Shape Memory Alloy

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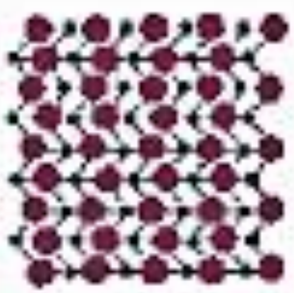
Shape memory alloys are a unique class of metal alloys that can recover apparent permanent strains when they are heated above a certain temperature. The shape memory alloys have two stable phases - the high–temperature phase, called austenite (named after English metallurgist William Chandler Austen) and the low–temperature phase, called martensite (named after German metallographer Adolf Martens .

Austenite

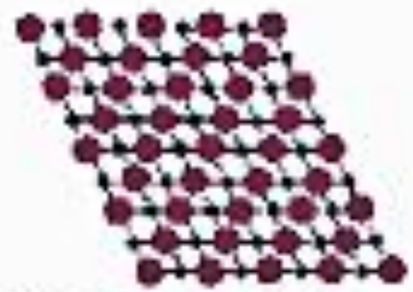
- High temperature phase
- Cubic Crystal Structure

Martensite

- Low temperature phase
- Monoclinic Crystal Structure



Twinned Martensite



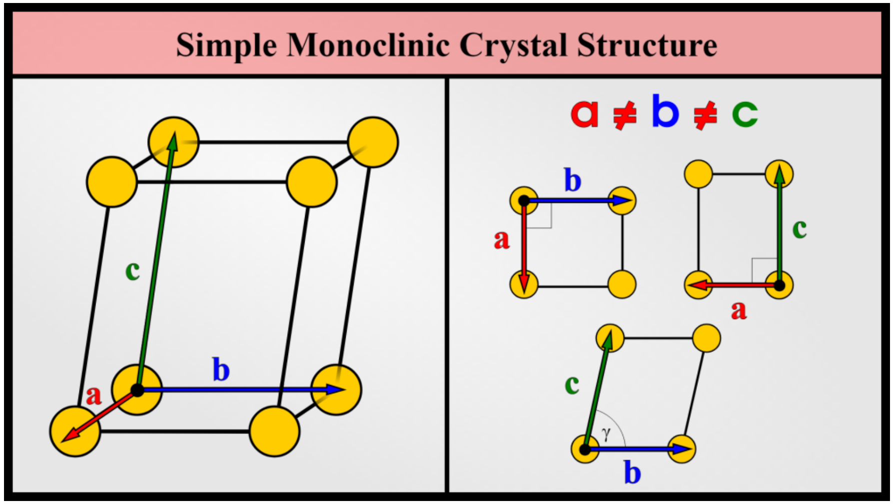
Detwinned Martensite

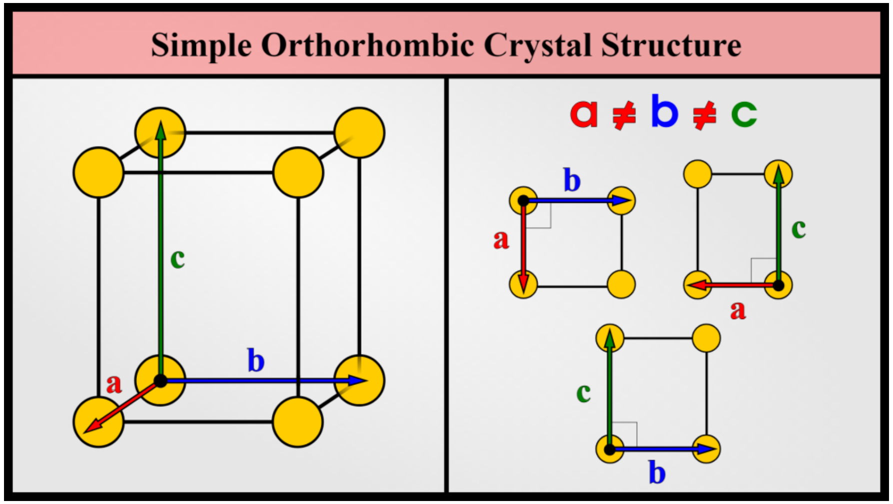
The key characteristic of all shape memory alloys is the occurrence of a **martensitic phase transformation** which is a phase change between two solid phases and involves rearrangement of atoms within the crystal lattice. The martensitic transformation is associated with an inelastic deformation of the crystal lattice with no diffusive process involved. The phase transformation results from a cooperative and collective motion of atoms on distances smaller than the lattice parameters.

When a shape memory alloy undergoes a martensitic phase transformation, it transforms from its high–symmetry (usually cubic) austenitic phase to a low symmetry martensitic phase (highly twinned monoclinic structure).

Martensite is a phase that, in the absence of stress, is stable only at low temperatures; in addition, it can be induced by either stress or temperature, easily deformed, and reach large strains (~8%) depending on the type of transformation experienced by these alloys, the crystal structure of martensite can be either monoclinic or orthorhombic.

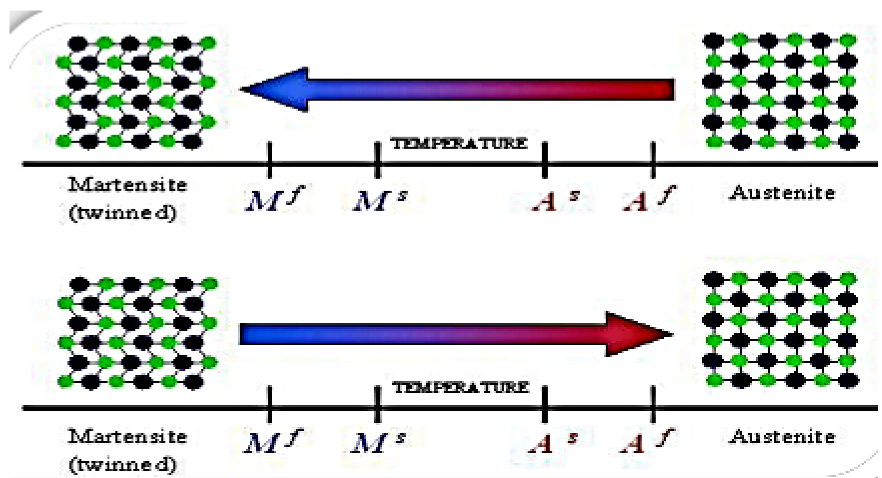
When martensite is induced by temperature, it is called twinned martensite. The twinned martensite has 24 variants, i.e., 24 subtypes with different crystallographic orientations . On the other hand, when martensite is induced by stress; these 24 variants of twinned martensite become only one variant. As a consequence, there is a crystallographic orientation, aligned with the stress direction, which is called detwinned martensite. The austenite phase is stable only at high temperatures, having a single variant with a body-centered cubic crystal structure





Martensitic transformation explains the shape recovery in SMA. This transformation occurs within a range of temperatures which varies according to the chemical content of each alloy . In general, four characteristic transformation temperatures can be defined: MS and MF, which are the temperatures at which the formation of martensite starts and finishes, respectively, and AS and AF, which are the temperatures at which the formation of austenite starts and finishes, respectively.

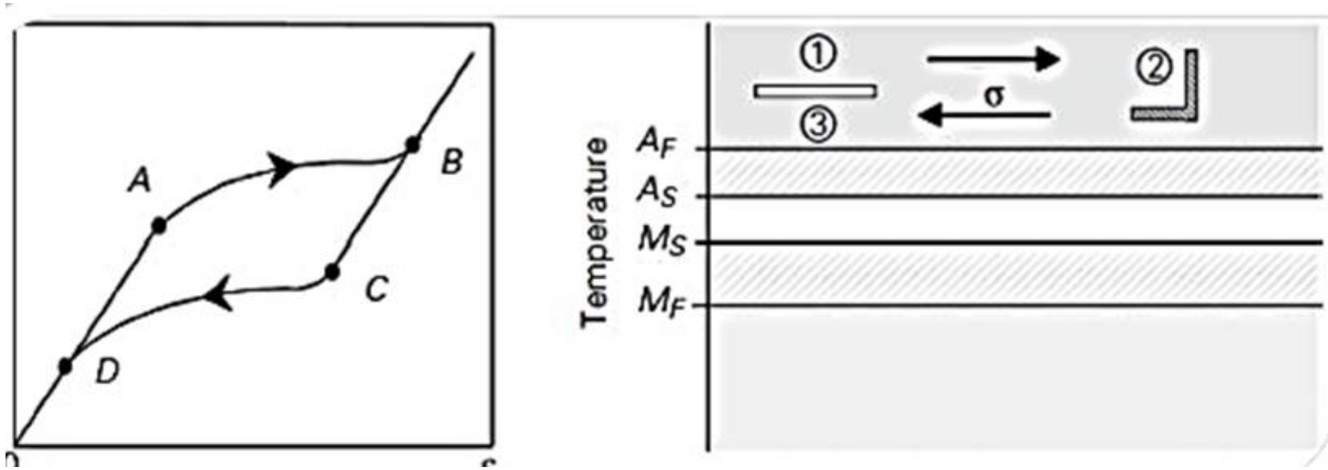
Martensitic start temperature (Ms) is the temperature at which the material starts transforming from austenite to martensite. Second is martensitic finish temperature (Mf), at which the transformation is complete and material becomes fully in the martensitic phase. Similar temperatures are defined for reversible transformation. Austenite start temperature (As) is the temperature at which the reverse transformation starts and austenite finish temperature (Af) at which the reverse transformation is finished and the material is in the austenitic phase



Thermo Mechanical Behavior of Shape Memory Alloys

1)Pseudoelasticity(super plasticity):

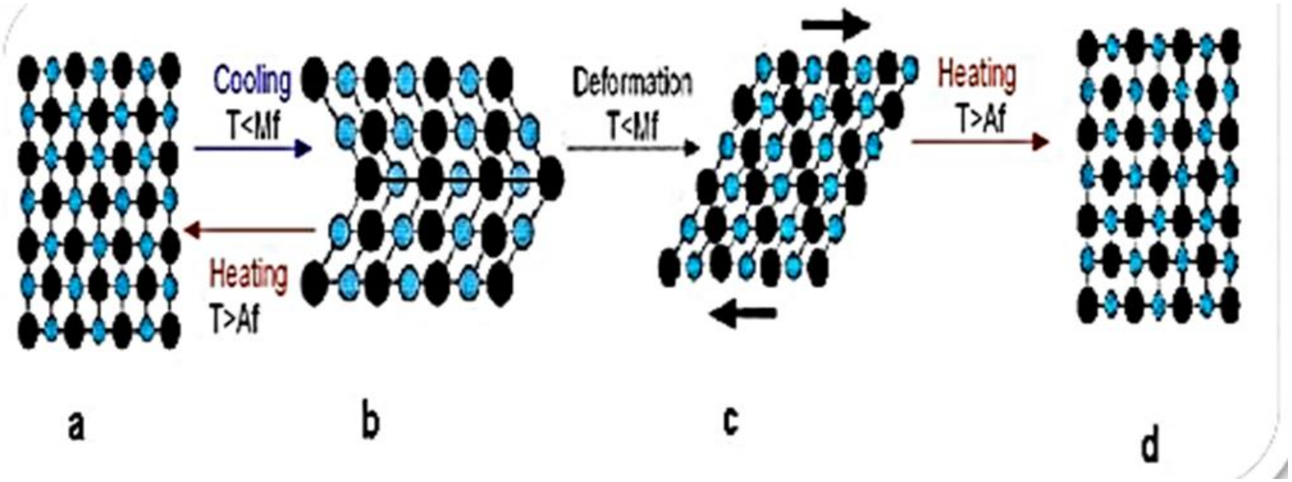
Pseudoelasticity occurs whenever an SMA sample is at a temperature above Af (The temperature above which only the austenitic phase is stable for a stress-free specimen). Thus, one can consider an SMA sample subjected to a mechanical loading at a constant temperature above Af.



A mechanical loading causes an elastic response until a critical value is reached, point A, when the martensitic transformation (austenite → martensite) arises, ending at point B. At this point, the crystal structure of the sample is totally composed of detwinned martensite. For higher stress values, SMA presents a linear response. During the unloading process, the sample presents an elastic recovery (B → C). From point C to D one can note the reverse martensitic transformation (martensite → austenite). From point D on, the sample presents an elastic discharge. When the loading�unloading process is finished, SMA has no residual strain. However, since the path of the forward martensitic transformation does not coincide with the reverse transformation path, there is a hysteresis loop associated with energy dissipation. Another way to observe the pseudoelastic effect is indicated on the right side of Figure (1.5). First, let us consider an SMA at a temperature above AF, (1). At this temperature, there is only one phase, i.e., austenite. At a constant temperature, a mechanical loading is applied promoting the appearance of the detwinned martensite, (2). During the unloading process, reverse transformation takes place (detwinned martensite → austenite) and when load vanishes, (3), the sample presents no residual strain

2)Shape Memory Effect

Shape memory effect (SME) is the ability to remember a predetermined shape even after several deformations. The shape changes with temperature variation are mainly attributed to martensite phase transformation. (SME) is a phenomenon such that even though a specimen is deformed below As, regains its original shape by virtue of the reverse transformation upon heating to a temperature above Af ,at which the martensite becomes unstable. Depending upon the temperature range, the SME phenomena are slightly different



As schematically shown in figures to simplify the model, consider a single crystal in parent phase (T ≤ Mf) (a), it is cooled the to a temperature below Mf (b), Then, martensite is formed in a self-accommodation manner(c). Thus, if an external stress is applied, and if the stress is high enough, it will become a single variant of martensite under stress. is such the high mobility of the twin boundary in which a single variant of martensite changes into the twin orientation by shear. When the specimen is heated to a temperature above Af, reverse transformation occurs. The reverse transformation induced by heating recovers the inelastic strain; since martensite variants have been reoriented by stress, the reversion to austenite produces a large transformation strain having the same amplitude but the opposite direction with the inelastic strain and the SMA returns to its original shape of the austenitic phase (d).