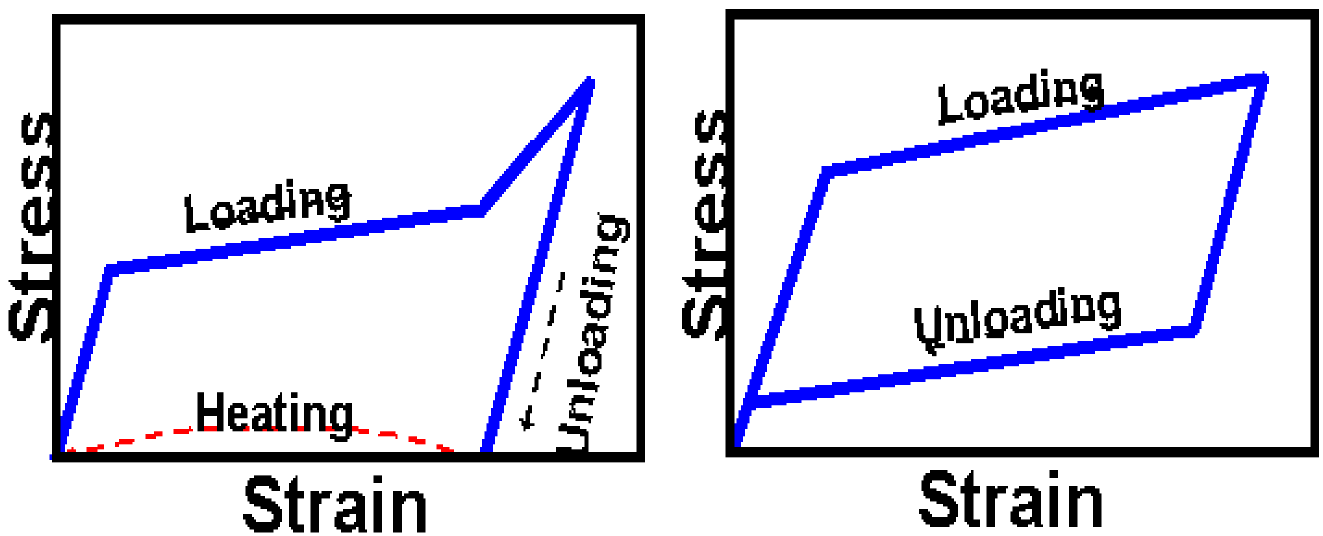


Fig 1. (a) Shape Memory Effect and (b) Superelasticity

Definition of a Shape Memory Alloy

Shape Memory Alloys (SMAs) are a unique class of metal alloys that can recover apparent permanent strains when they are heated above a certain temperature.

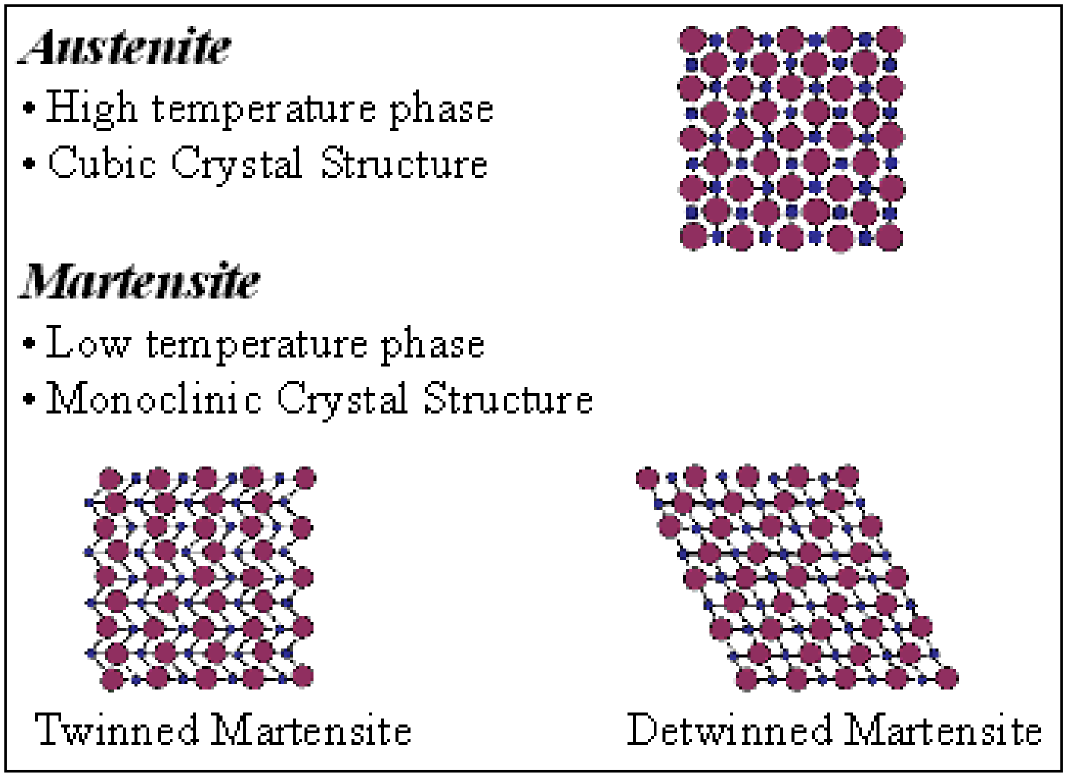


Fig 2. Different phases of an SMA.

Definition of a Shape Memory Alloy

•The SMAs have two stable phases - the high-temperature phase, called *austenite* and the low-temperature phase, called *martensite*. In addition, the martensite can be in one of two forms: *twinned* and *detwinned*, as shown in Figure 2.

•A phase transformation which occurs between these two phases upon heating/cooling is the basis for the unique properties of the SMAs. The key effects of SMAs associated with the phase transformation are *pseudoelasticity* and *shape memory effect*.

Definition of a Shape Memory Alloy

- Upon cooling in the absence of applied load the material transforms from austenite into twinned (self-accommodated) martensite.
- As a result of this phase transformation no observable macroscopic shape change occurs. Upon heating the material in the martensitic phase, a reverse phase transformation takes place and as a result the material transforms to austenite.
- The above process is shown in Figure 3.

Definition of a Shape Memory Alloy

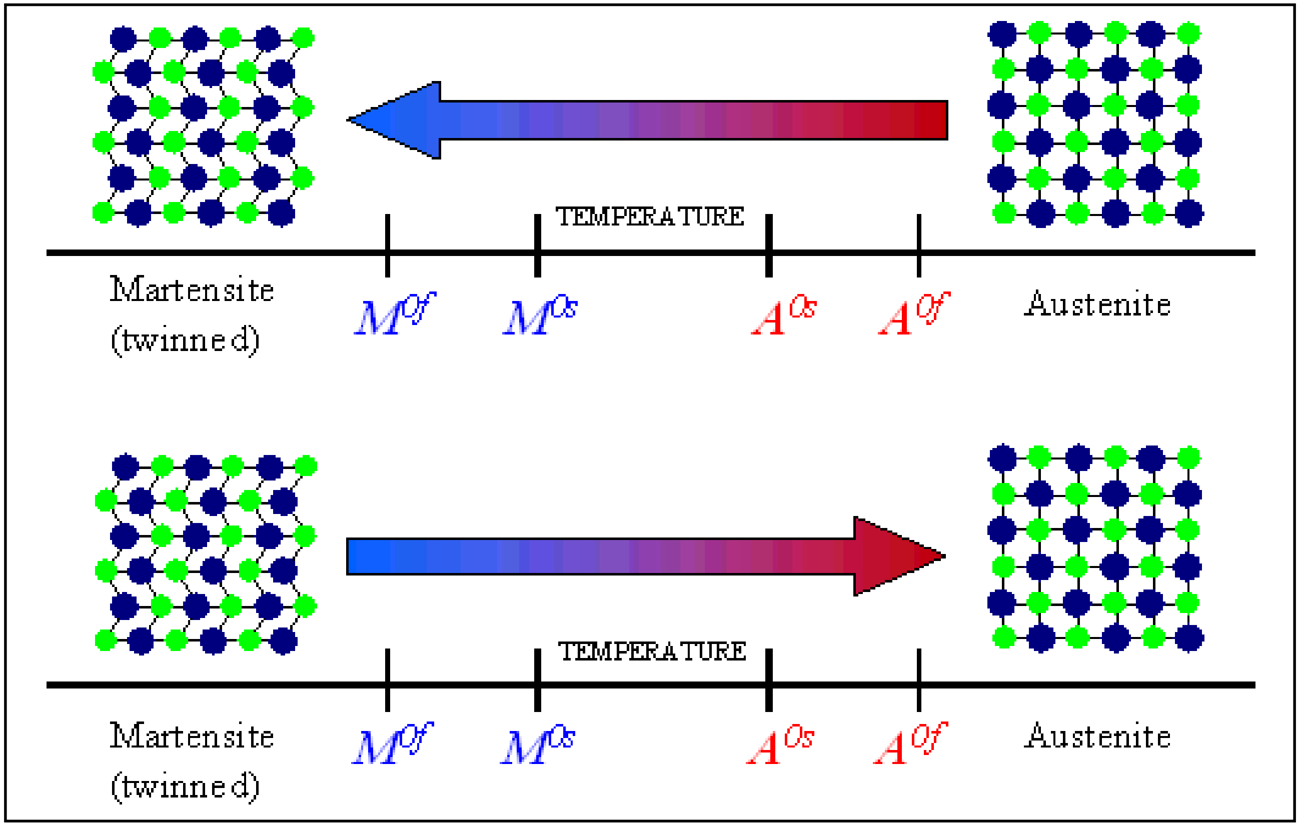


Fig 3. Temperature-induced phase transformation of an SMA without mechanical loading.

Definition of a Shape Memory Alloy

•Four characteristic temperatures are defined in Figure 3: martensitic start temperature (M^{0s}) which is the temperature at which the material starts transforming from austenite to martensite; martensitic finish temperature (M^{0f}), at which the transformation is complete and the material is fully in the martensitic phase; austenite start temperature (A^{os}) at which the reverse transformation (austenite to martensite) initiates; and austenite finish temperature (A^{of}) at which the reverse phase transformation is completed and the material is the austenitic phase.

Thermally-Induced Transformation with Applied Mechanical Load

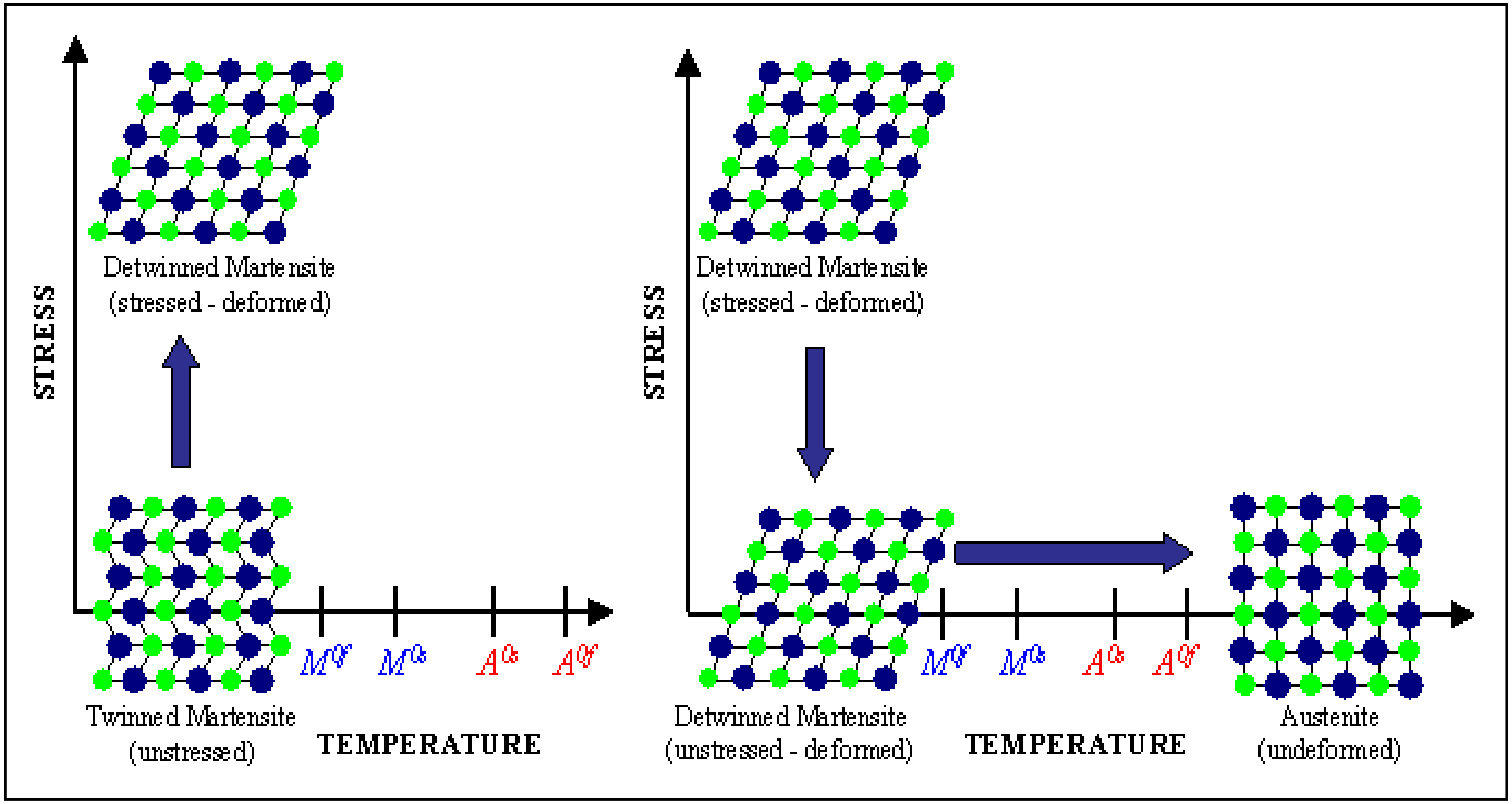
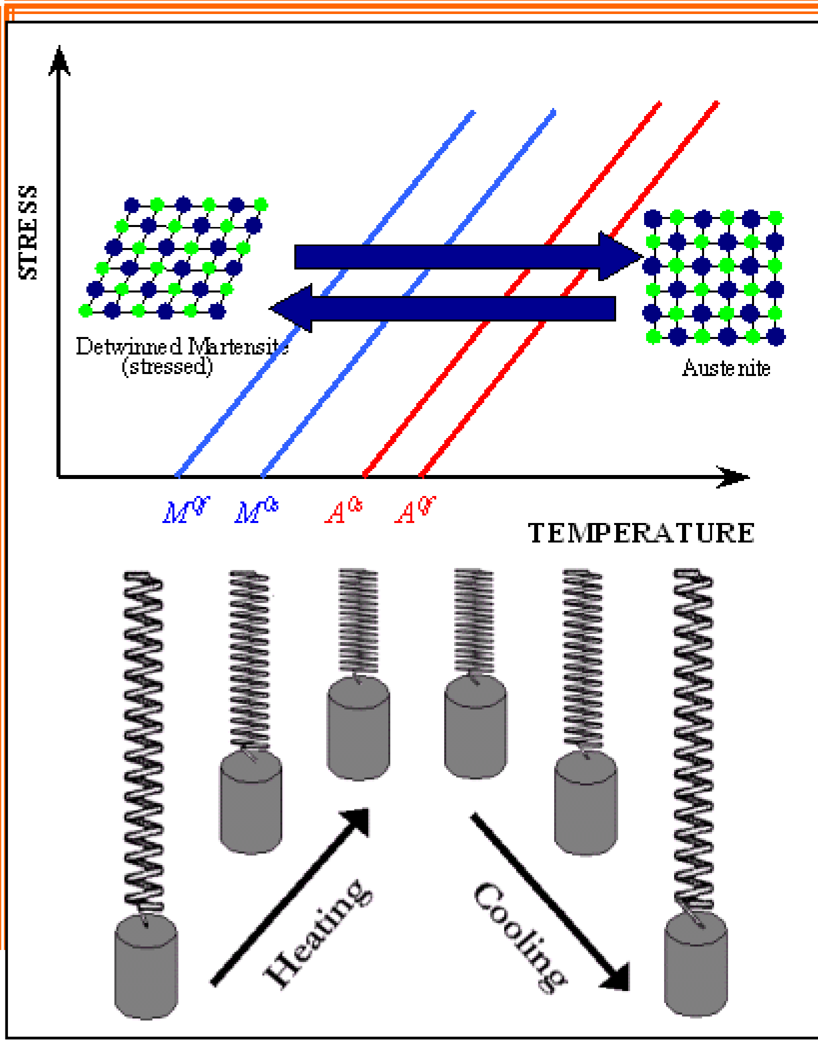


Fig 4. Shape Memory Effect of an SMA.

Thermally-Induced Transformation with Applied Mechanical Load

- If mechanical load is applied to the material in the state of twinned martensite (at low temperature) it is possible to *detwin* the martensite. Upon releasing of the load, the material remains deformed.
- A subsequent heating of the material to a temperature above A^{0f} will result in reverse phase transformation (martensite to austenite) and will lead to complete shape recovery, as shown in Figure 3.
- The above described process results in manifestation of the *Shape Memory Effect* (SME).

Thermally-Induced Transformation with Applied Mechanical Load



It is also possible to induce a martensitic transformation which would lead directly to detwinned martensite. If load is applied in the austenitic phase and the material is cooled, the phase transformation will result in detwinned martensite. Thus, very large strains (on the order of 5-8%) will be observed.

Fig 5. Temperature-induced phase transformation with applied load.

Thermally-Induced Transformation with Applied Mechanical Load

•Reheating the material will result in complete shape recovery. The above-described loading path is shown in Figure 5.

•The transformation temperatures in this case strongly depend on the magnitude of the applied load. Higher values of the applied load will lead to higher values of the transformation temperatures.

•Usually a linear relationship between the applied load and the transformation temperatures is assumed, as shown in Figure 5.

Pseudoelastic Behavior

- It is also possible to induce a phase transformation by applying a pure mechanical load. The result of this load application is fully detwinned martensite and very large strains are observed.
- If the temperature of the material is above A^{0f}, a complete shape recovery is observed upon unloading, thus, the material behavior resembles elasticity. Thus the above-described effect is known under the name of *Pseudoelastic Effect*.
- A loading path demonstrating the pseudoelastic effect is schematically shown in Figure 6, while the resulting stress-strain diagram is shown in Figure 7.

Pseudoelastic Behavior

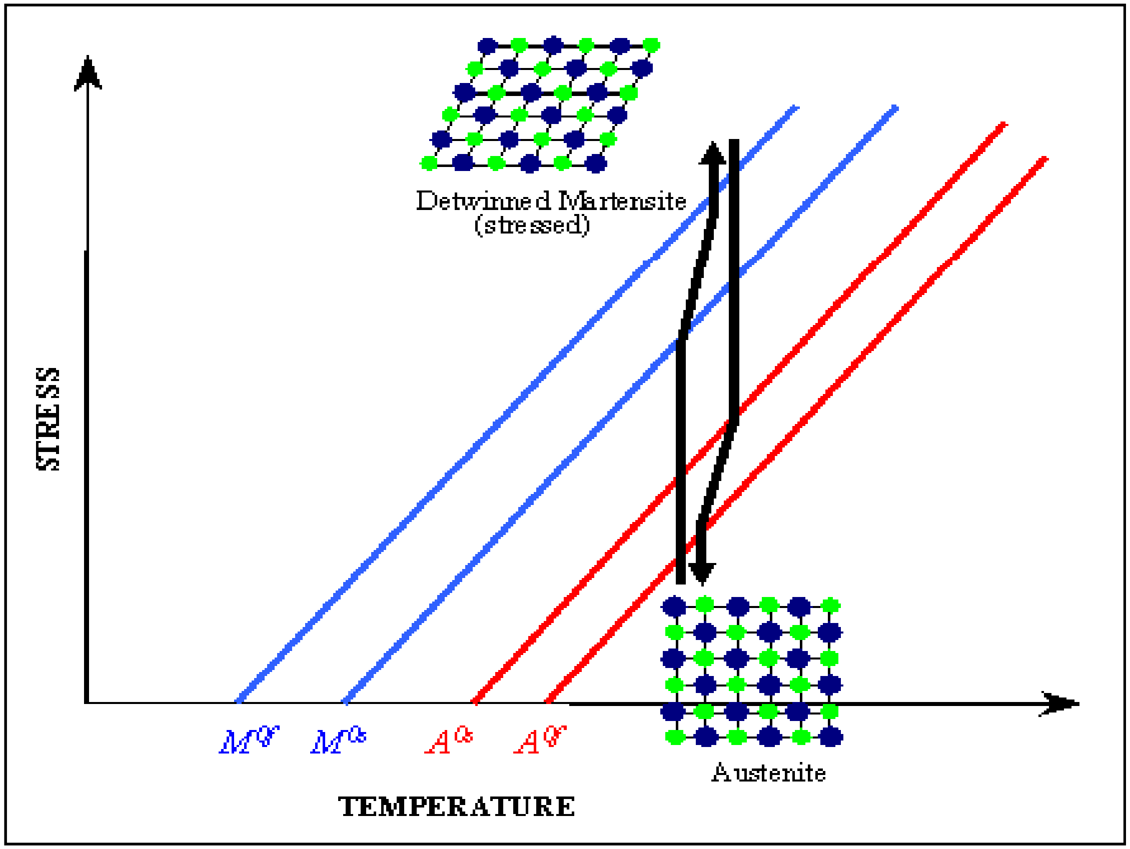


Fig 6. Pseudoelastic loading path.

Pseudoelastic Behavior

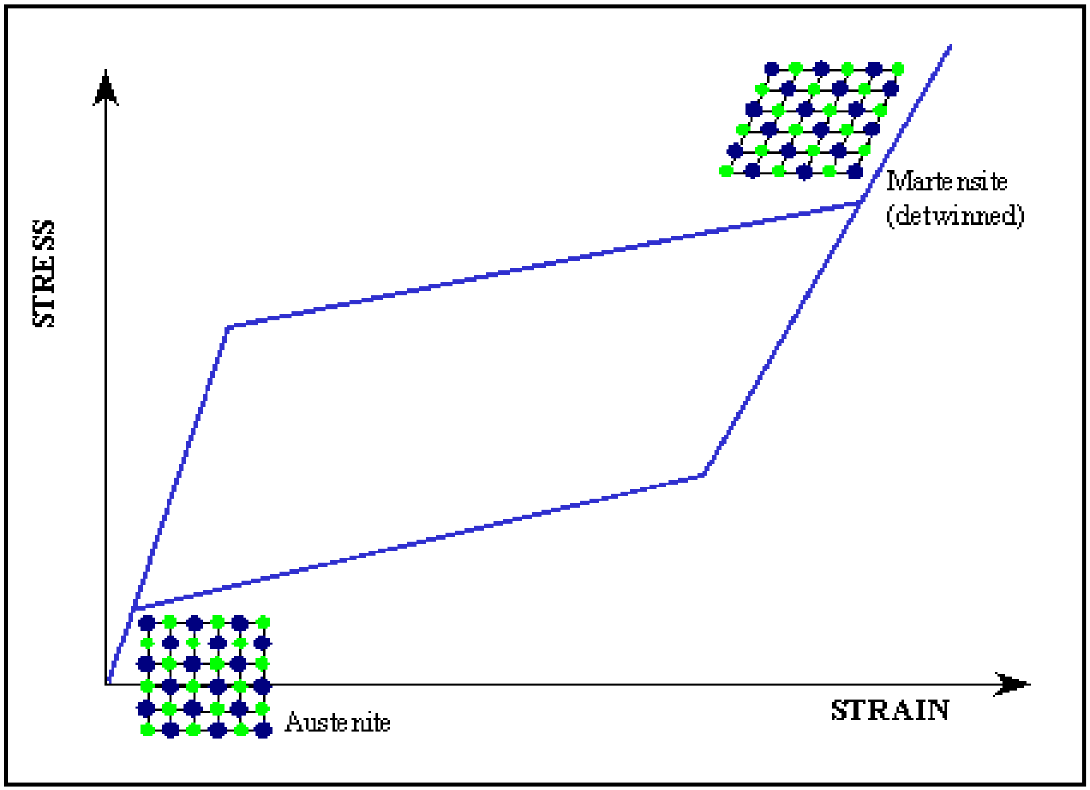
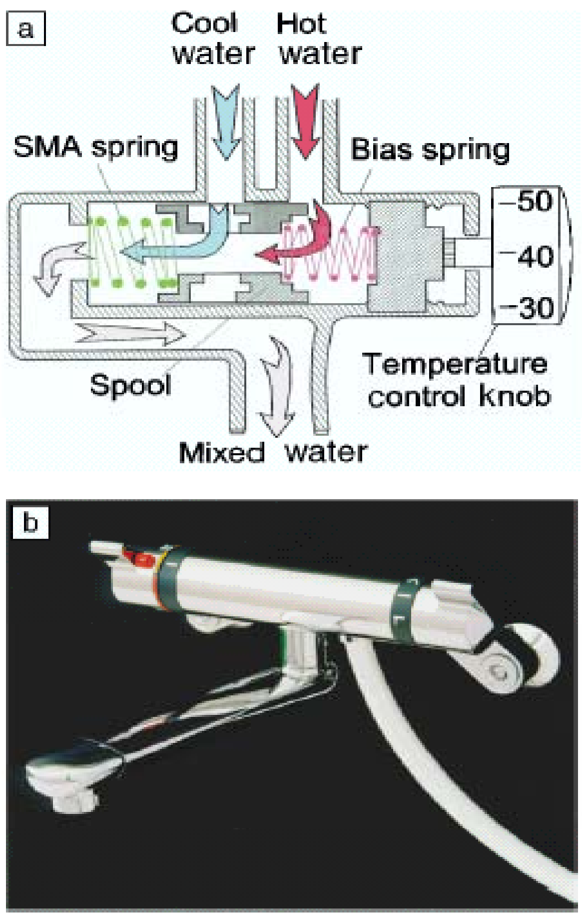


Fig 7. Pseudoelastic stress-strain diagram.

Applications:What can we do with shape memory alloy?



Various thermal actuators then came into existence as a part of electric appliances and automobile engineering: flaps in air conditioners, which charge the direction of airflow depending upon the temperature of the air, coffeemakers, rice cookers, drain systems for steam heaters in trains, outer vent control system to avoid fuel evaporation in automobiles, and devices to open parallel hydraulic channels in automatic transmissions.

Fig 8. Application of the SMAs

Applications: What can we do with shape memory alloy?

- Among there, the application of SMAs to air-conditioner flaps by Matsushita Electric Co. was the most successful, replacing the ordinary sensor/integrated-circuit/relay/motor system with a simple combination of a SMA spring and a bias spring. More than simple device have been sold.

- Let us see how a thermal actuator works, using as an example the recently developed thermostatic mixing valve shown in figure 8. In the application of SMAs to a thermal actuator, there are two basic components, a temperature-sensitive SMA spring and a temperature-insensitive bias spring, both of which are set in series(fig 8 (a)) and thus resist each other.

- Usually the SMA spring is harder than the bias spring in the parent phase and softer than the bias spring in the martensitic state. Thus, when the temperature is too high, the SMA spring is stronger than the bias one, and the opening for hot water becomes smaller than that for cold water.

Applications: What can we do with shape memory alloy?

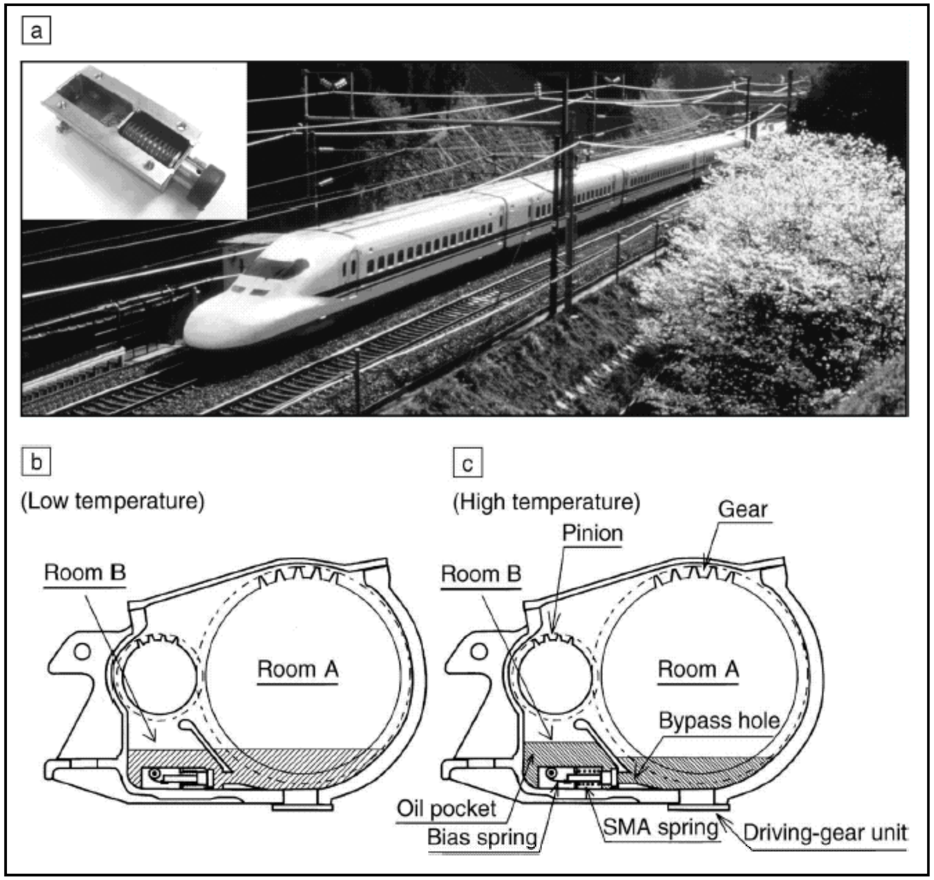


Fig 9. Application of SMAs to an automatic oil-level-adjustment device for the Shinkansen bullet train. (a) Photograph of the Shinkansen Nozomi-700 bullet train; the inset shows an iol-level-adjustment device, which consists of a SMA coil spring and a belt-type bias spring (b),(c) Structure of the gear unit.

Applications of shape memory alloys

1. Continuum applications
2. structures and machine systems
3. Discrete application
4. Impediments to applications of shape memory alloys
5. Shape memory plastics.

Thank You