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.

Austenite
High temperature phase
Cubic crystal structure

Martensite
Low temperature phase
Monoclinic structure

twinned martensite  detwinned martensite

Figure 1: Various phase diagrams of shape memory alloys. [1]
The SMA behavior can be most conveniently described by the Stress - Temperature phase diagram.

The two phases – Austenite & Martensite – are separated by 4 characteristic lines corresponding to the variation of the four transformation temperatures with stress.
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. $T_1$: transformation hysteresis; $Ms$: martensite start; $Mf$: martensite finish; $As$: austenite start, $Af$: austenite finish. [2]
High Temperature SMA’s

• High temperature SMA’s involve special considerations with regard to experimental setup and testing protocol.

• The high temperature SMA in this work (NiTiX) requires a minimum temperature ~ 420°C (788°F) to transform to the original state at zero stress.

• Thermal expansion of testing apparatus as well as material specimen must be considered.

• Application possibilities include aerospace vehicles, oil and gas industry, automotives, etc.
Research Objectives

• Determine material response (recoverable strain) at different stress levels for high temperature SMA’s.

• Study the actuation behavior of the material during cyclic loading.

• Evaluate material response after exposure to high temperatures for increasing amounts of time.
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

DSC analysis shows transformation temperatures at zero stress: $M_f = 369^\circ C$, $M_s = 390^\circ C$, $A_s = 403^\circ C$, and $A_f = 420^\circ C$.

Figure 5: DSC graph for as-received NiTiX material.
Recovery vs. Stress Levels

Stress vs. Strain test results demonstrate optimal material response when exposed to an applied strain with recovery at $\frac{1}{2}$ the maximum stress level.

Figure 6: Strain Vs Stress graph displaying the specimen loaded to multiple applied strain levels and unloaded to 50%, 75%, and 100% of the maximum stress level to determine recovery.
Cyclic Behavior Testing

Determining the material’s stable cyclic response involved exposure to an applied strain with recovery at \( \frac{1}{2} \) the maximum stress level for 10 actuation cycles.

- Testing shows decreasing material performance after the seventh actuation cycle.

Figure 7: Observed transformation strain versus number of actuations.
Environmental Exposure

To determine environmental effects, the specimen was cyclically exposed to 24 periods at 315°C, actuated to a constant applied strain, and recovered at \( \frac{1}{2} \) the maximum stress level.

- Testing shows decreasing performance on the 7\(^{th}\) cycle [144 hours].
- This result correlates with the results of the cyclic testing.

Figure 8: Transformation Strain vs. Time Exposed to 315°C (Environmental Temperature) with actuation every 24 hours.
Conclusions and Recommendations

Conclusions:
- High temperature experimental setup confirmed with consistent test results.
- Material delivers optimal strain recovery when exposed to an applied strain with recovery at $\frac{1}{2}$ the maximum stress level.
- Adequate material response observed through seven actuation cycles.
- The effect of long term exposure to environmental temperatures (315°C) is negligible.

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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