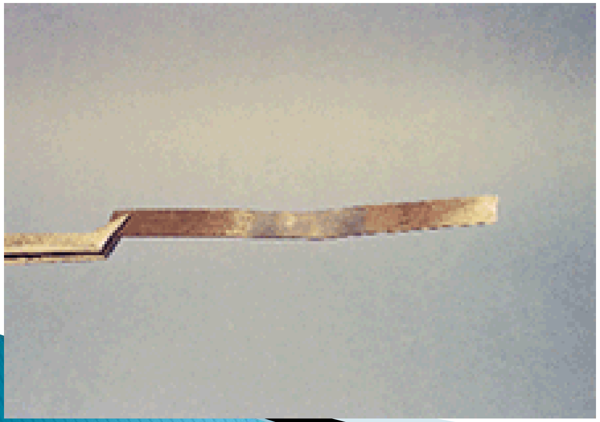
Shape Memory alloys

Shape Memory Alloys

- A shape-memory alloy is an alloy that "remembers" its original shape
- SMA, smart metal, memory metal, memory alloy, muscle wire, smart alloy
- An alloy after deformation returns to its pre-deformed shape when heated.
- An alloy that undergoes large strain & capable of recovering the initial configuration
- At the end of deformation process spontaneously or by heating.

SMA demonstration



SMA-HISTORY

- 1932 – A. Ölander discovered the pseudoelastic properties of Au-Cd alloy.
- 1949 – Memory effect of Au-Cd reported by Kurdjumov & Kandros.
- 1967 – At Naval Ordance Laboratory, Beuhler discovers shape memory effect in nickel titanium alloy, Nitinol, which proved to be a major breakthrough in the field of shape memory alloys.
- 1970-1980 – First reports of nickel-titanium implants were used in medical applications.
- Mid-1990s – Memory metals start to become widespread in medicine and soon move to other applications.

Manufacturing of SMA

- SMAs are typically made by casting, using vacuum arc melting or induction melting.
- These special techniques help to keep impurities in the alloy to a minimum and ensure the well mixing of the metals.
- The ingot is then hot rolled into longer sections and then drawn 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, shaped while hot, and then are cooled rapidly by quenching in water or by cooling with air.
- Shape-memory polymers have also been developed, and became commercially available in the late 1990s

SMA Properties

- The yield strength is lesser than conventional steel, but some SMAs have a higher yield strength than plastic or aluminum
- The yield stress for Ni Ti can reach 500 MPa.
- Exhibit the super elastic properties
- High level of recoverable plastic strain can be induced.
- The maximum recoverable strain SMAs can hold without permanent damage is up to 8 % for some alloys. (For conventional steels it is only 0.5 % only)
- The cost of the metals are high & therefore effective processing is required
- The processing is difficult and expensive to implement SMAs into a design.

SMA video- MIT

SMA examples

- Ag–Cd 44/49 wt.% Cd
- Au–Cd 46.5/50 at.% Cd
- Cu–Sn approx. 15 at% Sn
- Cu–Zn 38.5/41.5 wt.% Zn
- Cu–Zn–X (X = Si, Al, Sn)
- Fe–Pt approx. 25 at.% Pt
- Mn–Cu 5/35 at% Cu
- Fe–Mn–Si
- Co–Ni–Al
- Co–Ni–Ga
- Ni–Fe–Ga
- Ti–Nb
- Ni–Ti approx. 55–60 wt% Ni
- Ni–Ti–Hf
- Ni–Ti–Pd
- Ni–Mn–Ga
- Cu–Al–Ni 14/14.5 wt% Al and 3/4.5 wt% Ni

Wt %

Extensive properties

Actuator applications

At%

Intensive properties

Energy applications

Ex: 2 metals A,B form an alloy

Wt % of A= $m_A/(m_A+m_B)$

Wt % of B= $m_B/(m_A+m_B)$

at % of A= $N_A/(N_A+N_B)$

at % of B= $N_B/(N_A+N_B)$

SMA– NiTiNOL (SE508 Wire)

PHYSICAL PROPERTIES

Melting Point:	2390°F	1310°C
Density:	0.234 lb/in^3	6.5 g/cm^3
Electrical Resistivity:	32 μohm-in	82 μohm-cm
Modulus of Elasticity:	6-11 x 10^6 psi	41-75 x 10^3 MPa
Coefficient of Thermal Expansion:	6.1 x 10^{-6}/°F	11 x 10^{-6}/°C

MECHANICAL PROPERTIES

Ultimate Tensile Strength (UTS):	160-200 x 10^3 psi	1100-1150 MPa
Total Elongation (min):	10%	10%

SUPERELASTIC PROPERTIES

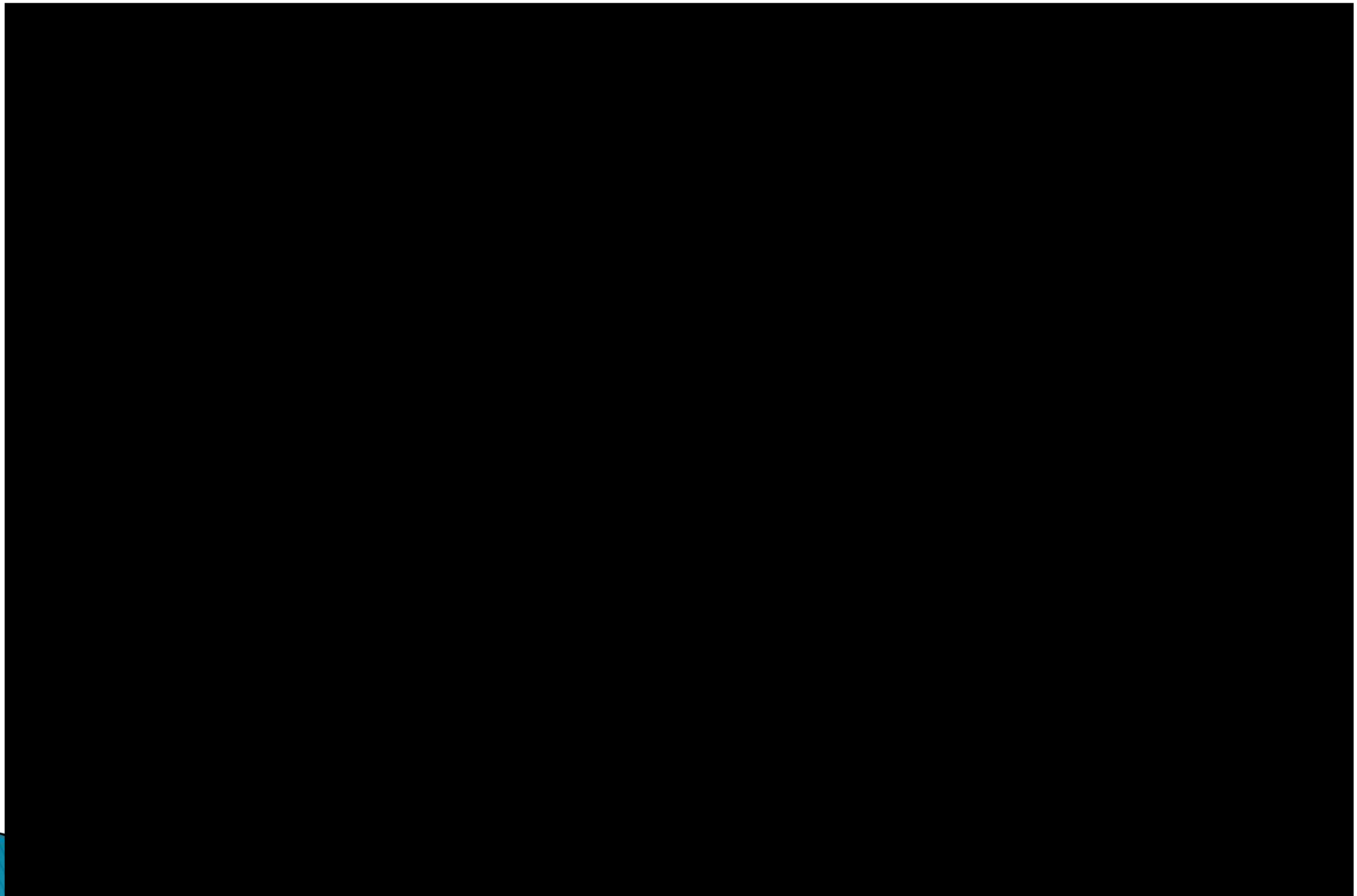
Loading Plateau Stress @ 3% strain (min):	65 x 10^3 psi	450 MPa
Permanent Set (after 6% strain) (max):	0.2%	0.2%
Transformation Temperature (A_f):	41 to 64° F	5 to 18° C

COMPOSITION (Meets ASTM F2063 requirements)

Nickel (nominal):	55.8 wt.%
Titanium:	Balance
Oxygen (max):	0.05 wt.%
Carbon (max):	0.02 wt.%

Ferris rotation using NiTi

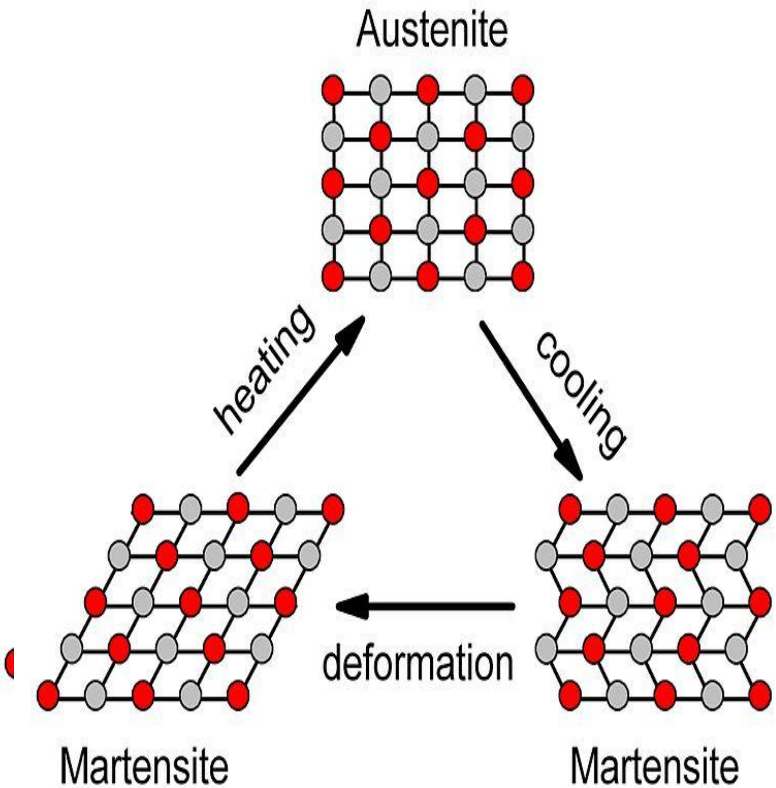
NiTiNol metallic muscles wire

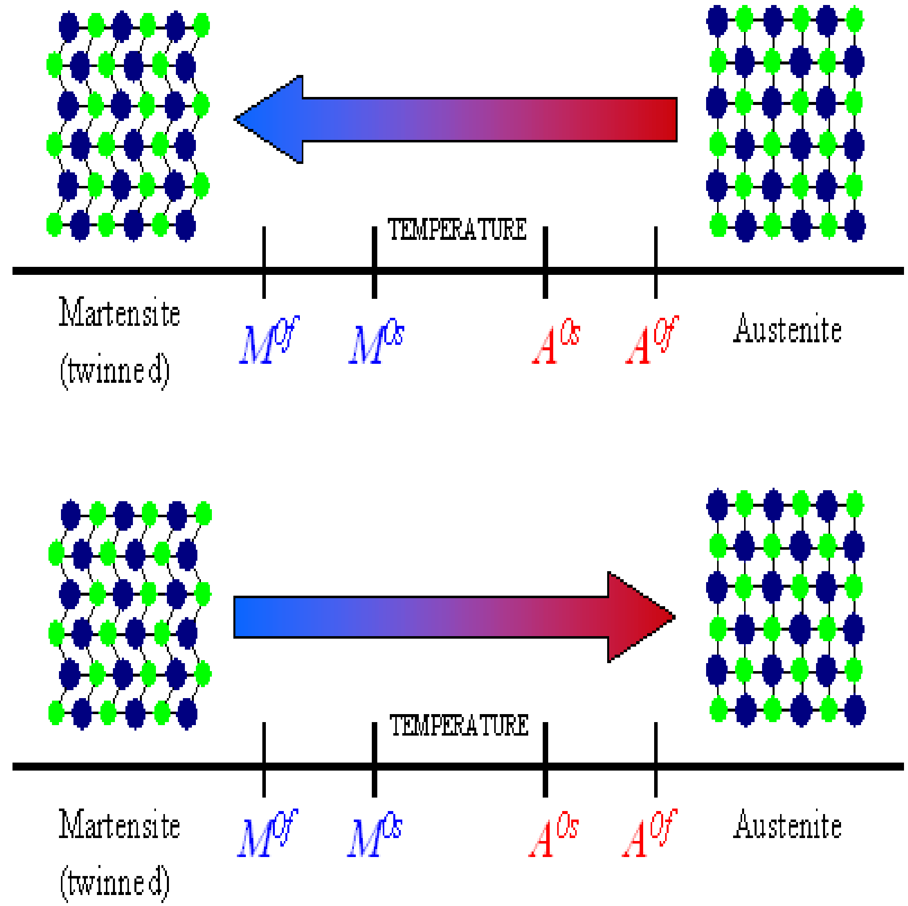


Two phases of SMA

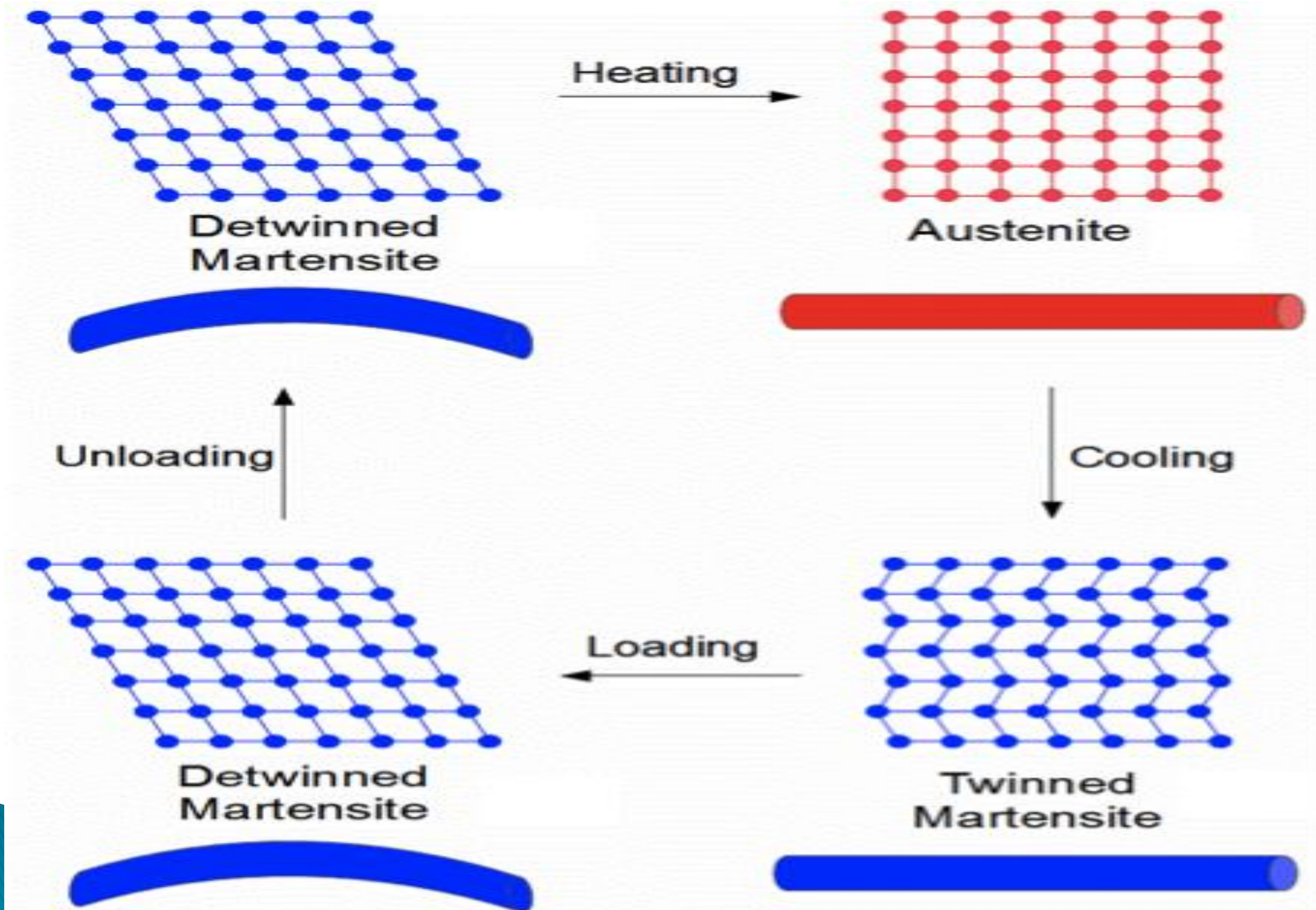
Austenite	Martensite
High Temperature state	Low temperature state
Hard, firm	Soft
Symmetric	Less Symmetric
Inelastic	Elastic
Resembles titanium	Complex structure
Simple FCC structure	Twinned& un twinned
Thermal/Mechanical deformation	Heat/stress induced transformation

SHAPE MEMORY EFFECT

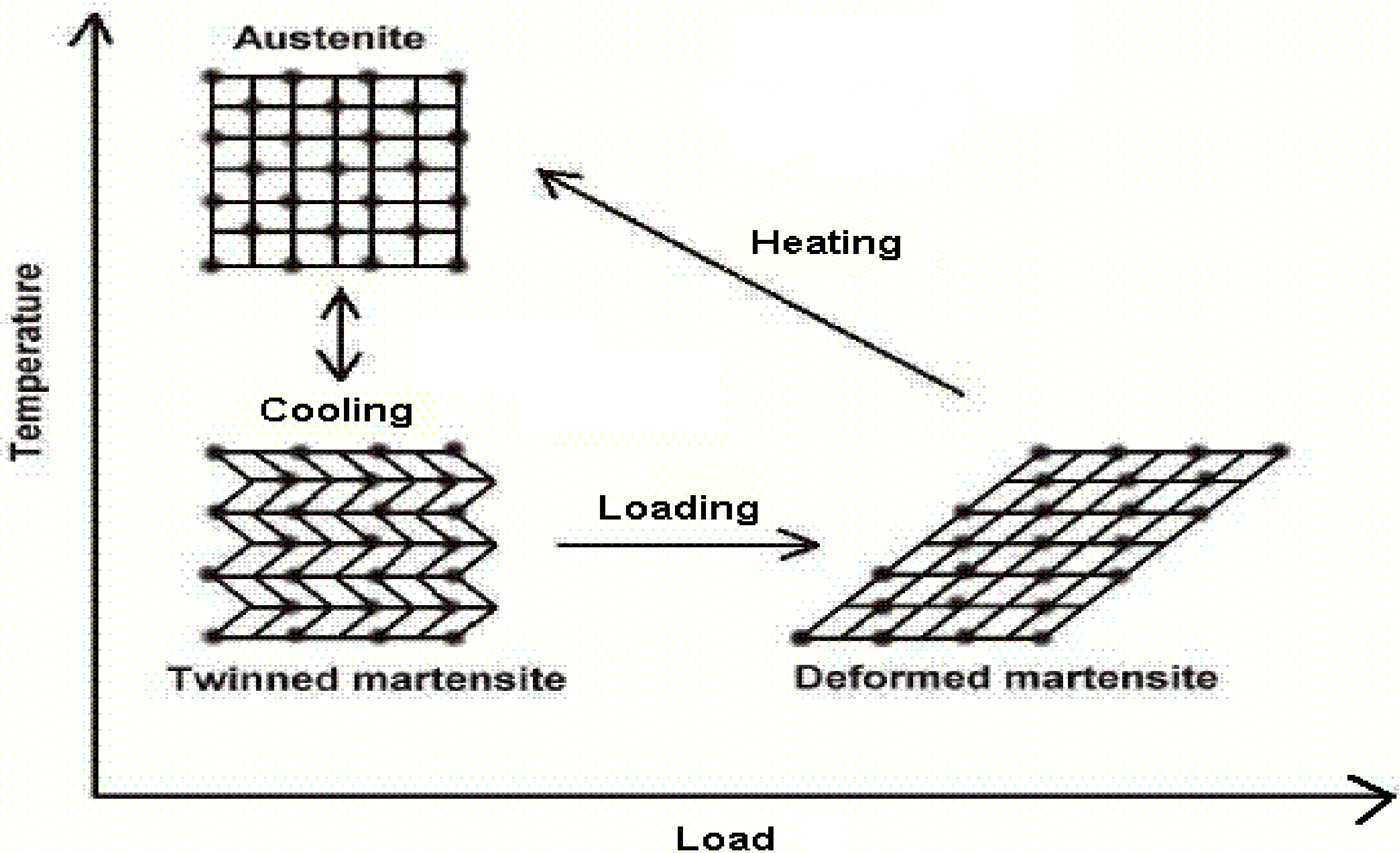




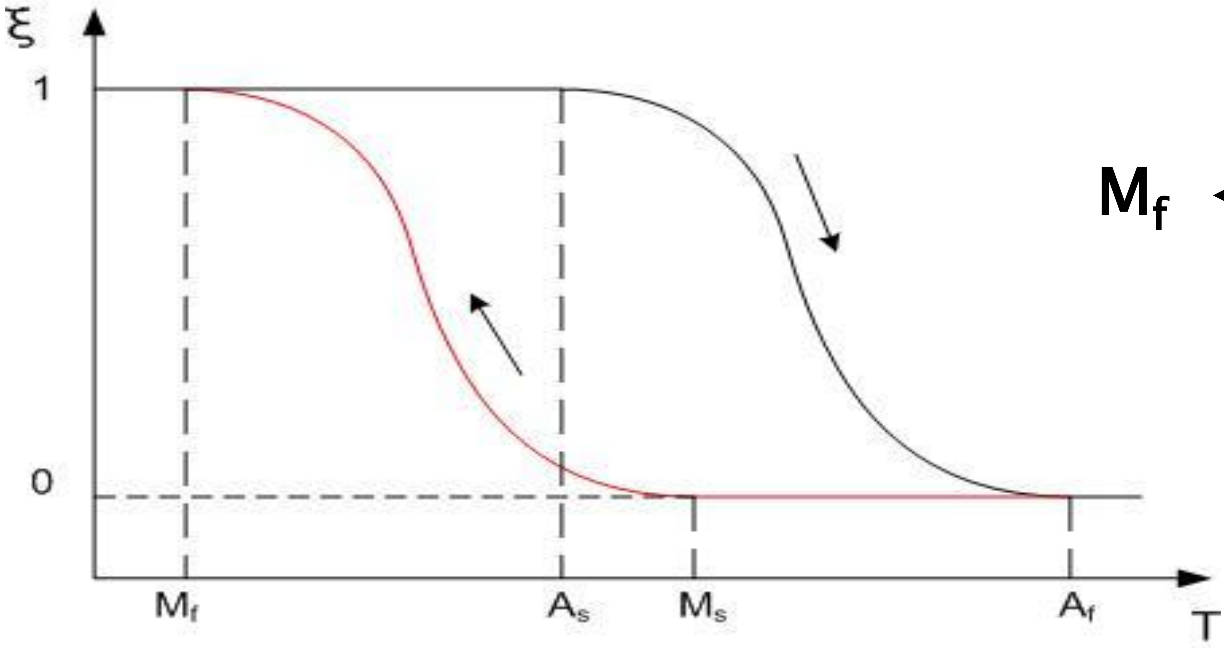
Austenite & Martensite transformations



SMA phase transformations



Temperature –Transformations



$$M_f < A_s < M_s < A_f$$

M_s: T at which austenite starts to transform to martensite upon cooling

M_f: T at which transformation of austenite to martensite is complete upon cooling

A_s: T at which martensite begins to transform to austenite upon heating

A_f: T at which transformation of martensite to austenite is complete upon heating

Advantages of SMA

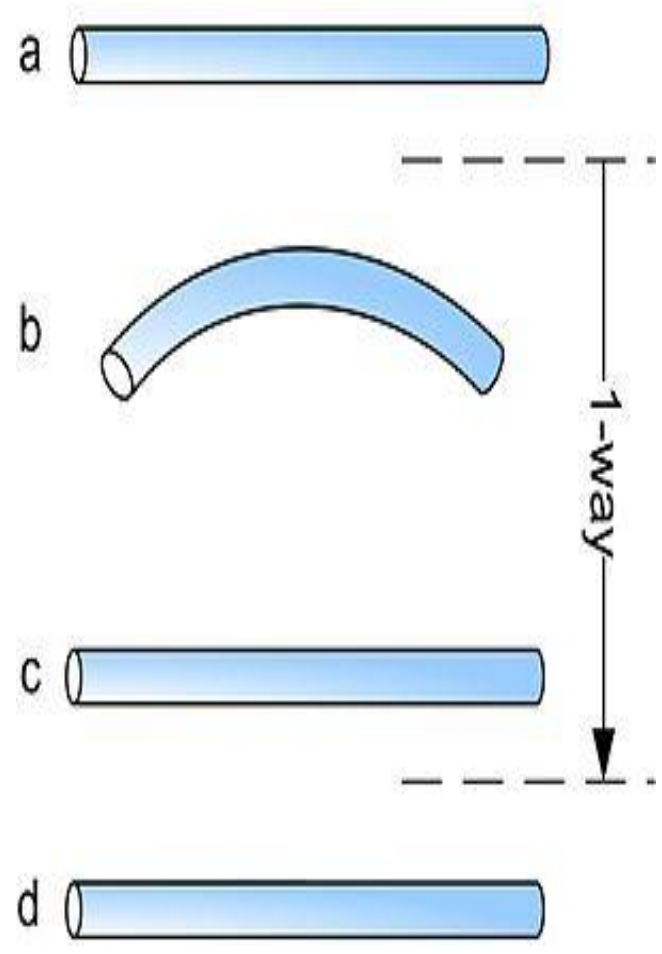
- High strength
- Super elasticity
- Fatigue resistance
- Wear resistance
- Easy fabrication
- High power/weight ratio
- Light weight
- Bio compatibility
- Shape memory property

Disadvantages of SMA

- Initial investment
- Sensitive fabrication
- Residual stress
- Lower max freq of actuators
- Non-linear actuation force

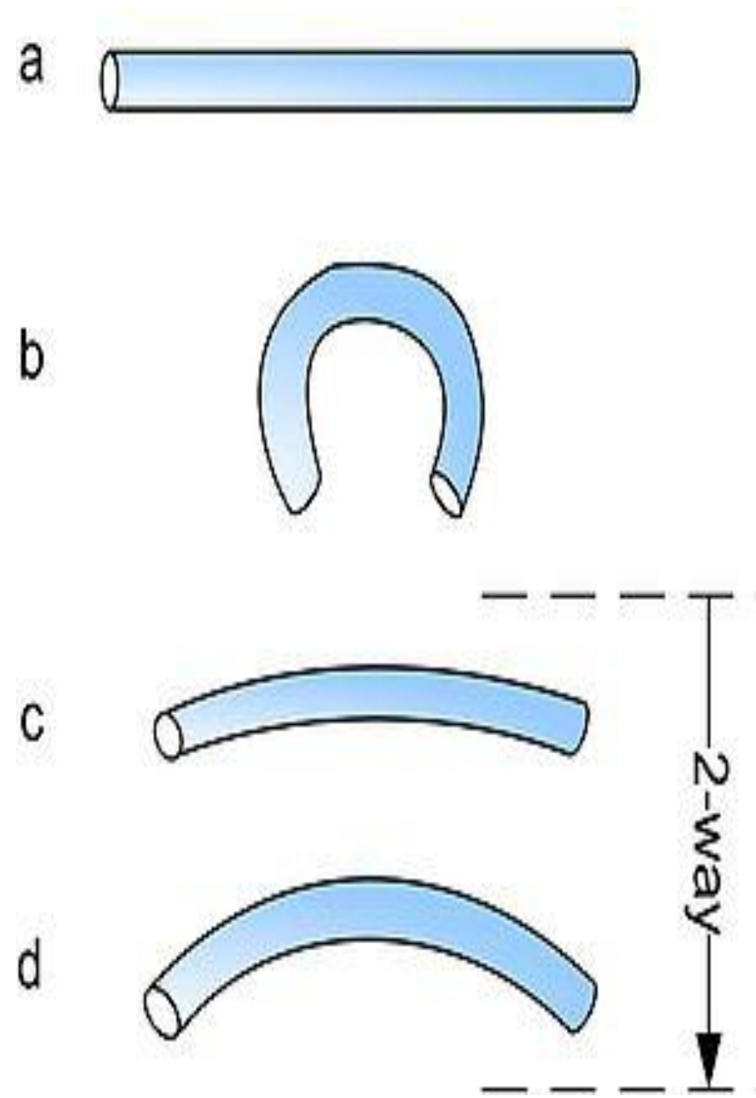
One Way Shape Memory Effect

- When a SMA is in its cold state (below As), the metal can be bent or stretched and will hold this shape until heated above the transition T.
- Upon heating, the shape changes to its original.
- When the metal cools again, it will remain in the hot shape until deformed again.
- In this case, cooling from high Tdoes not cause macroscopic shape change.

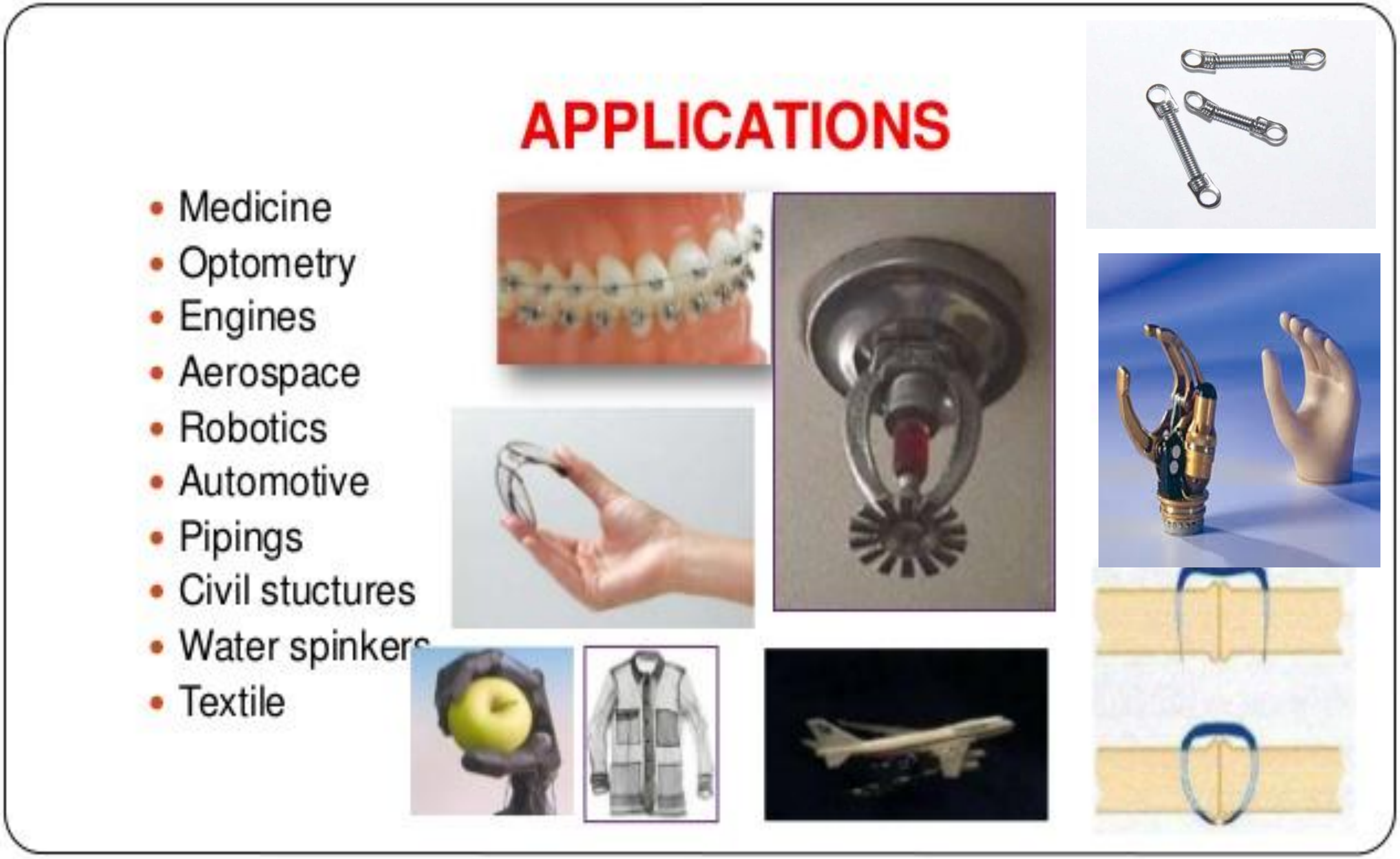


Two Way Shape Memory Effect

- The material remembers two shapes: one at high T & the other at low T.
- Shows shape memory effect during both cooling and heating.
- The metal can be trained to leave some reminders of the deformed low temp condition in the high temperature phases.
- Above a certain T, the metal loses the 2 way memory effect. This is called "amnesia"



APPLICATIONS of SMAs



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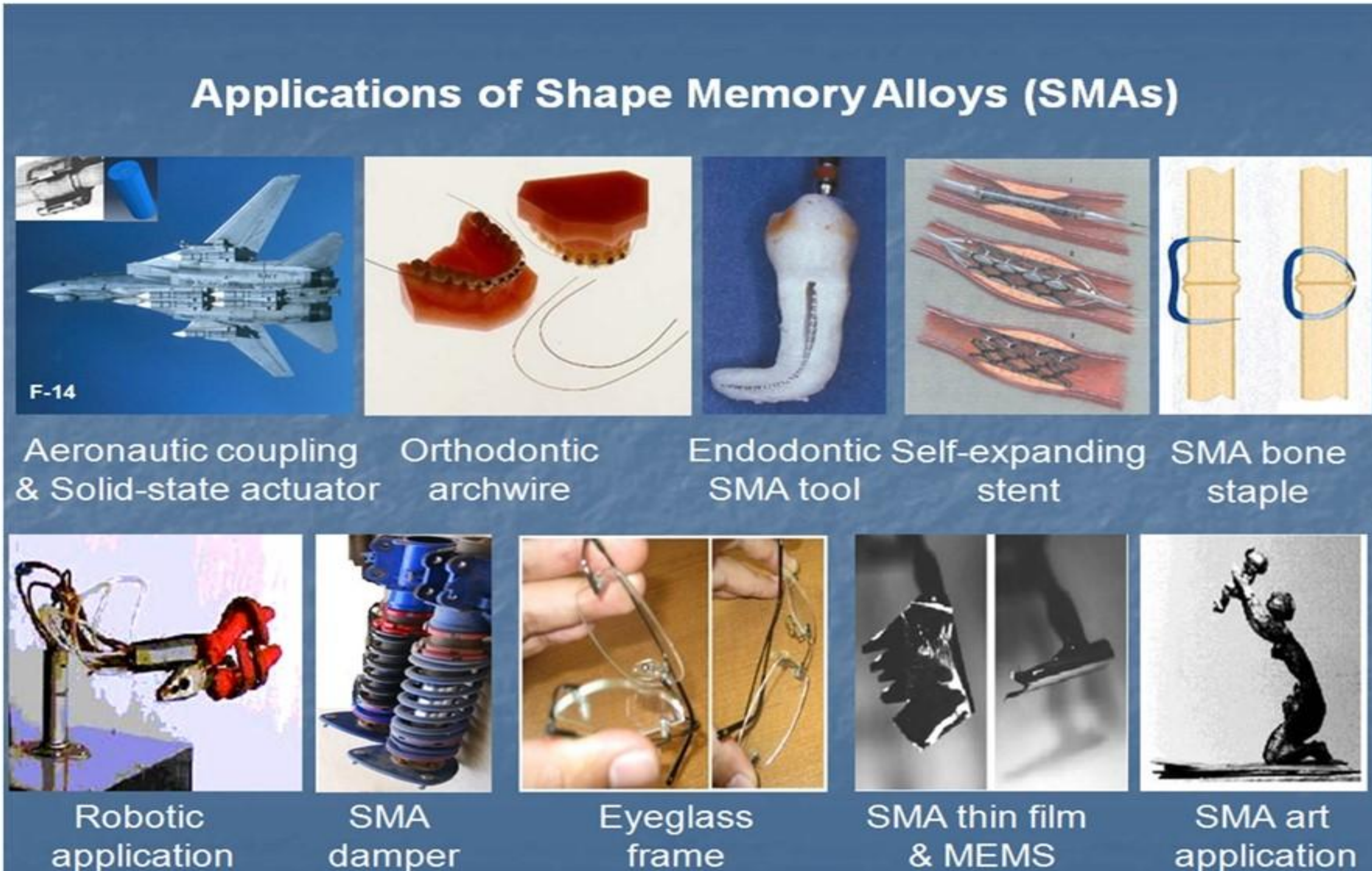

CIVIL ENGINEERING APPLICATIONS

Aerospace applications

Automotive applications

Transport

Robotics

Communication

Medicine