National Aeronautics and Space Administration

4D Printing of Shape Memory Alloys for Solid-State Staged Deployment of Structures

Principal Investigator: Richard Otis (357); Co-Investigators: Ryan Watkins (357), Christine Gebara (355), Nicholas Ury (357), Raymundo Arróyave (Texas A&M University), Ibrahim Karaman (Texas A&M University), Raymond Neuberger (Texas A&M University)

Program: FY22 SURP
Strategic Focus Area: Additive Manufacturing, Multifunctional Systems

Objectives:

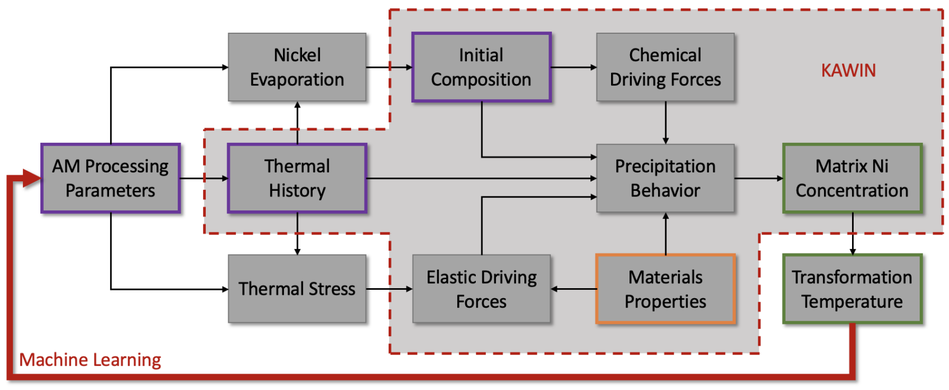

Figure 1: Process map of the end-goal project workflow.

1. Develop a physics-based model capable of predicting precipitation behavior in additively manufactured NiTi shape-memory alloys .

2. Use machine-learning on data generated by the model to predict the thermal history necessary to induce a desired precipitation response.

3. Design additive manufacturing processes capable of producing this target thermal history, allowing for NiTi parts with tailored transformation temperatures.

Background:

The shape-memory behavior of NiTi is extremely sensitive to matrix Ni concentration. Heat treatment of NiTi can result in the formation of Ni-rich Ni_4Ti_3 precipitates.

AM processes can be designed to selectively induce precipitation and locally control transformation temperature

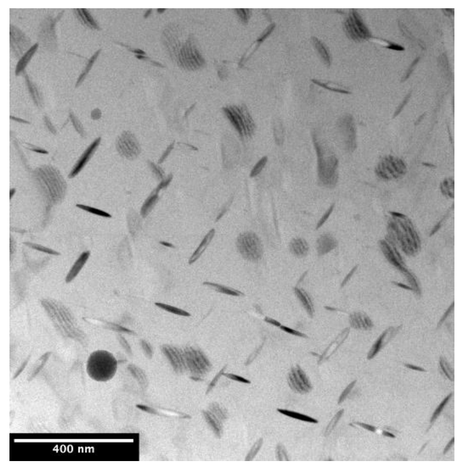

Figure 2: Micrograph of Ni_4Ti_3 precipitates in $Ni_{50.8}Ti_{49.2}$

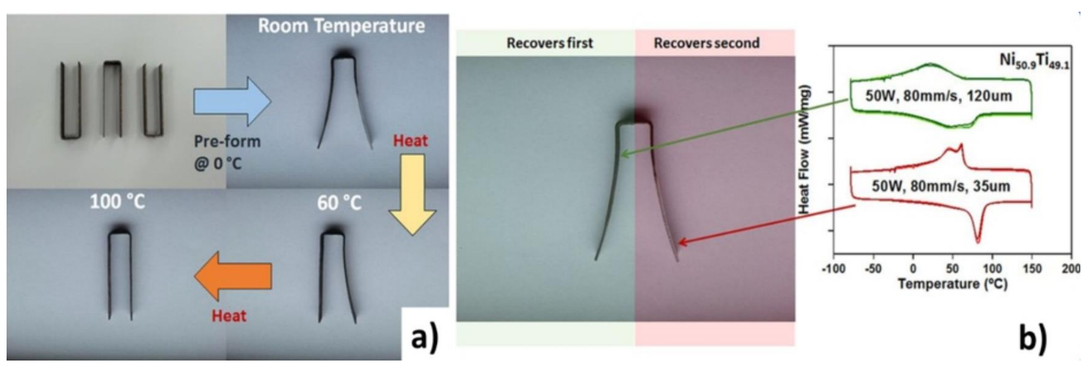

Figure 3: Example of location-dependent transformation temperatures.

Approach and Results:

- Kawin, an open-source implementation of the KWN algorithm for precipitation modelling, has been developed.
- Kawin can now natively compute the effects of elastic considerations to model the impact of the significant thermal stresses encountered during AM.
- A high-throughput framework for precipitation simulation has been developed and used to significantly optimize performance and model stability.
- High-throughput simulations have been used to perform a sensitivity analysis of model inputs, quantify and propagate uncertainty in model predictions, and calibrate a model for Ni4Ti3 precipitation that can reproduce experimental results.

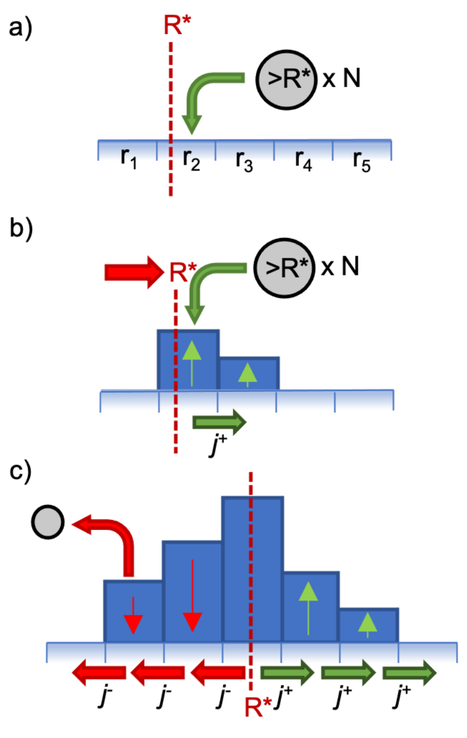

Figure 4: Schematic representation of how a particle distribution evolves via a KWN algorithm

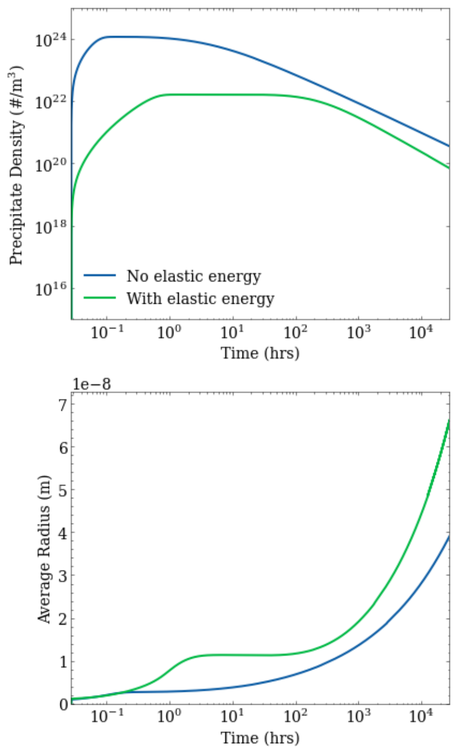

Figure 5: The significant impact of considering elastic contributions on precipitation behavior in Ni_4Ti_3

Significance/Benefits to JPL and NASA:

NiTi based SMA actuators can lift up to 100x their weight, simultaneously actuate in all 3 dimensions, and have little mechanical complexity or failure potential.

Finely controllable SMA based actuators will allow for a significant reduction in the mass and volume required for deployable structures such as solar panels and communications arrays.

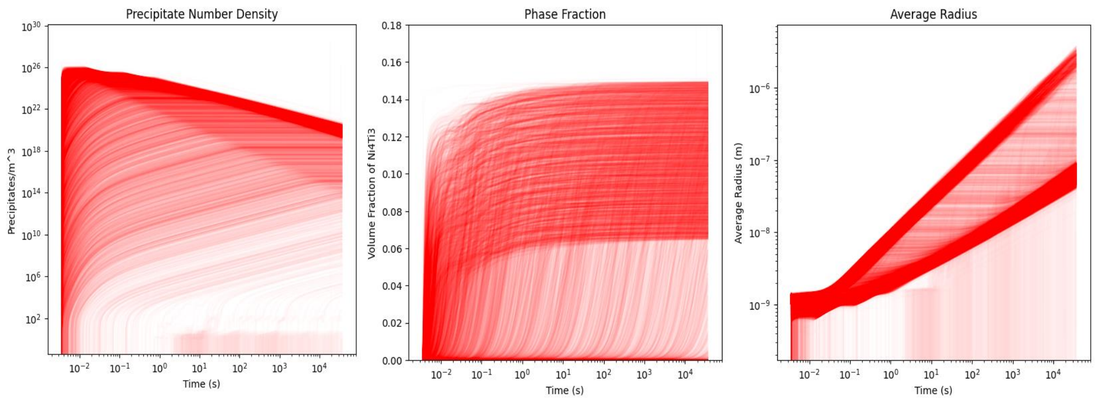

Figure 6: Composite results of high-throughput simulations characterizing the potential output space of prec. number density, phase fraction, and average radius.

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

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PI/Task Mgr. Contact Information:
Email: Richard.Otis@jpl.nasa.gov