Shape memory

Topic 11

Reading assignment

- Lecture notes on “Shape Memory” on the course webpage
- Askeland and Phule, The Science and Engineering of Materials, 4th Ed., Sec. 11-11 (first page only) and Sec. 11-12.

Shape-memory alloy (SMA)

- A material that can remember its shape
- A class of smart materials
- SMA also exhibits superelastic (pseudoelastic) behavior

Superelastic behavior

SMAs deformed above a critical temperature show a large reversible elastic deformation (recoverable strains up to 10%. much exceeding the elasticity) as a result of stress-induced martensitic transformation

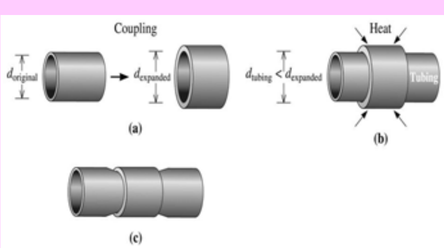
Applications of superelastic behavior

- Orthodontal braces
- Frames for eyeglasses
- Underwires for brassieres
- Antennas for cellular phones

Applications of shape-memory effect

- Self-expandable cardiovascular stent
- Blood clot filters
- Engines
- Actuators for smart systems
- Flaps that change direction of airflow depending upon temperature (for air conditioners)
- Couplings

Coupling for Tubing



Use of memory alloys for coupling tubing: A memory alloy coupling is expanded (a) so it fits over the tubing (b). When the coupling is reheated, it shrinks back to its original diameter (c), squeezing the tubing for a tight fit

Examples of SMAs

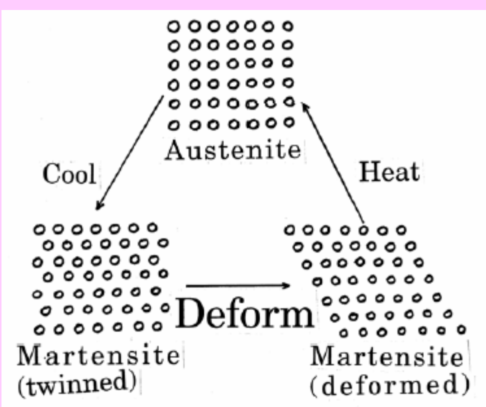
- Cu-Zn-Al
- Cu-Al-Ni
- Ni-Ti (50 at.% Ti, nitinol, which stands for Nickel Titanium Naval Ordinance Laboratory)

Origin of shape-memory effect

Martensitic phase transformation that occurs as a result of stress or temperature change

Triggers for martensitic transformation

- **Stress**
- **Temperature**



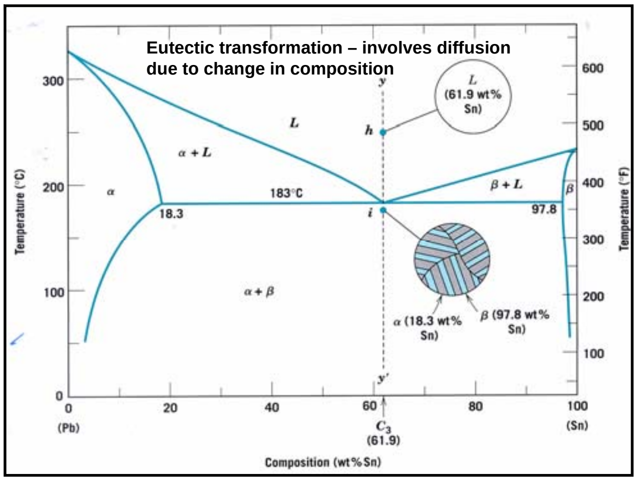
Steps of using an SMA

- **Betatizing (heating to equilibrate at the austenite phase field of the phase diagram)**
- **Quench to form martensite**
- **Deform the martensite**
- **Heat to return to the austenite phase and to restore the original shape**

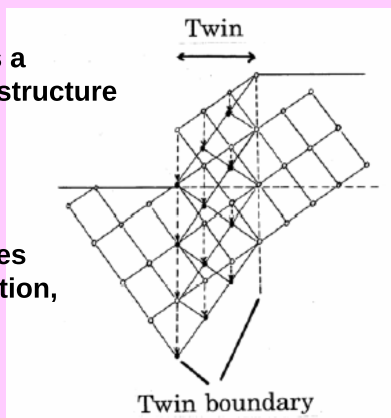
Martensitic transformation

- A diffusionless solid-state phase transformation; no change in composition.
- Also known as athermal or displacive transformations.
- Transformation results in a metastable phase known as martensite.
- The growth rate is so high that nucleation becomes the rate-controlling step.

Eutectic transformation – involves diffusion due to change in composition



Martensite has a twinned microstructure

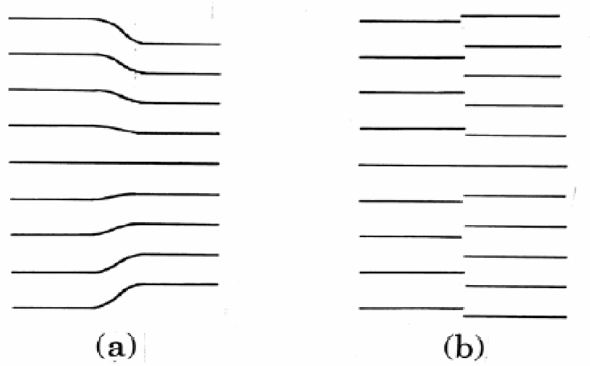


Twinning enables plastic deformation, hence superelasticity.

Variants of martensite

Due to various twinning configurations

Interface between austenite and martensite phases



Coherent interface Incoherent interface

Martensitic transformation temperatures

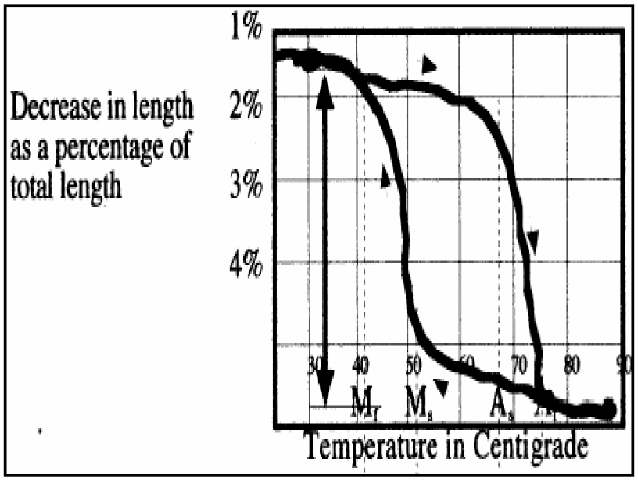
- M_s: temperature at which austenite begins to transform to martensite upon cooling
- M_f: temperature at which transformation of austenite to martensite is complete upon cooling

Martensitic transformation temperatures

- A_s: temperature at which martensite begins to transform to austenite upon heating
- A_f: temperature at which transformation of martensite to austenite is complete upon heating

Hysteresis

$M_f < M_s < A_s < A_f$

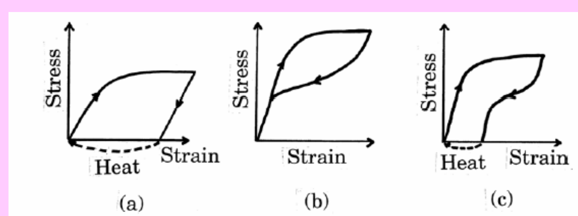


Stress generation

If an SMA is constrained from recovering (e.g., within a composite material), a recovery stress if generated.

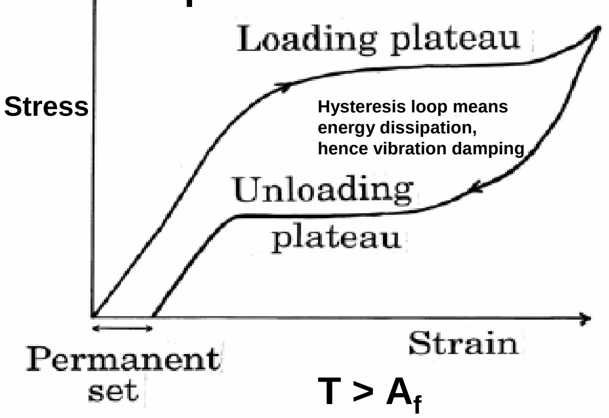
Mechanisms of deformation of martensite

- Growth of favorably oriented twins
- Deformation twinning (twinning upon shear during deformation)

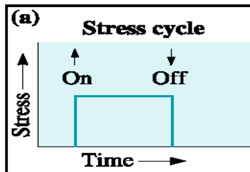


$T < A_s$ $T > A_f$ $A_s < T < A_f$

Superelastic behavior



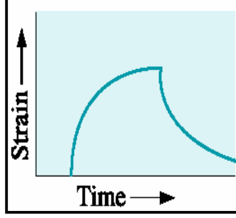
$T > A_f$



Comments

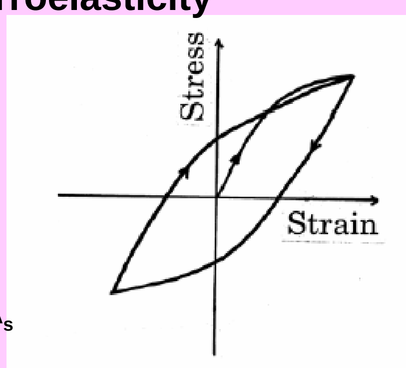
Specimen is loaded to a given stress and subsequently unloaded

Shape memory in polymers using viscoelastic behavior



Viscoelastic: some instantaneous elastic strain followed by elastic strain which increases with time under stress and recovers slowly; some viscous (plastic) flow may also occur

Ferroelasticity



$T < A_s$

Types of shape-memory behavior

- **One-way shape memory: transformation to the desired shape occurs only upon heating, i.e., memory is with the austenite phase.**
- **Two-way shape memory: the deformed shape is remembered during cooling, in addition to the original shape being remembered during heating, i.e., memory is with both austenite and martensite phases (requires training to attain memory during cooling; formation of favorably oriented twins during cooling between M_s and M_f)**

Ferromagnetic shape-memory alloys

- **Shows shape-memory effect in response to a magnetic field**
- **Deformation due to magnetic field is known as magnetoelastic deformation.**
- **Ni-Ti is non-magnetic**
- **Examples of ferromagnetic SMAs: Ni_2MnGa, Fe-Pd, Fe_3Pt**