IEEE POSTER WEEK

Shape memory alloys: computational models for industrial applications

Computational Mechanics and Advanced Materials Group

Dipartimento di Ingegneria Civile e Architettura (DICAr), Via Ferrata 3, 27100 Pavia, Italy

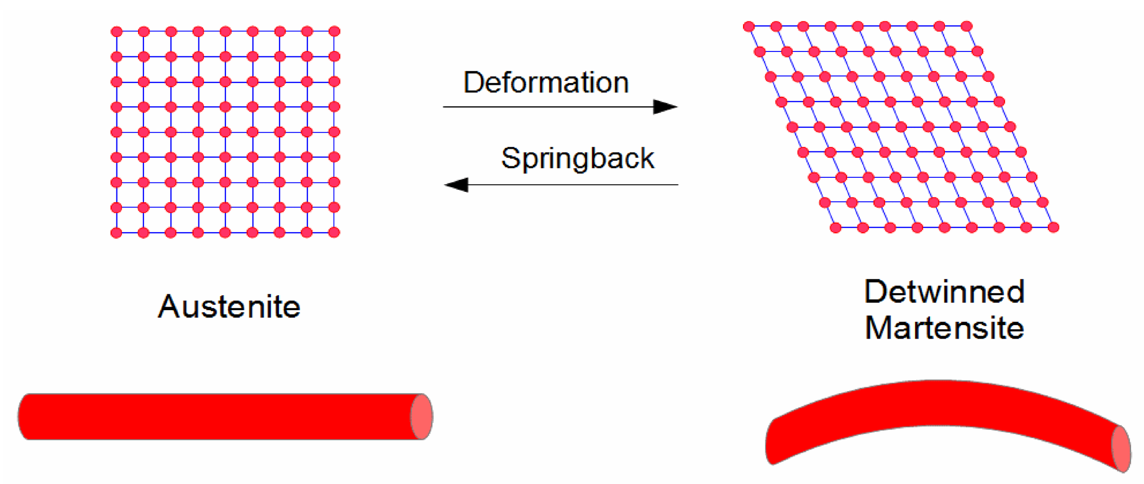
Istituto Universitario di Studi Superiori (IUSS), Piazza della Vittoria 15, 27100 Pavia, Italy

Website: www.unipv.it/compmech

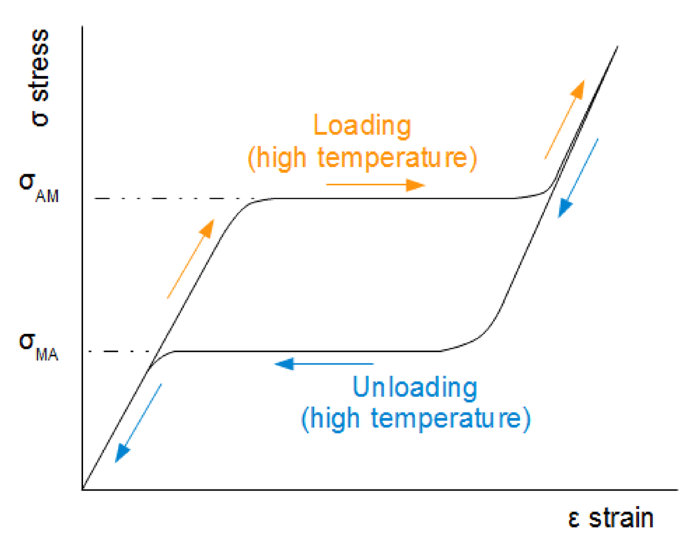
Shape Memory Alloys

Shape memory alloys (SMAs) are a particular group of metallic materials exhibiting unique properties, mainly represented by superelastic and shape memory effects.

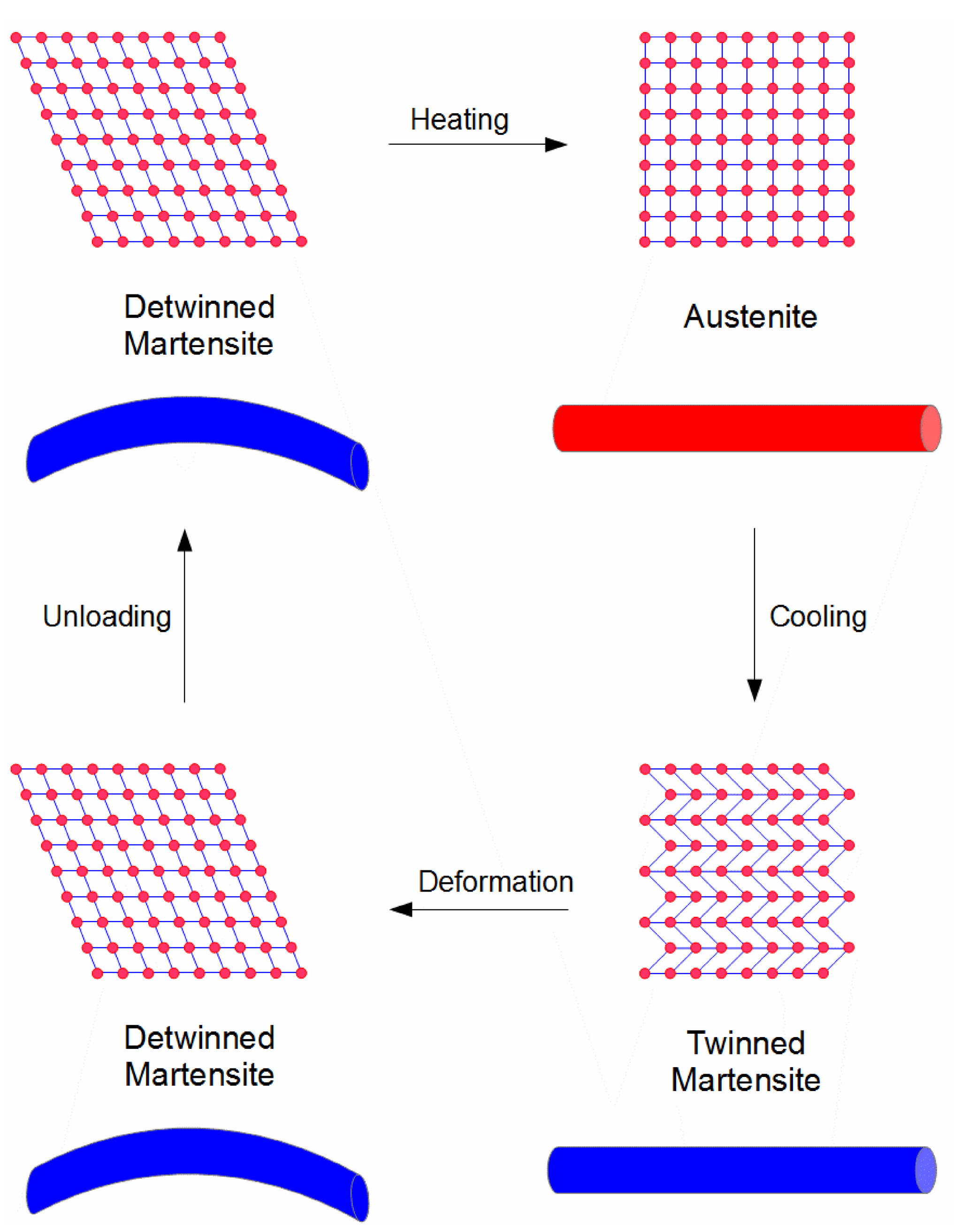
Superelasticity is the capability of recovering the original shape after large deformations (large strains can be undergone, until 8-10%) induced by mechanical loading.



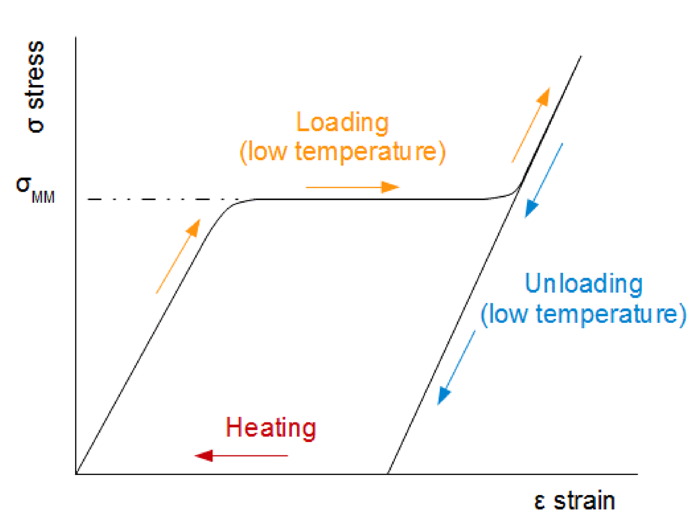
Superelasticity. When the alloy is mechanically loaded at a temperature higher than *austenite finish* temperature, superelasticity can be exhibited. If the value of applied stress is sufficiently high (i.e. over the value σ_{AM} in the graph), austenite to martensite transformation is induced. Upon unloading, inverse martensite to austenite transformation occurs, because austenite is the stable phase at higher temperature, and original shape is recovered.



Shape memory effect is the ability to maintain a deformed shape up to heat induced recovery of the original shape.

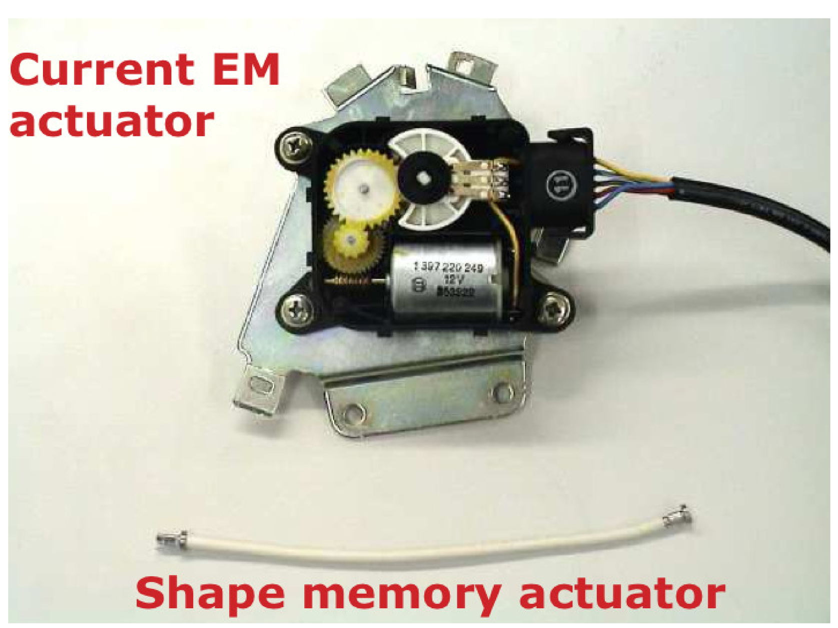


Shape memory effect. When the material is mechanically deformed at a temperature lower than *martensite finish* temperature, a transformation from multi-variant to single-variant martensite occurs, if the stress is higher than a determinate value (σ_{MM} in the figure). Upon unloading, a residual deformation remains. When the material, in an unloaded state, is heated above *austenite finish* temperature, the transformation from martensite to austenite allows shape recovery (shape memory effect). Upon cooling, most SMAs show no macroscopic deformation and the original shape is maintained.



SMA particular characteristics allow a variety of innovative applications in different engineering fields, such as biomedical (e.g. stents, surgery tools, active implants), structural (e.g. damping devices), automotive (e.g. actuators), aeronautical (e.g. the Variable Geometry Chevron), mechanical (e.g. heat engines, coupling devices) and robotic (e.g. SMA actuated microrobots) engineering.

Shape memory eyeglass frame. Shape memory eyeglass frame is a real life example of superelastic behavior. It can undergo severe deformation and still recover original shape.

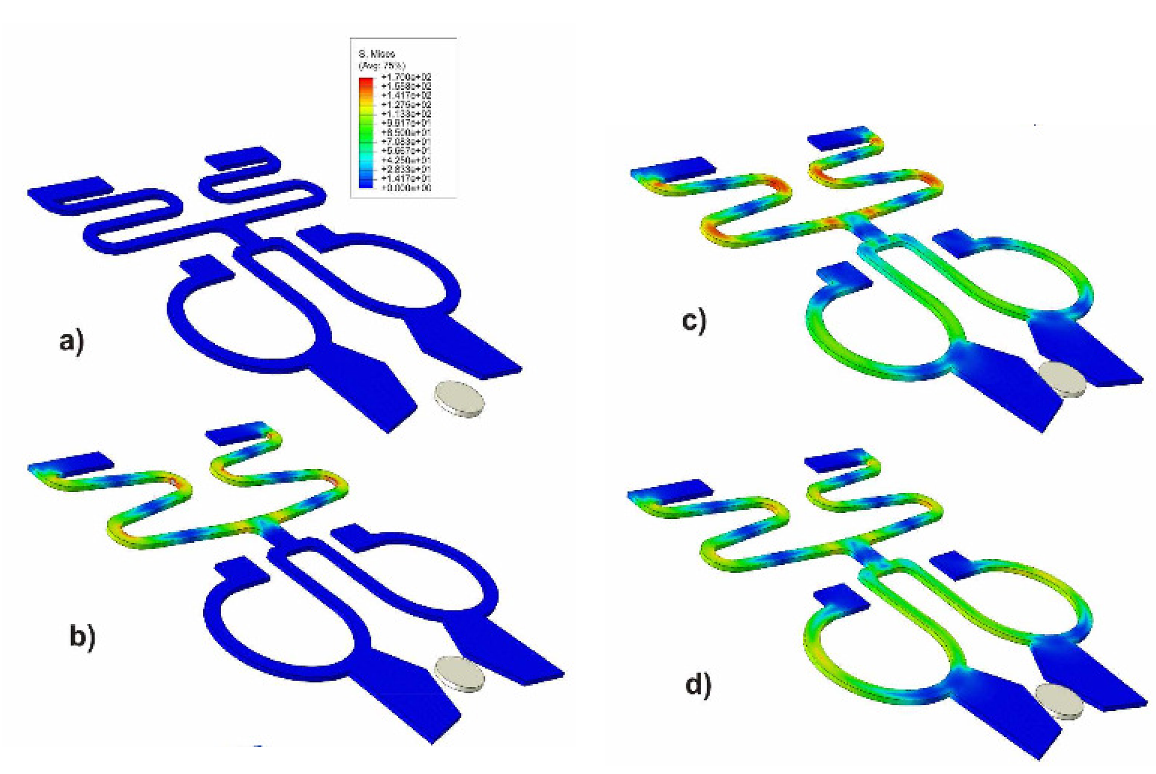


Shape memory actuator vs. EM actuator. Few centimeters of SMA wire can replace bulky electromagnetic (EM) actuators for automotive applications.

Industrial Applications

SMA Microgripper

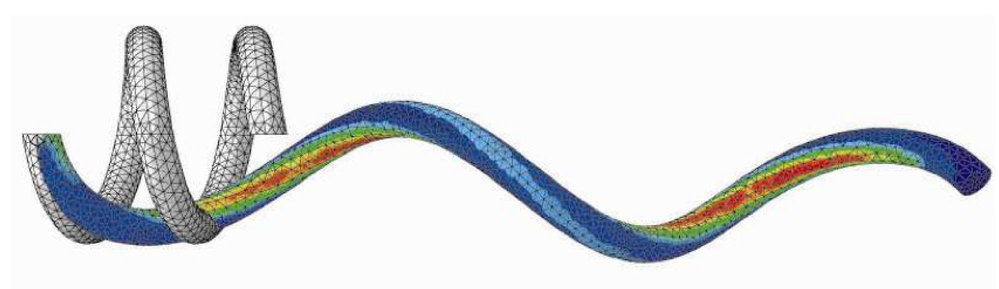
The SMA micro-gripper shown in the figure below has been simulated [1,2]. The micro-gripper has two parts: the upper part (gear actuator) and the lower part (linear actuator). After laser cutting, a pre-deformation is applied to the linear actuator, while heating the gear one. From now on, at each time, one actuator is martensitic while another one is austenitic.



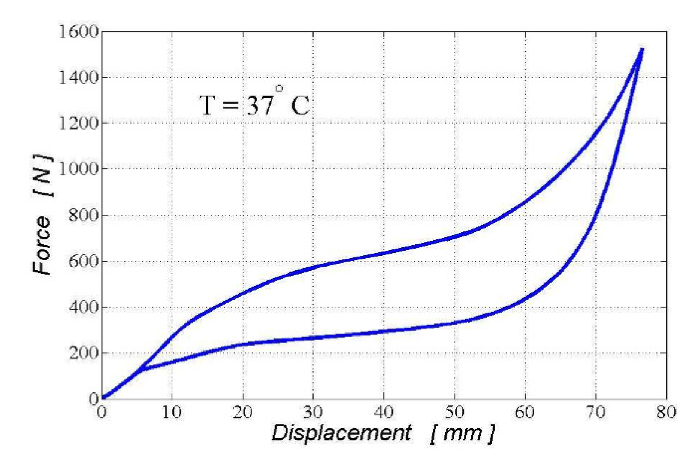
Simulation of micro-gripper with a sample. a) starting configuration; b) memorization step; c) heating of linear actuator and sample gripping; d) heating of rotary actuator with consequent re-opening. von Mises stress [MPa] distribution in the micro-gripper are depicted in the contour plot.

SMA helical spring actuator

We simulate a helical spring at two different temperatures [1,2]. An axial force is applied to one end of the helical spring while the other end is completely fixed. The force is increased from zero to its maximum value and unloaded back to zero. After unloading, the spring recovers its original shape as it is expected in the pseudo-elastic regime. It is observed that the spring shape is fully recovered after load removal.

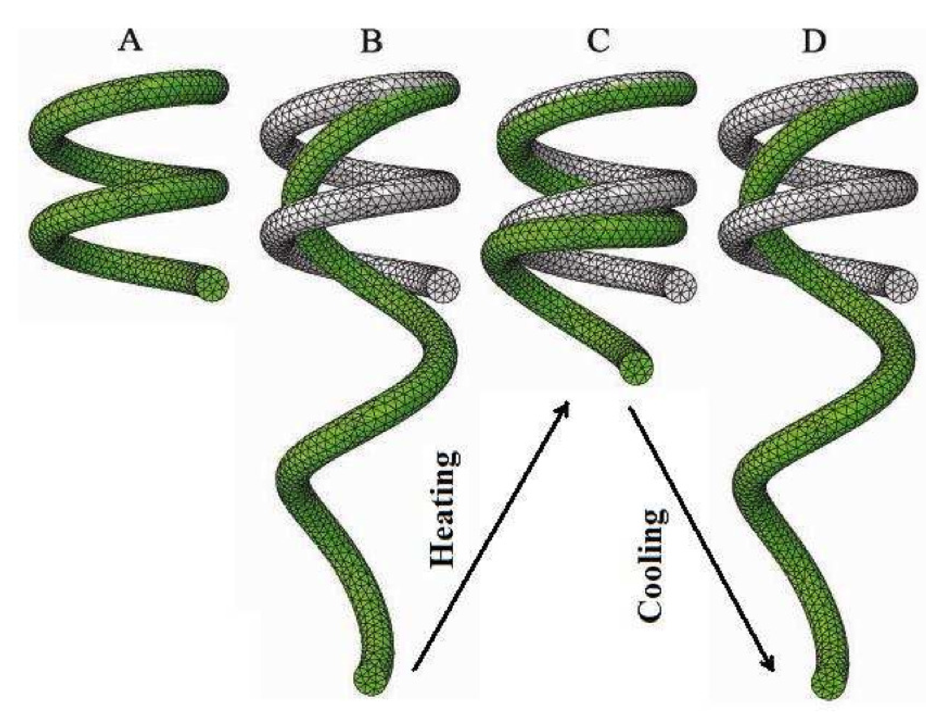


Pseudo-elastic spring. Initial and deformed configurations.

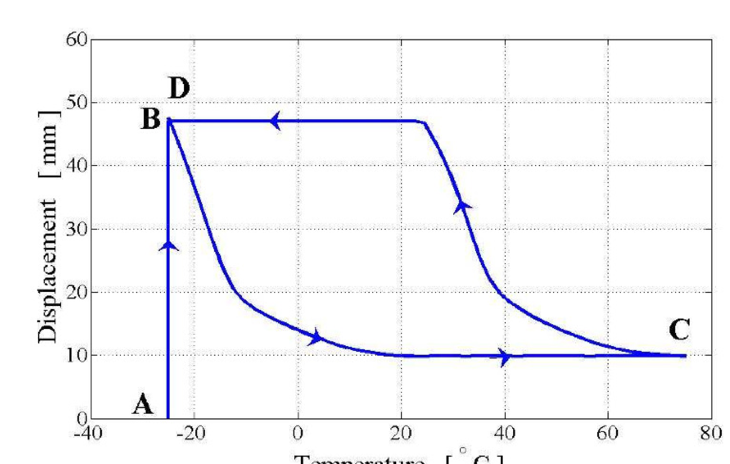


Pseudo-elasticity. Force-displacement diagram for SMA spring.

We also investigate the two-way shape memory effect and consider the spring fixed at the top end, initially loaded by a vertical force at the bottom end (A) and then, keeping constant the load, subjected to temperature cycle (B,C,D).



Spring actuator. A) initial geometry; B)deformed shape due to the weight application at T=-25 C; C) spring shape recovery and weight lifting due to heating to T=100 C; D) spring stretching due to cooling to T=-25 C



Spring actuator. Vertical displacement of the lower loaded end of spring versus temperature variation.

References

[1] F. Auricchio, L. Petrini. A three-dimensional model describing stress-temperature induced solid phase transformations. Part I: solution algorithm and boundary value problems. International Journal for Numerical Methods in Engineering, 61:807-836.

[2] F. Auricchio, J. Arghavani, M. Conti, S. Morganti, A. Reali, U. Stefanelli. Shape-memory alloys: effective 3D modeling, computational aspects and analysis of actuator and biomedical devices, Proceedings of ACTUATOR10 - International Conference and Exhibition on New Actuators and Drive Systems (2010).