Modeling of Hybrid Shape Memory Alloy – Ceramic Composites

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- Collaboration of 29 Students and Faculty
  - Texas A&M University
  - Prairie View A&M University
  - Texas State University
- Research Themes:
  - Developing new multifunctional and nanofabricated materials
  - Incorporating atomic and mesoscale information in macroscale models
- Ph.D. students in Materials Science and Mathematics:
  - Curriculum focuses on advanced materials modeling incorporating multiscale methods
  - Interdisciplinary effort combining applied mathematics with materials science

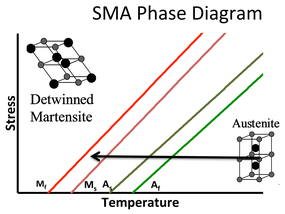
Introduction

- A new metal-ceramic composite is being developed for extreme environments
  - *Shape Memory Alloys* (NiTi) as the metal phase
  - *MAX Phase* (Ti_2AlC) Ceramics
- By combining these two materials, it is intended that *residual stress states* may be developed
  - Compressive residual stress on the ceramic phase would take advantage of superior mechanical properties
- Need to develop *numerical models*
  - Determine effective transformation response
  - Virtually process the composite to find the residual stress state and select a thermomechanical loading path
  - Account for the effects of the microstructure

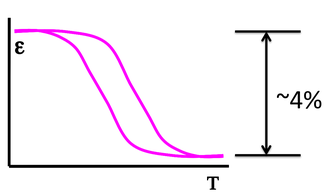
Constituent Phase Responses

- Before determining effective response, need to describe response of each constituent phase
- *Shape Memory Alloys (SMAs)* undergo a reversible martensitic phase transformation leading to large, recoverable strains

SMA Phase Diagram

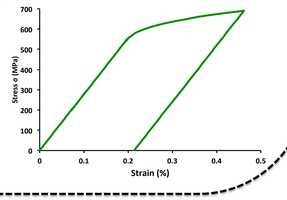


Strain-Temperature SMA Response



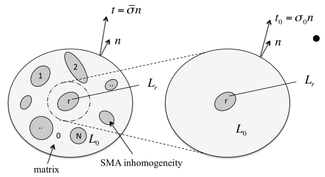
- *MAX Phase Ceramics* are nanolayered ternary carbides which exhibit a unique kinking response
  - Approximate as elasto-plastic response

Assumed MAX Phase Response



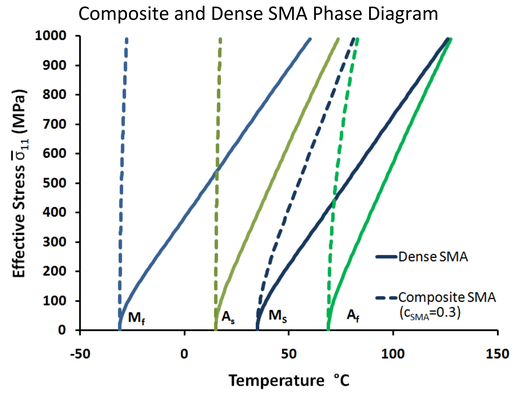
Effective Transformation Characteristics

- Need to determine influence of stiff, ceramic phase on *transformation characteristics of hybrid SMA-composites*



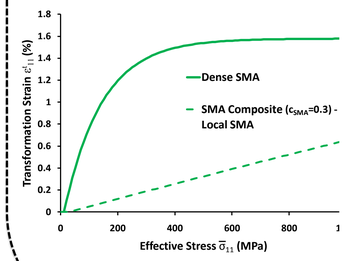
- Micromechanical scheme using *Mori-Tanaka Method*
  - SMA inhomogeneities in a stiff, ceramic matrix

Composite and Dense SMA Phase Diagram

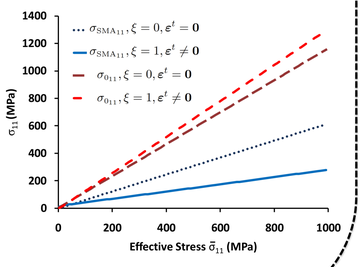


- Composite requires a *lower temperature* at a given applied stress level to initiate or complete transformation
  - *Stress redistributed* from SMA phase to ceramic phase due to transformation
  - Lower effective transformation strain than dense SMA

Effective Transformation Strain



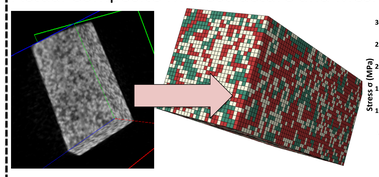
Phase Average Stress Before and After Transformation



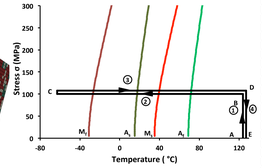
Finite Element Modeling

- To account for the influences of the *microstructure*, *finite element meshes* are developed based on *tomography* of actual composite specimens
- Subjected composite to actuation loading

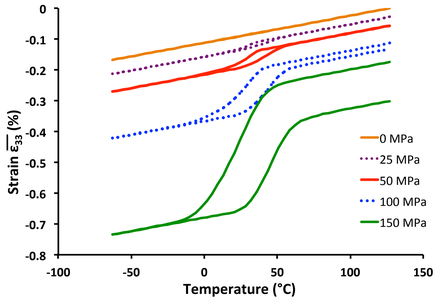
Actual Composite Microstructure and Mesh



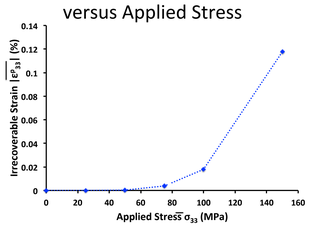
Actuation Loading Path



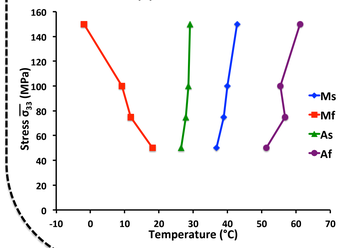
Effective Composite Actuation Response at Various Applied Stresses



Effective Irrecoverable Strain versus Applied Stress



Effective Phase Diagram versus Applied Stress

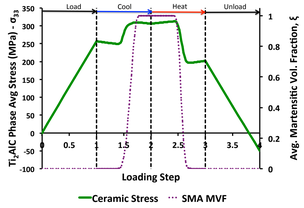


- With increasing applied stress
  - Increase in transformation strain
  - Decrease in martensitic finish (M_f) temperatures
  - Higher loads lead to open hysteresis loops
  - *Generation of irrecoverable strains*
- Generation of irrecoverable strains lead to *negative slope for martensitic finish* temperature

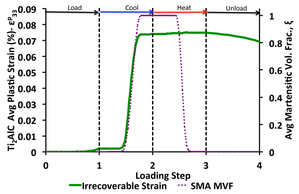
Residual Stress States

- *Transformation induces irrecoverable strains*
- Lead to *residual stress states*

Ceramic Phase Average Stress through Loading



Ceramic Phase Average Irrecoverable Strain



Summary

- Developed *models* to describe behavior of hybrid SMA-Ceramic Composites
  - *Micromechanical model to explore effective transformation characteristics*
  - *Finite element model incorporating actual microstructures*
- Composite transformation response has *decreased strains* and *transformation temperatures*
- Irrecoverable strains in MAX phase lead to *compressive residual stress state*

Acknowledgements

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