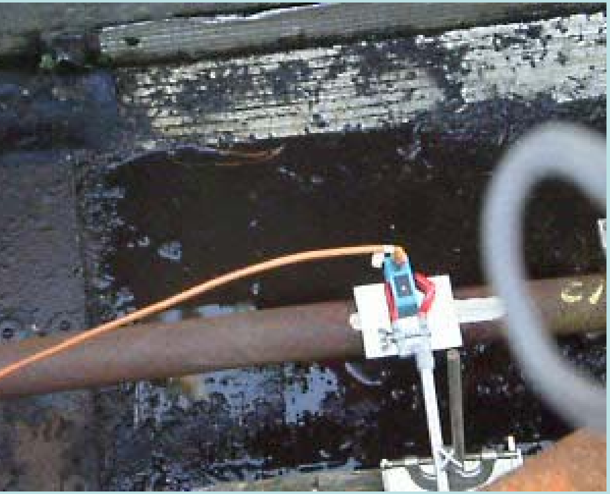
Functional fatigue recovery of superelastic cycled NiTi wires based on near 100ºC aging treatments

Antonio Isalgue[1], Hugo Soul[2], Alejandro Yawny[2], and Carlota Auguet[1]

1 Dep. Física Aplicada, UPC, Campus Nord B4, C. Jordi Girona, 31, 08034 Barcelona, Spain
2 Centro Atómico Bariloche, Div. Metales, Av. Bustillo, km 10.5, S.C. Bariloche, Argentina

Superelastic NiTi wires: Use as dampers.



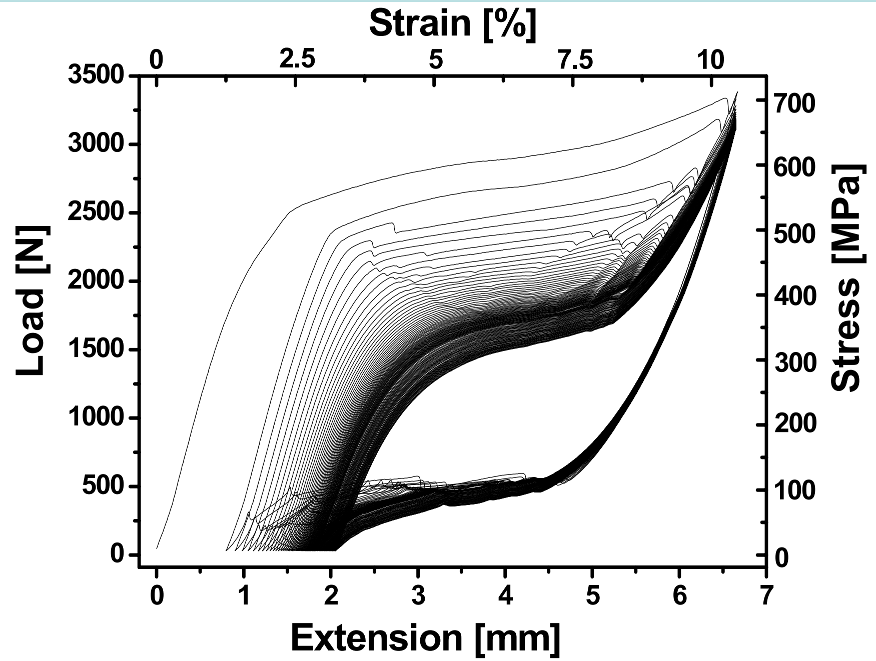
Superelastic NiTi wires: Use as dampers.

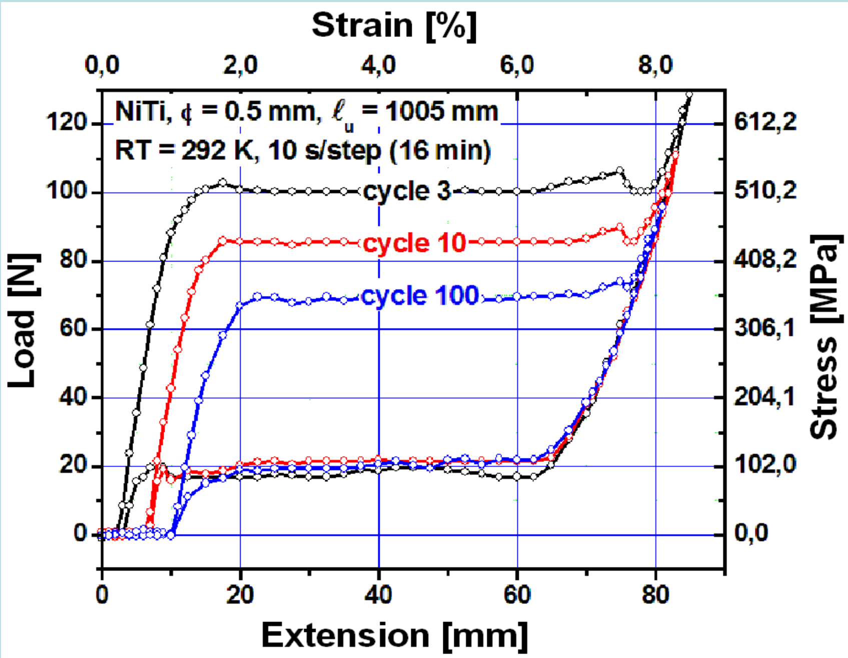
Functional fatigue: accumulation of residual strain and decrease of transformation stress on cycling

"Near assymptotic" behaviour,
but important loss of damping capacities

Here: Effect of "relatively low" temperature treatment (recovery)

Cycling effect:





Cycling effect: Left: 2.46 mm diameter NiTi wire. Cycles 1 to 100. The first cycle includes some gripping effects from the mechanical testing machine.

Right: Cycling effect on 0.5 mm diameter wire: cycles 3, 10 and 100.

Two pseudoelastic wires used: 2.46 mm diameter and 0.5 mm diameter (55.95 wt% Ni)

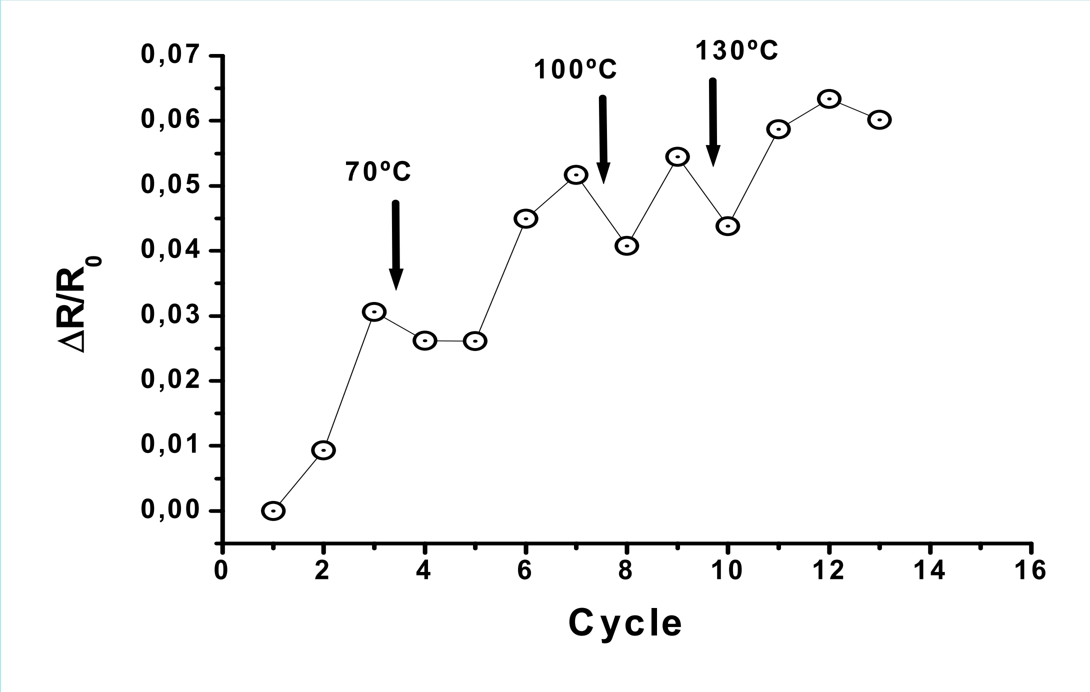
Thermal treatments near 100ºC

Recovery on the residual strains and the transformation stresses?

Electrical resistance changes (in beta) follow the residual strain

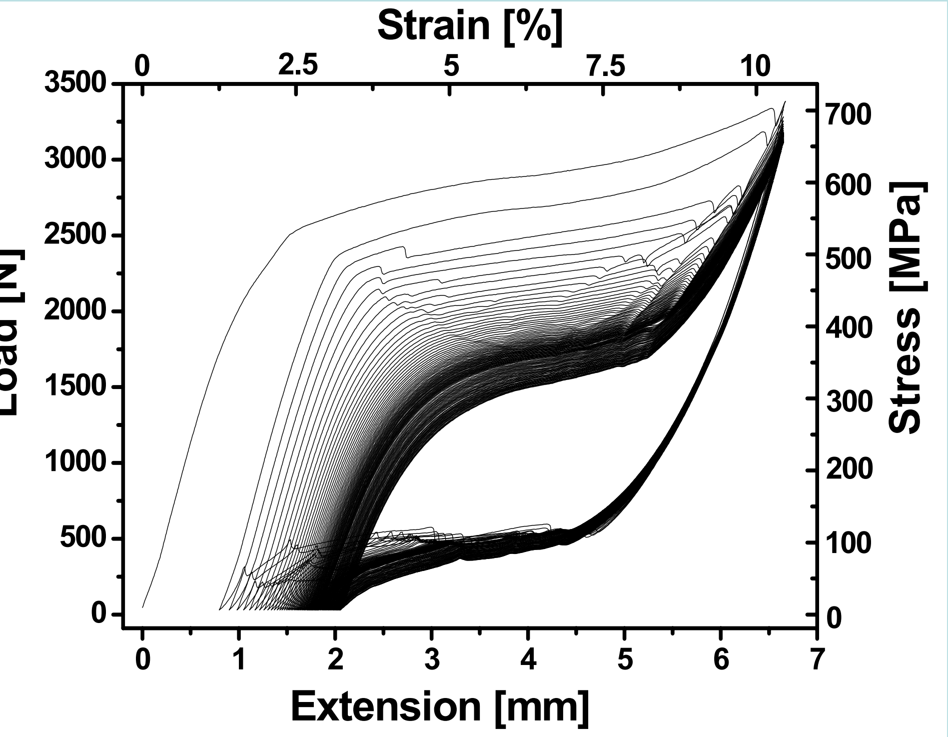
How do electrical resistance behave on cycled samples when heated?

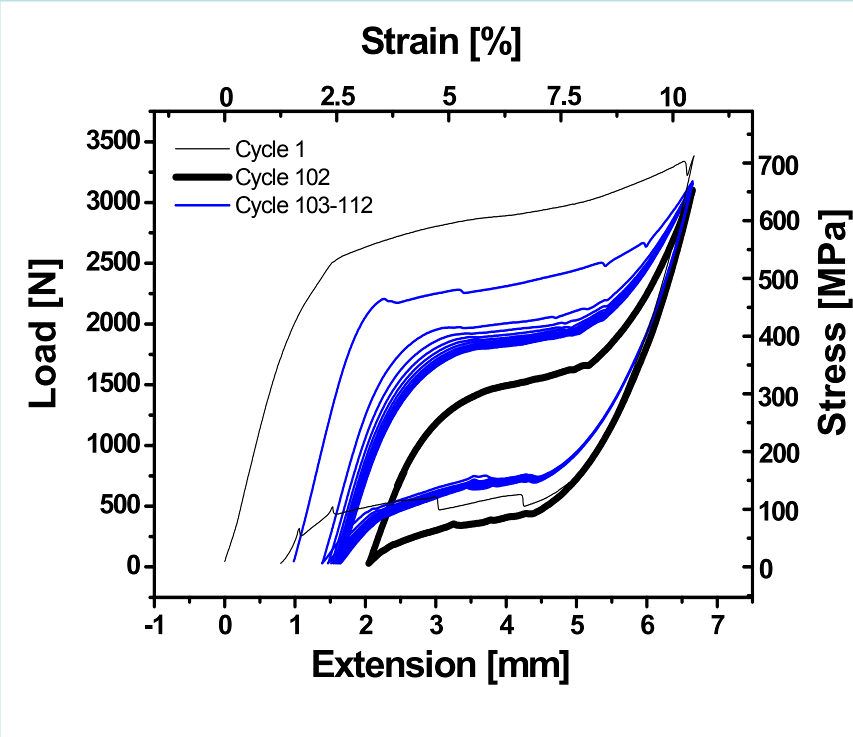
Resistance measurements:



Cycling effect to 8% strain on 0.5 mm diameter NiTi wire. Relative change of electrical resistance on cycling (lines are only visual guides). Cycles 1, 2, 3, 4, 5 to 8% strain. Cycles 6, 7, 8, 9, 10, 11, 12, to 9.5% strain. Cycle 14, to 8% strain. A thermal treatment at 70ºC (during 5 min) produces a small electrical resistance recovery. A thermal treatment to 100ºC (5 min) produces a recovery very near that of a 130ºC thermal treatment

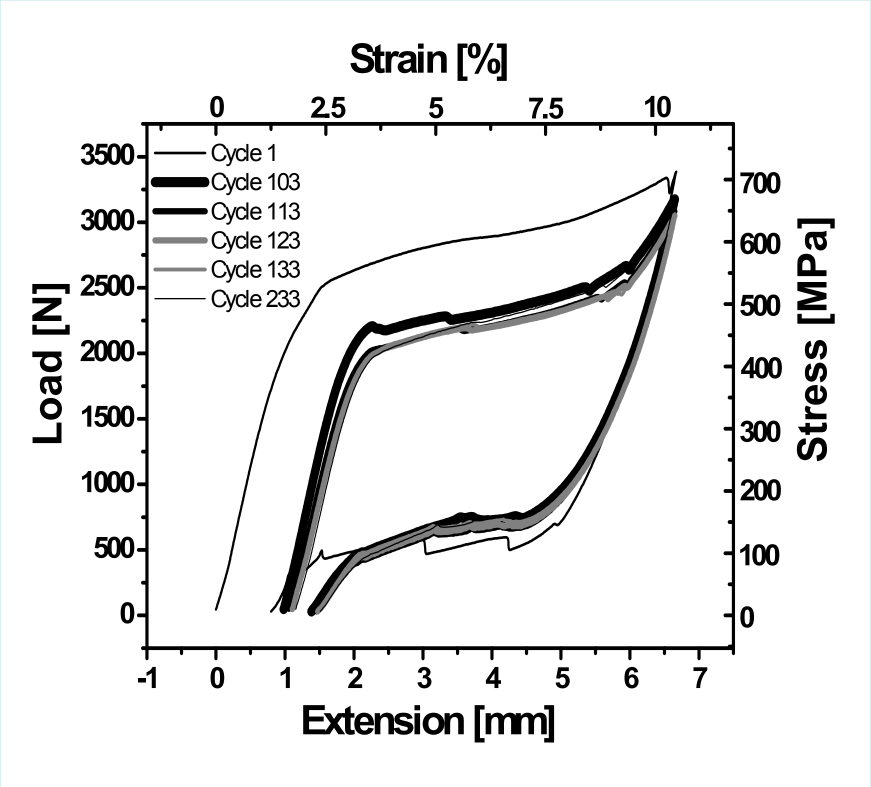
Recovery effect:





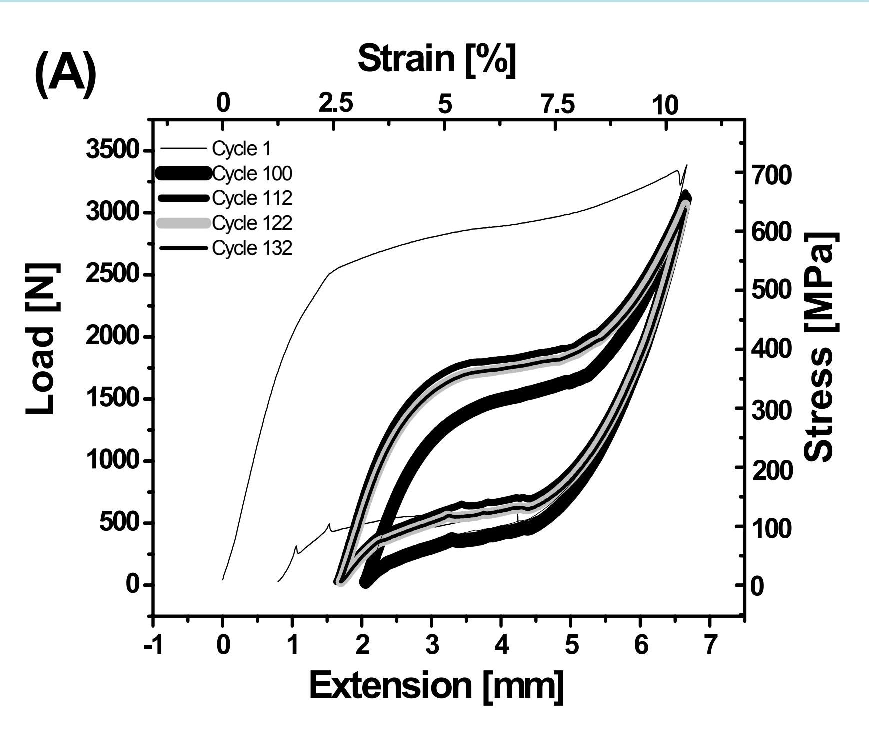
Recovery effect on 2.46 mm diameter NiTi wire. Left, first 100 cycles. Right, Cycles 1, 102 done after 5 h at room temperature once finished the first 100 cycles, and cycles 103-112 after heating to 100ºC for 3.5 h.

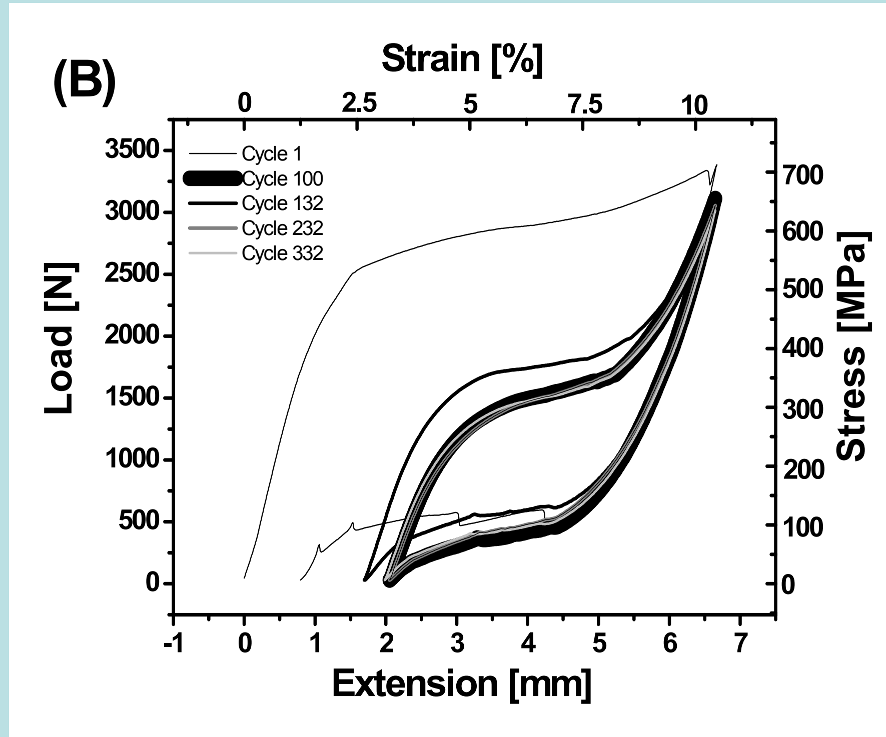
Different recoveries:



Recovery of 2.46 mm diameter NiTi wire by heating to 100ºC. Cycle 1 compared with the cycles after thermal treatments to 100ºC: cycles 103 (first recovery), 113 (second recovery), 123 (third recovery), 133 (fourth recovery), 233 (fifth recovery). The cycles after heat treatment to 100ºC result very similar among them

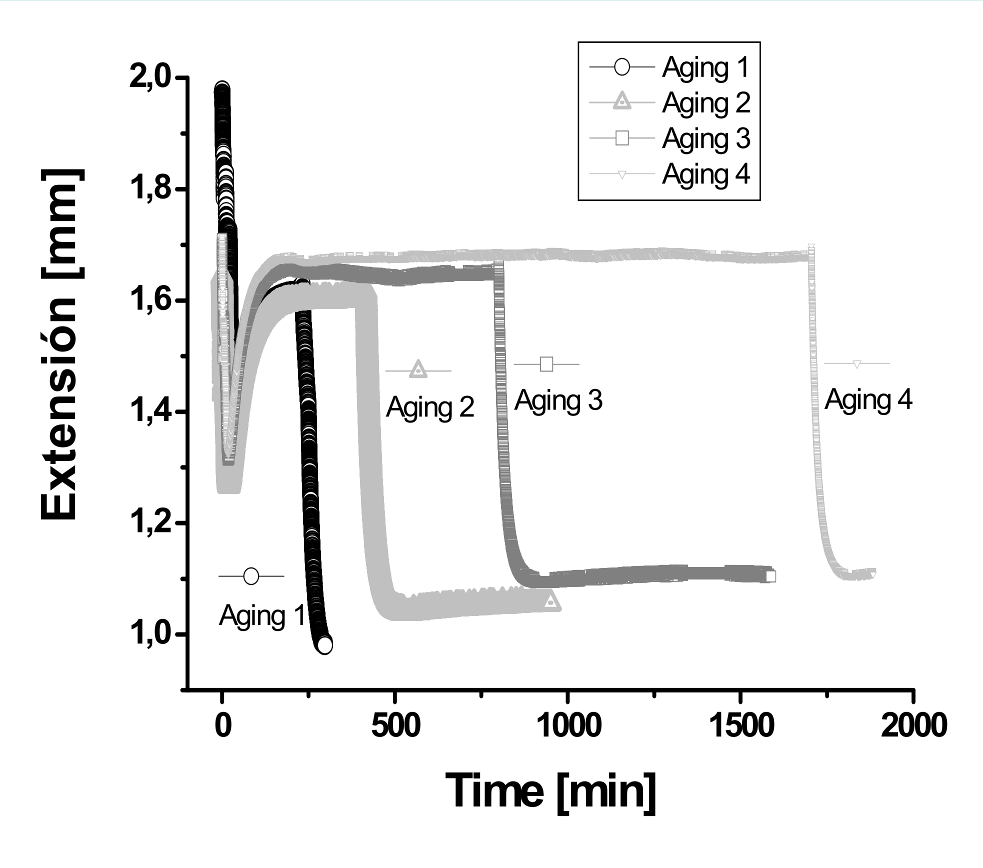
Different recoveries:





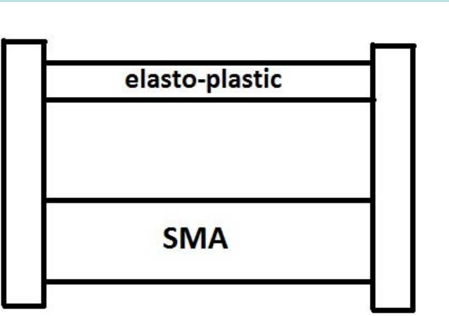
Cycling effect on 2.46 mm diameter NiTi wire. (A): Cycles 1, 100 (at the end of ontinuous cycling), 112 (10 cycles more after first heat treatment), 122 (10 cycles mor fter second heat treatment), 132 (10 cycles more after third heat treatment). (B): Cycle 1, 100, 132, 232 (100 cycles more after fourth heat treatment), 332 (100 cycles more after fifth heat treatment).

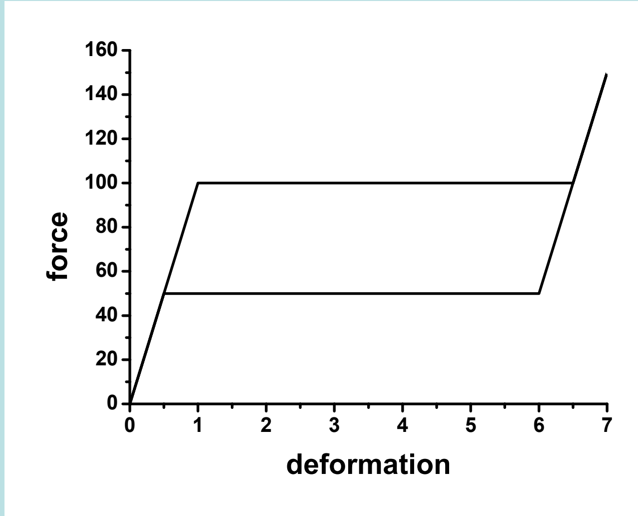
Effect of time at 100ºC:

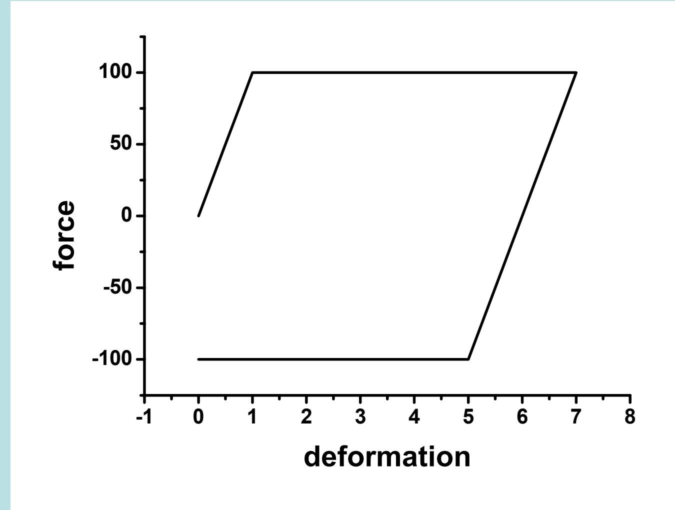


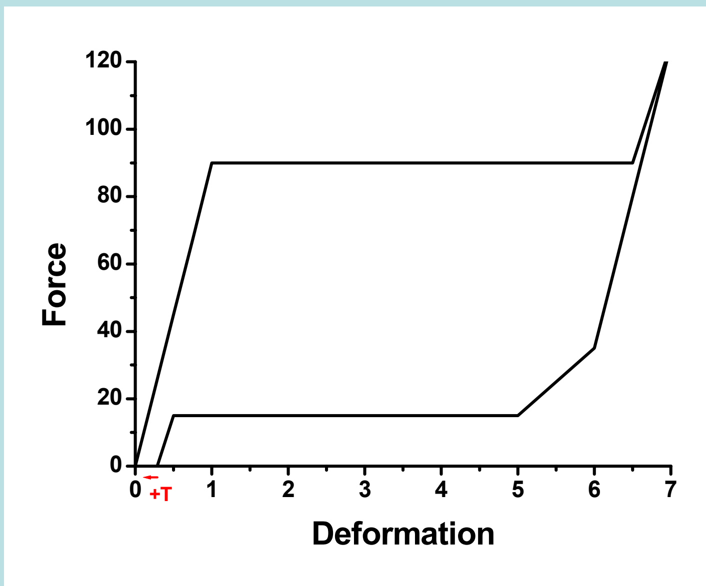
Extension as a function of time during the thermal treatment of NiTi wire 2.46 mm diameter, at 100ºC, for different recoveries.

Understand the behaviour: simple model









Include material with pseudoelasticity plus elasto-plastic behaviour

Recovery:

-100ºC considered “good” temperature of recovery for actual NiTi wires (As=247/248 K by DSC). Higher T not improve.

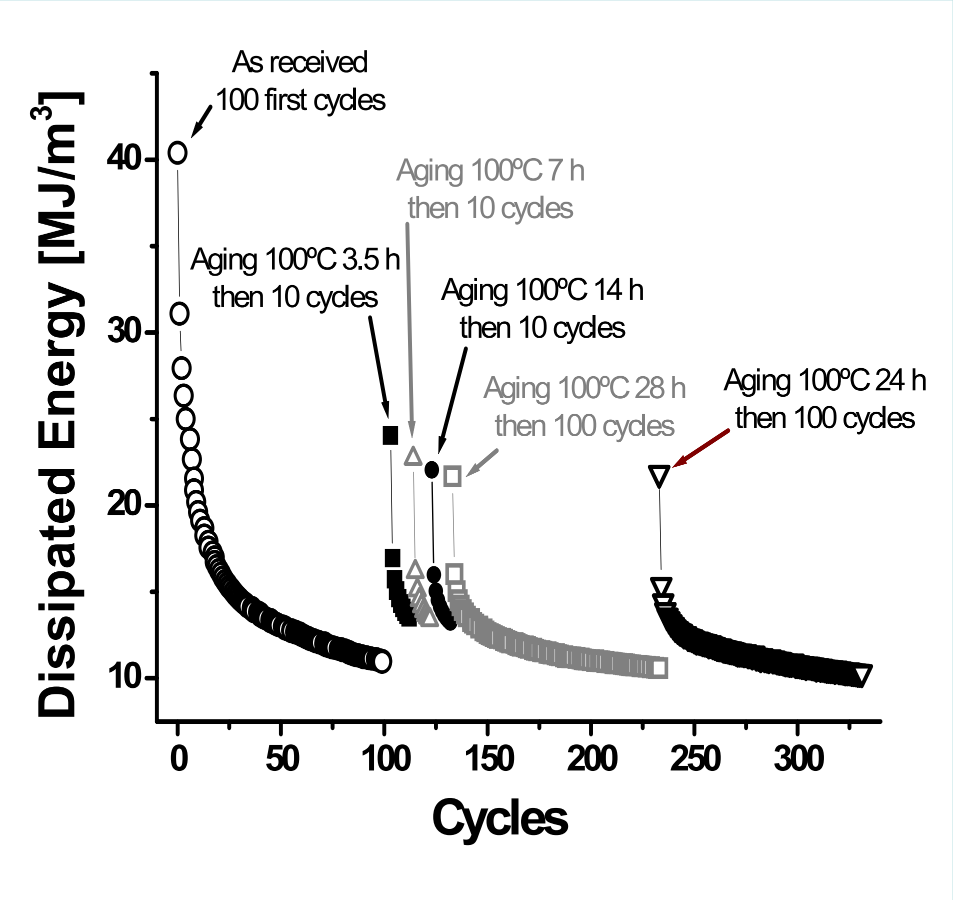
-Partial recovery on residual strain

-Partial recovery on stress to transform

-Succesive recoverings tend to keep accumulating residual strain

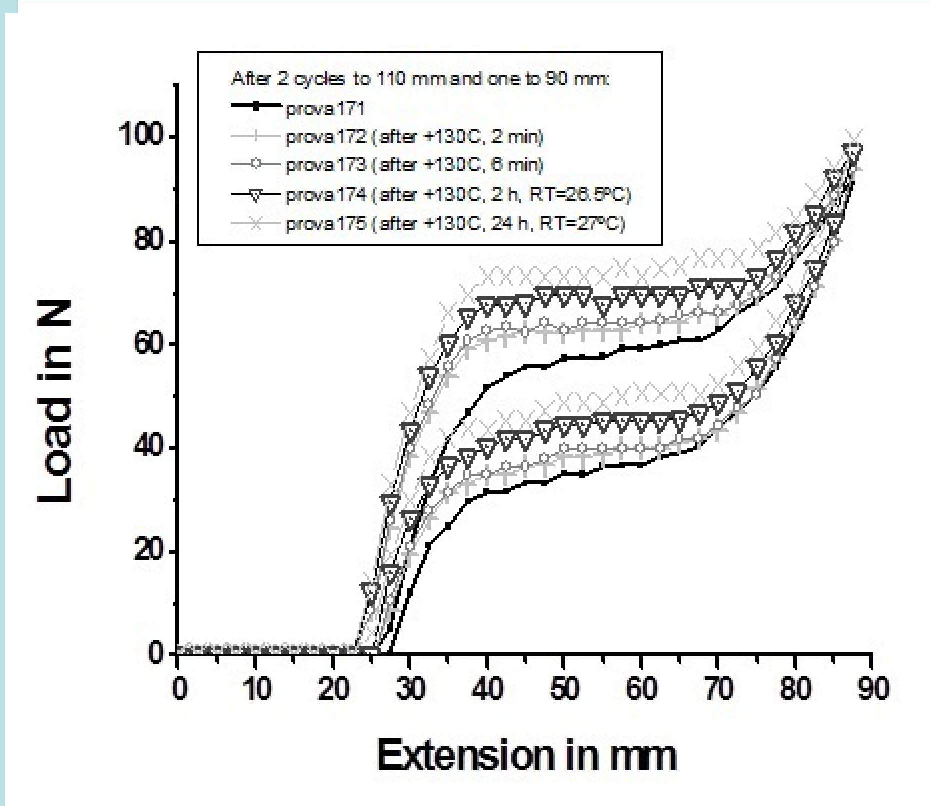
-Low importance of time at 100ºC

Effect on energy dissipation:



Specific dissipated energy per cycle. Recovery with thermal treatment to 100ºC on 2.46 mm diameter NiTi wire.

Lower recovery on overstrained wire:



Overstrained 1m long, 0.5 mm diameter NiTi wire. An as furnished wire was subjected t 2 cycles to 11% and one to 9%, and then followed the represented cycles: one cycle (prova171) to 8.75%, 2 min at 130ºC, one cycle to 8.75%, 6 min at 130ºC, one cycle to 8.75%, 2 hour at 130ºC, one cycle to 8.75%, 24 h at 130ºC and one cycle to 8.75% (prova175).

Conclusions:

Properties of SMA degrade with mechanical cycling: functional fatigue

Pseudoelastic NiTi wires tested: transformation stress decreases, residual permanent deformation increases with number of cycles in nearly asymptotic way, if maximum strain is kept constant. Dissipated energy cycle decreases.

Results show that important levels of recovery on the residual strains and the transformation stresses were attained after the aging treatments

Conclusions

Electrical resistance increase produced by cycling can be interpreted as due to two terms: the retained martensite, and defect accumulation (plasticity).

The 100ºC treatment relieves retained martensite that retransforms to beta. Above 100ºC: stress cannot increase more because of maximum tension in NiTi (CC 6.5 MPa/K).

Temperature of the thermal treatment able to give partial recovery of electrical resistance, in a parallel way to the residual deformation reduction.

Near no observable time dependence of treatment at 100ºC is coherent with a very slow change of properties with time at 100ºC. (NiTi alloy has been shown to present a very slow change of transformation temperature with time at 100ºC, representative times of the order of a year).

Conclusions:

Part of the functional fatigue produced by mechanical cycling on NiTi 2.46 diameter wires can be recovered by moderate thermal treatment (to 100ºC, during some hour).

However, the degradation of properties with cycling continues after the thermal treatment.

The thermal treatment at 100ºC would ease the use of NiTi wires as dampers for extreme situations as cable damping or as earthquake mitigation in civil engineering, because after an event it is easy to recover partly the properties of the implied material.

Thanks for your attention!

E-mail: antonio.isalgue@upc.edu

By moderate thermal treatment of the wires after cycling, part of the residual permanent deformation was recovered, as well as part of the specific energy dissipated per cycle, and the stress to transform did also recover. The recovery at 100ºC was larger than the recovery at 70ºC, but the recovery at 130ºC was similar to the one at 100ºC. It is suggested that part of the degradation of properties was due to retained martensite in the samples, producing residual ermanent deformation. The retained martensite coexists with an internal stress distribution chang (respect the material without martensite) and different density of defects. These internal stress distribution and density of defects are related to the decreased stress to transform in the cycled samples.

Both changes in properties, residual strain and reduced stress to transform, would produce the reduction in dissipated mechanical energy per cycle. The moderate heating to 100ºC is able to retransform a large part of the retained martensite, producing a change in residual strain. A large part of the remaining residual strain should be due to plastic deformation. The retransformation of martensite would give a change in the distribution of internal stresses that recovers partially the transformation stress, and, as a consequence of extended strain span useful and higher transformation stress, the dissipated energy per cycle recovers.

The properties of SMA tend to degrade with mechanical cycling, this is called functional fatigue when mechanical failure (fracture) does not occur, but the working point of the material can hinde its applications. For the NiTi wires tested, the transformation stress decreased, and the residual permanent deformation increased with number of cycles in an asymptotic, nearly exponential way f maximum strain on cycling was kept constant. The dissipated energy per cycle also decreased.

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The electrical resistance increase produced by cycling can be interpreted as due to two terms: the appearance of retained martensite, and the defect accumulation (related to plasticity) [23]. The thermal treatment applied relieves retained martensite that retransforms to beta, this quantity increases when the thermal treatment temperature is increased respect to room temperature. At 100ºC most of the retained martensite is relieved. The temperature of the thermal treatment is abl to give a partial recovery of the electrical resistance, in a parallel way to the residual deformation reduction.

The very low dependence of the recovery with the time at 100ºC is coherent with a very slow change of defect density with time at 100ºC. In fact, NiTi alloy has been shown to present a very slow change of transformation temperature with time at 100ºC, with representative times of the order of a year [24]. At 130ºC, however, the dependence of recovery with time becomes more ffective. The observed near constancy of residual strain on the time, and the increase of the stres to transform on the time at this temperature, are coherent with the strain being determined by etained martensite in the sample, and slow evolution of defect density with time would relate to th increase of transformation stress with time at 130ºC.

n conclusion, part of the functional fatigue produced by mechanical cycling on NiTi 2.46 diameter ires can be recovered by moderate thermal treatment (to 100ºC, during some hour). However, th degradation of properties with cycling continues after the thermal treatment (see figure 8). The hermal treatment at 100ºC would ease the use of NiTi wires as dampers for extreme situations as earthquake mitigation in civil engineering, because after an event it is easy to recover partly the properties of the implied material.