Development of Metallic Sensory Alloys

T. A. Wallace, J. A. Newman, W. P. Leser
NASA Langley Research Center
Hampton, VA

P. E. Leser
North Carolina State University
Raleigh, NC

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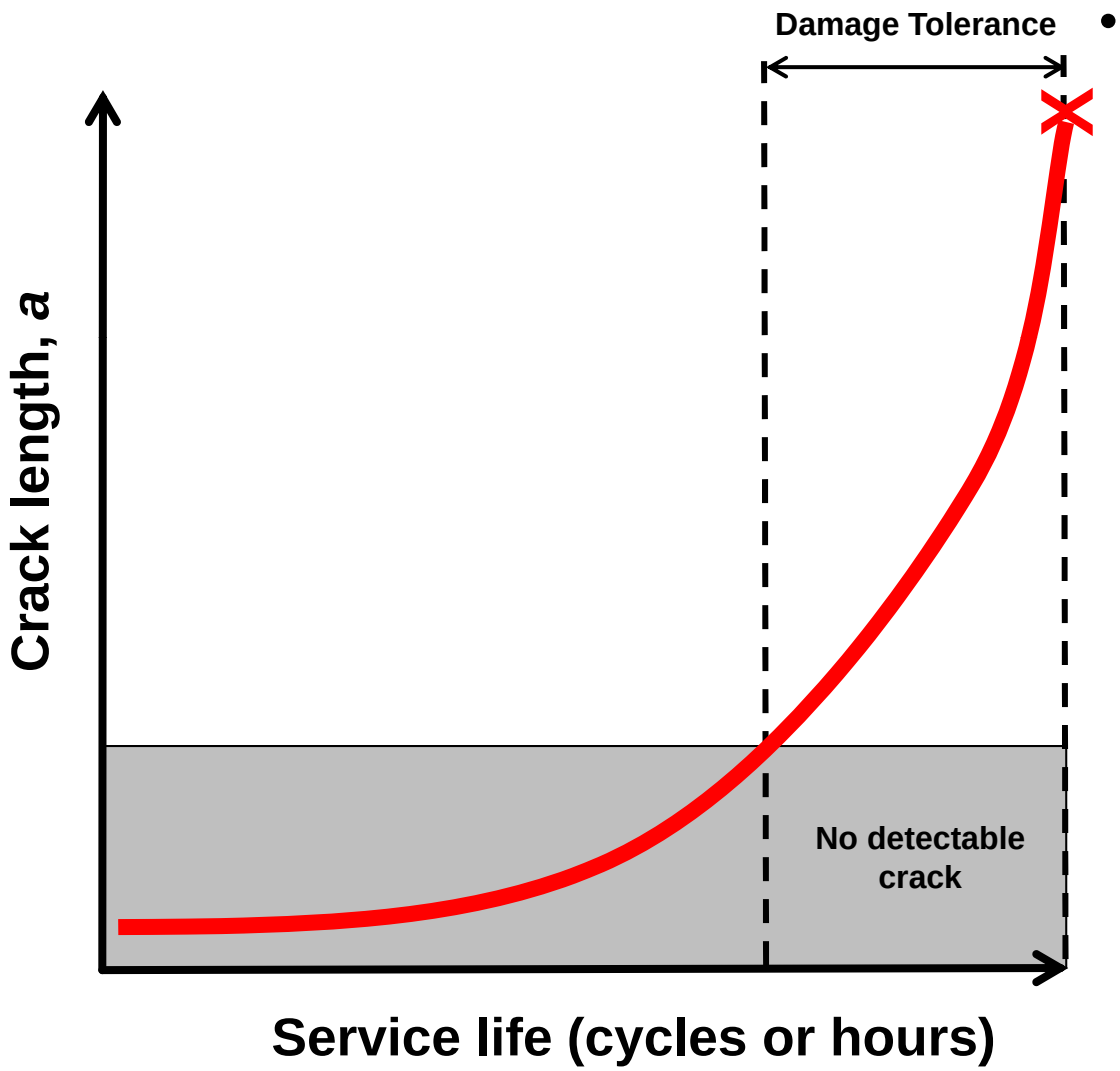
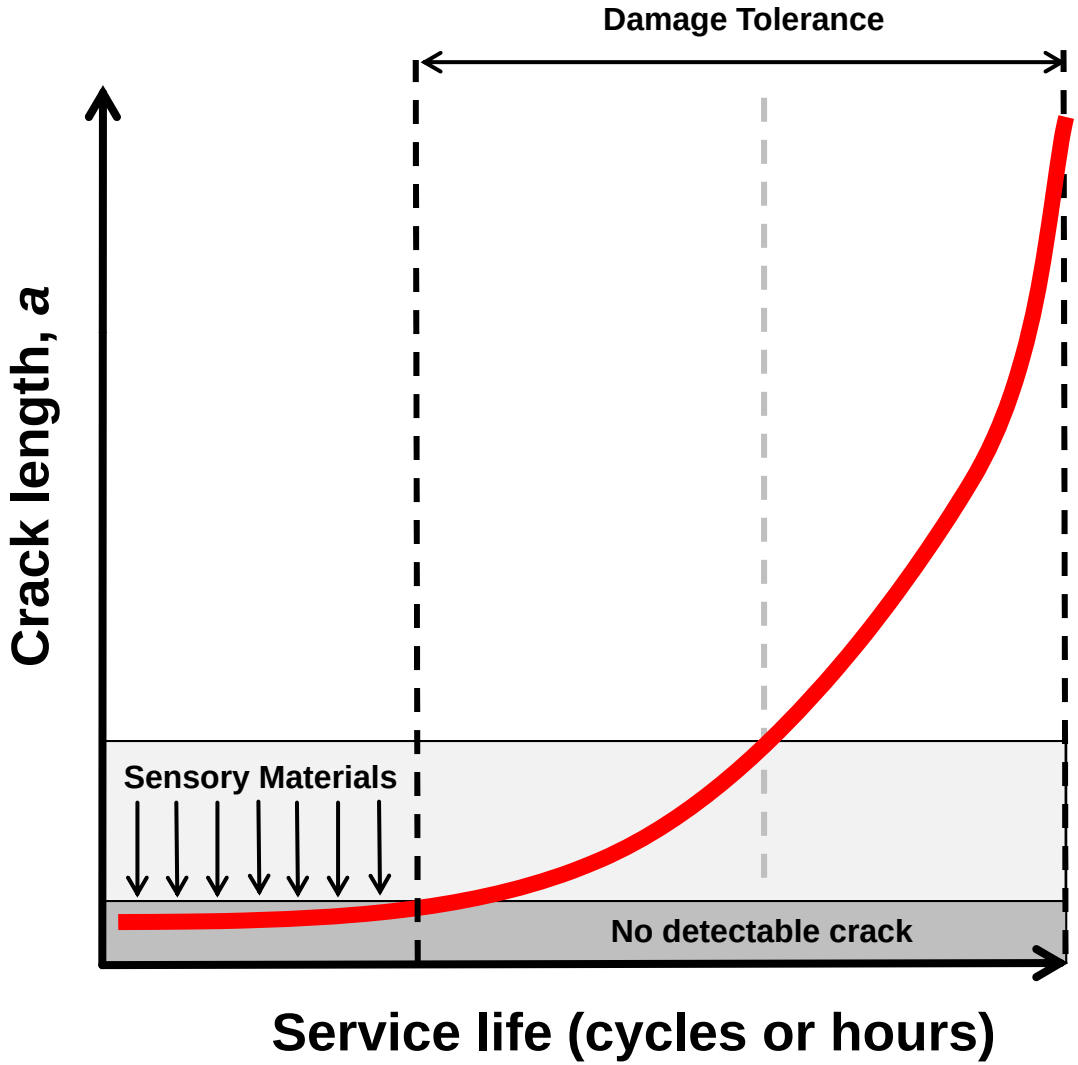
Problem



- Problem
  - Portion of service life manageable by damage tolerance methodology is too small
  - Frequent inspections are costly

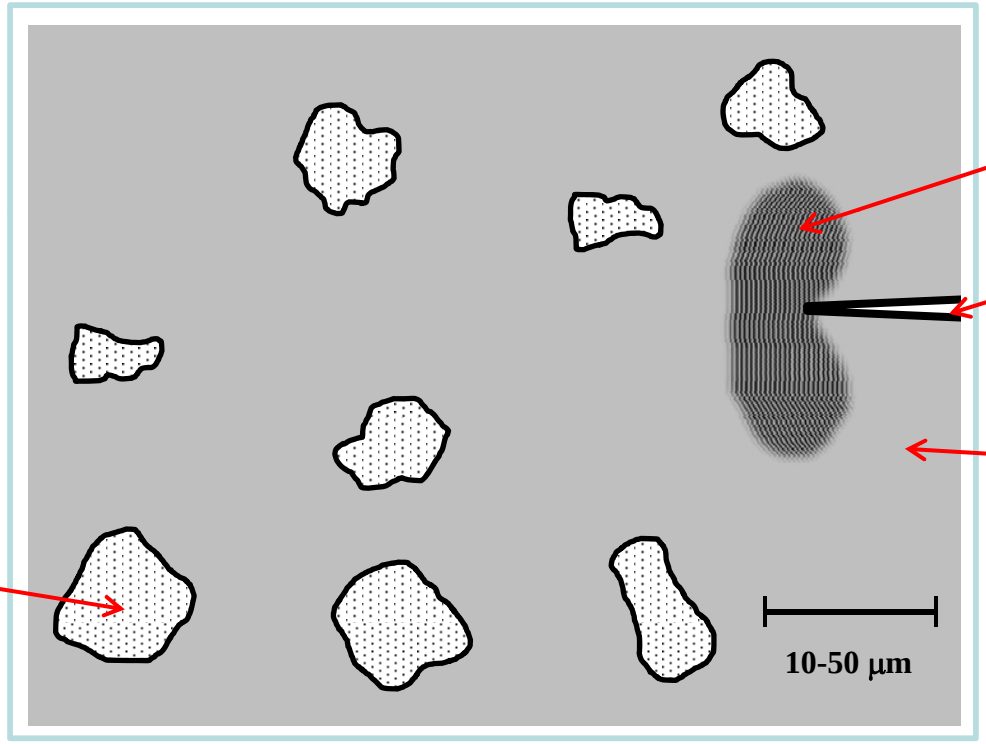
Problem



- Improvement in:
  - Safety
  - Weight
  - Cost
- Vehicle Safety Systems
  - “Real time” damage detection
  - *In-situ* healing of damage

Sensory Alloy Concept

Motivation: **Safe operation of modern aircraft depends on the ability to detect small cracks before they reach a critical size; however, existing NDE techniques can be ineffective in existing structural materials.**



Approach: Embed particles with enhanced NDE response

Sensory Alloy Concept

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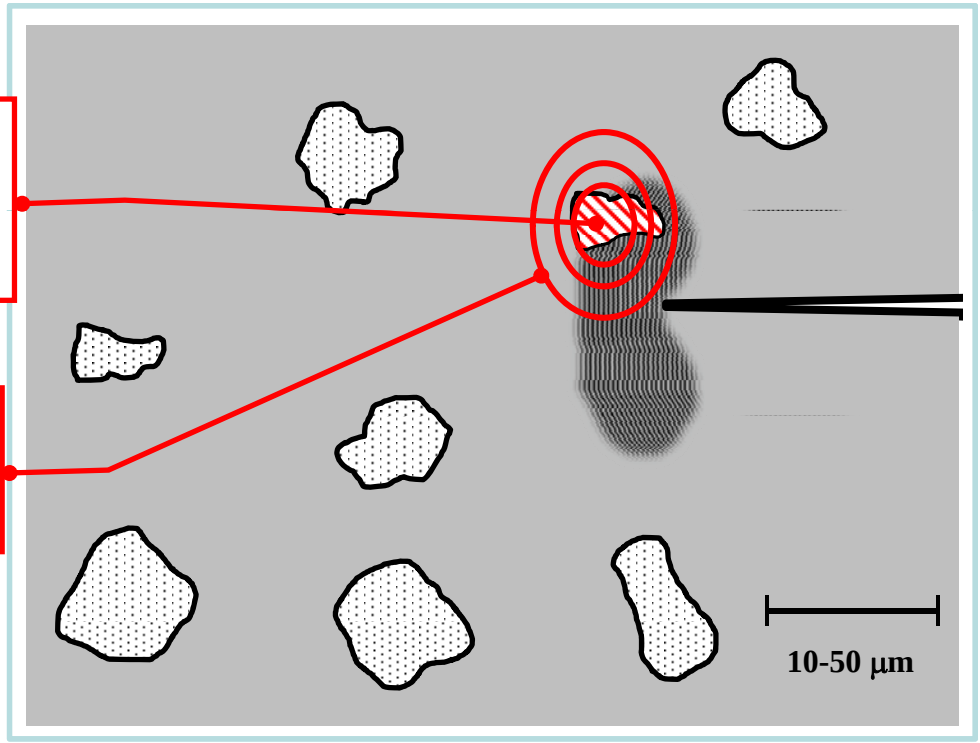
Phase Transformation:
Produced by increased strain in front of growing crack

Acoustic Emission:
Real-time measurement of damage



Sensory Alloy Concept

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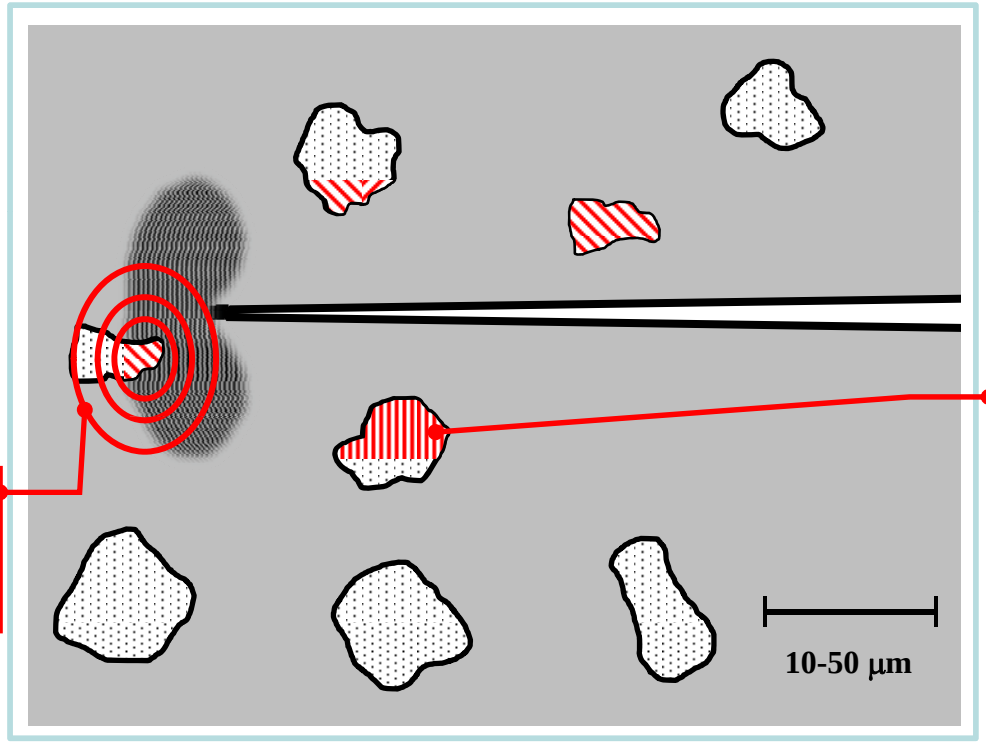

Acoustic Emission:
Real-time measurement of damage

Transformed Region of embedded particle:
Measure change in properties:
- Magnetic
- Resistivity
- Other

High strain in damage zone causes phase transformation
- **Acoustic emission (AE) that can be measured during flight**
- **Magnetic changes measurable using ground-based inspection equipment**

Sensory Alloy Concept

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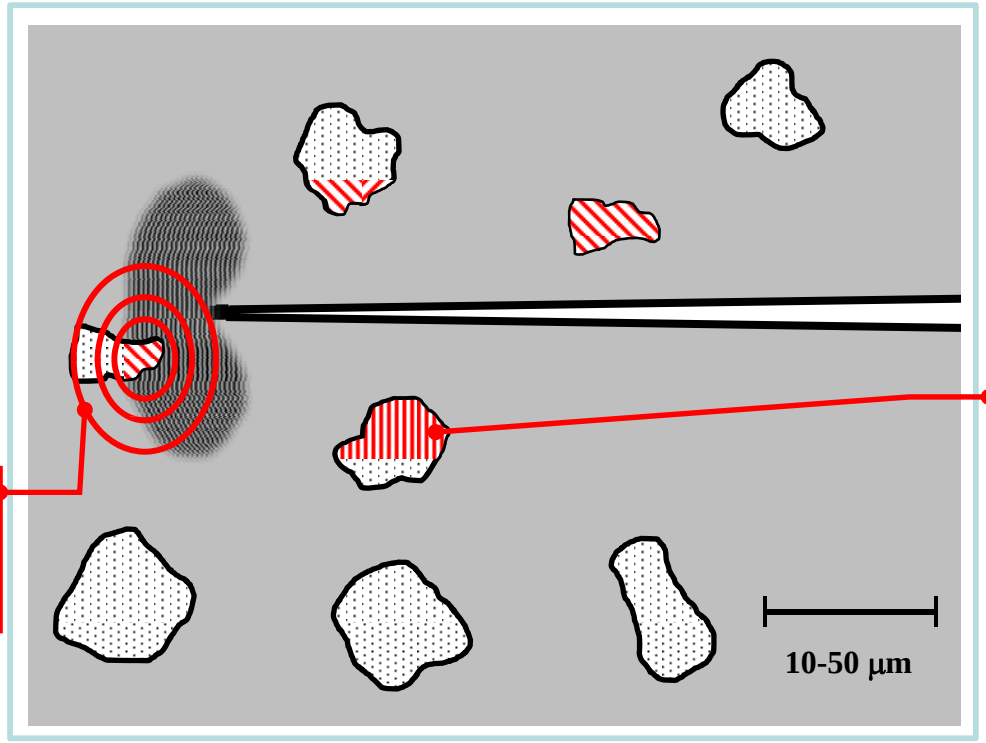


Acoustic Emission:
Real-time measurement of damage

Transformed Region of embedded particle:
Measure change in properties:
- Magnetic
- Resistivity
- Other

Ferromagnetic Shape Memory Alloys (FSMA) are ideal

Technical Approach

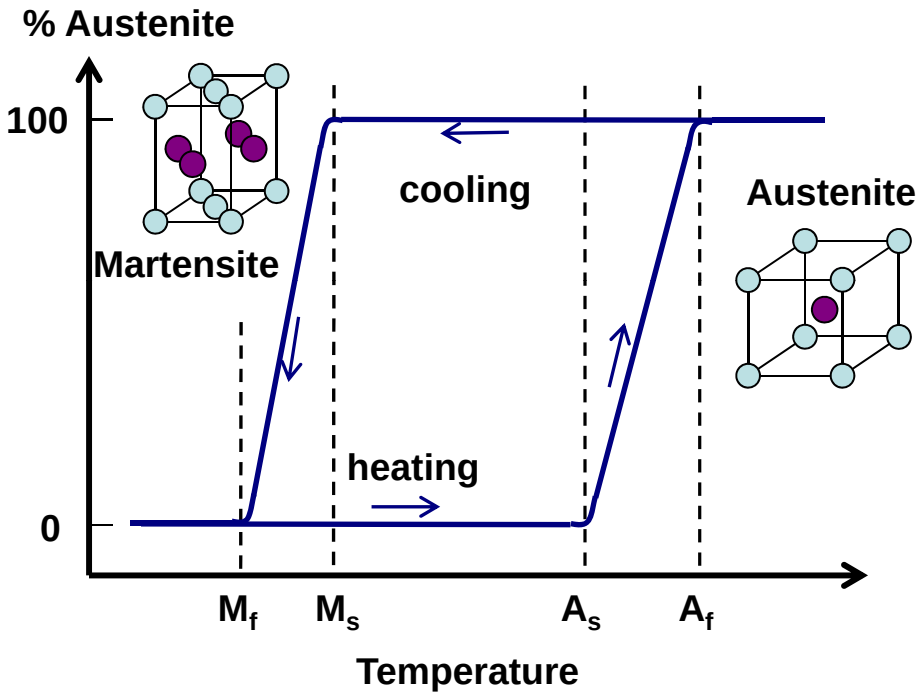
Develop FSMA Sensory Material
- **Background**
- **FSMA selection and optimization**
- **Evaluate NDE response**

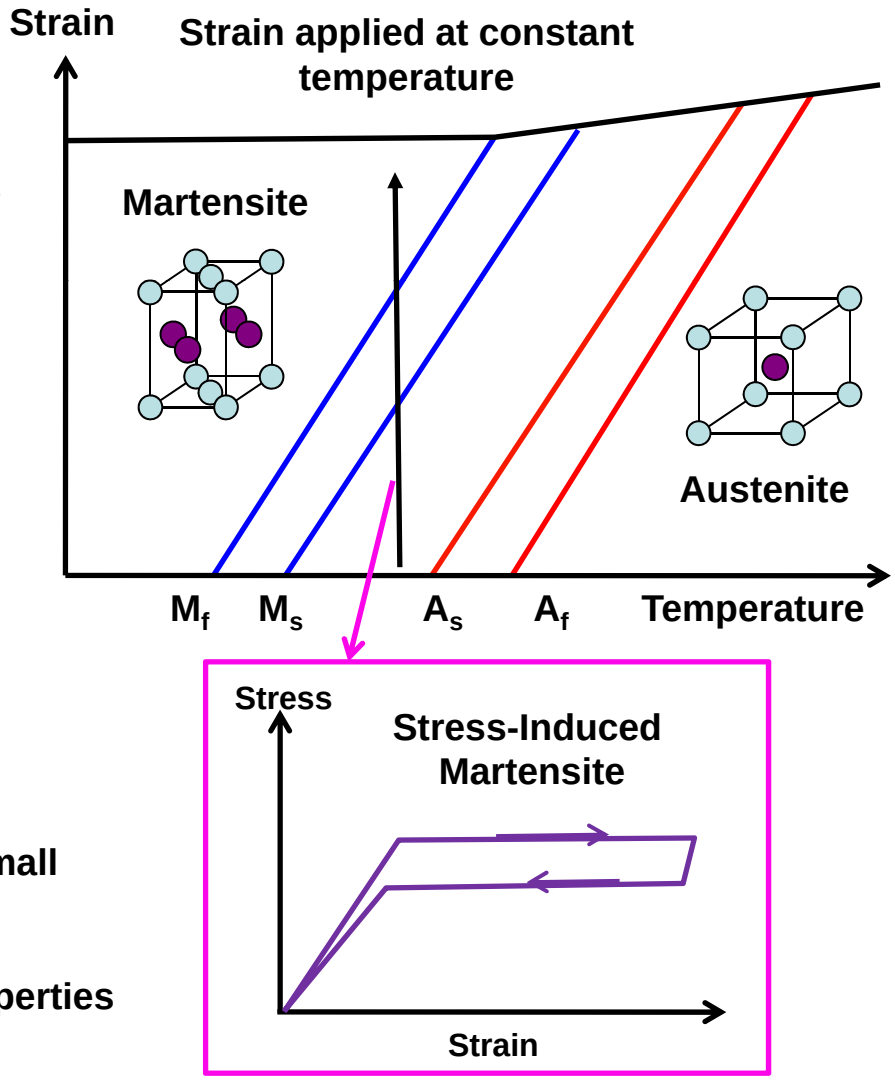
Embed Particles in Structural Al Alloy
- **Production of sensory particles**
- **Investigate embedding techniques**
- **Evaluate effect on fatigue properties**

Understand NDE Response of Sensory Alloy

Shape-Memory Materials

Shape Memory phenomenon is driven by temperature OR strain

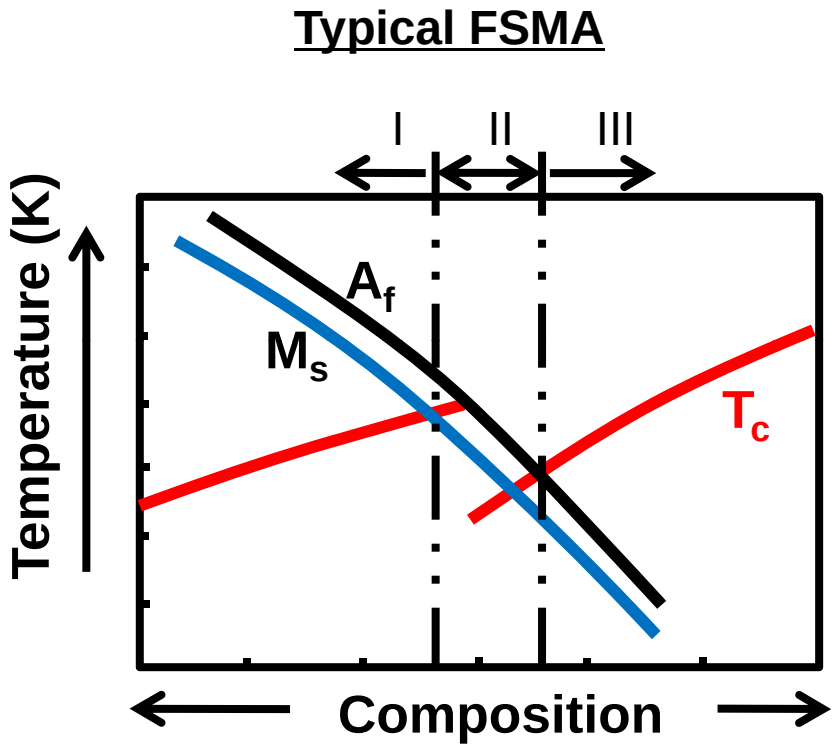




Martensitic Transformation

- Rapid and diffusionless change produced by small changes in crystal structure
- Transformation produces AE response
- Austenite and martensite possess different properties

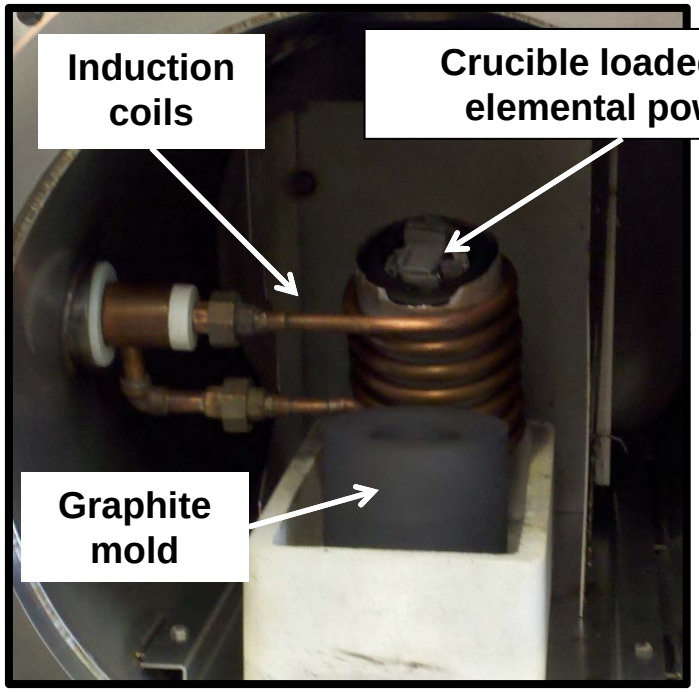
Alloy Selection for Sensory Particles

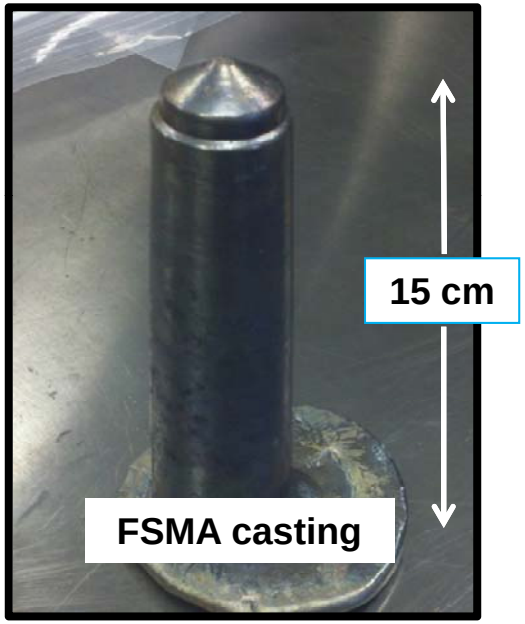


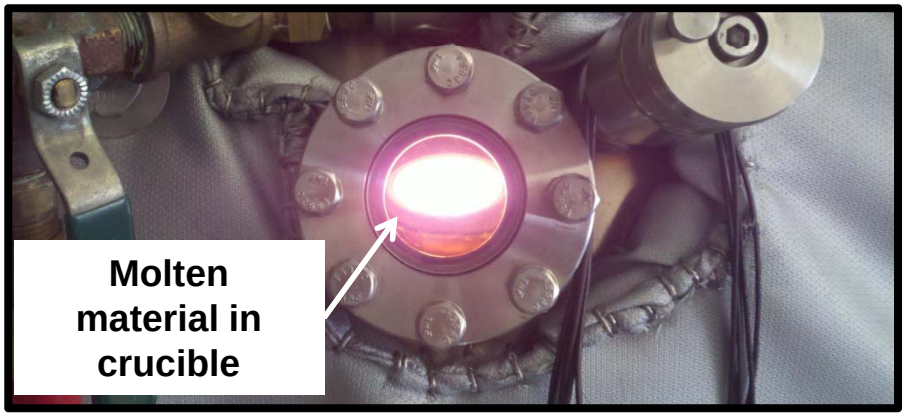
- **Challenges:**
  - **Martensitic and magnetic changes not necessarily coincident**
  - **Transition temperatures very sensitive to small changes in composition**

Processing of Sensory Materials

Production of Bulk Sensory Material





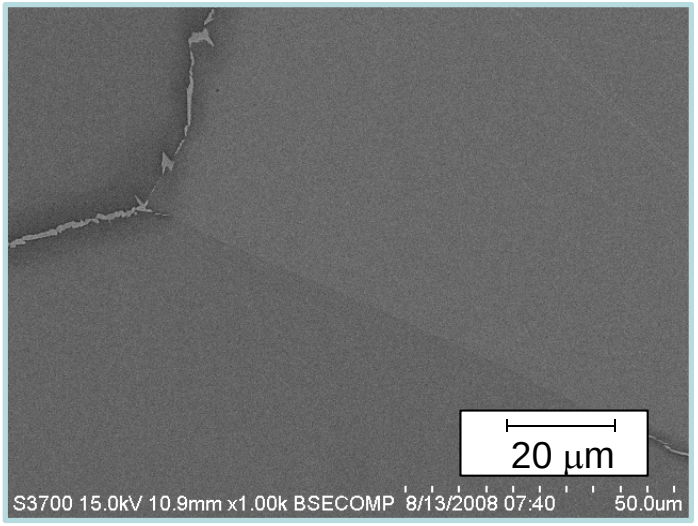


Can produce large (1 kg) casting with repeatable chemistry

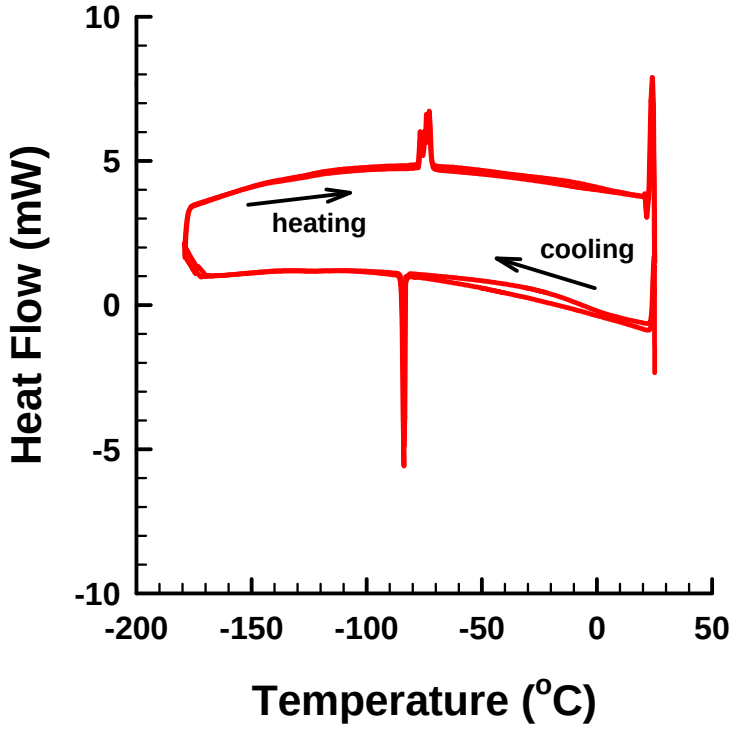
Processing of Sensory Materials

Cast + Solution Treated and Quenched

Microstructure



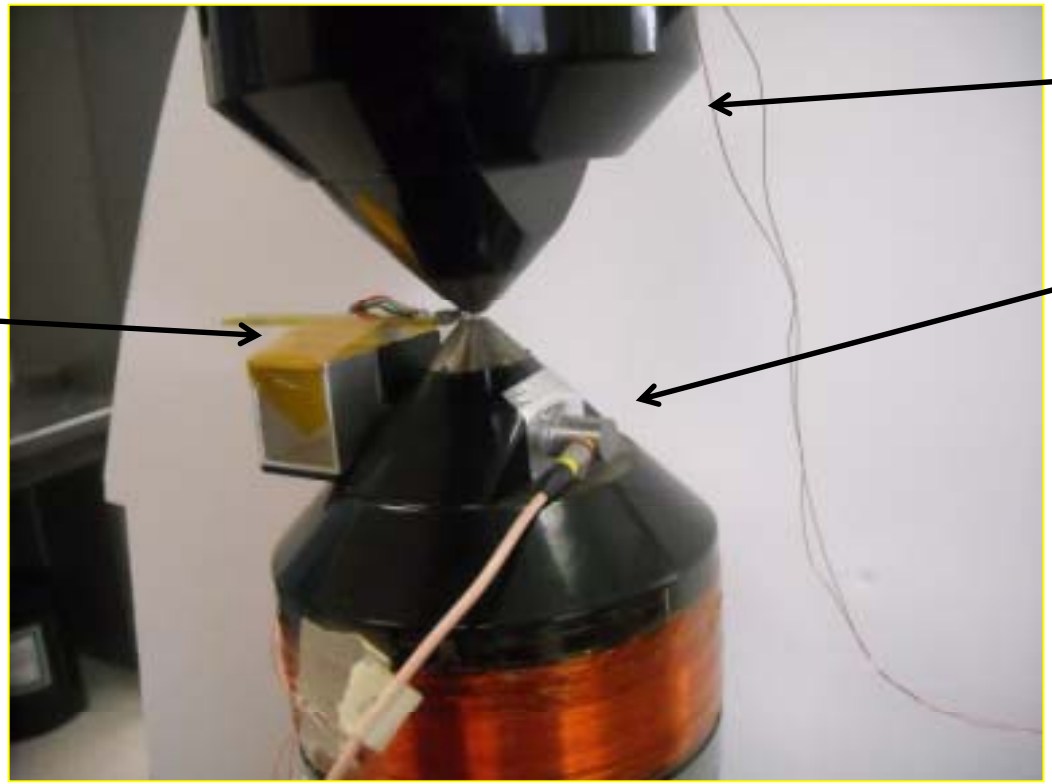
Differential Scanning Calorimetry (DSC) Results



Proper heat treatment produces uniform chemistry and a sharp, repeatable phase transformation

NDE Response of Sensory Materials

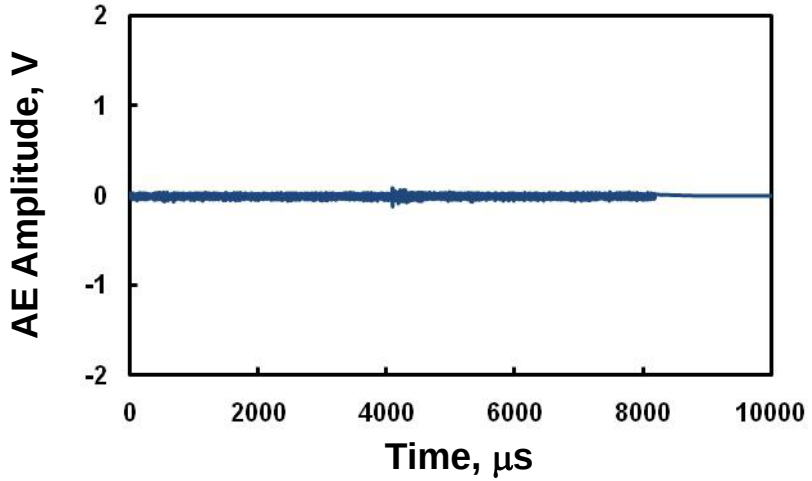
Acoustic Emission Response to Increasing Strain



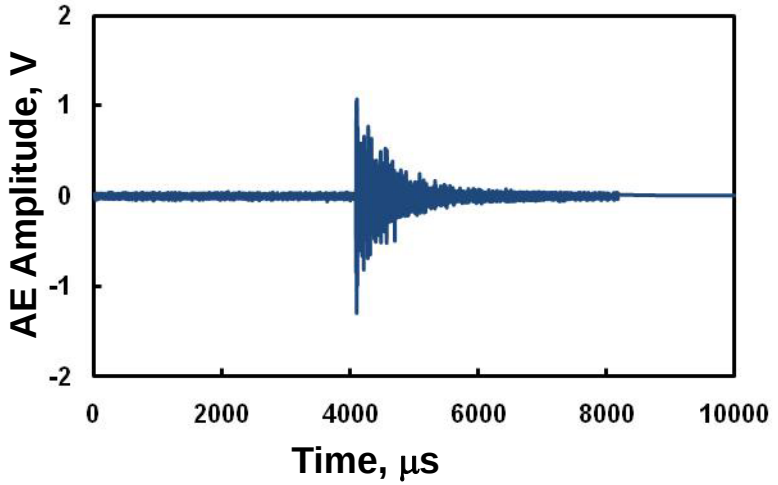
NDE Response of Sensory Materials

Acoustic Emission Response to Increasing Strain

Aluminum



Bulk FSMA



NDE Response of Sensory Materials

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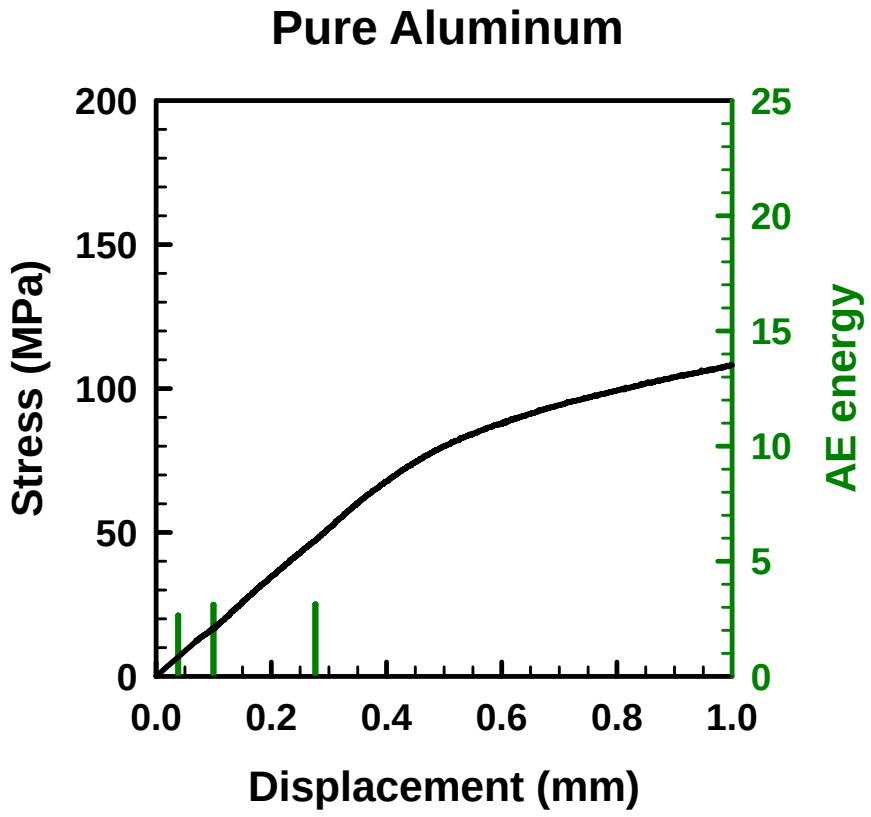
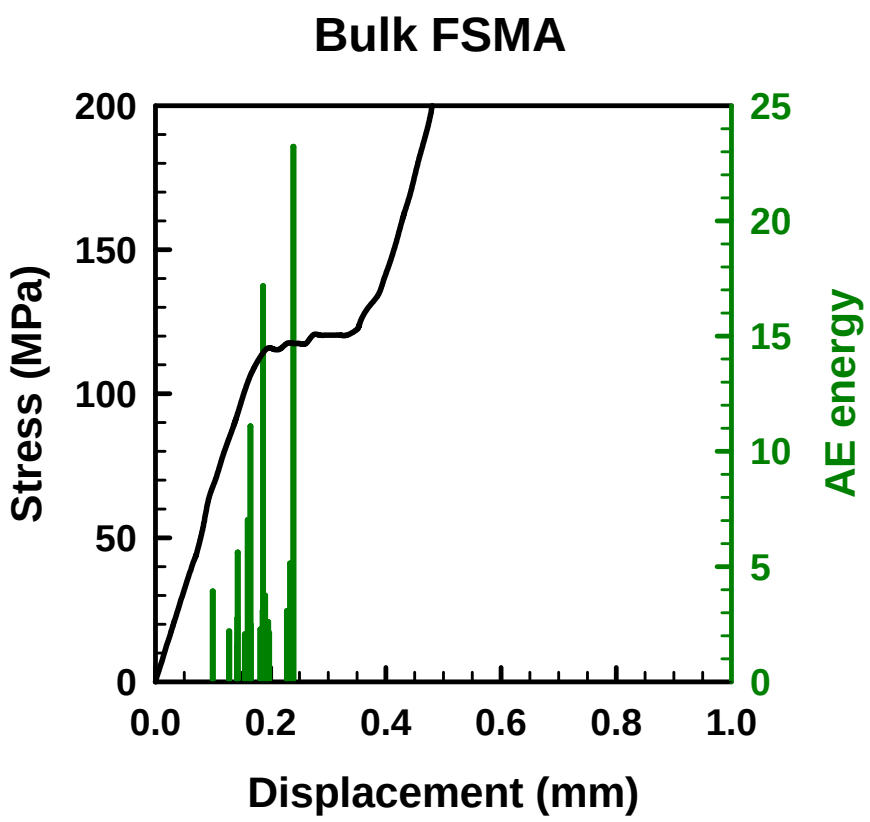
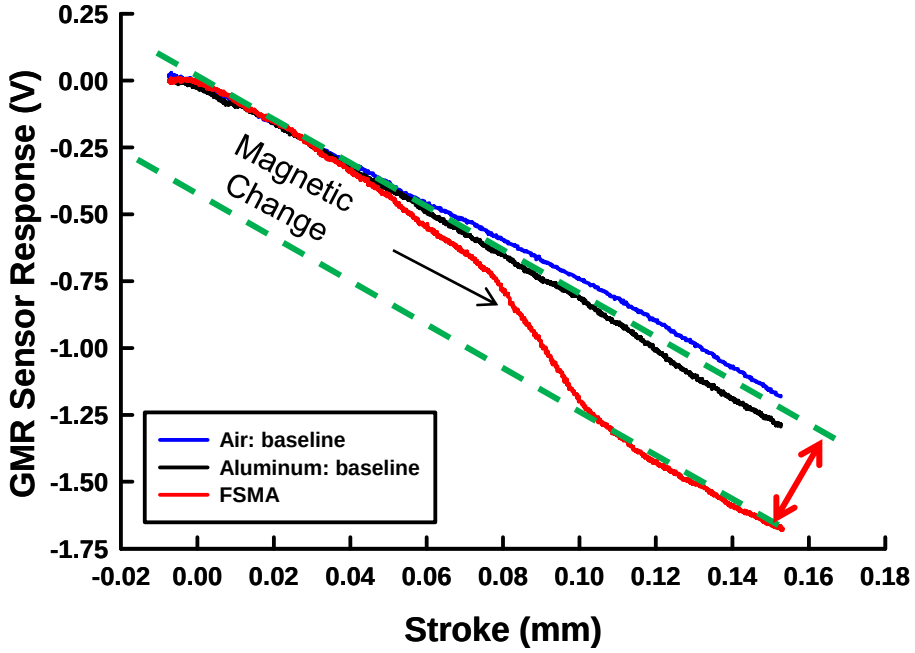




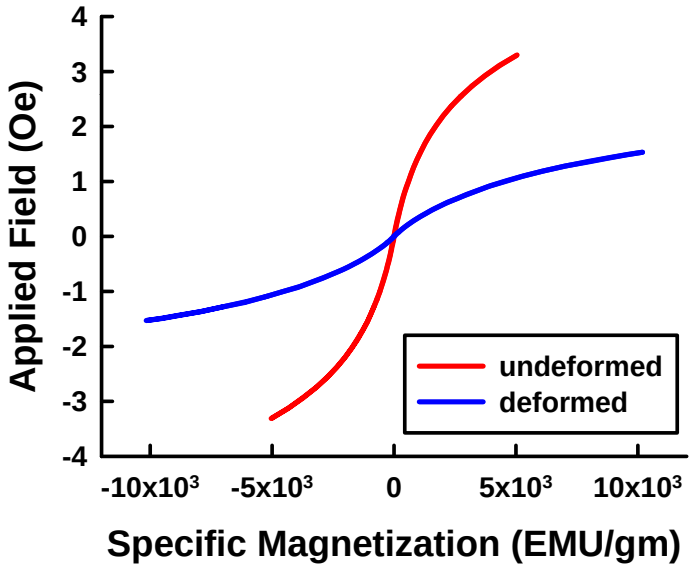
Shape memory alloy has enhanced NDE response compared to pure aluminum – increased number of events and energy

NDE Response of Sensory Materials

Magnetic Response to Increasing Strain (GMR)



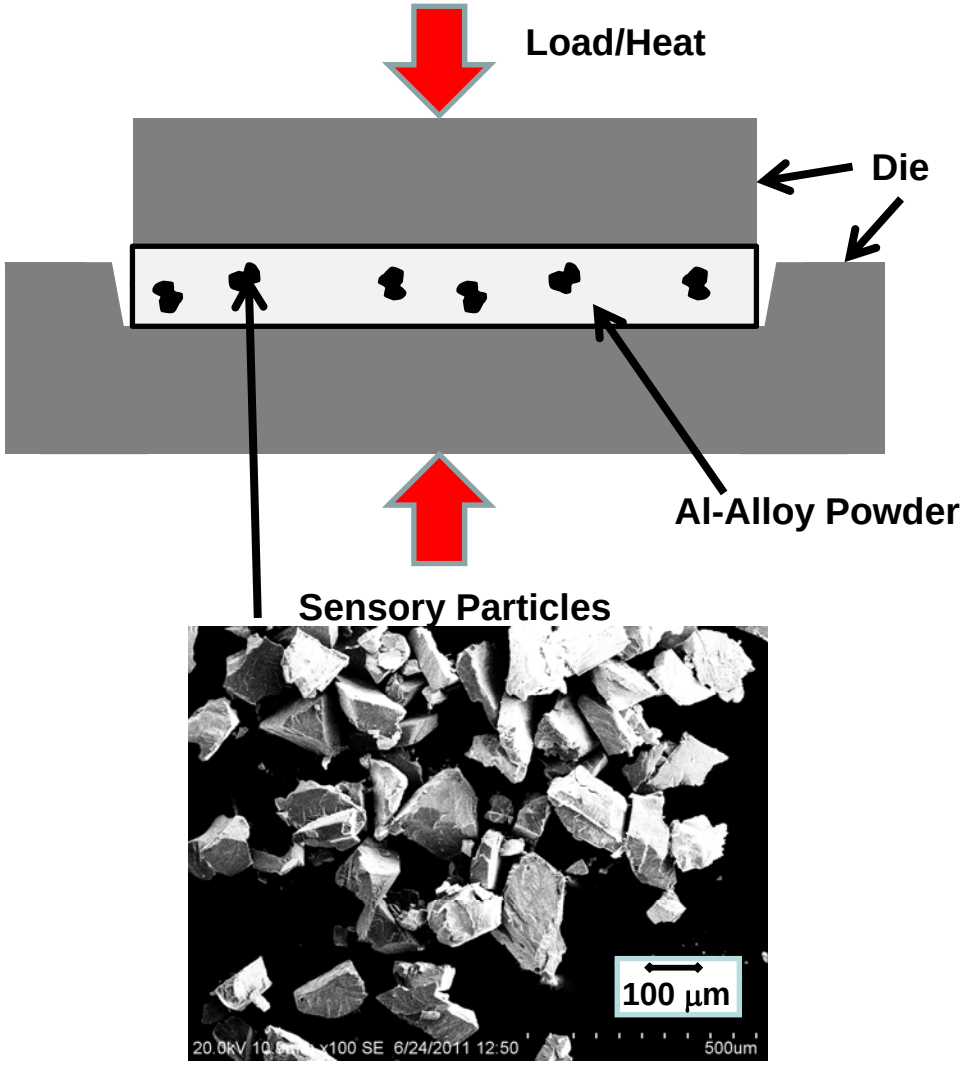
Eddy Current Response



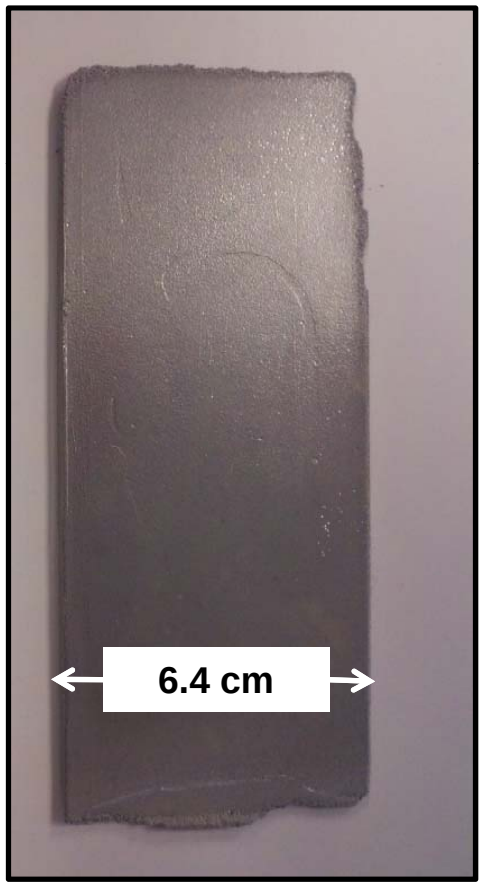
Strain in FSMA produces a change in magnetic properties that can be characterized using Eddy Current

Production of Sensory Alloys

Vacuum Hot Press



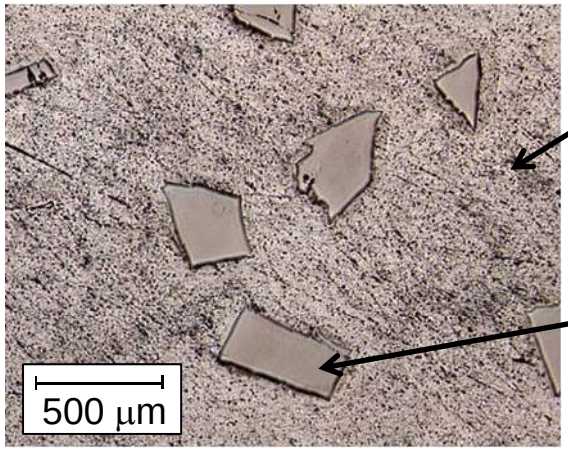
Sensory Panel



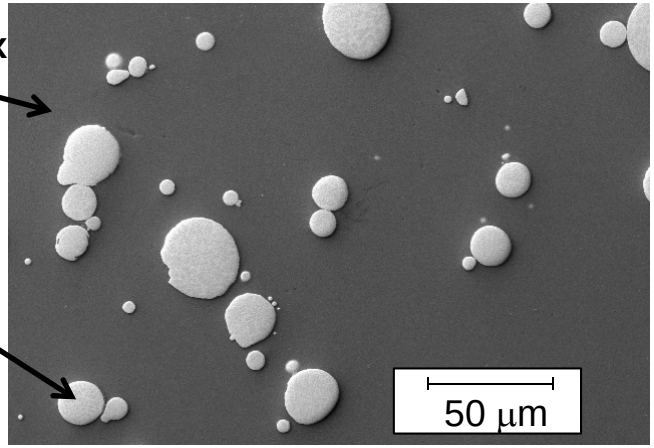
Production of Sensory Alloys

Can produce sensory particles in various sizes and shapes

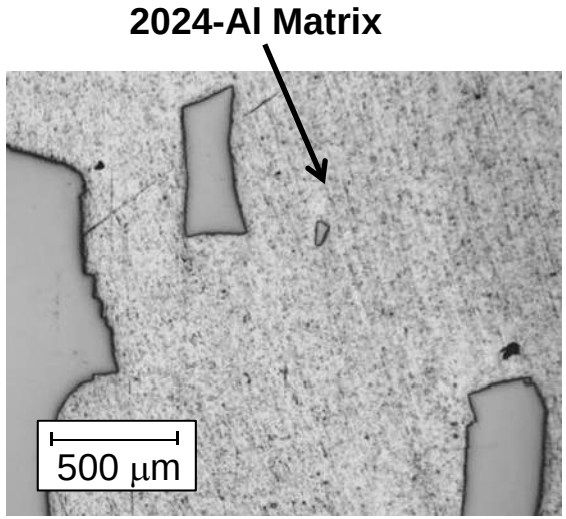
Mechanically Fragmented



Gas Atomized



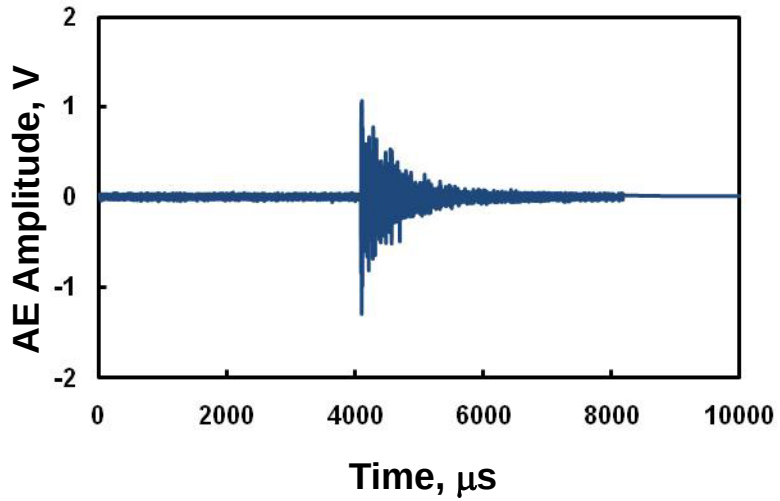
Good consolidation for different Al-alloy matrices



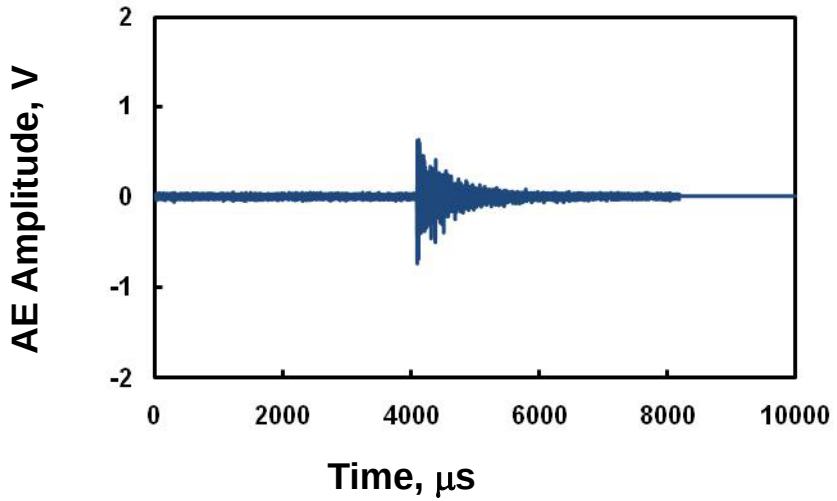
NDE Response of Sensory Alloys

Acoustic Emission Response to Increasing Strain

Bulk FSMA

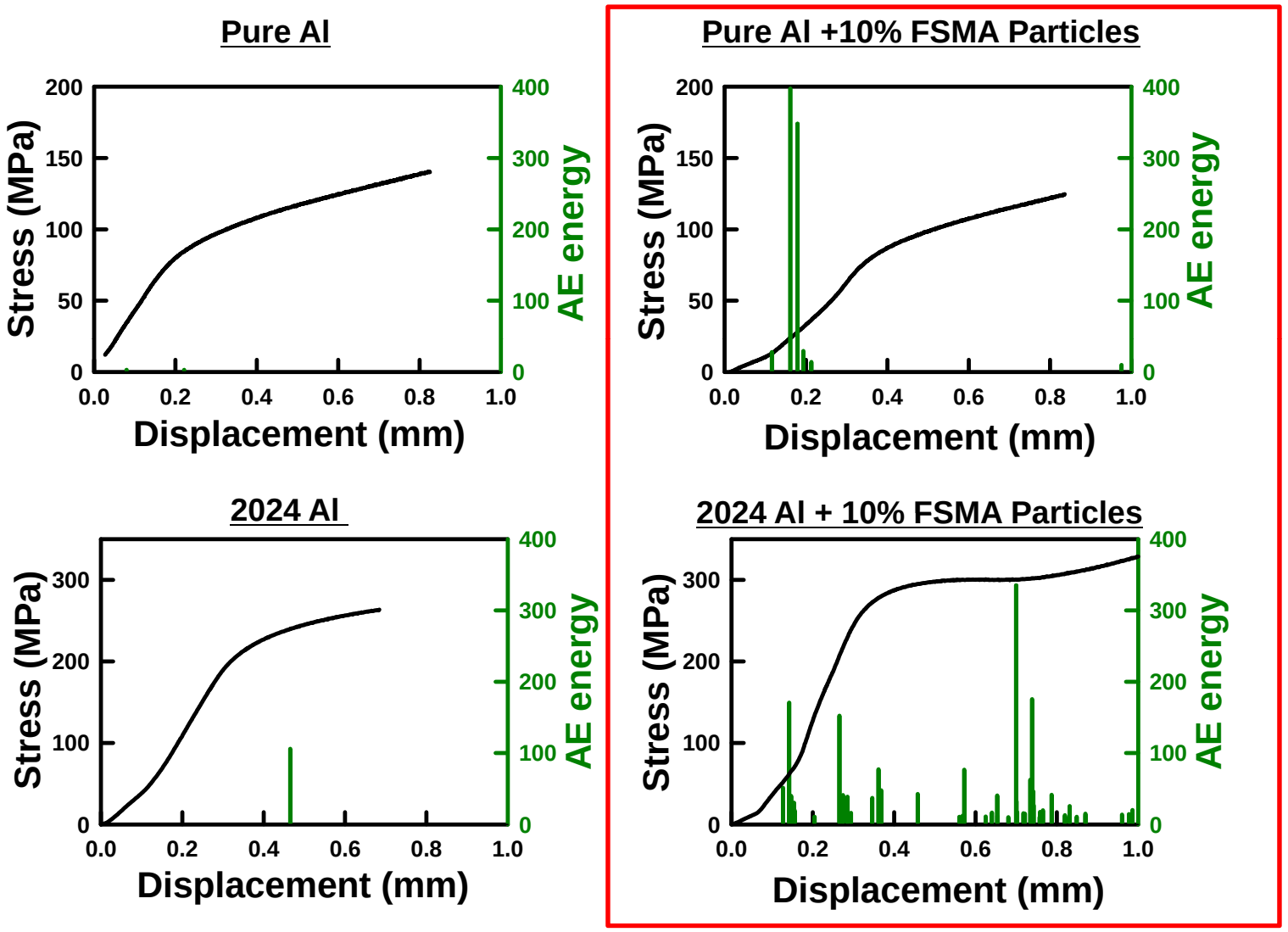


10% Embedded FSMA in Pure Al



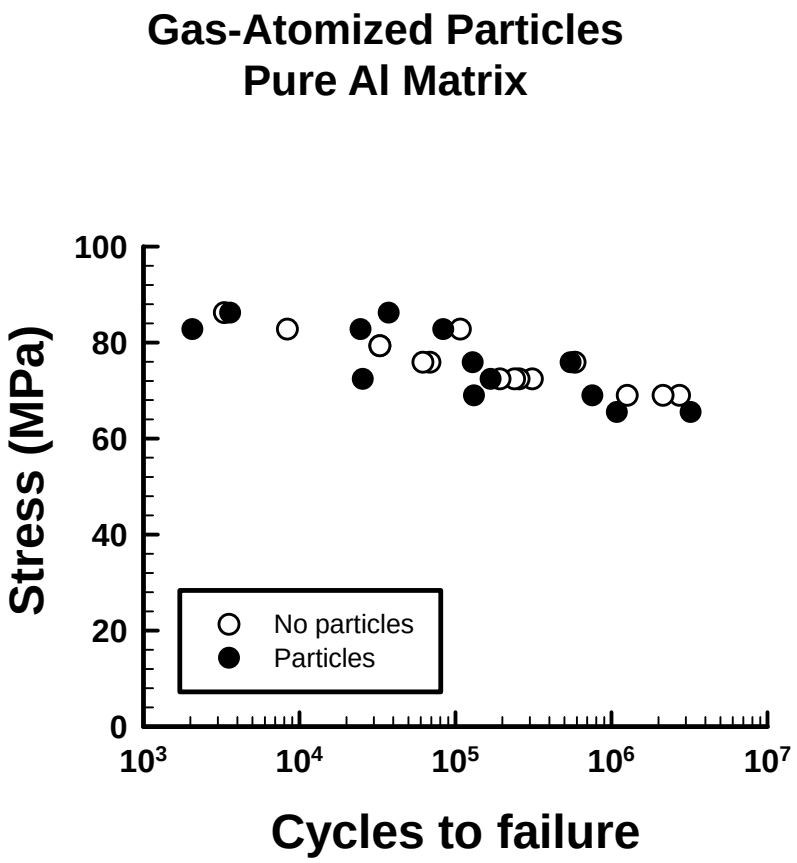
Sensory alloy has comparable NDE response to bulk FSMA

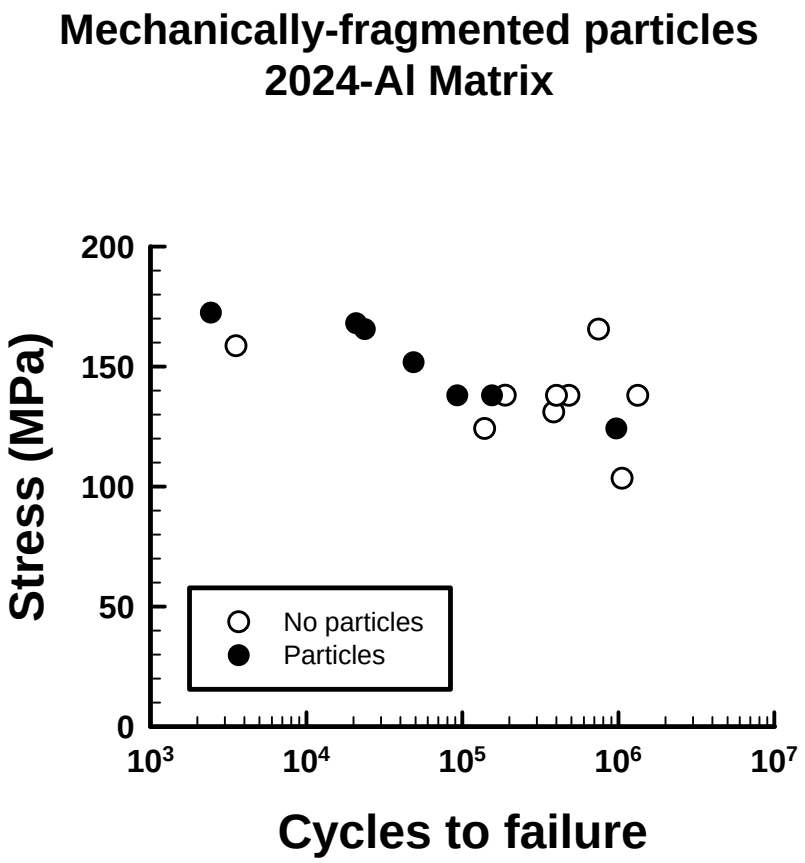
NDE Response of Sensory Alloys



Sensory alloy can be produced by embedding FSMA in aluminum alloys

Production of Sensory Alloys

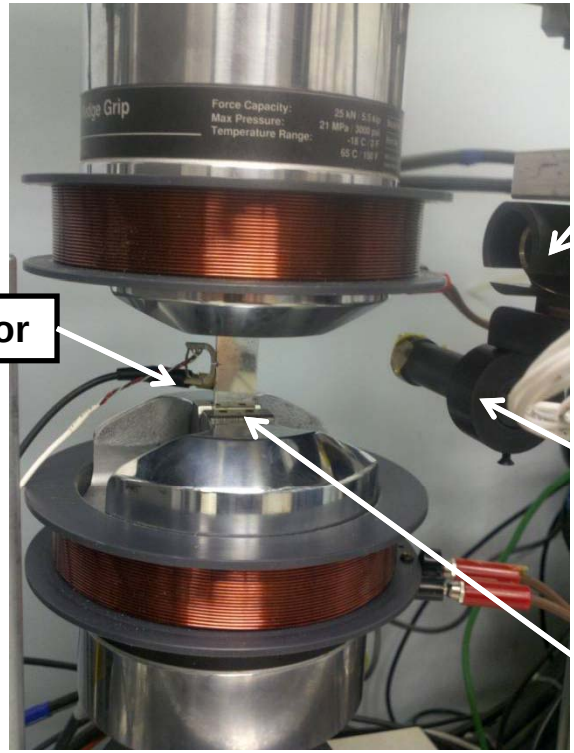




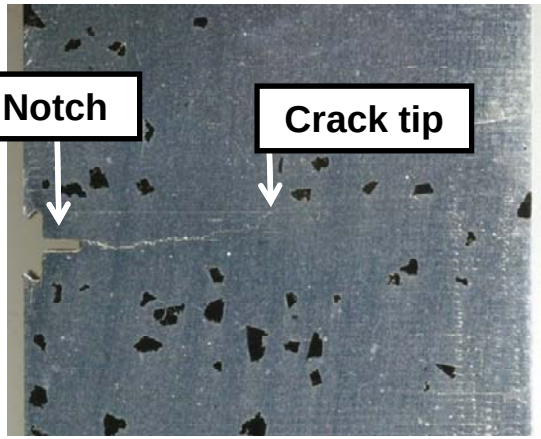
No apparent decrease in fatigue life compared to panels without particles

NDE Response of Sensory Alloys

Test Set-Up



Specimen



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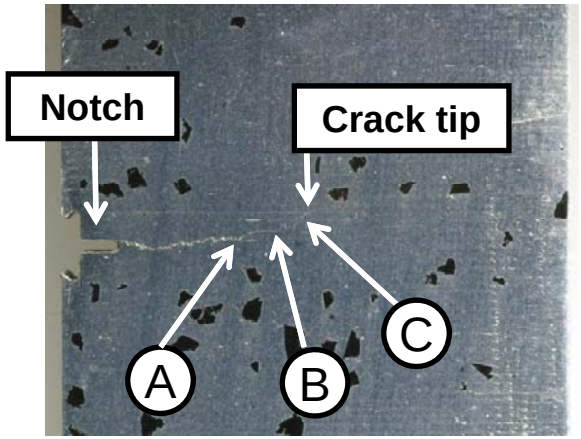
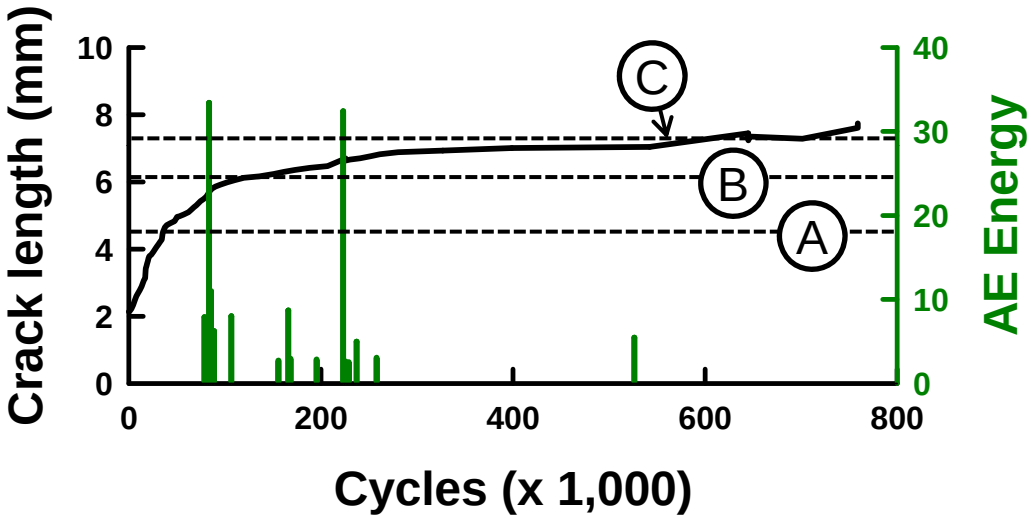
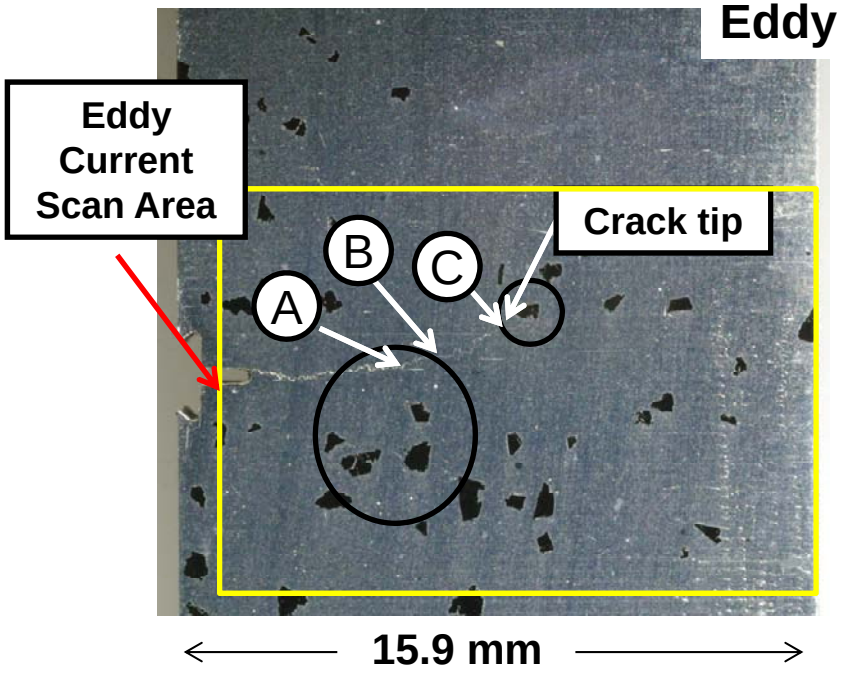


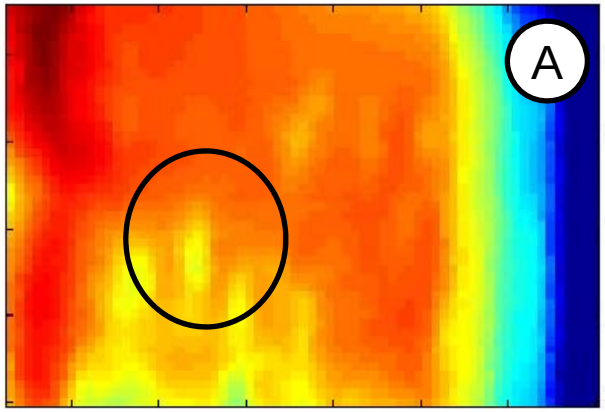


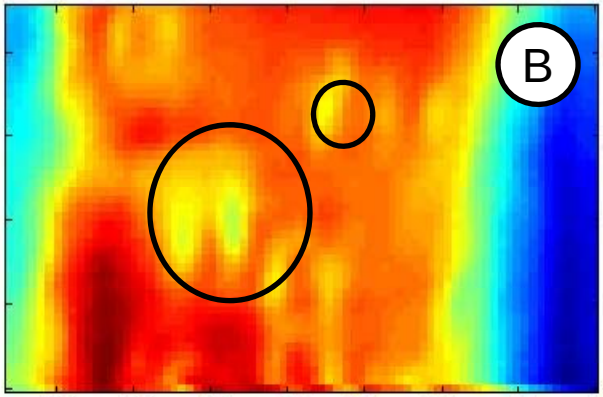
High intensity AE signals are measured as the crack tip approaches sensory particles

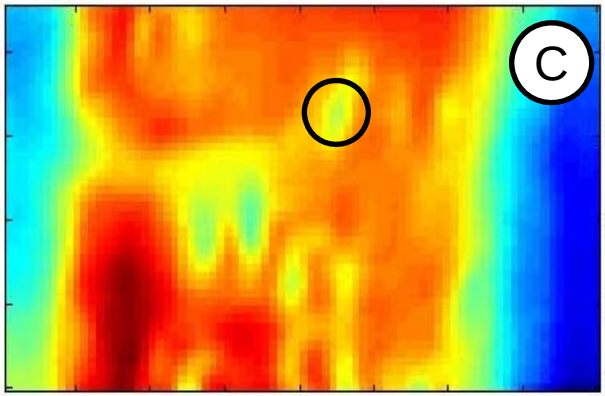
NDE Response of Sensory Alloys



Eddy Current Scans







Summary

- An FSMA was developed that demonstrated acoustic emission and magnetic property changes when strained
- Particles of the FSMA were successfully produced and consolidated within an aluminum matrix
- Sensory alloys demonstrate acoustic emission and change in magnetic properties for compressive and fatigue loading
- Patents:
  - "*Strain-Detecting Composite Materials*," LAR-17738, provisional patent filed January 11, 2010