TiiMS
TEXAS INSTITUTE FOR INTELLIGENT BIO-NANO MATERIALS AND STRUCTURES FOR AEROSPACE VEHICLES
A NASA University Research, Engineering and Technology Institute (URETI)

Characterization of High Temperature Shape Memory Alloys

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Shape Memory Alloys

- Shape Memory Alloys (SMA’s) are materials that are capable of undergoing high strain absorption and recovery by solid to solid thermo elastic phase transformation.

- The two phases are the low temperature Martensitic phase and the high temperature Austenitic phase.

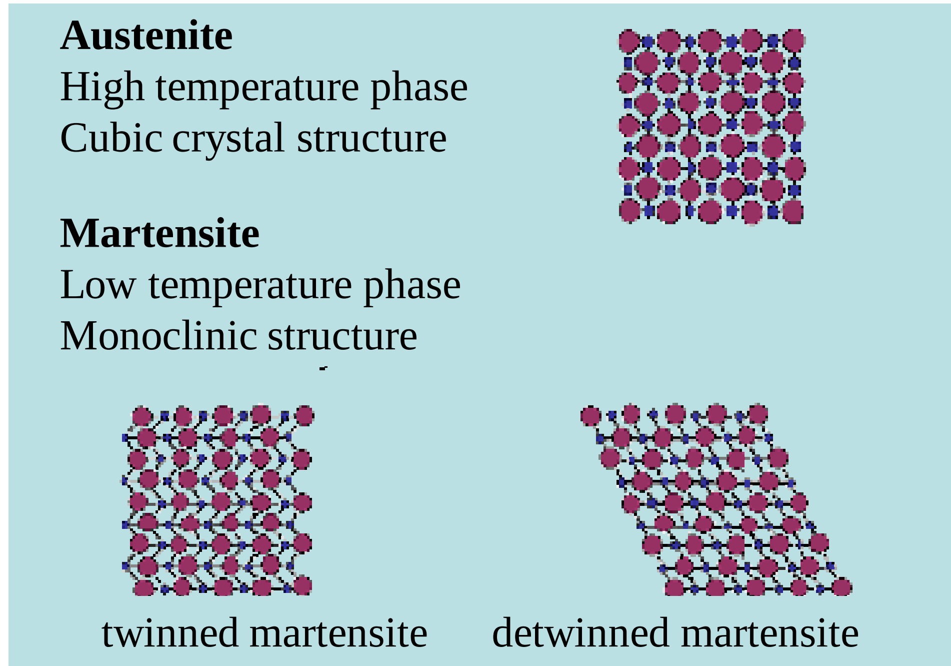

Figure 1: Various phase diagrams of shape memory alloys. [1]

SMA Phase Diagram

- **The SMA behavior can be most conveniently described by the Stress - Temperature phase diagram.**
- **The two phases – Austenite and Martensite – are separated by 4 characteristic lines corresponding to the variation of the four transformation temperatures with stress.**
- **The high temperature SMA in this work (NiTiX) requires a minimum temperature ~ 450C (869F) to transform to the original state at a stress level of 100 MPa.**

SMA Phase Diagram

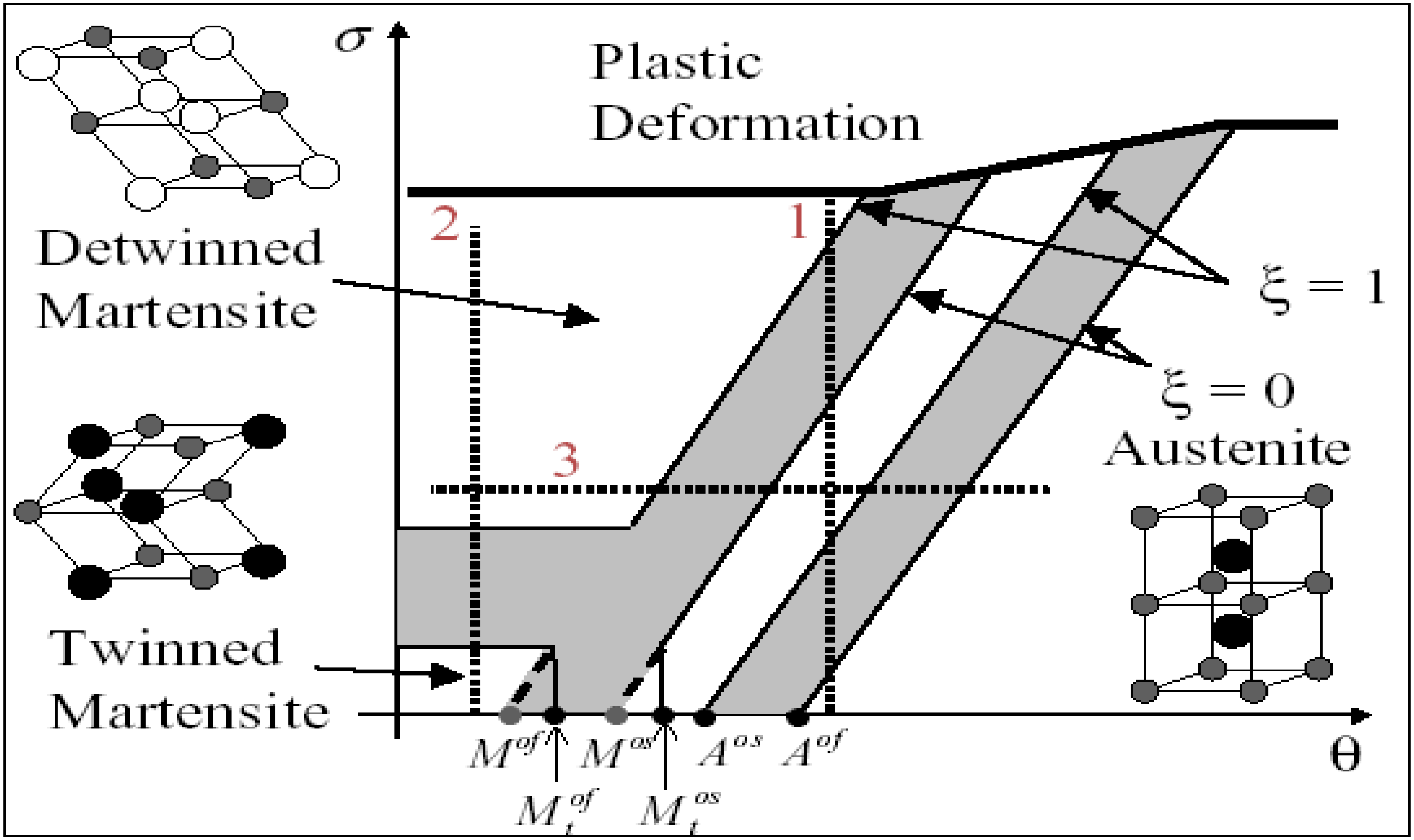

Figure 2: Stress versus Temperature diagram with SMA phases shown.

Shape Memory Effect

Shape Memory Effect (SME) refers to the strain recovery of an SMA resulting from martensite to austenite transformation when heated above A_f after detwinning the material in the martensitic phase.

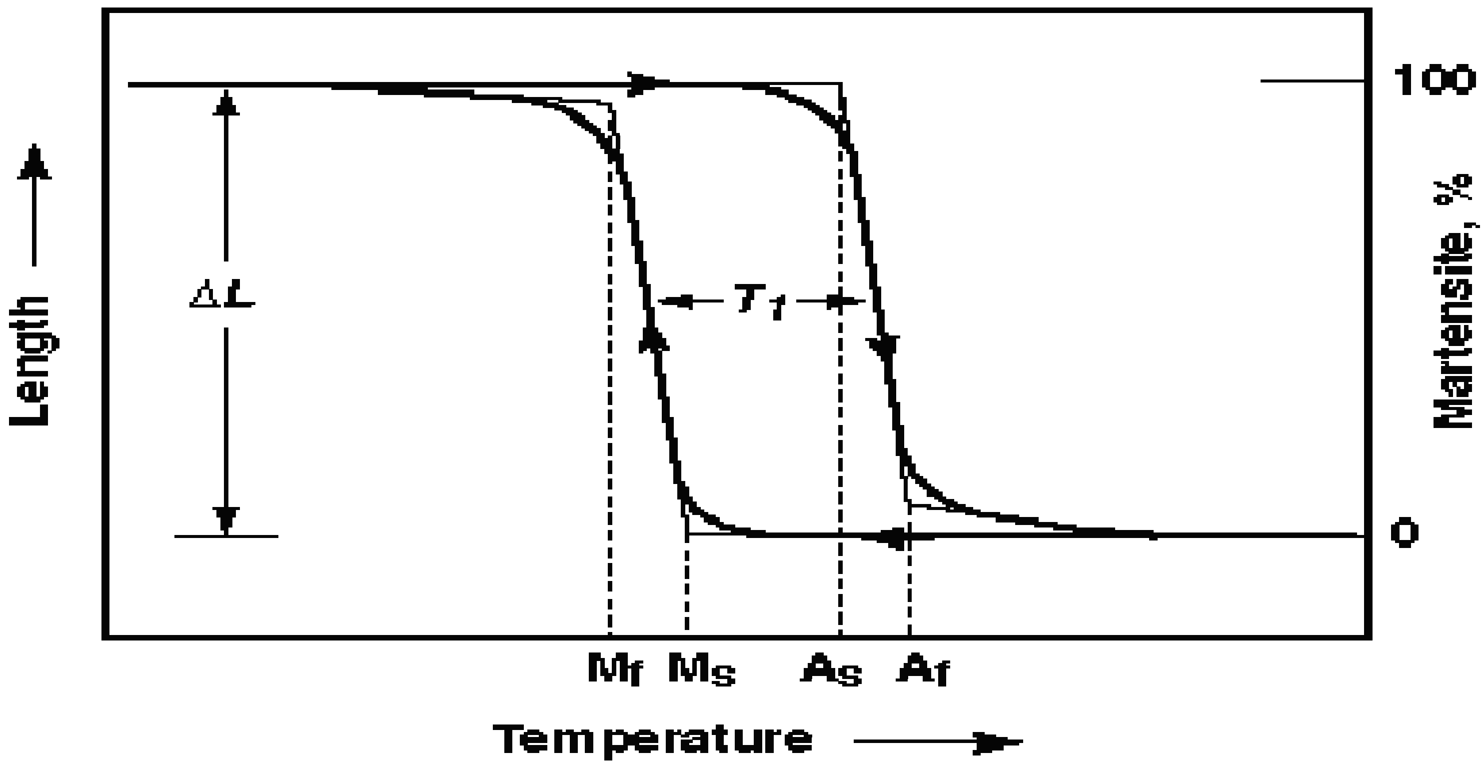

Figure 3: Shape Memory Effect Diagram. T1: transformation hysteresis; Ms: martensite start; Mf: martensite finish; As: austenite start, Af: austenite finish. [2]

Research Objectives

- **Determine material response (recoverable strain) at different stress levels.**
- **Study the actuation behavior of the material during cyclic loading.**
- **Evaluate material response after exposure to high temperatures for increasing amounts of time.**
- **Compare specimen size effects and material fabrication consistency.**

Experimental Setup

Hydraulic material testing load frame with appropriate grips

Water-cooled, high temperature MTS extensometer

Water-cooled quartz furnace

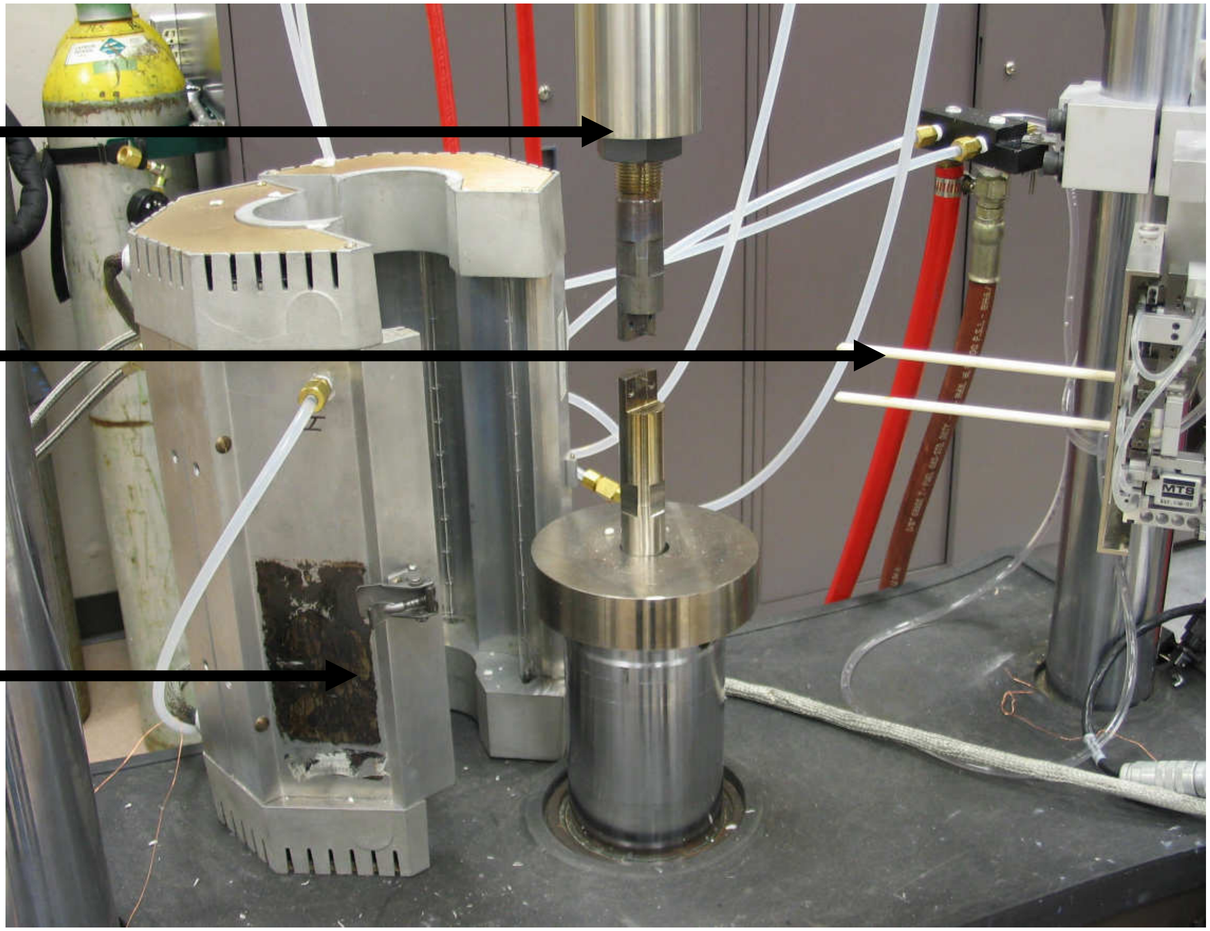

Figure 4: Experimental setup with tension grips shown.

Differential Scanning Calorimetry

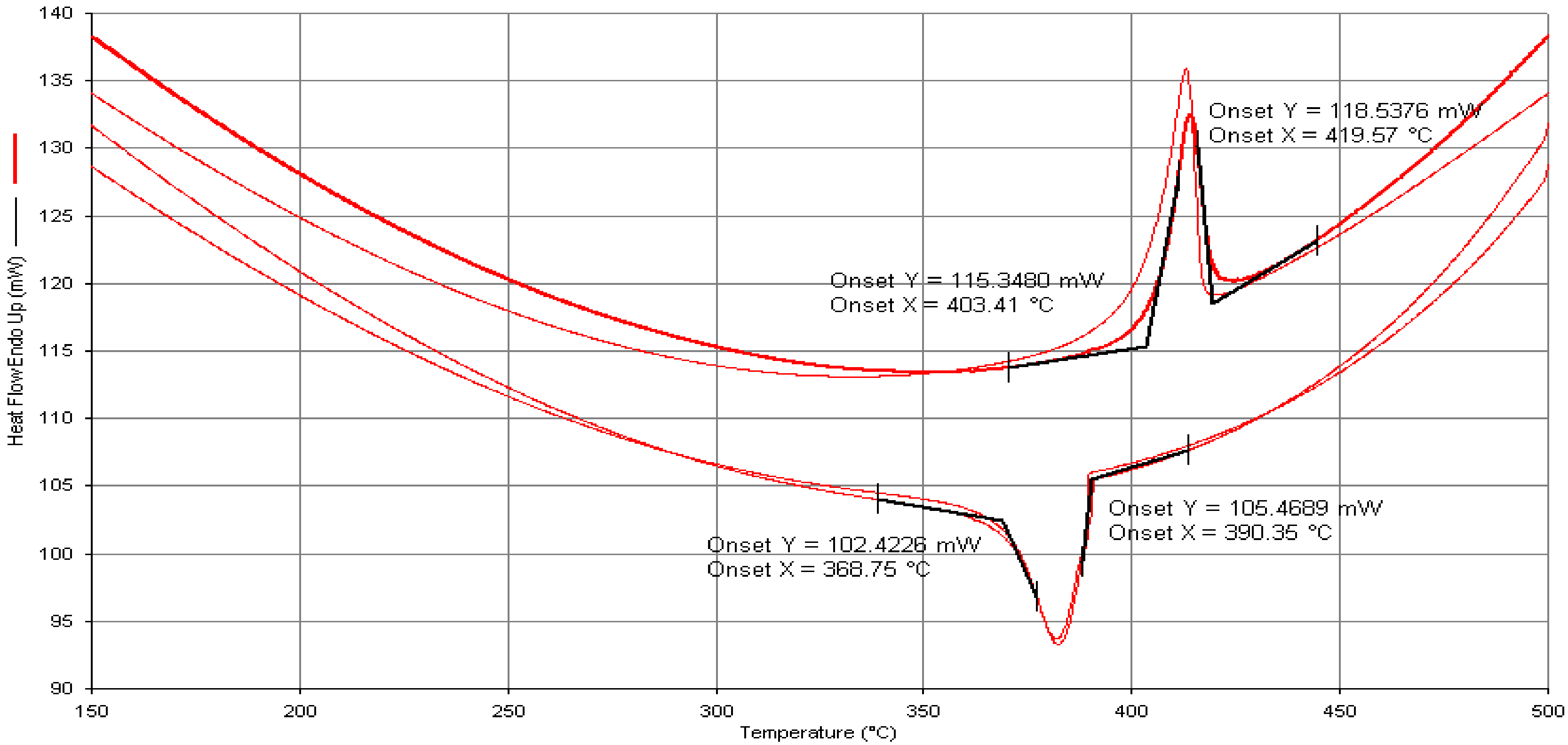

Figure 5: DSC graph for as-received NiTiX material.

DSC analysis shows transformation temperatures at zero stress: M_f = 369℃, M_s = 390℃, A_s = 403℃, and A_f = 420℃.

Recovery vs. Stress Levels

Stress vs. Strain test results demonstrate optimal material response when exposed to 4% applied strain and recovery at 100 MPa.

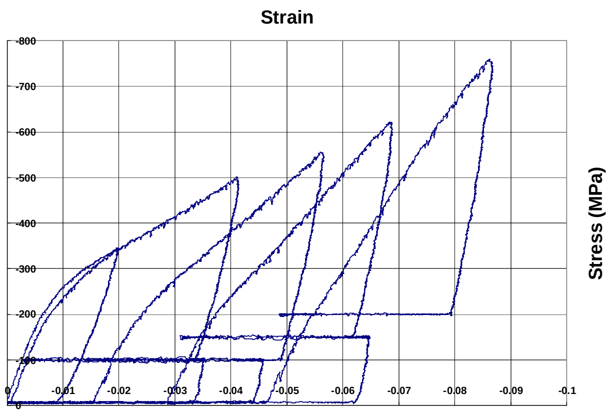

Figure 6: Schematic of the test performed

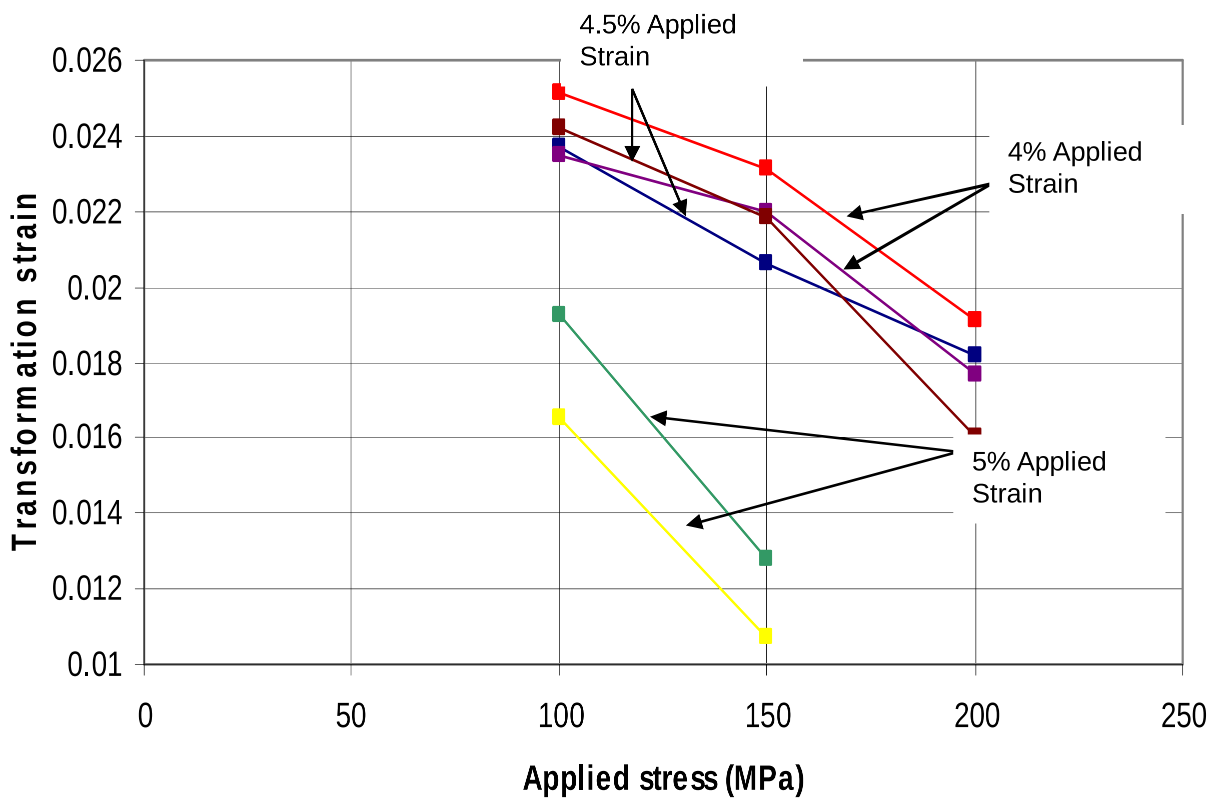

Figure 7: Strain Vs Stress graph displaying the specimen loaded to 4%, 4.5%, and 5% applied strain and unloaded to 100, 150, and 200 MPa stress levels to determine recovery.

Cyclic Behavior Testing

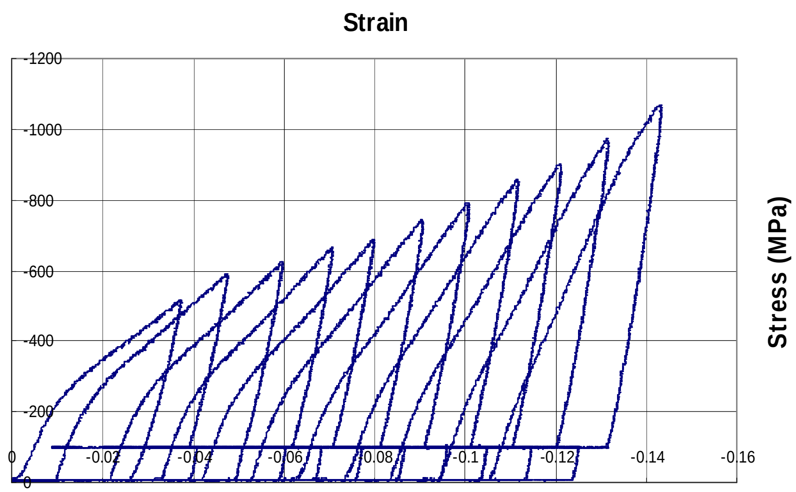

Figure 8: Stress vs. Strain graph displaying ten actuations following one training cycle.

Determining the material's stable cyclic response involved exposure to 4% applied strain with recovery at 100 MPa for 10 actuation cycles.

Testing shows onset of decreasing material performance after the seventh actuation cycle.

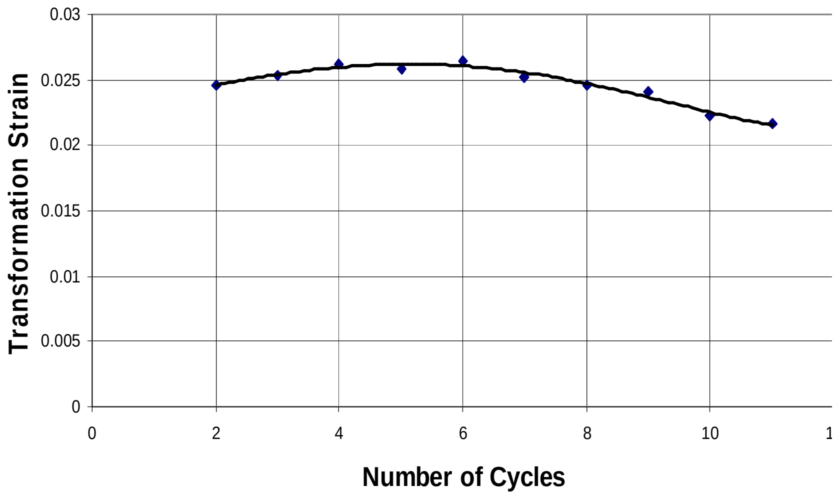

Figure 9: Observed transformation strain versus the number of actuations.

Environmental Exposure

To determine environmental effects, the specimen was cyclically exposed to 24 periods at 315℃, actuated to 4% appl ied strain, and recovered at 100 MPa.

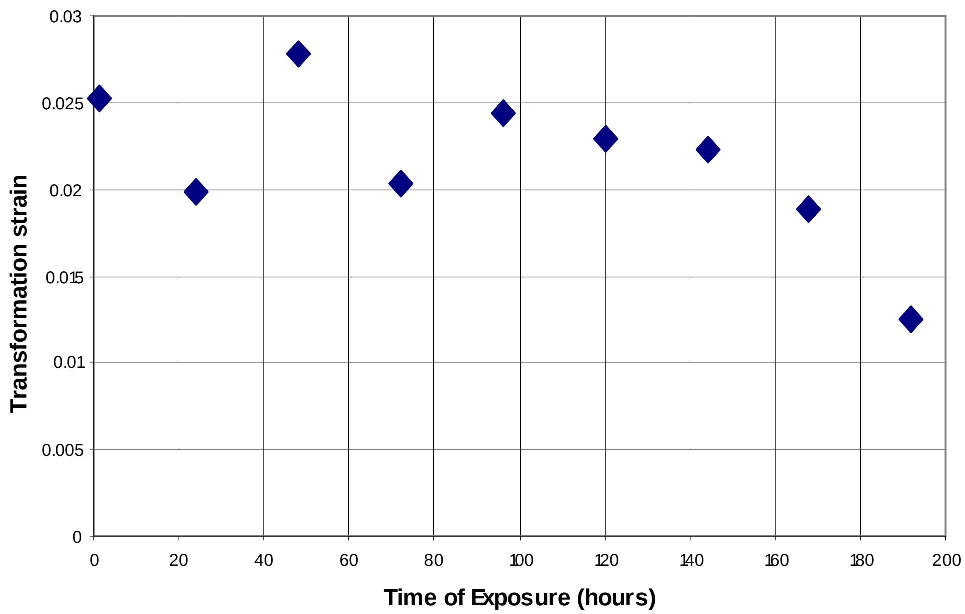

Figure 10: Transformation Strain vs. Time Exposed to 315℃ (Environmental Temperature) with actuation every 24 hours.

- **Testing shows decreasing performance on the 7th cycle [144 hours].**

- **This result correlates with the results of the cyclic testing.**

Size Effect and Material Consistency

- Testing recently began with new fabricated material of a different batch.
- New material properties versus old specimens:
  - Cross sectional area 4.5x - 14x larger.
  - 1.5x longer.
- Initial results show no variation of material response due to size effect.

Conclusions and Recommendations

Conclusions:

- ***Material delivers optimal strain recovery when exposed to 4% applied strain with recovery at 100 MPa.***
- ***Adequate material response observed through seven actuation cycles.***
- ***The effect of long term exposure to environmental temperatures (315℃) is negligible.***
- ***Preliminary testing shows no size effect on material properties.***

Recommendations:

- ***Engineer a method to better attach the thermocouple to the specimen.***
- ***Decrease error tolerance by using extensometer leads which directly touch the specimen.***

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List of Citations

[1] Texas A&M Smart Lab. Texas A&M University. 26 July 2005 <http://smart.tamu.edu>.

[2] Shape Memory Alloys. Johnson Matthey. 26 July 2005 <http://www.jmmedical.com/html/_shape_memory_alloys_.html>