A Decade of SMA Activities at NASA-GRC, Material Challenges, and Future Prospects

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High Temperature & Smart Alloys Branch
Materials and Structures Division

HIGH TEMPERATURE SHAPE MEMORY ALLOY RESEARCH and TECHNOLOGY (HT-SMART)

Mar. 24, 2015
It Takes a Team…

- Neutron/synchrotron diffraction
- HTSMAs characterization
- Superelastic/bearing alloys
- Lattice deformation theory
- Constitutive modeling

- Alloy development
- Mechanical Characterization
- Single crystals
- SMA machining
- HTSMA Microstructure
- Modeling

- Atom probes
- Microstructure

**STRUCTURAL SCALE** (COMPONENTS)

**MICRO-SCALE** (MICROSTRUCTURES)

**ATOMIC SCALE** (NANOMATERIALS)

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www.nasa.gov
NASA SMA Team

- Ron Noebe
- Santo Padula II
- Glen Bigelow
- Anita Garg
- Darrell Gaydosh
- Timothy Halsmer
- Othmane Benafan
- (Branch Chief: Joyce Dever)
Our Goals – Materials, Infrastructure, Applications

• **Materials:**
  – Develop new shape memory alloys ranging from cryogenic to high temperature for use in adaptive structures, and lightweight, solid-state actuation systems.
  – Adjust material properties through alloying, processing, and thermo mechanical understanding.
  – Identify methods to establish good stability, durability, workability, and work output amongst others

• **Infrastructure:**
  – Develop laboratory testing capability and methods to evaluate and characterize SMA properties/performance.
  – Generate material(s) data sheets and databases
  – Determine test standards/methodologies
  – Component or subcomponent testing/modeling

• **Applications:**
  – Identify/build applications to benefit the aeronautics and space design challenges
  – Design methodologies
  – Commercialization
Development of Shape Memory Alloys: Challenges and Lessons Learned
Development of Shape Memory Alloys: Challenges and Lessons Learned

High transformation temperatures
- Above 100 °C
- Good work output
- Thermal stability

Durability
- Loading history
- Functional fatigue
- Structural fatigue

Modeling
- Micromechanics
- Phenomenological
- Evolutions/transients

Workability/Processing
- Ductility
- Composition control
- Heat treatment

Certification
- Testing standards
- Material certification
- Database

Dimensional stability
- Cyclic stability
- Stress-strain relationship
55 Years after Nitinol Discovery

Metals
- NiTi, NiTiFe, NiTiNb, NiTiCu, NiTiPd, NiFeGa, NiTiCo CuZn, CuZnAl, CuAlNi, CuAlNiMn, CuSn, FePt, FeMnSi, FeNiC
  - NiTiHf, NiTiZr, TiNiPd, TiNiPt, ZrRh, ZrCu, ZrCu NiCo,
  - ZrCuNi CoTi, TiMo, TiNb,
  - TiTa, TiAu, UNb, TaRu, NbRu, FeMnSi

Magnetic/Ferromagnetic
- NiMnGa, FePd, NiMnAl,
  - FePt, Dy, Tb, LaSrCuO, ReCu, NiMnIn, CoNiGa

Ceramics
- ZrO2 (PSZ), MgO, CeO2, PLZT, PNZST

Polymers
- PTFE, PU, Poly-caprolactone, EVA + nitrile rubber, PE, Poly-cyclooctene, PCO–CPE blend
  - PCL–BA copolymer, Poly(ODVE)-co-BA, EVA + CSM, PMMA, Copolyesters, PET-PEG

Others
- Thin films, hybrids…
Development of Shape Memory Alloys:
High Temperature Shape Memory Alloys (HTSMAs)

Ma et al. (2010)
Development of Shape Memory Alloys: 

**NiTi –Based HTSMAs**

![NiTiHf Graph](image)
Development of Shape Memory Alloys: HTSMAs Summary
Materials – High and Low Temperature SMA

Low Temperature SMAs
- NiTi
- NiTiFe
- NiTiCo/Cr
- NiTiCu
- NiTiHf/Zr

High Temperature SMAs
- NiTiHf
- NiTiZr
- NiTiPd
- NiTiPt
- NiTiAu
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How to make the material/actuator stable?

- Solution 1: Thermomechanical “training” (e.g., cycling, reverse loading…)
- Solution 2: Alloying and microstructural control (e.g., precipitation hardening, grain refinement)
Thermomechanical Testing

Uniaxial (tension/compression)

- Isothermal monotonic
- Isothermal cyclic
- Isostrain cyclic
- Isobaric cyclic

Geometries

- Proportional/non-proportional loading
- 3D strain measurement
- Torque/force/twist/displacement control capability

Multiaxial

- Torsion

Control mode: torque/load

(a) Control mode: torque/load
(b) Isostrain cyclic

Hot grip testing
Thermomechanical Testing
Microstructural Control towards Stability

Electron diffraction

In situ diffraction

Outcome

55NiTi

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Development of Shape Memory Alloys: How about Durability/Fatigue?

- Loss of actuation strain
- Shifts in transformation characteristics (Hysteresis, temperatures…)

![Graph showing temperature vs. strain for cooling and heating cycles.](image)

![Graph showing true strain vs. temperature for multiple cycles.](image)
Durability Assessment Underway…

Data exists up to 1000’s of cycles, how about 1M cycles? Currently collecting durability data on NiTiHf tubes
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Processing and Workability of HTSMAs

NiTiPt

Induction Melt + Homogenization

Extrusion

Multiple-Pass Extrusion
60 mil NiTi-20Pt rod

Wire Grinding
44 & 5 mil NiTiPt

Wire Drawing
5 mil NiTiPt wire
Processing and Workability of HTSMAs

**NiTiHf**

High temperature extrusion proved to be problematic (C. Wojcik 2008)

Successful hot rolled button (C. Wojcik 2008)

Successful hot extrusion (rods and tubes)
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Certification and Test Standards

ASTM Standards for biomedical and or superelastic

• F2004-05
• F2005-05
• F2063-05
• F2082-06
• F2516-07
• F2633-07

ASTM Standards for SMA Actuation

• None
Certification and Test Standards

ASTM Standards for biomedical and or superelastic
- F2004-05
- F2005-05
- F2063-05
- F2082-06
- F2516-07
- F2633-07

ASTM Standards for SMA Actuation
- None

Deliver the first ever regulatory agency-accepted material specification and test standards for shape memory alloys as employed as actuators for commercial and military aviation applications
Promoting Growth of SMA Technologies....
Applications of SMAs
Some SMA Components
Shape Memory Alloy Applications

**Space**

**SMA Bellows**
- Dynamic sealing
- Fluid handling
- Flexibility (structure alignment)

**SMA Spring Tire**
- Superelastic technology
- Lunar rovers
- Terrestrial tires

**SMA Docking Coupling**
- Cryogenic transfer coupling
- Orbital propellant depots
- Propellant handling/protection

**SMA Thermal Switch**
- Thermal management
- Clean & spark-free operation
- Passive or active control

**SMA Bearings**
- Corrosion resistant
- Non-galling properties
- High yield

**SMA rock splitters**

**RXN**
Shape Memory Alloy Applications

Aeronautics

Adaptive Fan Blade
- Embedded SMA actuators
- Aerodynamic efficiency
- Specific fuel consumption reduction

SMA Cellular Structures
- Airframe and engine components
- Morphing airfoils
- Light weight trusses

The Mars Atmosphere and Volatile Evolution (MAVEN) mission.
- SMA Pinpullers (From TiNi Aerospace) were used to secure and release deployables

Variable Area Nozzle
- High bypass turbofan
- SMA torque tubes provide flap rotation
- Engine noise reduction
Thank You