University Of Technology- Iraq
Department of Materials Engineering
General Materials Branch
Fourth class

Smart Materials

Lecture 2 : Shape Memory Alloys

Class Code on Google Classroom :2shhens

What is the Shape Memory Alloys

- Shape memory alloys (SMAs) or “smart alloys” are a unique class of smart materials that can change their form (shape or size), and can return back to their original form with applied heat, stress, or magnetic field.
- They have the ability to produce very high actuation strain, stress, and work output due to reversible martensitic phase transformations

Shape Memory Alloys

- Shape memory alloys are

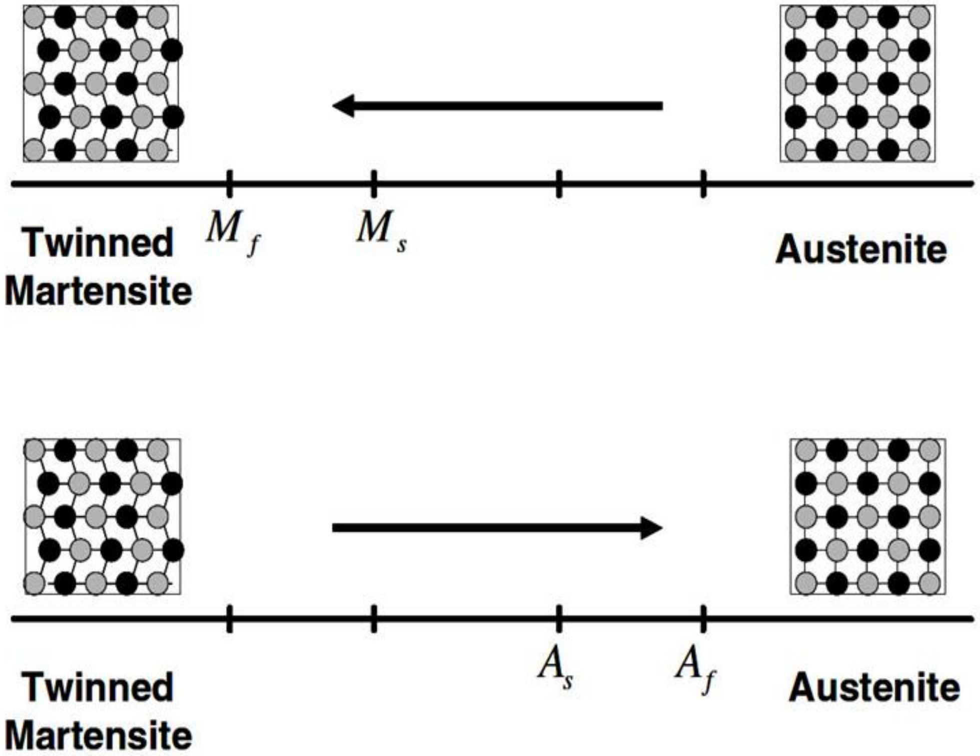
1. compact
2. robust
3. Lightweight
4. frictionless,
5. quiet biocompatible,
6. environmentally friendly,
7. possess superior properties in actuation, vibration damping and sensing.

Shape Memory Effect

- Shape Memory Alloys(SMA) are alloys that display the capacity to hold it 's unique shape after a connected load is gone , this effect is known as ***the shape memory effect (SME)*** ,
- it is a one of a kind property for certain combinations showing martensitic change despite the fact that the alloy is twisted at low temperature phase.

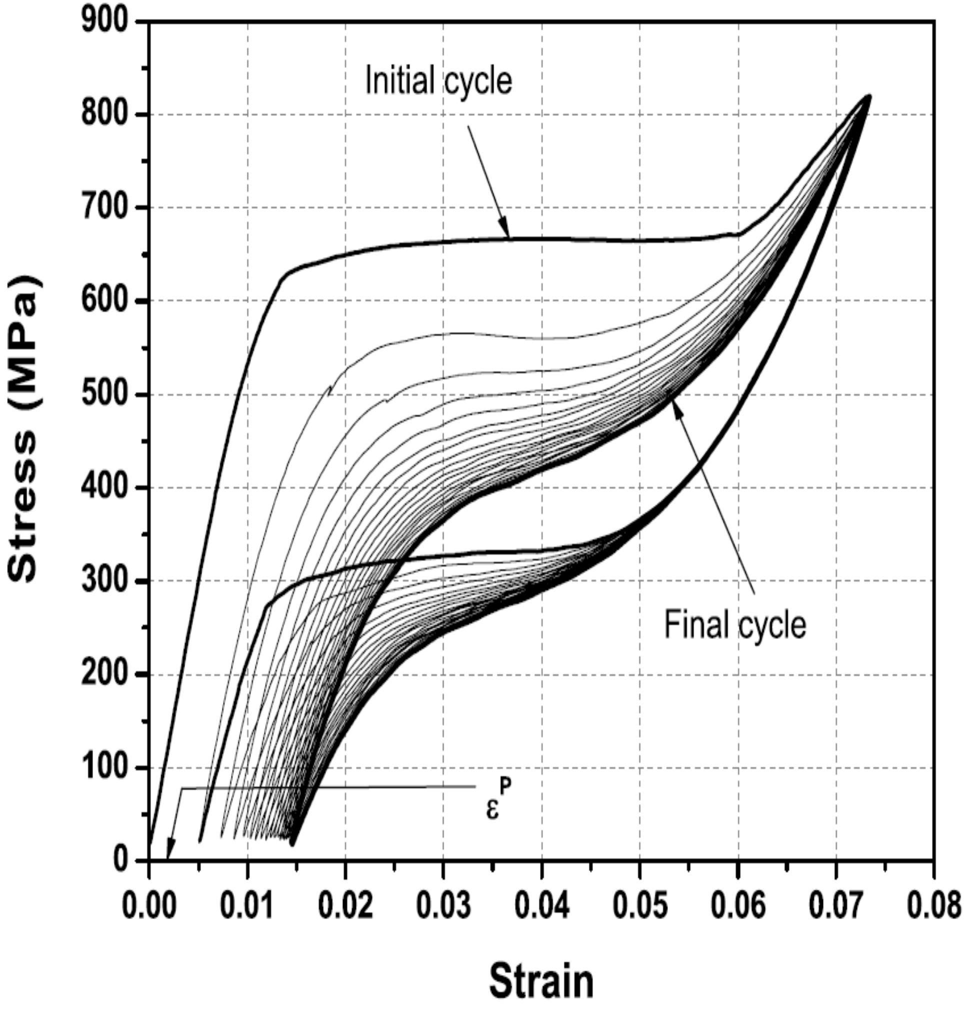
Shape Memory Alloys(SMAs)

- These materials are called "memory" materials, meaning that they have the property of "remembering" thermomechanical treatments to which they have been subjected (traction, torsion, flexion, etc.).
- Specifically, the geometric shape that they had, at high and low temperatures, constitute two states which they "remember".



Training of Shape Memory Alloys

- This memory is developed by way of training – i.e. often by the repetition of the same thermodynamic loading: this is in terms of stress or strain imposed and/or in terms of temperature



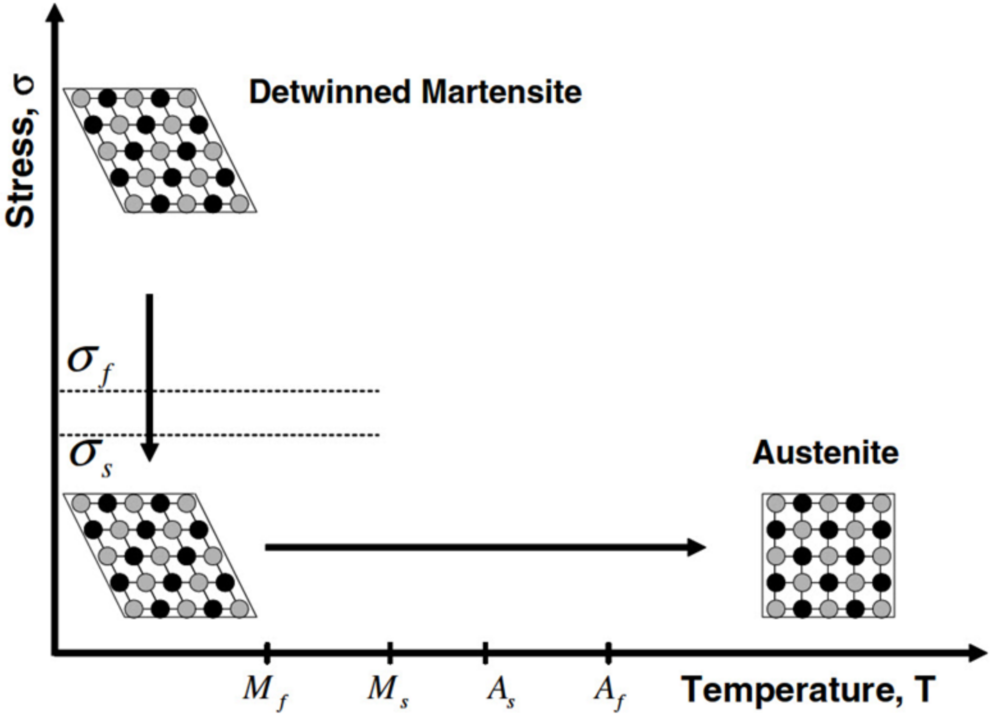
Shape Memory Alloy Training

two of the most common training methods are :

1. Cyclic deformation at a temperature below M_f followed by constructed heating in the cold shape to above the A_f temperature
2. Cyclic deformation between the hot and cold shapes at temperature above A_f

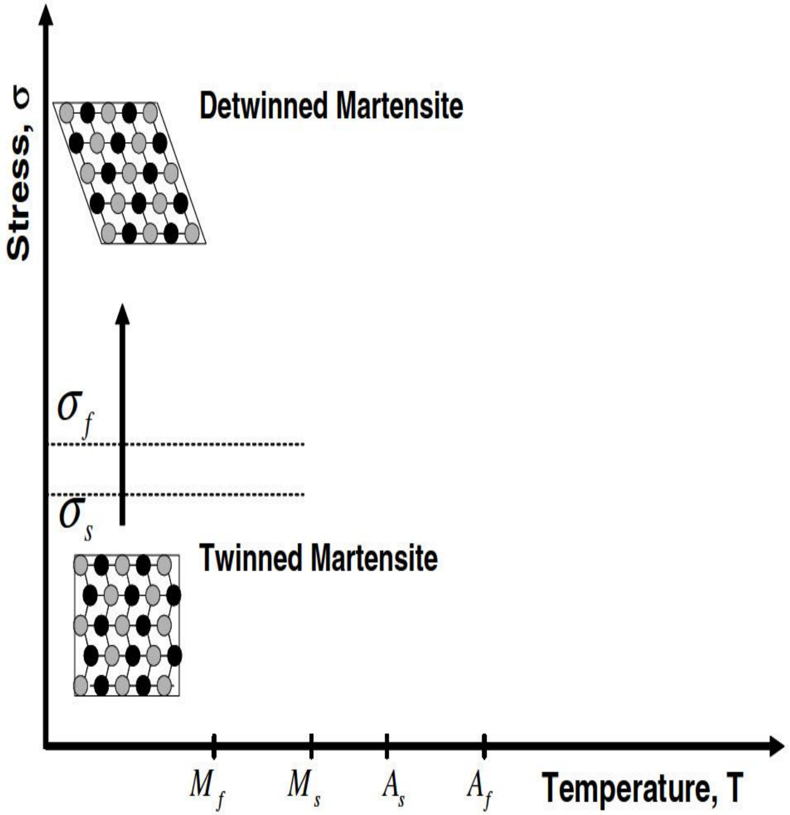
Shape Memory Alloys(SMAs)

- The physical key to “shape memory” lies in a phase transformation between a parent phase called austenite (A) and a produced phase called martensite (M). For SMAs, this phase transformation is described as thermoelastic.

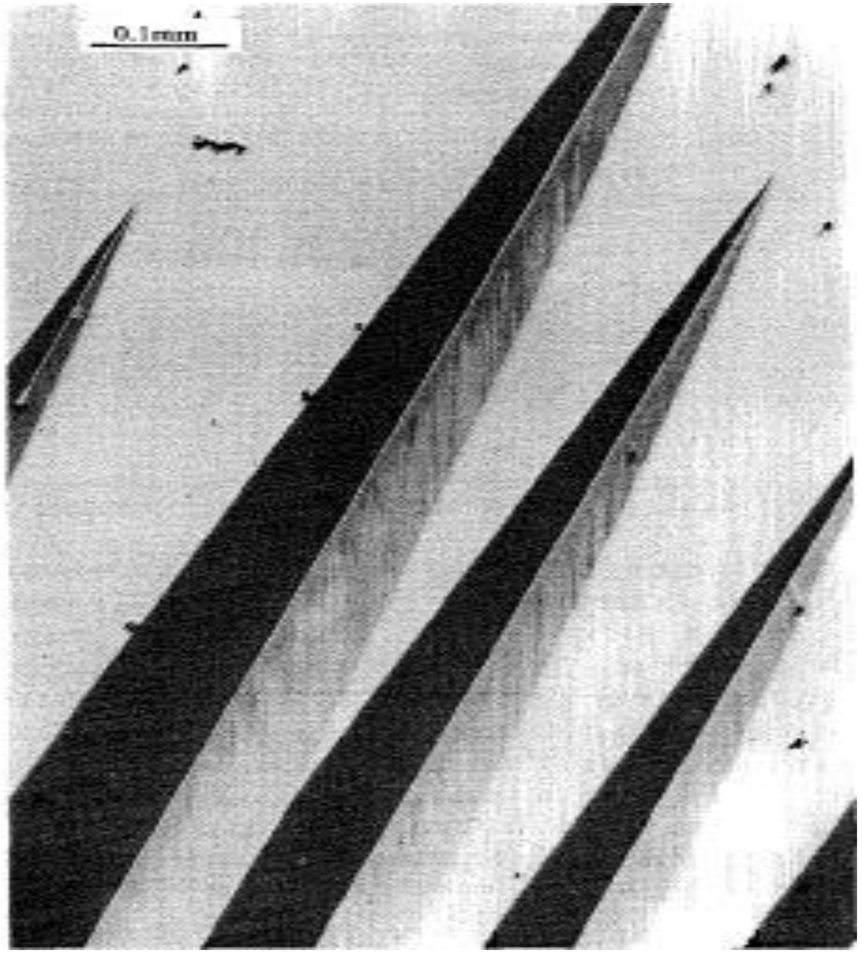


Shape Memory Alloys(SMAs)

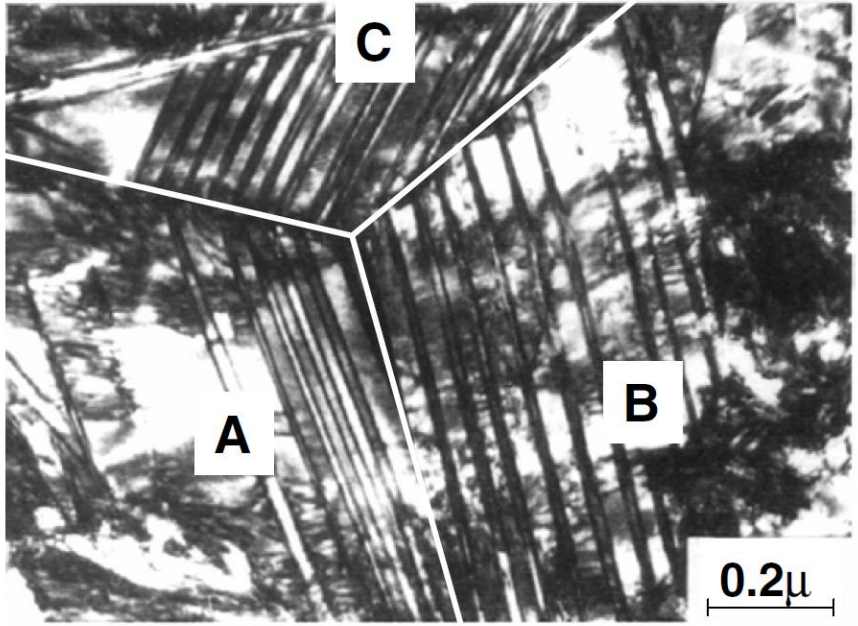
- It involves a change of crystalline lattice between the phase A, also known as the “high temperature” phaseand a phase M, also known as the “low temperature” phase.



Shape Memory Alloys(SMAs)



- This change is called a "martensitic transformation". The austenite is transformed into "martensite variants"



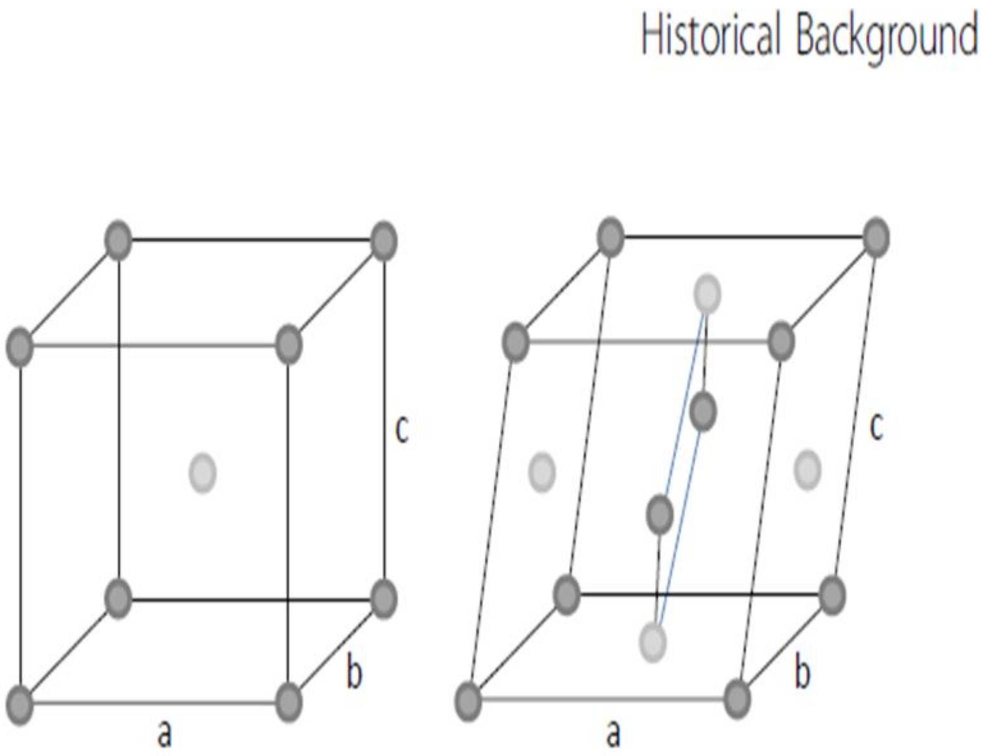
Shape Memory Alloys(SMAs)

- In SMAs, such as nickel-titanium based alloys, the original shape can be regained after heating to a higher temperature, if they are initially deformed or shaped under proper thermomechanical conditions.
- Depending upon the alloy material properties and the external conditions, shape recovery can occur in two ways:

1. if the material is deformed at low temperature, its original shape can be recovered by heating it above a characteristic temperature. This property is known as the shape memory effect (SME);
2. if the material is deformed at high temperature, its original shape can be recovered by simply removing the applied load. This property is known as super-elasticity or pseudoelasticity (SE).

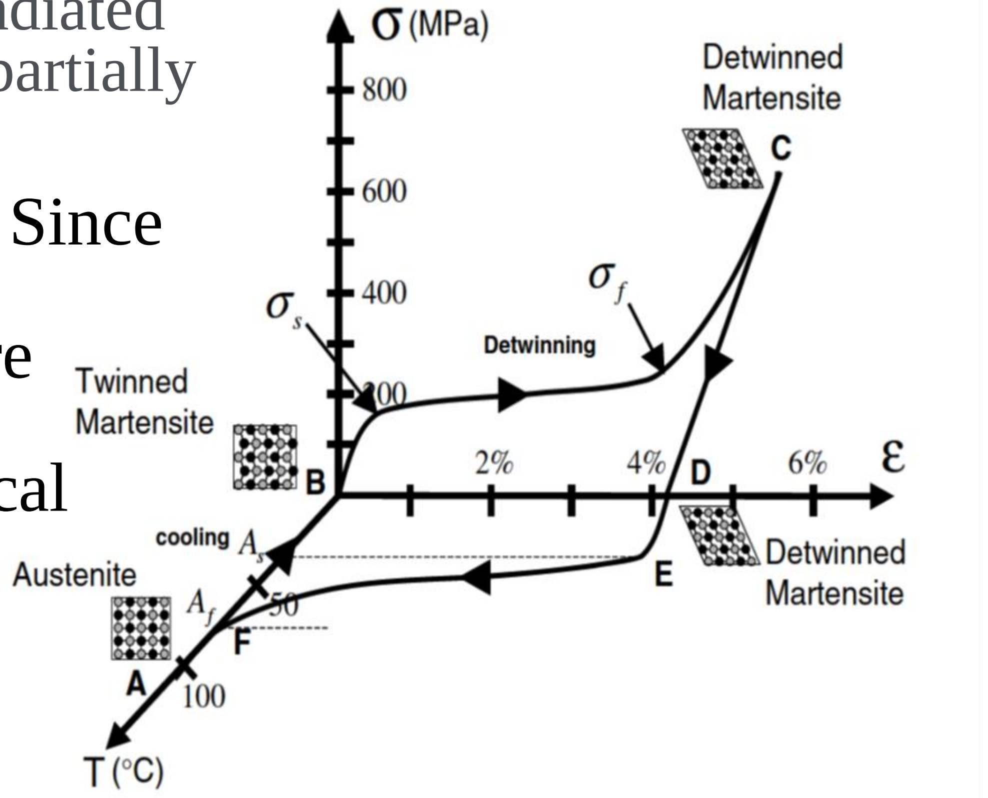
Shape Memory Effect

- An SMA exhibits the *shape memory effect* (SME) when it is deformed while in the twinned martensitic phase and then unloaded while at a temperature below A_s. When it is subsequently heated above A_f , the SMA will regain its original shape by transforming back into the parent austenitic phase. The nature of the SME can be better understood by following the thermomechanical loading path in a combined stress-strain-temperature space as shown in Fig. 1.10



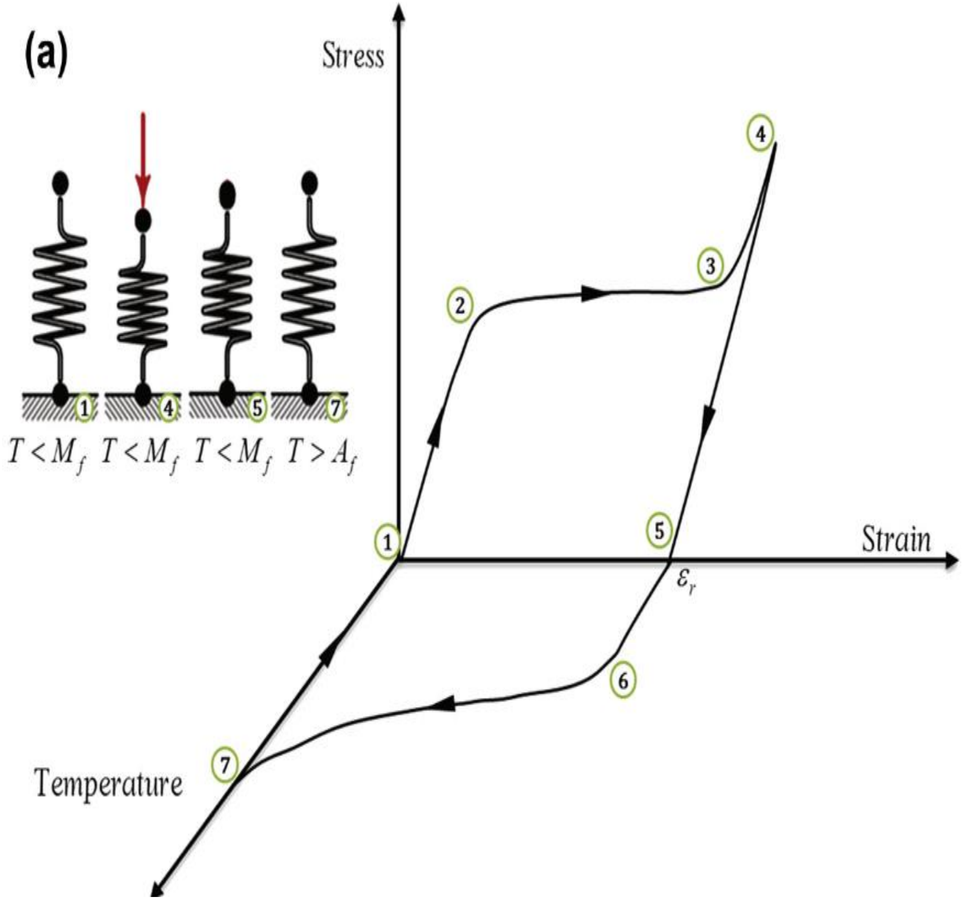
Shape Memory Alloys(SMAs)

- Thermomechanical coupling between temperature and stress fields modifies the heat equation considered for nonequilibrium energy transport. In this case, energy absorbed by the irradiated material is partially dissipated through heat transfer and partially used for thermal expansion of the substrate material.
- thermomechanical coupling is very strong in SMAs. Since latent heat is produced/absorbed during the forward/ reverse martensitic phase transformation, temperature variations can occur in the material, influencing its mechanical behavior. Therefore, the thermomechanical coupling can be a key factor to be considered in the modeling of SMAs



One way Shape Memory Effect

- One way Shape Memory Effect
- If an alloy is deformed by applying mechanical load and then unloaded remains deformed if the alloy is then related to a temperature above the austenite finish temperature (A_f) it recover the original macroscopic shape as long as the total strain does not induce permanent plastic flow as shown in the figure this is known as the hot shape



Two way Shape Memory Effect

- Shape memory alloy can retain to remember both endothermic and exothermic shape they can be cycled between two shapes without the need to a external stress as shown in figure
- .Two shape memory change relay entirely on microstructural change during martensitic transformation which occur under the influence of the internal stress Internal stress may be introduced in a number of ways it must be stable on thermal cycling load through the transformation after each loading and unloading a small residual strain so the alloy must be trained
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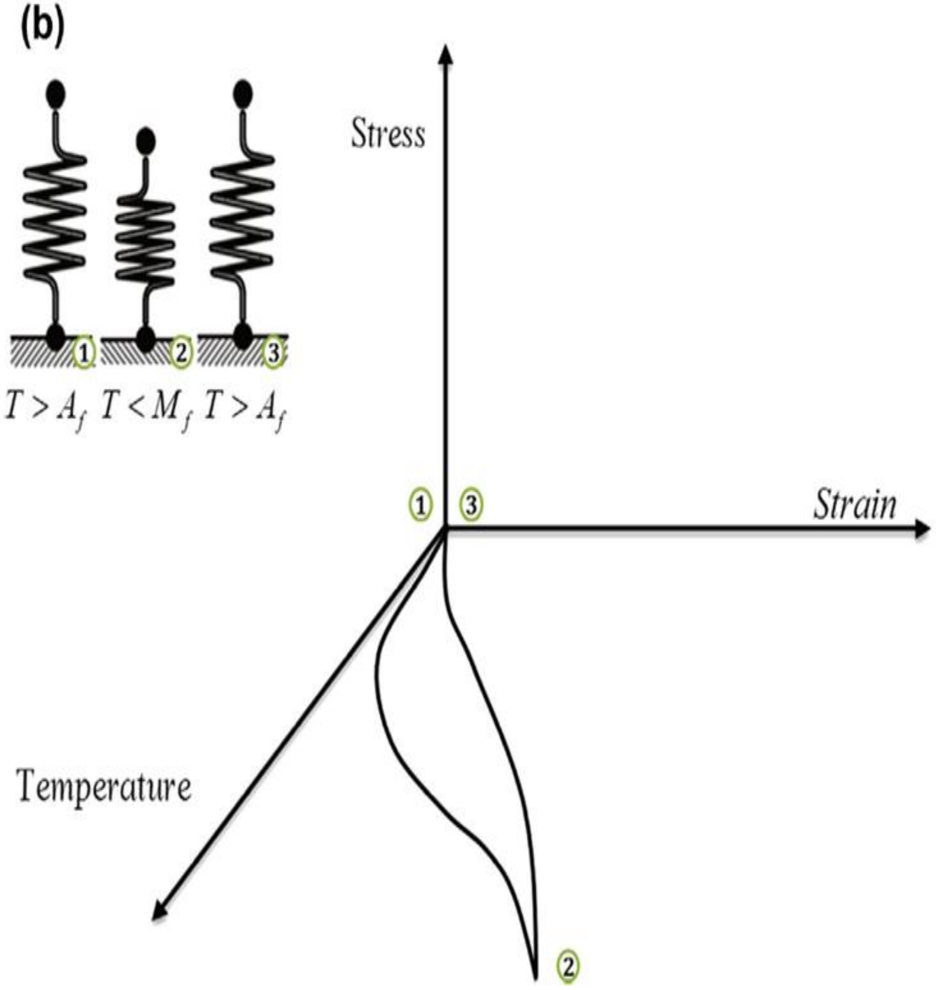
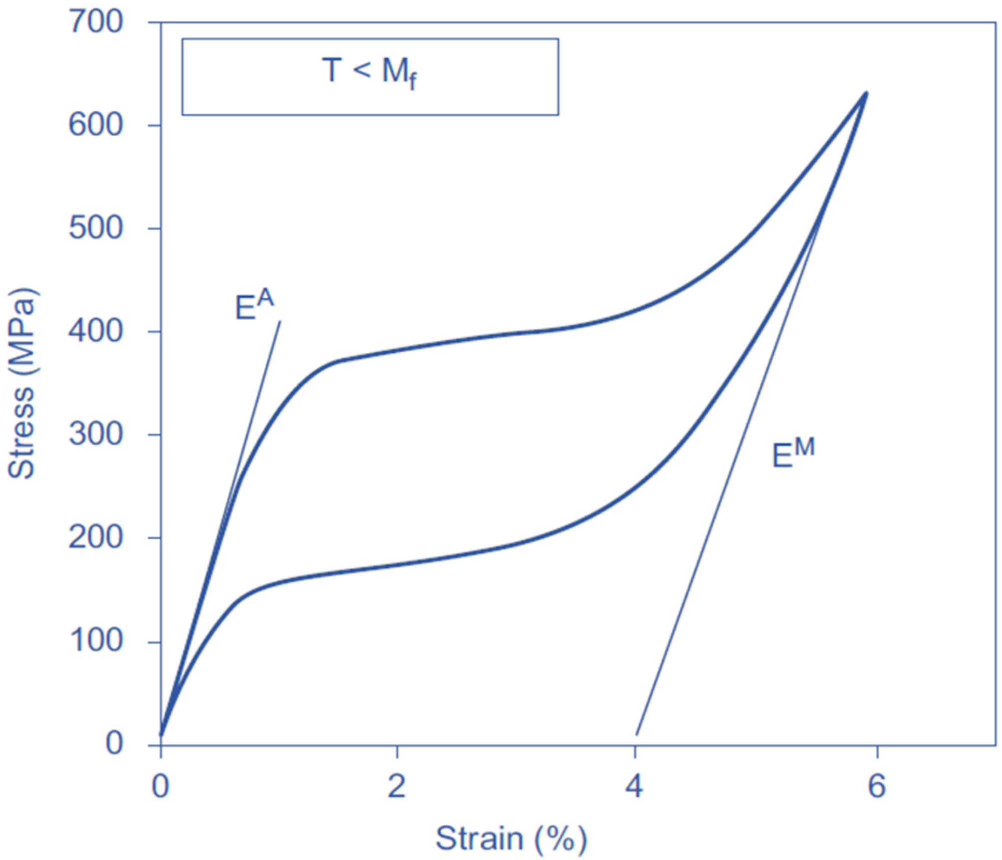
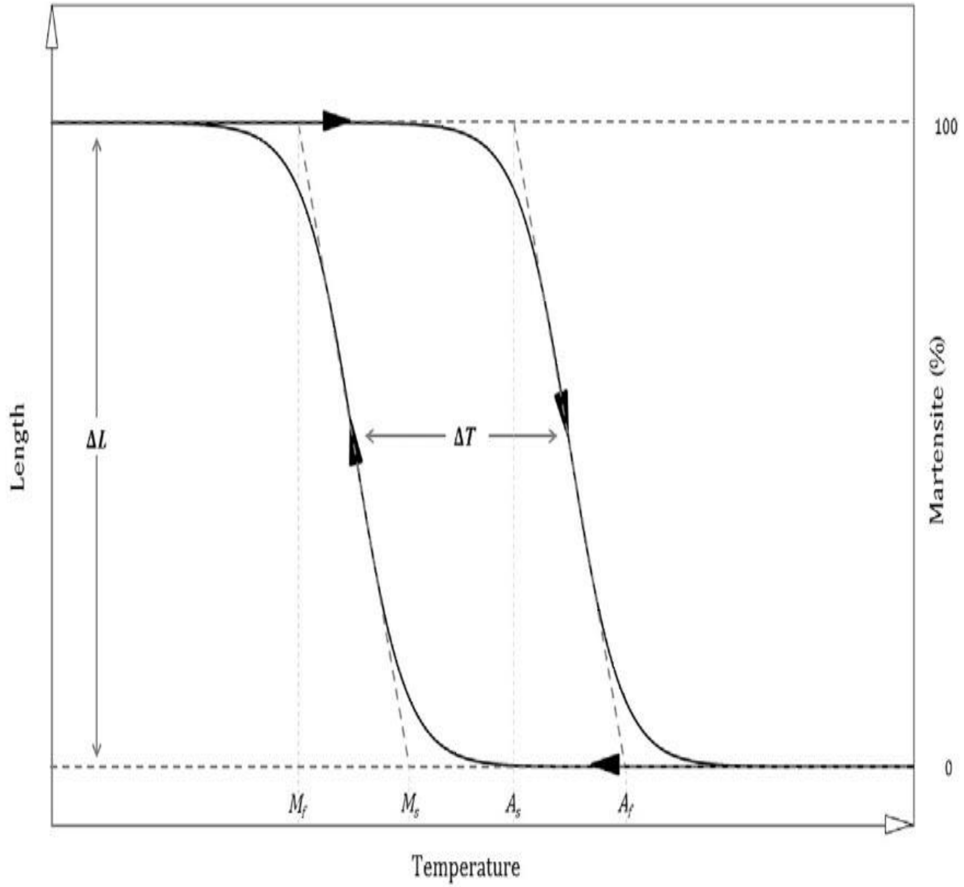


Thermomechanical Hysteresis





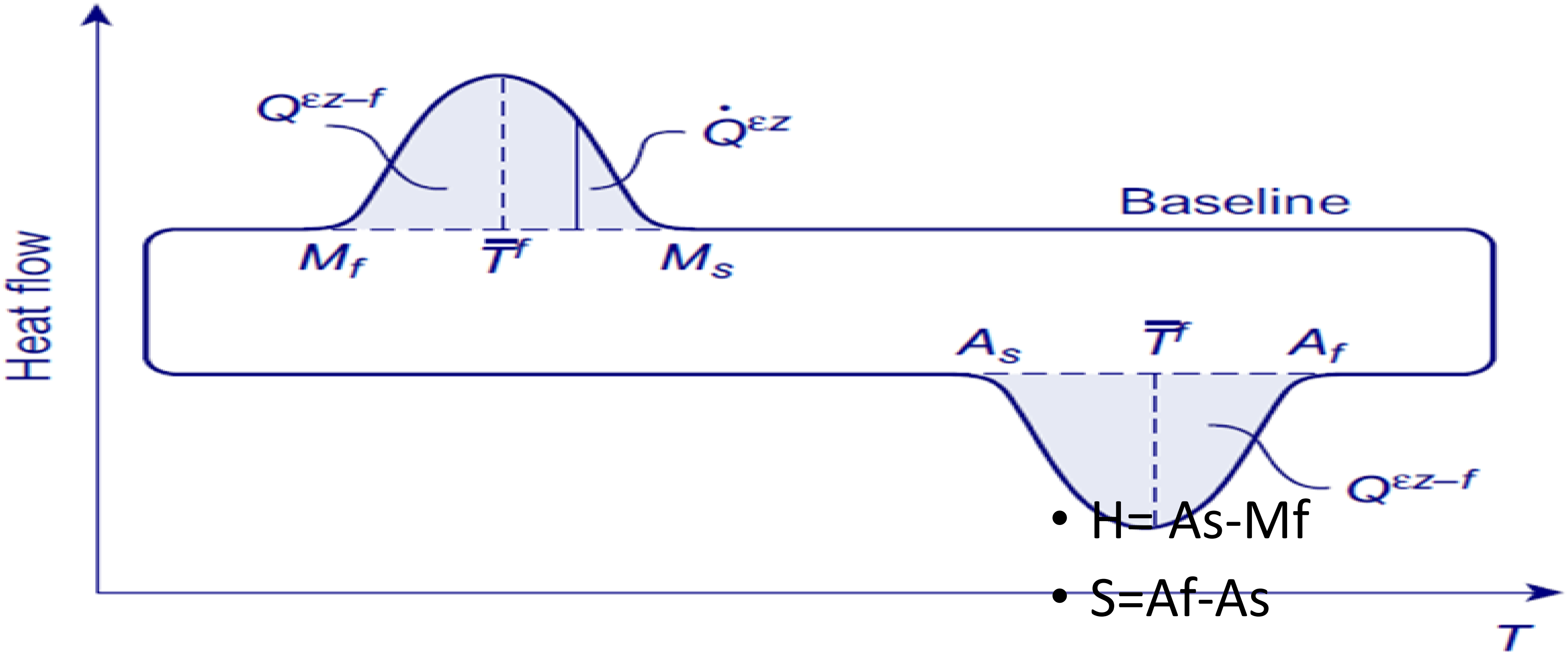
Measuring Shape Memory Effect

1. Differential scanning calorimeter (DSC)
2. Electrical Resistance Measurements (ER)
3. Neutron Diffraction Analysis (NDA)

Differential Scanning Calorimeter (DSC).

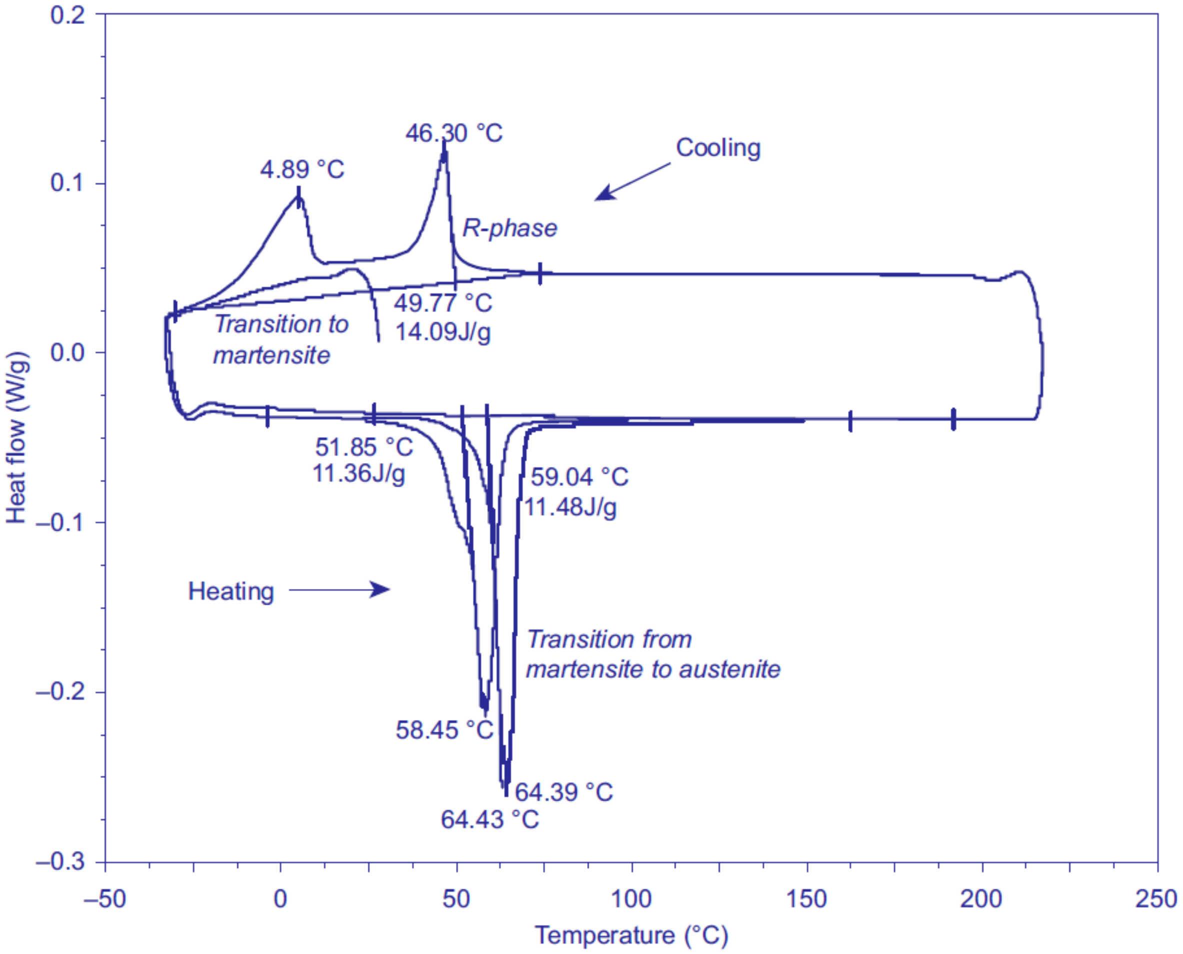
- The most direct method is by differential scanning calorimeter (DSC). This technique measures the heat absorbed or given off by a small sample of the material as it is heated and cooled through the transformation-temperature range.
- The sample can be very small, such as a few milligrams, and because the sample is unstressed this is not a factor in the measurement

Differential Scanning Calorimeter (DSC).



- H= As-Mf
- S=Af-As
- $T^\circ = \frac{M_s + \boldsymbol{A_f}}{2}$
- $\Delta S = \frac{\Delta H}{T^\circ}$

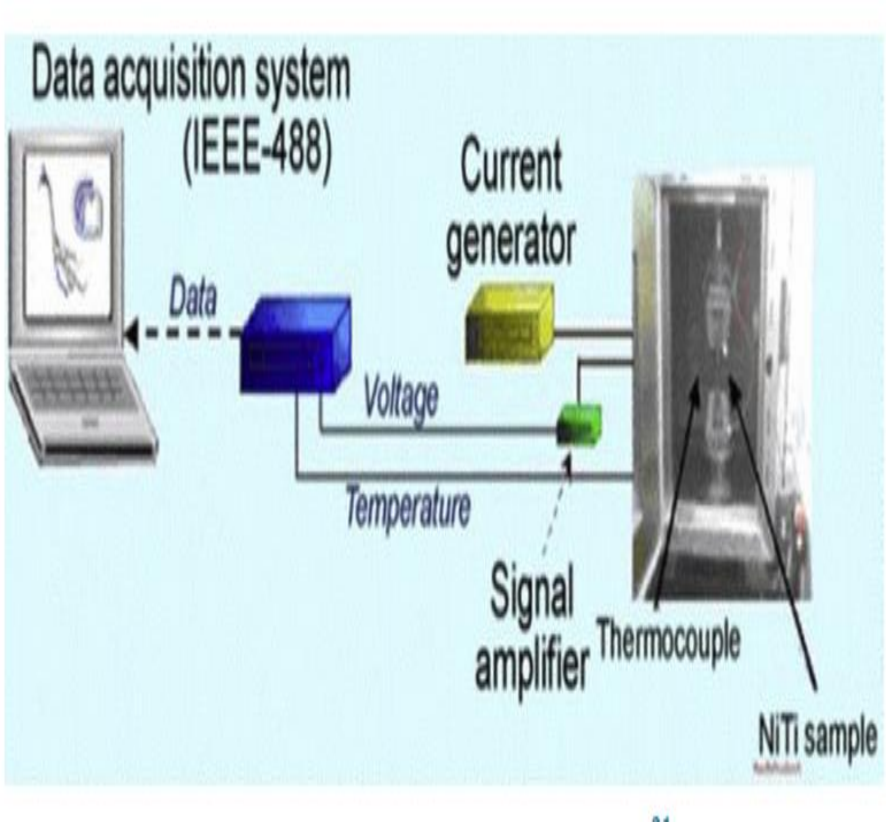
Differential Scanning Calorimeter (DSC).



- Upon cooling, some NiTi alloys can display a two-step phase transition starting from austenite, transforming first into known as the ***R-phase***,.
- ***R-phase is*** a trigonal structure which in turn, changes into martensite as the temperature continues to decrease.

ELECTRICAL RESISTANCE MEASUREMENTS

- When detecting transformation temperatures, electricalresistivity (ER) measurements can be a useful and good probe to identify both temperature- and stress-induced transformations involving SMA crystallographic phases

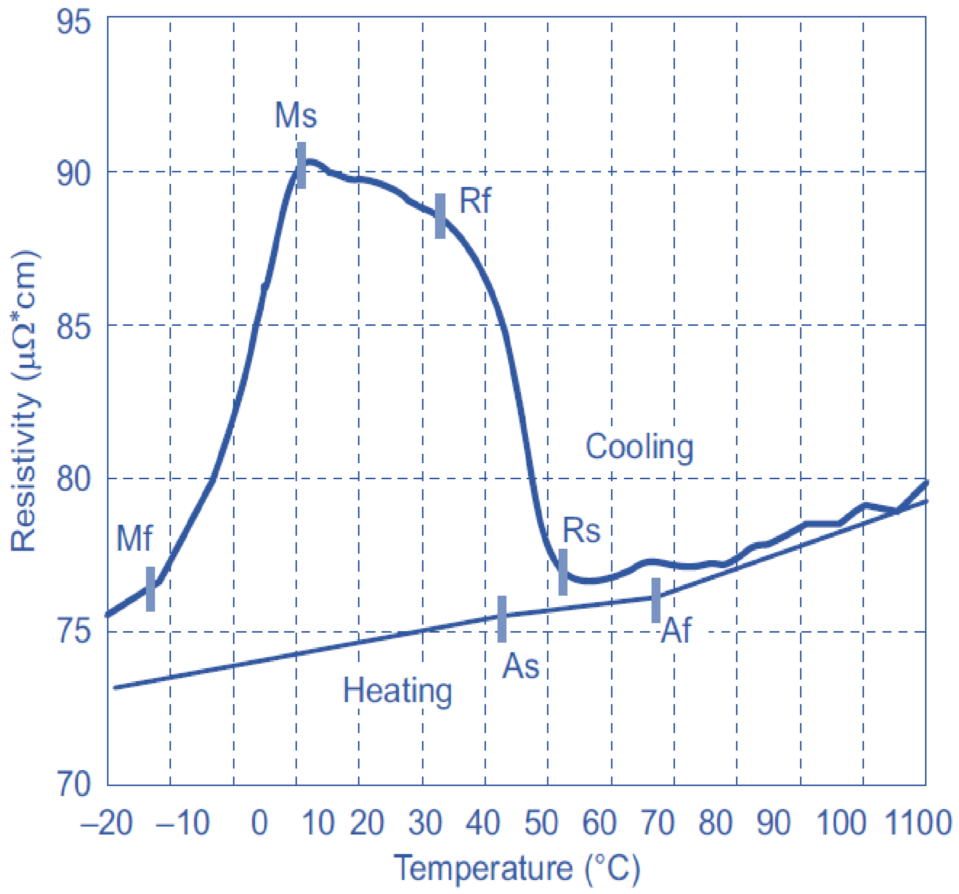


ELECTRICAL RESISTANCE MEASUREMENTS

- The comparison between calorimetric and electrical measurements points out the importance of temperature dependence of NiTi ER for identifying particular transformations that otherwise could not be identified using calorimetric techniques.
- ER measurement, in fact, has proved to be a good probe for identifying the R-phase and its start and finish transition temperatures. Moreover, the presence of a mixed phase consisting of martensite and the R-phase has been detected from ER measurements but not from DSC analysis, in which only a large peak transition in the cooling part of heat flow curve is present.

ELECTRICAL RESISTANCE MEASUREMENTS

- ER measurements clearly revealed the presence of an R-phase both during heating and cooling, because R-phase resistance is higher than both the resistances of the austernite and of the martensite



Neutron Diffraction Analysis (NDA)

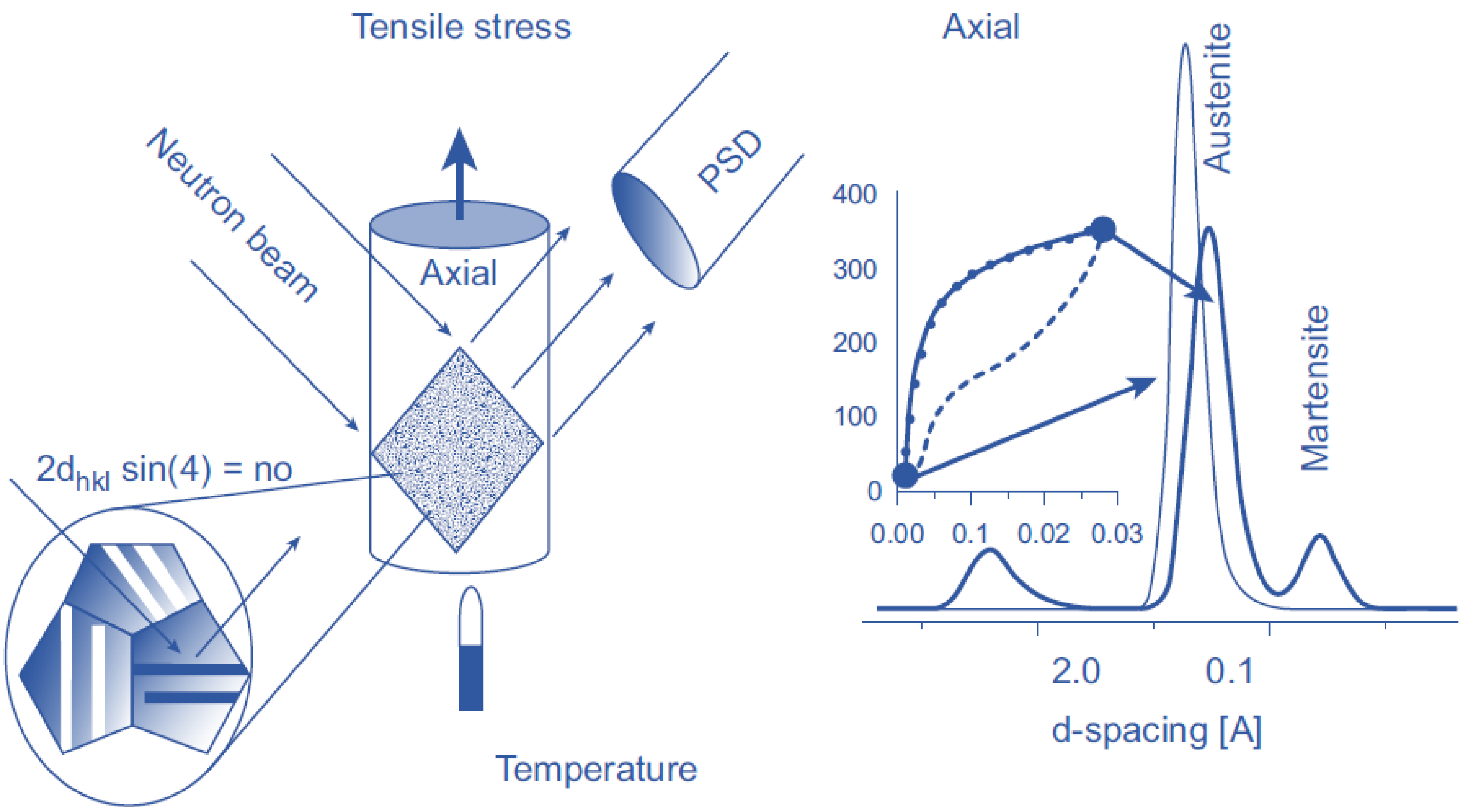
- One problem related to the mechanics of SMAs is the variety of deformations that can be activated during thermomechanical transformation while an SMA element is subjected to a thermomechanical load, because these depend on the current stress-strain temperature conditions and also on the thermomechanical history of the specimen.

Neutron Diffraction Analysis (NDA)

- Although the properties related to these transformations are relatively well known, the mechanics of the transformations occurring in the polycrystalline environment are less well understood.
- A useful tool in this respect has proved to be neutron diffraction, which combined with micromechanics modeling of SMA gives information on the deformation and transformation processes in NiTi polycrystal

Neutron Diffraction Analysis (NDA)

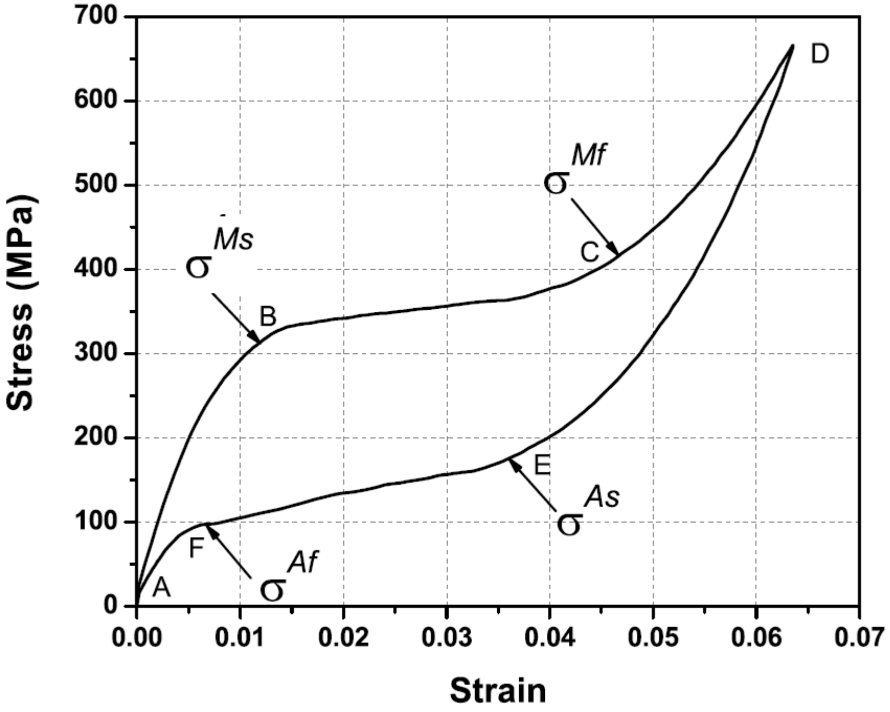
- Neutron diffraction, with respect to X-ray analysis, has the advantage of using neutrons, which can penetrate the bulk of the material. In this way, experimental information averaged on the whole-gauge volume of the specimen subjected to thermomechanical stresses can be obtained.
- The experimental information that can be obtained using this technique is related to the evolution of elastic lattice strains and the phase fraction in oriented grains and phases of transforming polycrystalline SMA



- The principle of the method is depicted in Figure above
- The specimen is loaded mechanically and thermally inside the neutron diffractometer. Integral intensities and positions of reflections of austenite and martensite phases are measured at selected states of stress, temperature, and strain, and their evolution with these external forces can be monitored

The Pseudoelastic Behavior

- The *pseudoelastic* behavior of SMAs is associated with stress-induced transformation, which leads to strain generation during loading and subsequent strain recovery upon unloading at temperatures above *Af* .
- A pseudoelastic thermomechanical loading path generally starts at a sufficiently high temperature where stable austenite exists, then develops under an applied load to a state at which detwinned martensite is stable, and finally returns to the austenitic phase when returned to zero stress state



The *pseudoelastic* behavior

- The detwinned martensite that forms from austenite as a result of the applied stress during Path 1 or 2 in is one form of stress-induced martensite (SIM). SIM, in general, is martensite that forms from austenite in the presence of stress. There are many thermomechanical loading paths that can result in the formation of SIM