Development of Stable Two-Way Shape Memory Behavior in a Polycrystalline NiTi Shape Memory Alloy

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Acknowledgment

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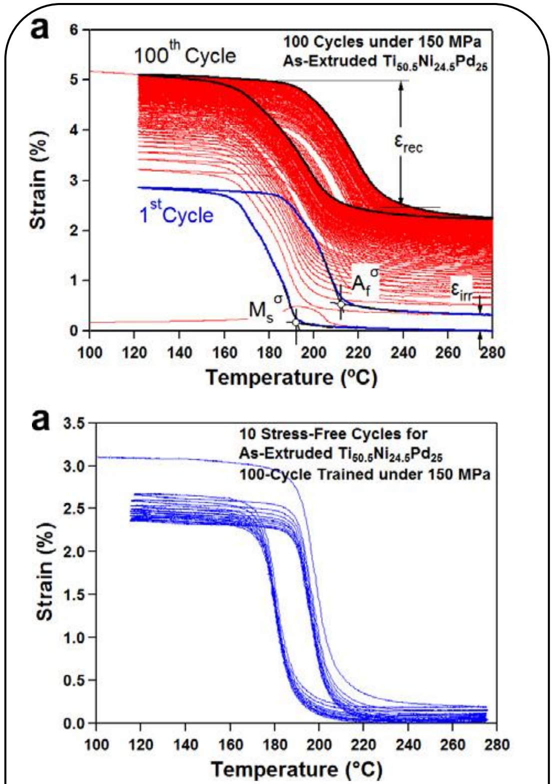
- **Basic Energy Sciences (DOE)**

- **CASMART**

Two-Way Shape Memory Effect (TWSME)

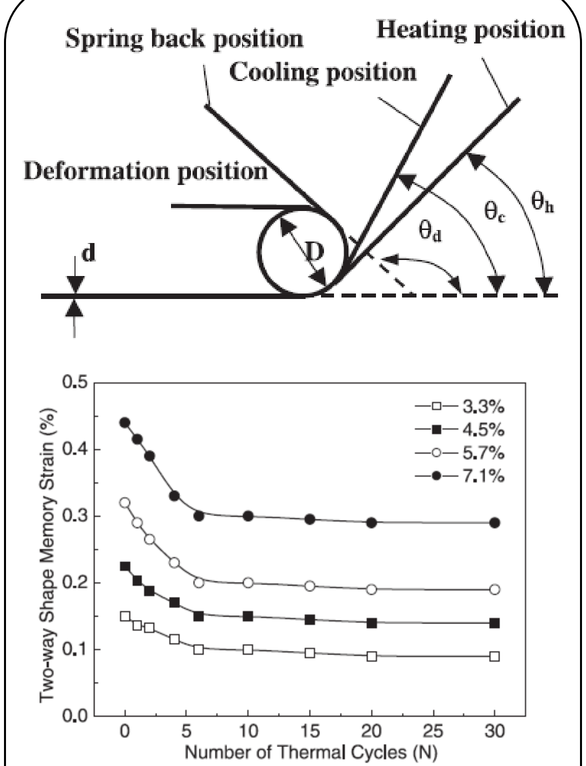
- Two-Way Shape Memory effect (TWSME) is not an inherent behavior of SMAs
- Can be obtained after specific thermomechanical training procedures (***many different training methods have been developed***)

Thermomechanical cycling



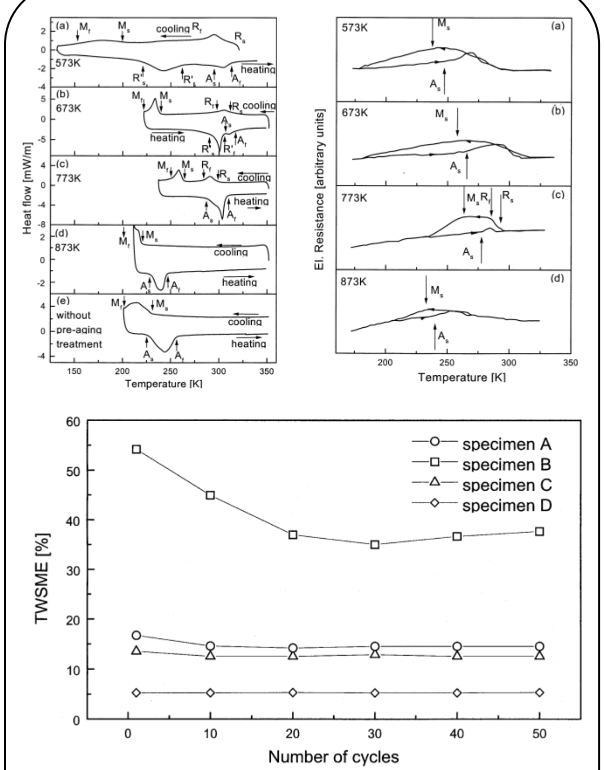
[1] K. C. Atli et al. / Scripta Materialia 65 (2011) 903–906

Martensite deformation



[2] X.L. Meng et al. / Materials Letters 57 (2003) 4206–4211

Precipitation/aging



[3] C.-Y. Chang et al./ Metall. Mater. Trans. A **32** (2001) 1629

Motivation and Objectives

Motivation:

- **Training by martensite deformation is relatively easy and quick** [4] **Y. Liu et al./Acta Mater. 47, (1998)**
- **Requires little more than a onetime deformation of the material**
- **Multiple thermomechanical cycles are NOT REQUIRED**

Objectives:

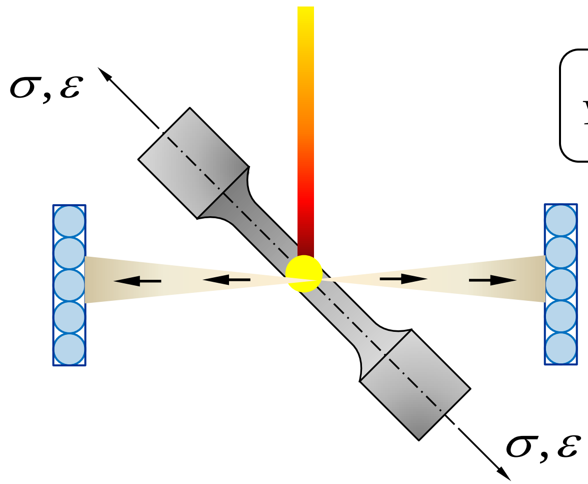
- **Investigate the role of deformation on the stability and efficacy of the TWSME**
- **Examine the micromechanical and microstructural changes associated with the training procedure (neutron diffraction)**
- **Optimize training for a specific TWSME actuator application**
- **Use the same training method to obtain different properties**

- **Can we apply this to the load-biased actuators??**

Neutron Diffraction at LANL

(*i*) Experiment

neutron beam



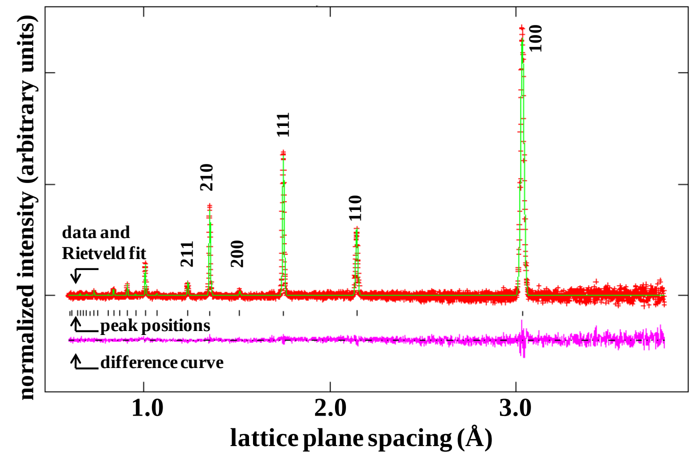
(*ii*) Model

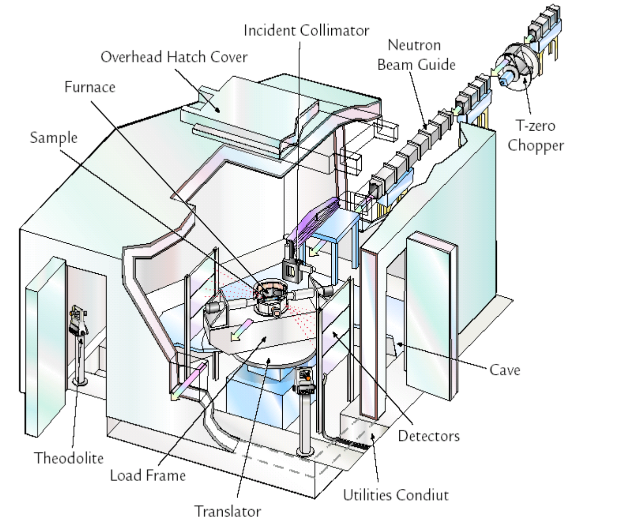
Rietveld refinement
multi parameter curve fitting

$$Y_{ci} = Y_{bi} + s\sum_{k} L_k \left|F_k\right|^2 \phi\left(2\theta_i - 2\theta_k\right) P_k A$$

Y_{bi} :background intensity
s: scale factor
L_k :Lorentz factor a
F_k :structure factor
f :refection profile function
$2\theta_i$:observed Bragg peak position
$2\theta_k$:corrected calculated Bragg peak position
P_k: preferred orientation function
A: absorption factor

(*iii*) Result





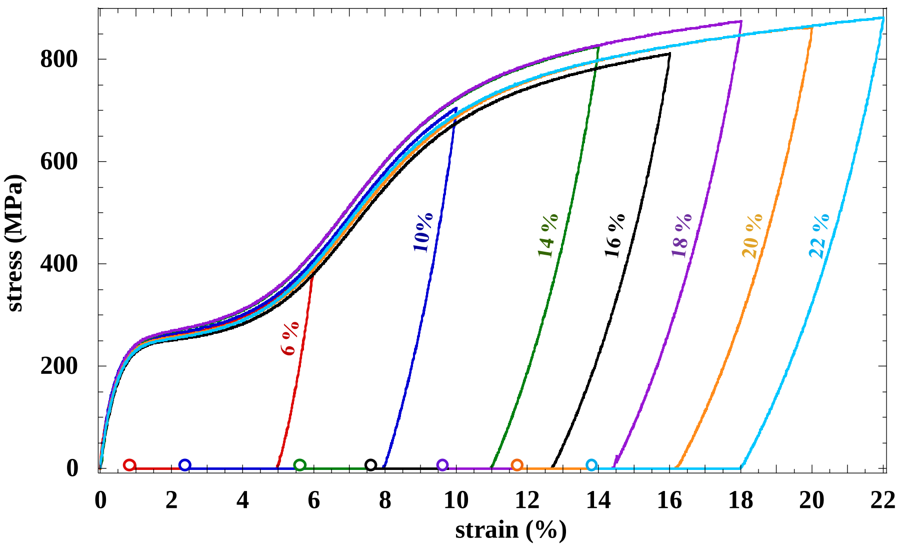
Spectrometer for MAterials Research at Temperature and Stress (SMARTS)

- Bulk penetration ~1cm
- Ability to follow micromechanical and microstructural changes
- Phase specific, quantitative information during heating/cooling and loading
- **Material: 55NiTi (wt%), d = 5.08 mm**

Training Procedures

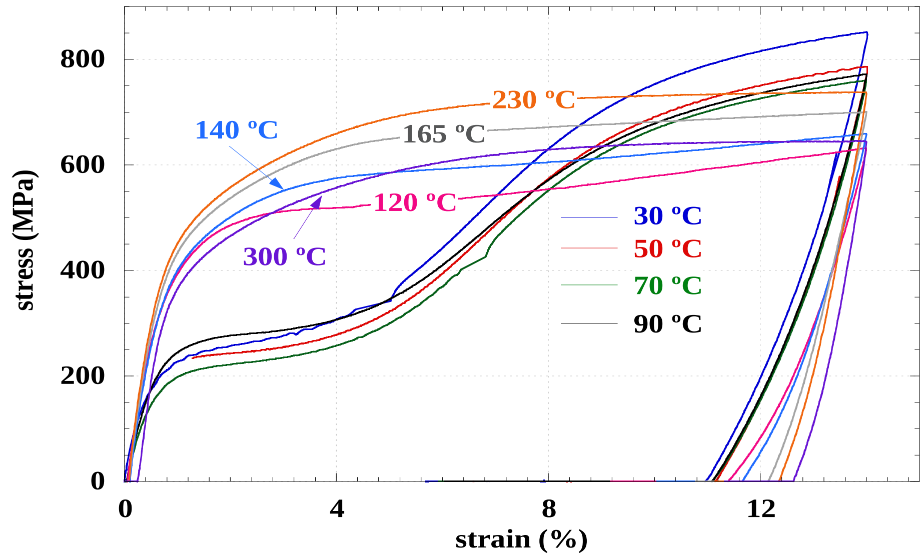
Training I

Constant temperature
Variable strain

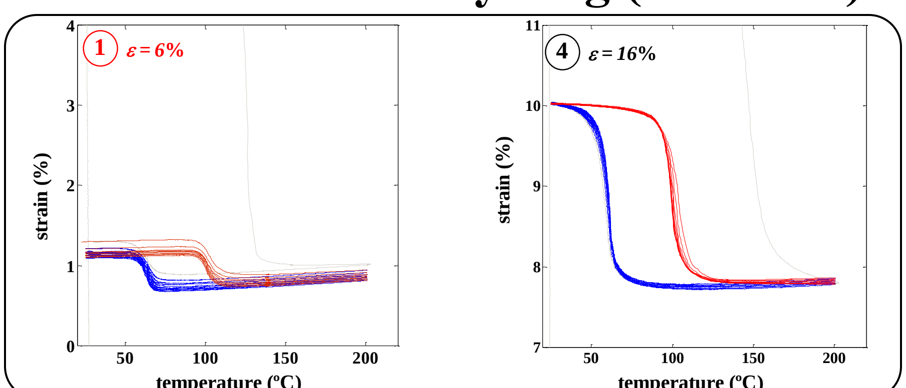


Training II

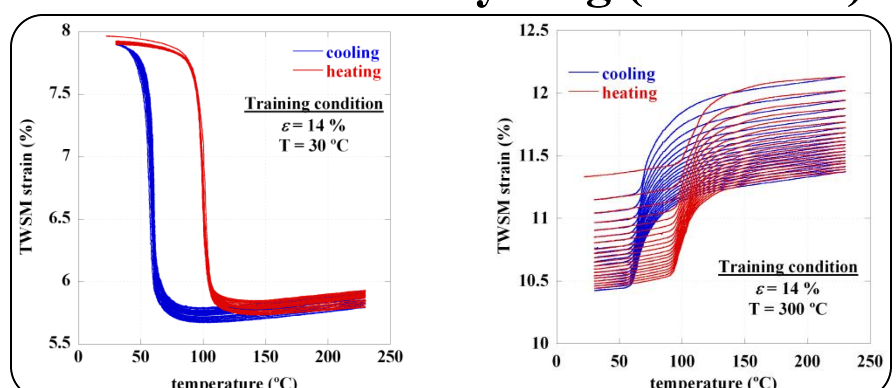
Constant strain
Variable temperature



No-load thermal cycling (TWSME)

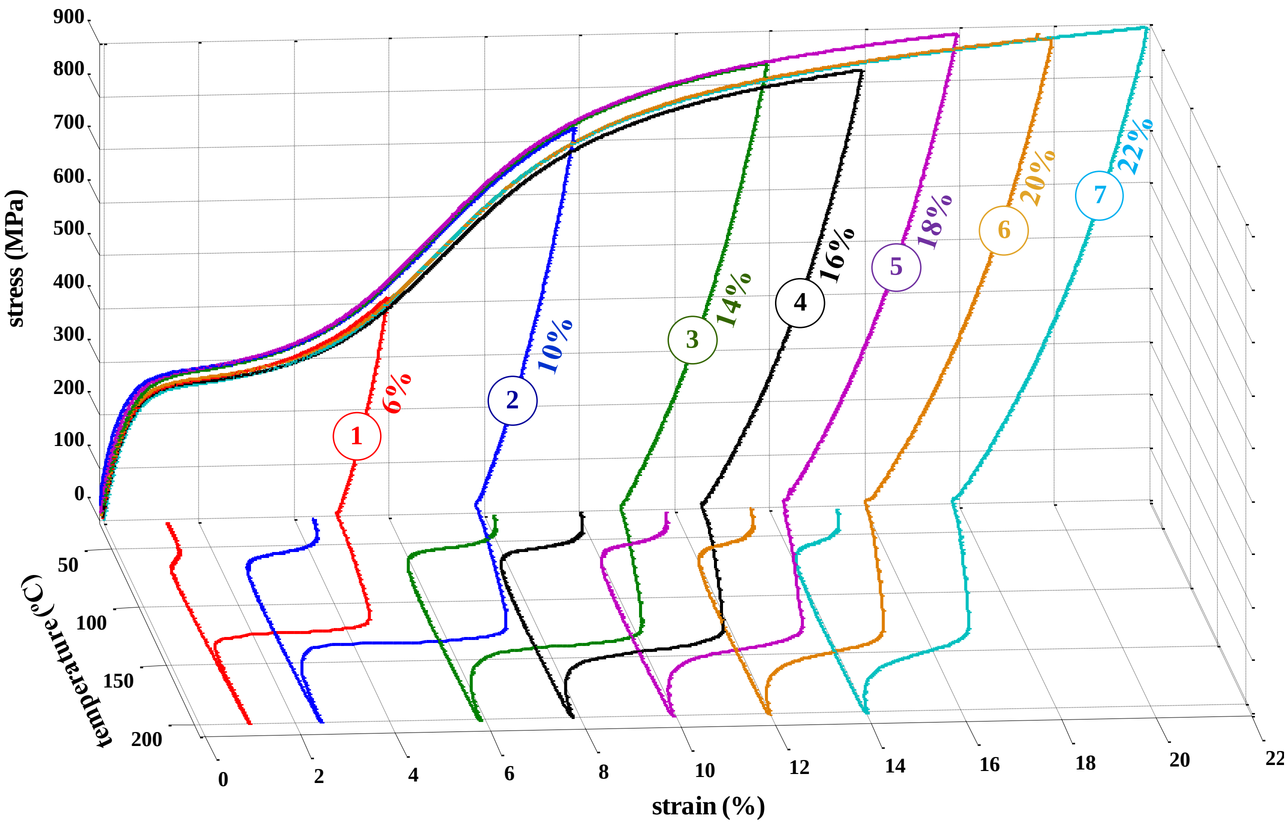


No-load thermal cycling (TWSME)

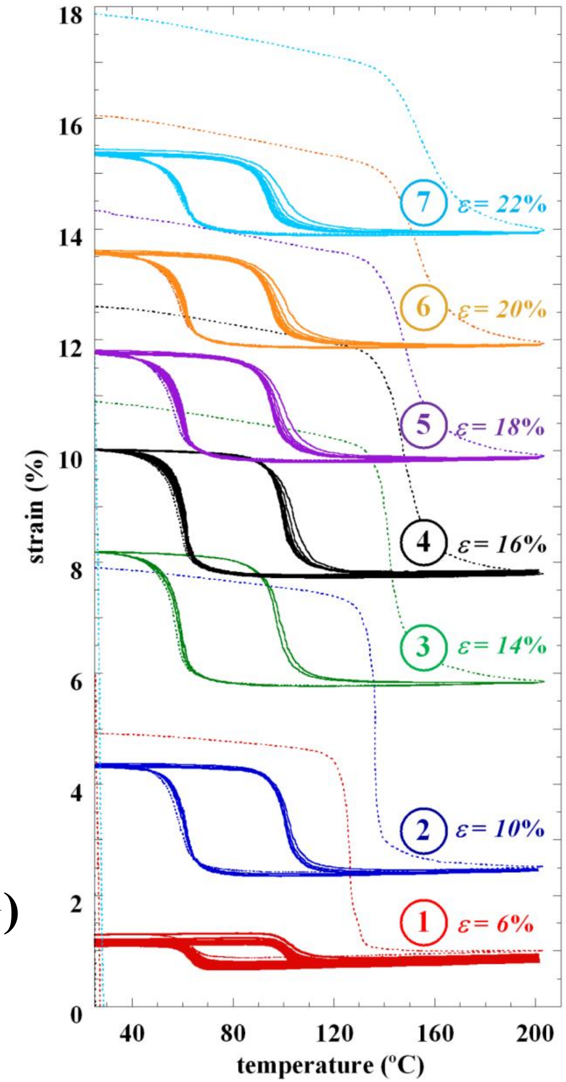


Training I: Constant Temperature/Variable Strain

Isothermal deformation



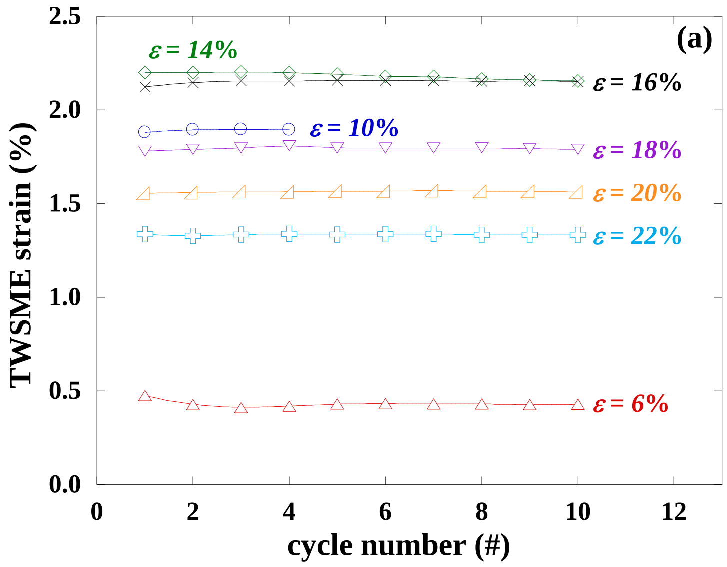
TWSME



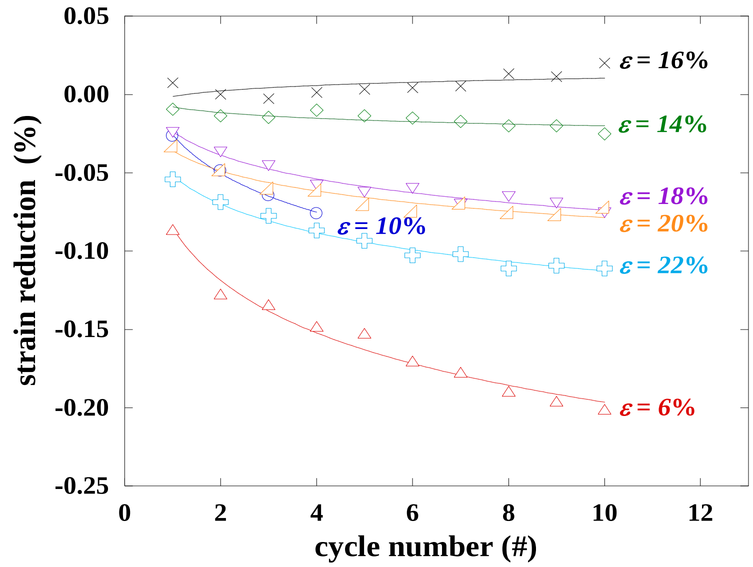
- Room temperature deformation in strain control (1 x 10^{-4} sec^{-1})
- No-load thermal cycling (30 ↔ 200 °C)

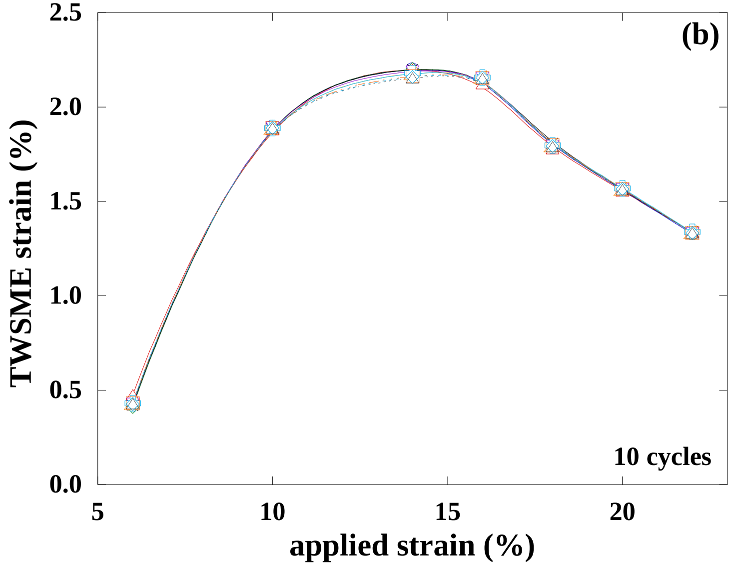
Training I: Constant Temperature/Variable Strain

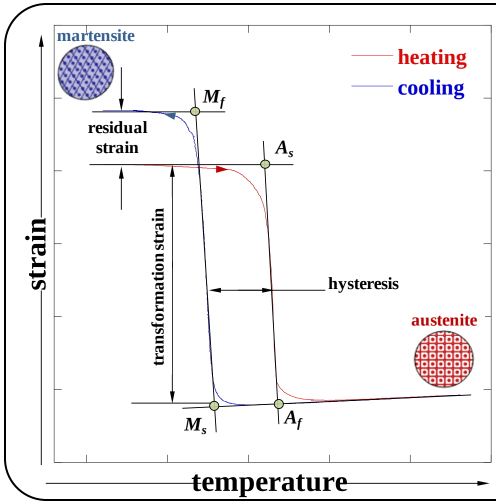
TWSME magnitude



TWSME stability

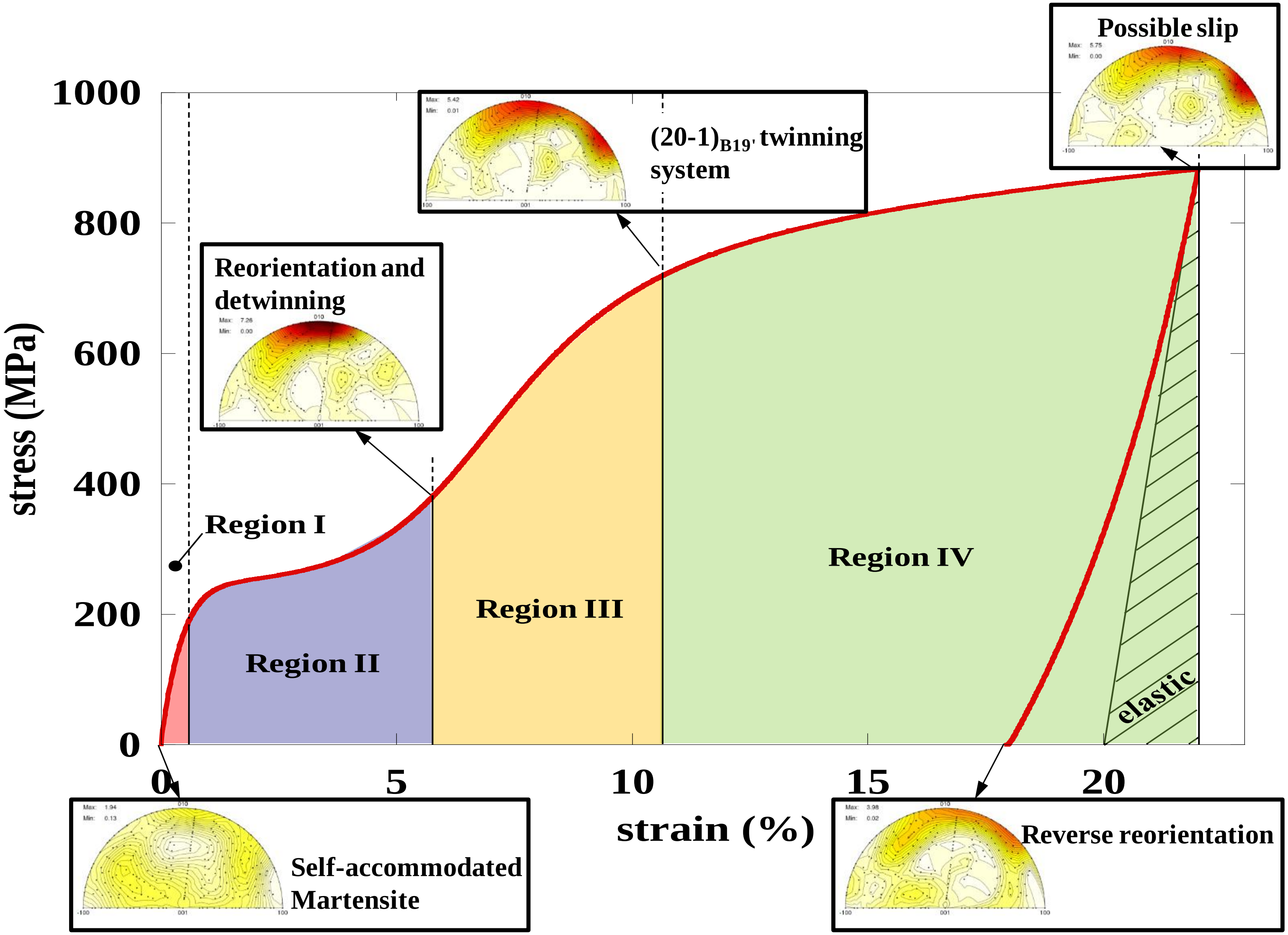






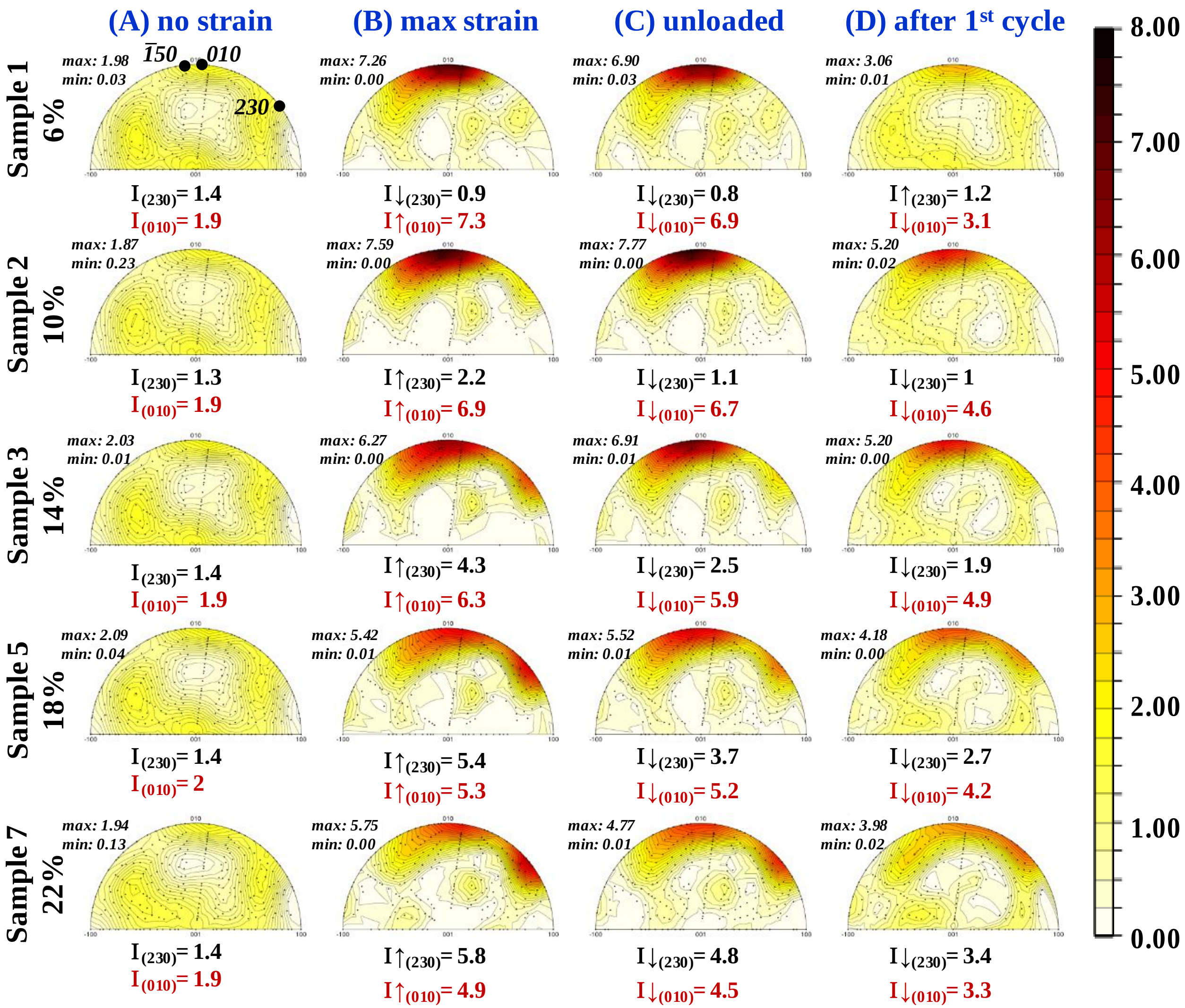
- Straining to 14 - 16% was found to be optimum for this material
- Stable TWSME strain of 2.2% was obtained with near-zero strain reduction
- **Why 14-16%?**

Deformation Mechanisms in Martensitic NiTi

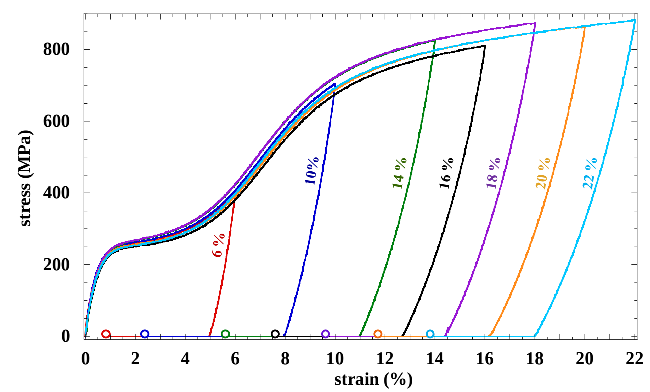


Training I: Constant Temperature/Variable Strain

Microstructure

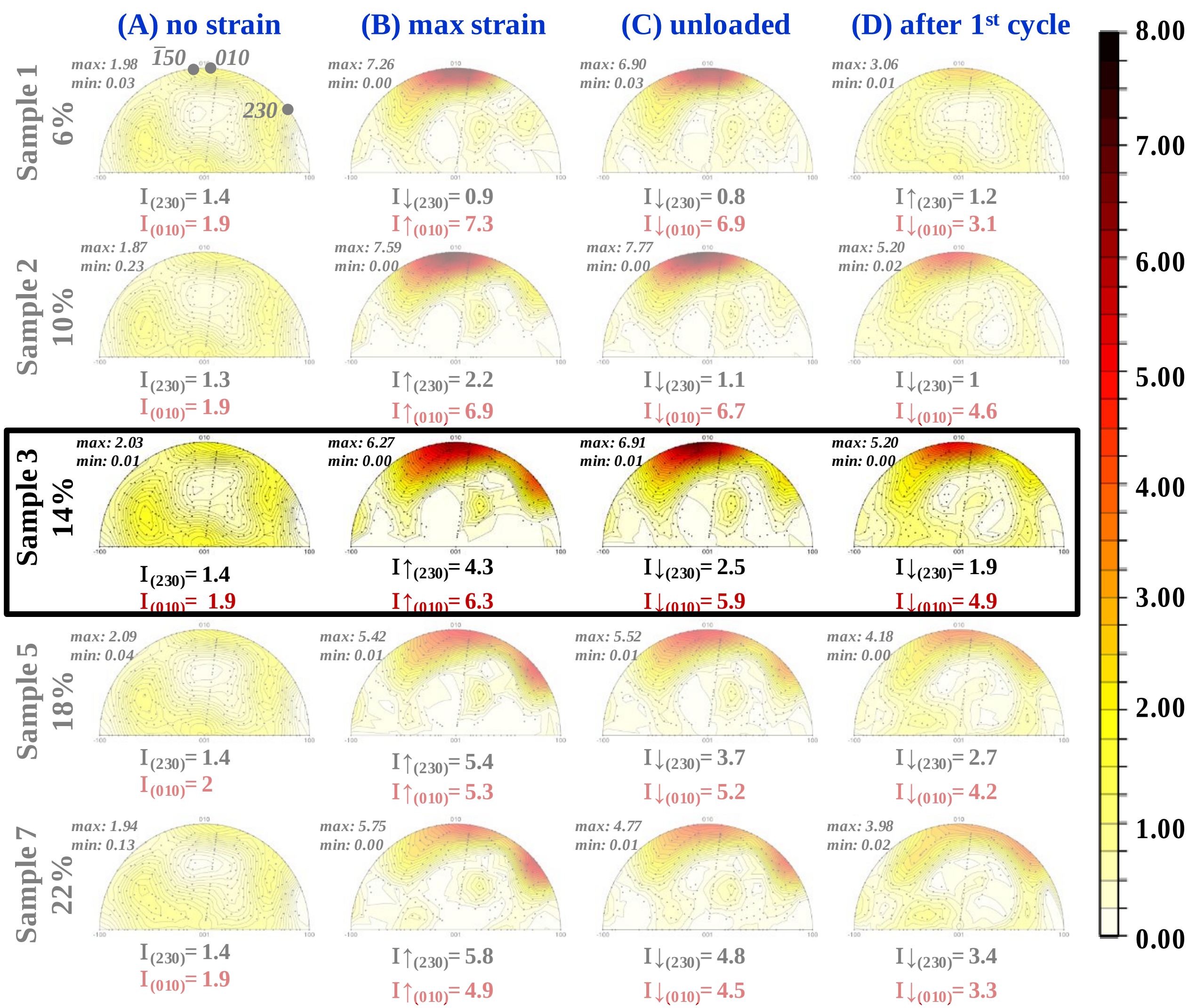


Macroscopic response

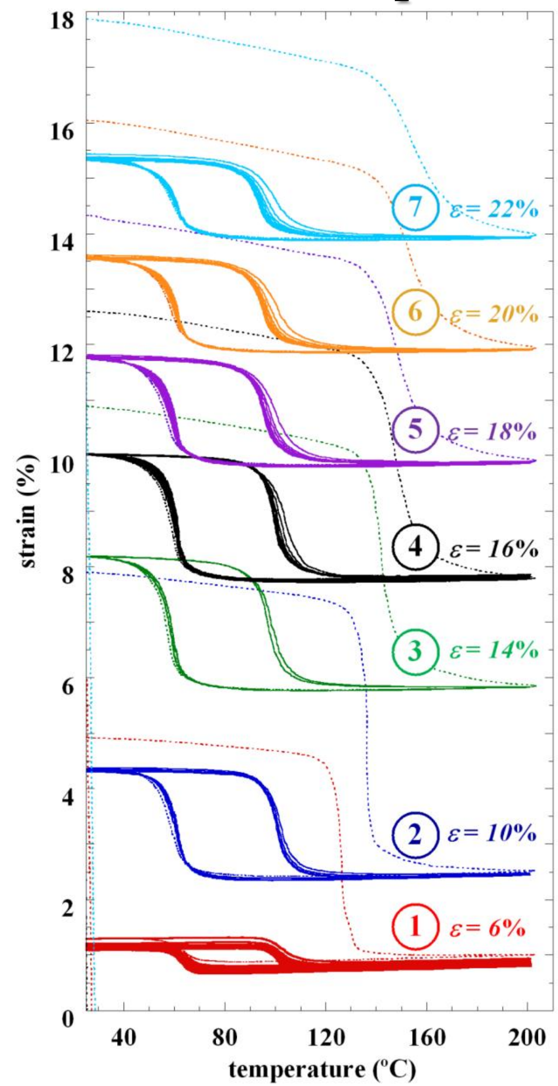


Training I: Constant Temperature/Variable Strain

Microstructure



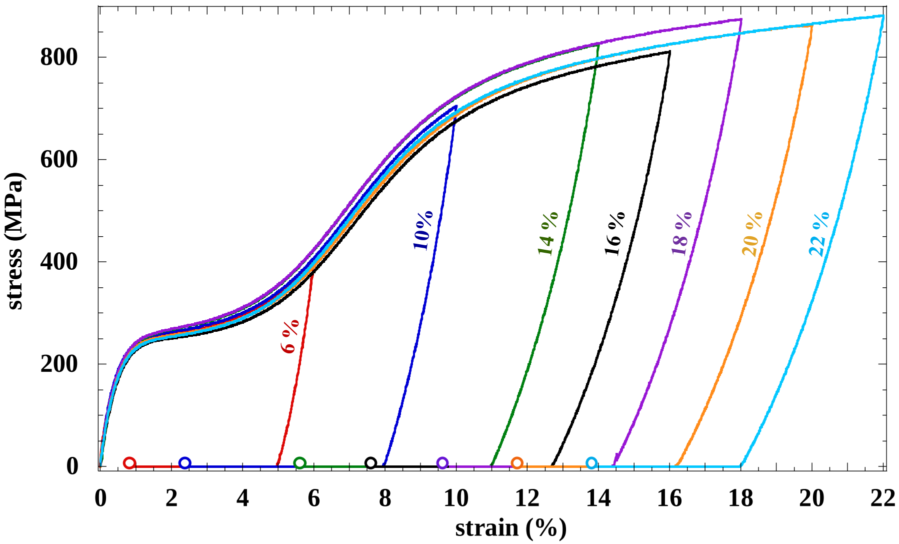
TWSME Response



Training Procedures

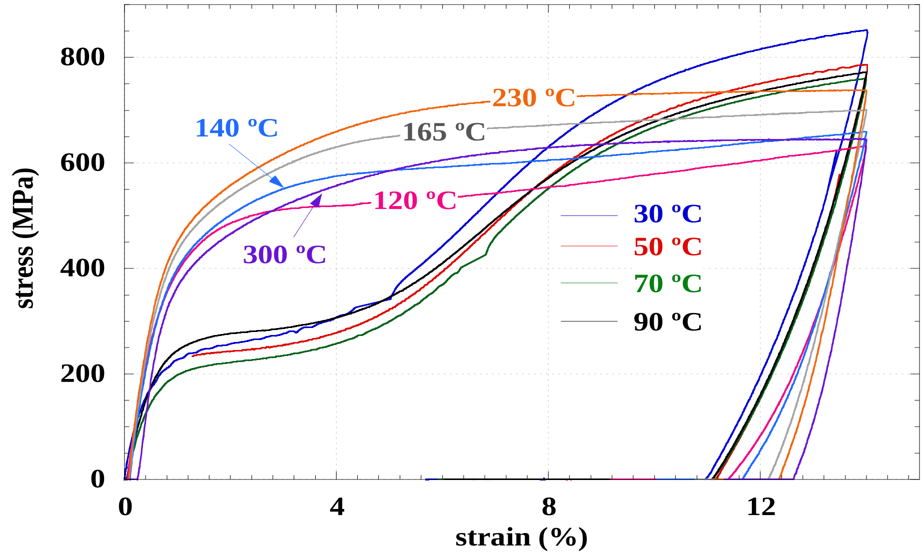
Training I

Constant temperature
Variable strain

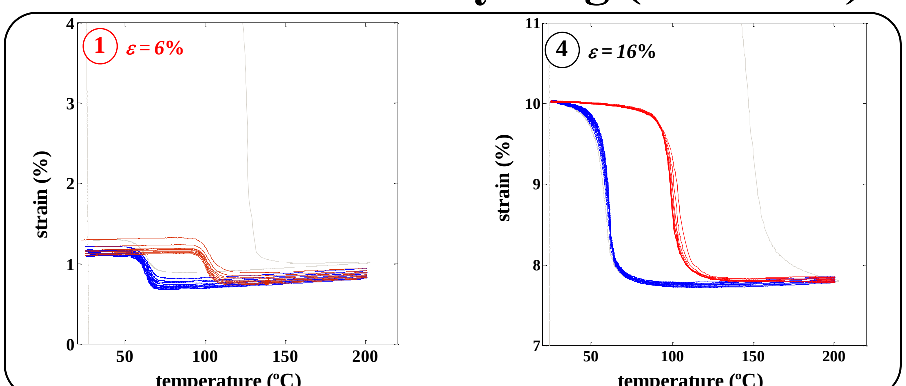


Training II

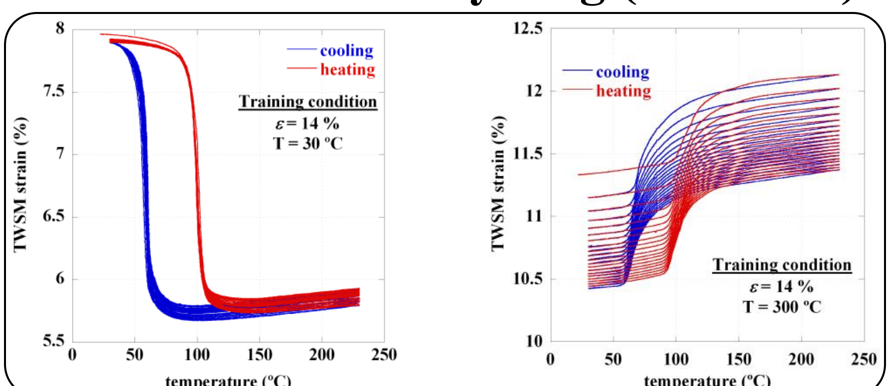
Constant strain
Variable temperature



No-load thermal cycling (TWSME)

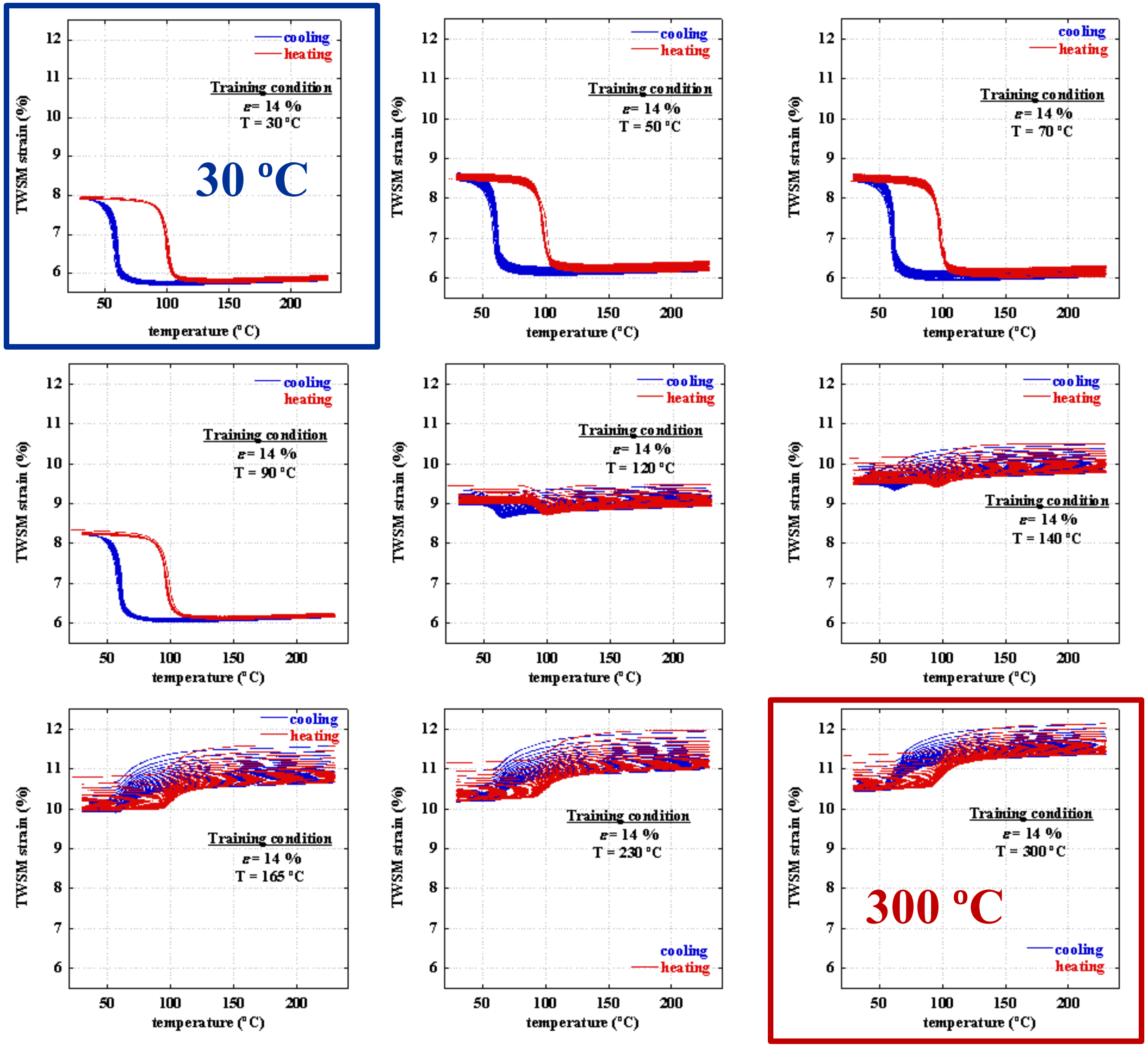


No-load thermal cycling (TWSME)



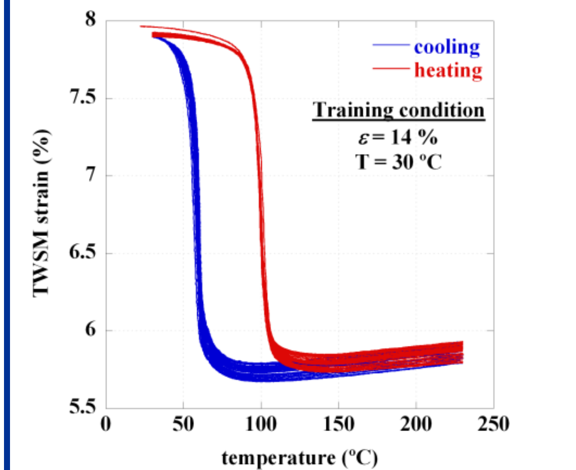
Training II: Constant Strain/Variable Temperature

TWSME Response



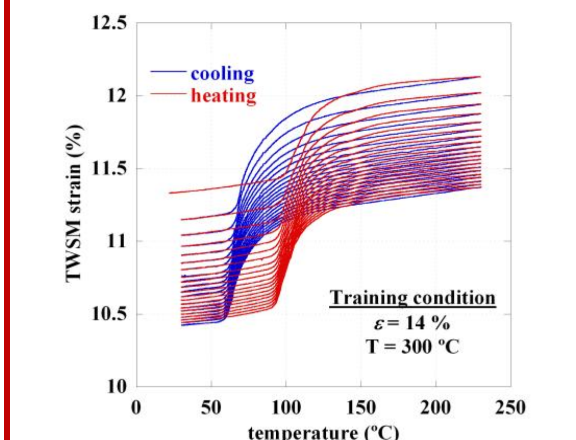
30 °C

Positive TWSME = 2.4%



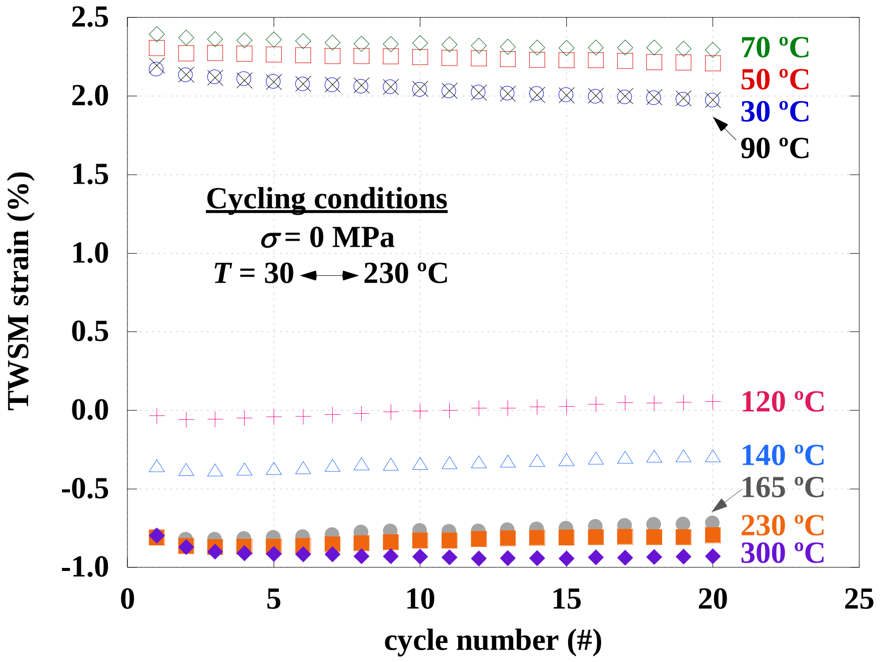
300 °C

Negative TWSME = 0.8%

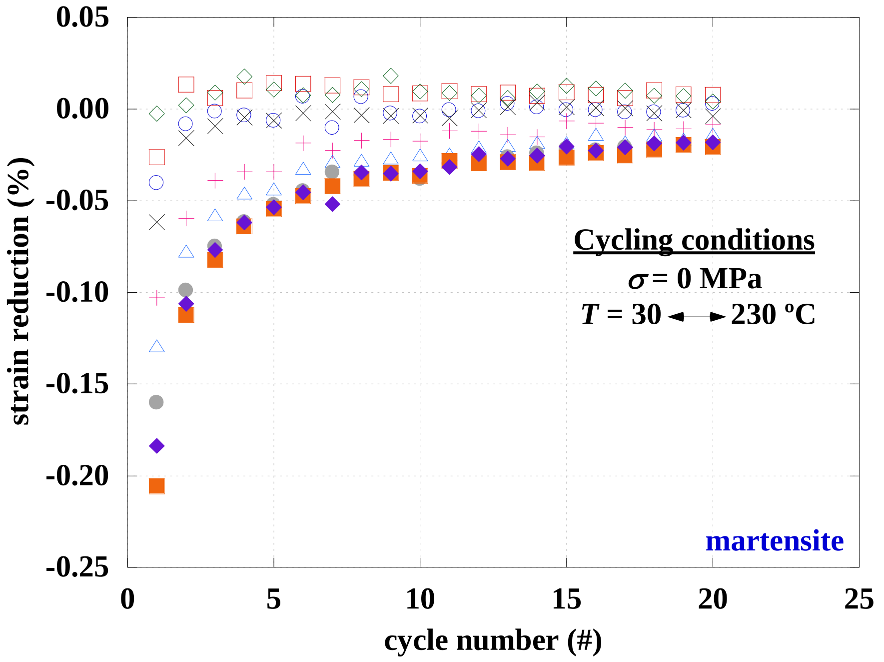


Training II: Constant Strain/Variable Temperature

TWSME magnitude

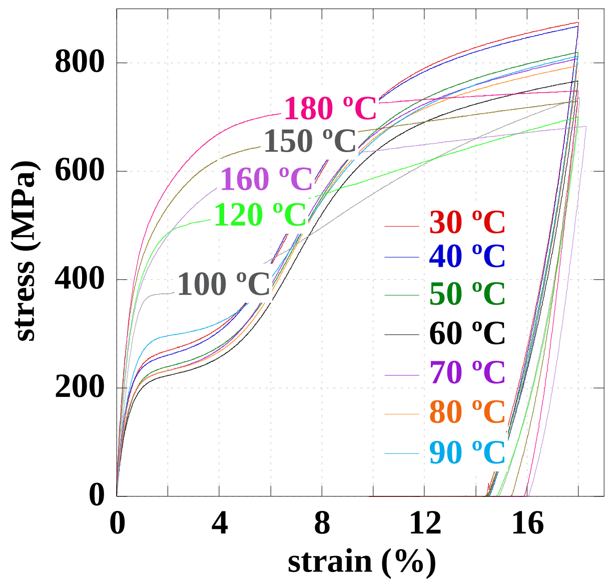


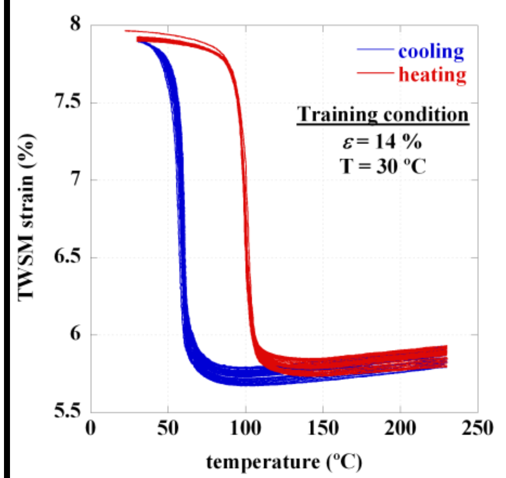
TWSME stability

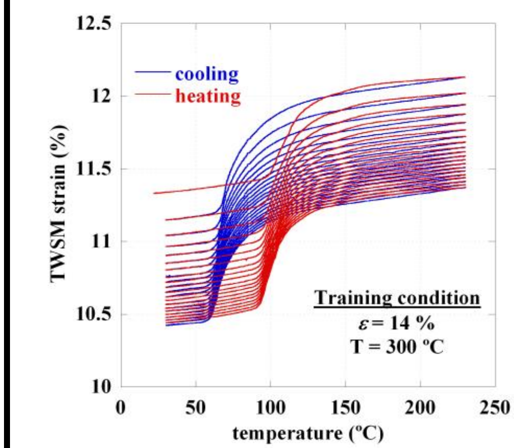


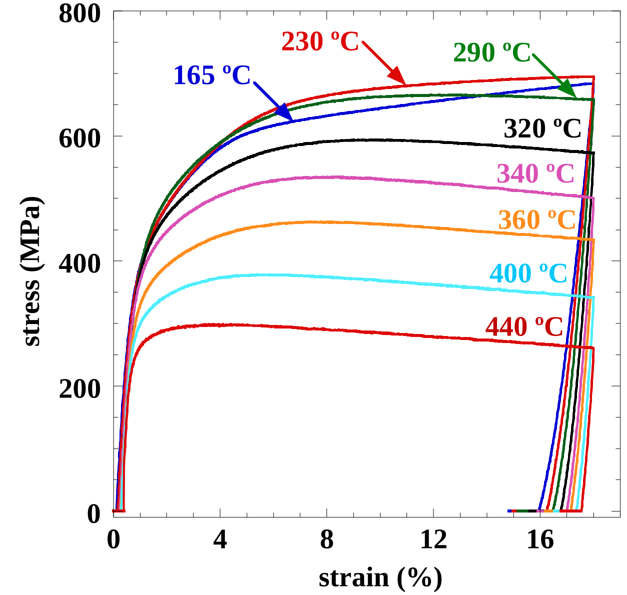
- Positive TSWME → ~2.4%
- No TWSME → 0%
- Negative TWSME → ~-1%

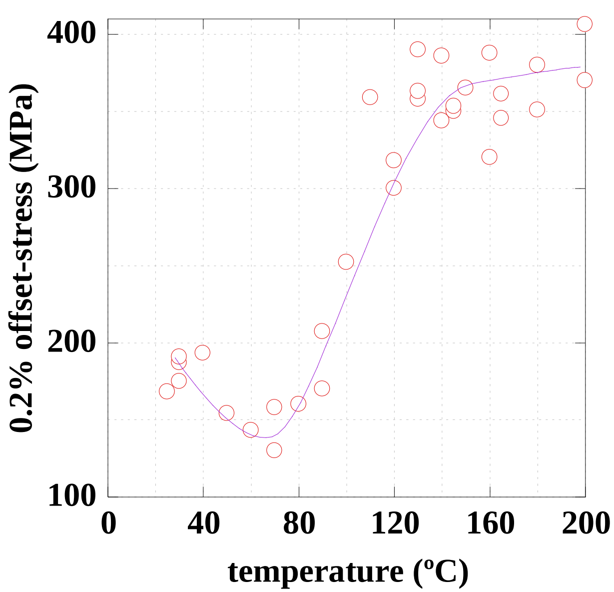
Training II: Constant Strain/Variable Temperature

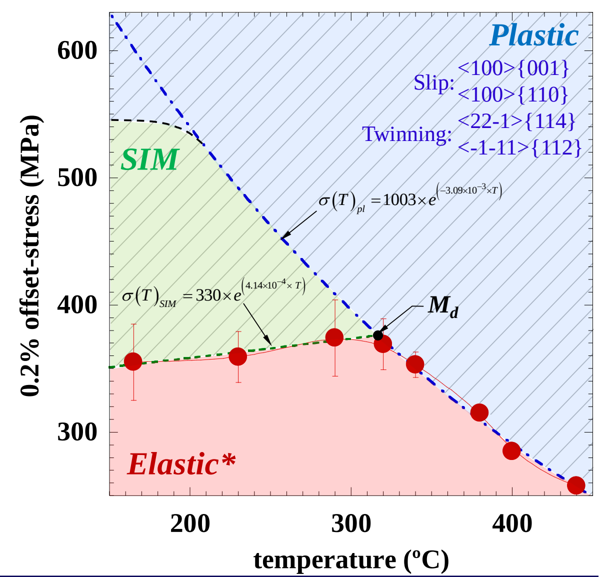






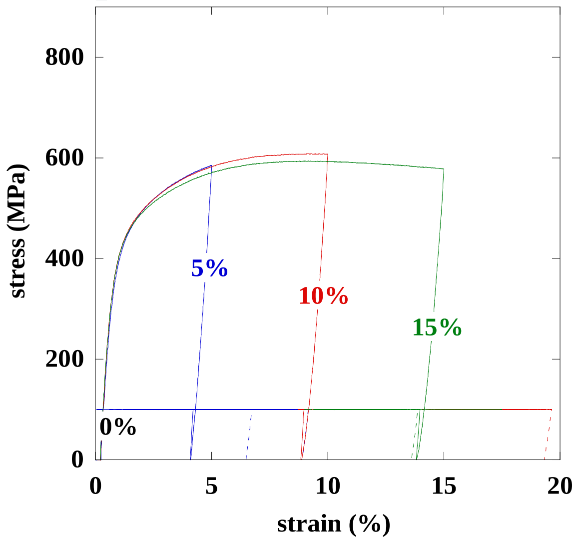


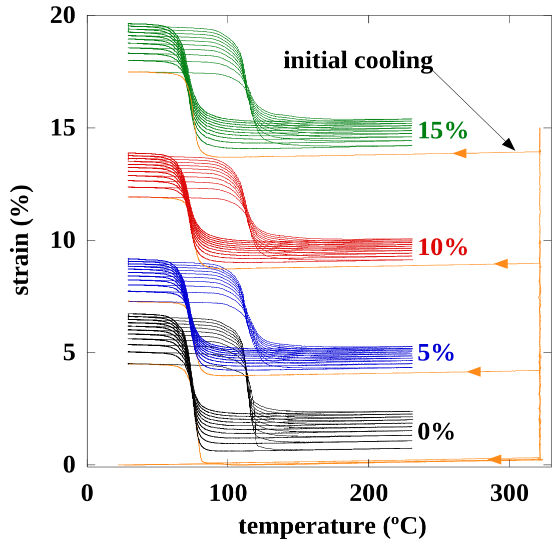


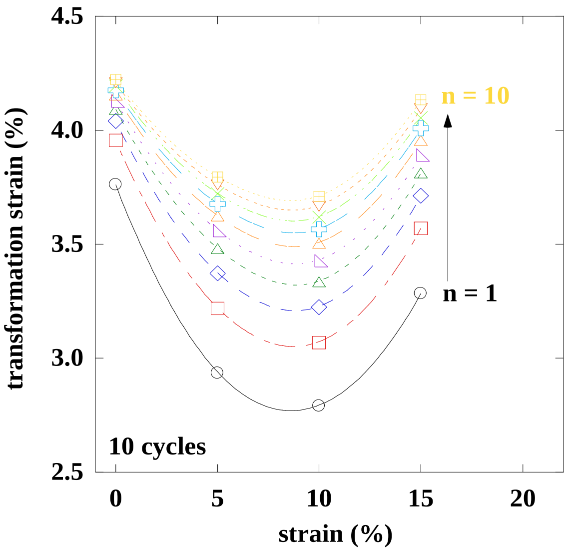


Extend from TWSME to Load-Biased On the Optimization of Actuator Properties

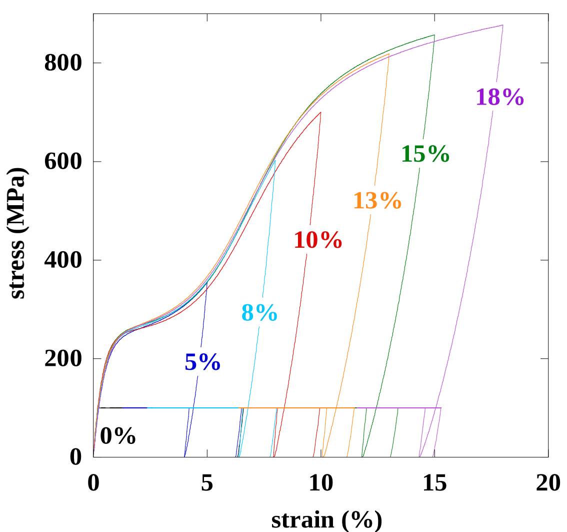
Samples deformed at 320 ºC

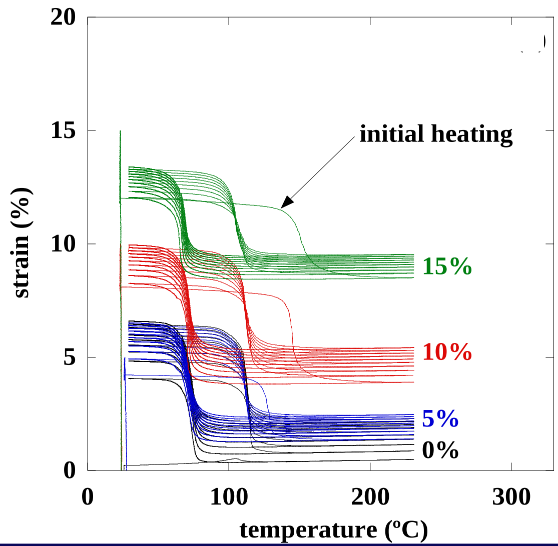


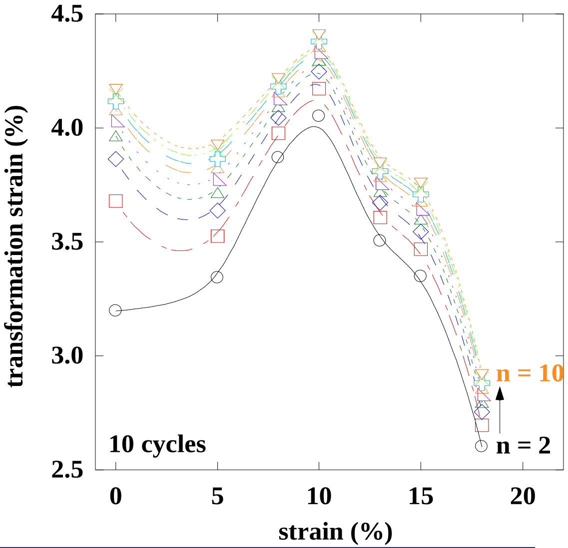




Samples deformed at RT







Summary and Conclusions

- **The role of deformation and the corresponding microstructure on the TWSME training was investigated**

- **The TWSME can be optimized to fit several applications using the same training procedure**

- **In this alloy (55NiTi):**
  - **Positive TSWME → ~2.2%**
  - **No TWSME → 0%**
  - **Negative TWSME → ~-1%**

- **Can be extended to optimize SMA actuators under load**

- **Understanding the microstructure (in this work using neutron diffraction) is key in training and optimizing the structure (e.g., SMA actuators)**