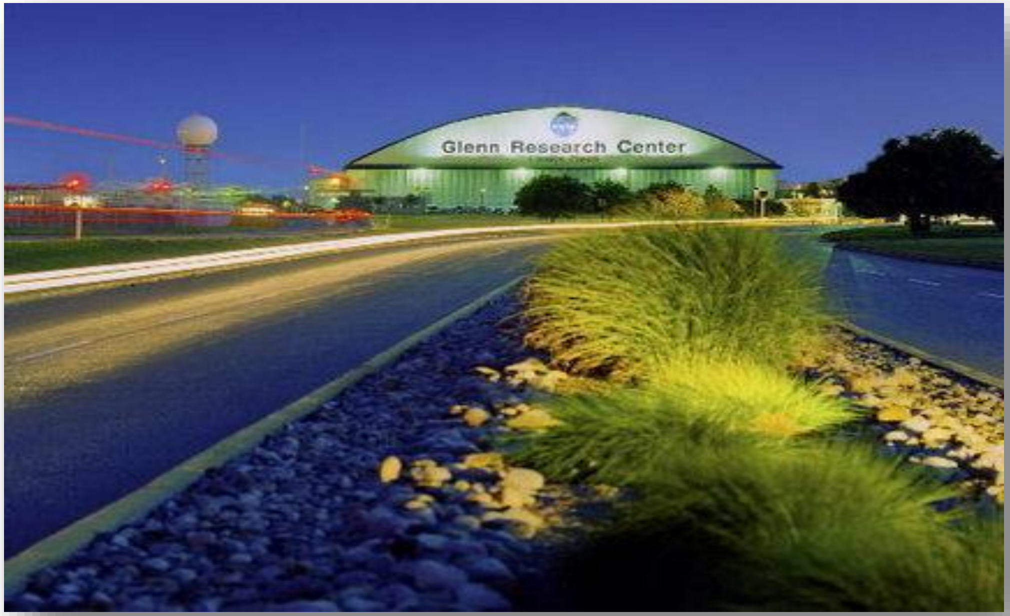
A Decade of SMA Activities at NASA-GRC, Material Challenges, and Future Prospects



Othmane Benafan– NASA Glenn
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…

The University of Akron
- Constitutive modeling

Colorado School of Mines
- Superelastic/bearing alloys
- Lattice deformation theory

University of Central Florida
- Neutron/synchrotron diffraction
- HTSMAs characterization

Texas A&M University
- Alloy development
- Mechanical Characterization

University of Kentucky
- Single crystals
- SMA machining

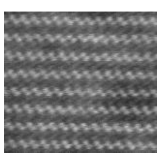
The Ohio State University
- HTSMA Microstructure
- Modeling

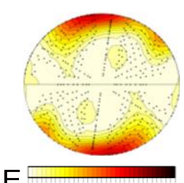
The University of Alabama
- Atom probes
- Microstructure

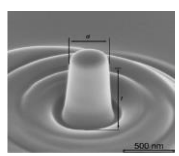
TEES AVSI Aerospace Vehicle Systems Institute, Texas A&M Engineering Experiment Station

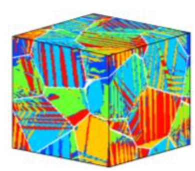
NASA

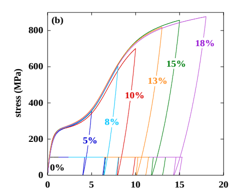
CASMART — Consortium for the Advancement of Shape Memory Alloy Research and Technology — Government, Academia, Industry

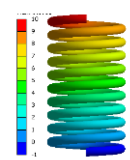












ATOMIC SCALE (NANOMATERIALS) — MICRO-SCALE (MICROSTRUCTURES) — STRUCTURAL SCALE (COMPONENTS)

10^{-10} Å — 10^{-9} nm — 10^{-8} — 10^{-7} — 10^{-6} µm — 10^{-5} — 10^{-4} — 10^{-3} mm — 10^{-2} — 10^{-1} — 10^{0} m

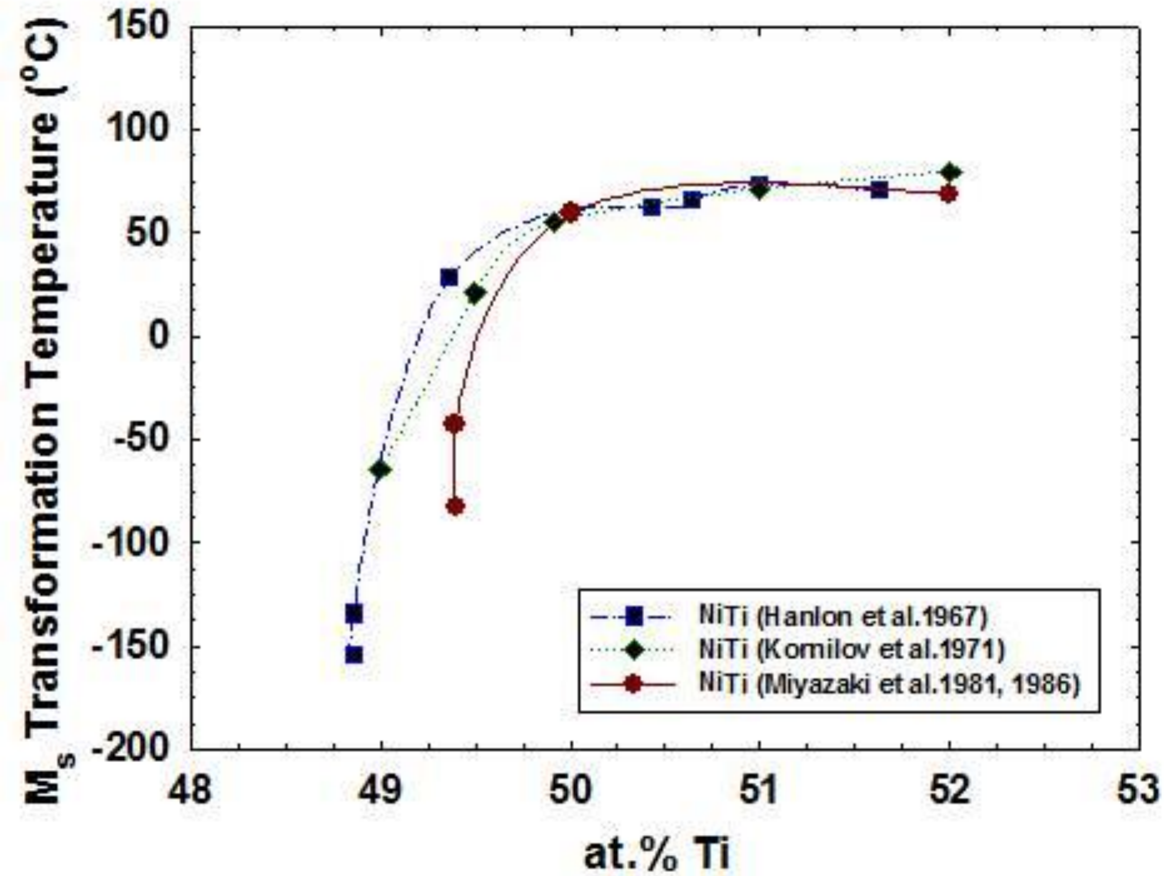
NASA SMA Team

- **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 though 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

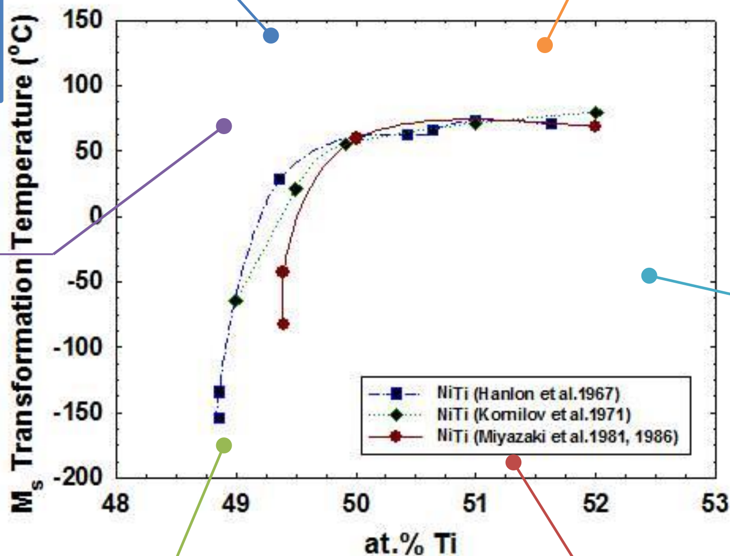


Development of Shape Memory Alloys: Challenges and Lessons Learned

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

Dimensional stability
- Cyclic stability
- Stress-strain relationship

Certification
- Testing standards
- Material certification
- Database

55 Years after Nitinol Discovery

Metals

NiTi, NiTiFe, NiTiNb, NiTiCu, NiTiPd, NiFeGa, NiTiCo CuZn, CuZnAl, CuAlNi, CuAlNiMn, CuSn FePt, FeMnSi, FeNiC

AgCd
AuCd
CoNiAl

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

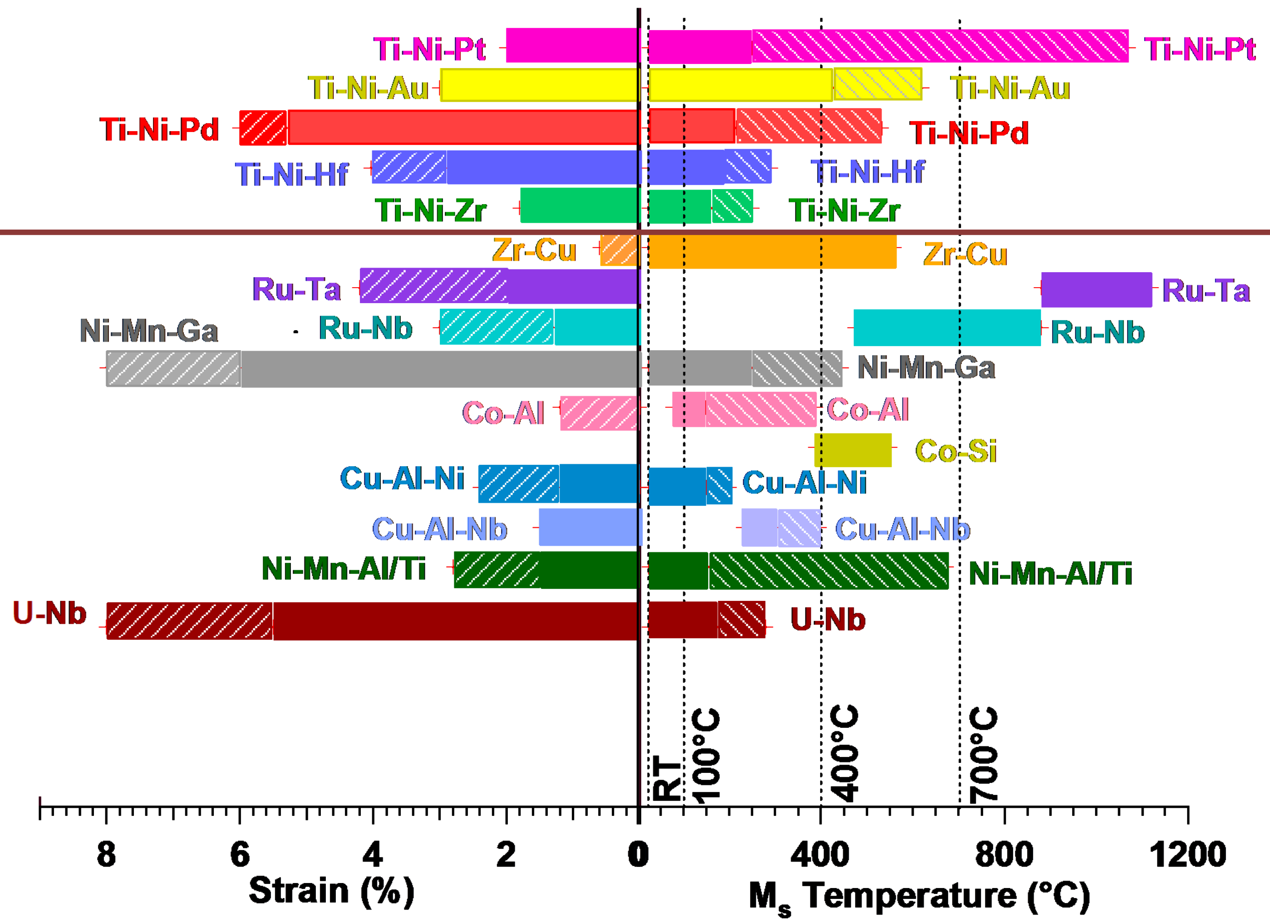
PCL–BA copolymer, Poly(ODVE)-co-BA, EVA + CSM, PMMA, Copolyesters, PET-PEG

Others

Thin films, hybrids…

Development of Shape Memory Alloys:

High Temperature Shape Memory Alloys (HTSMAs)

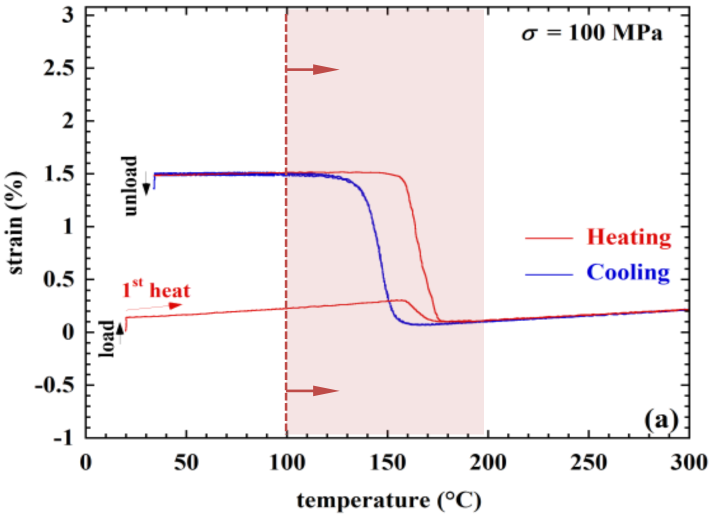


Ma et al. (2010)

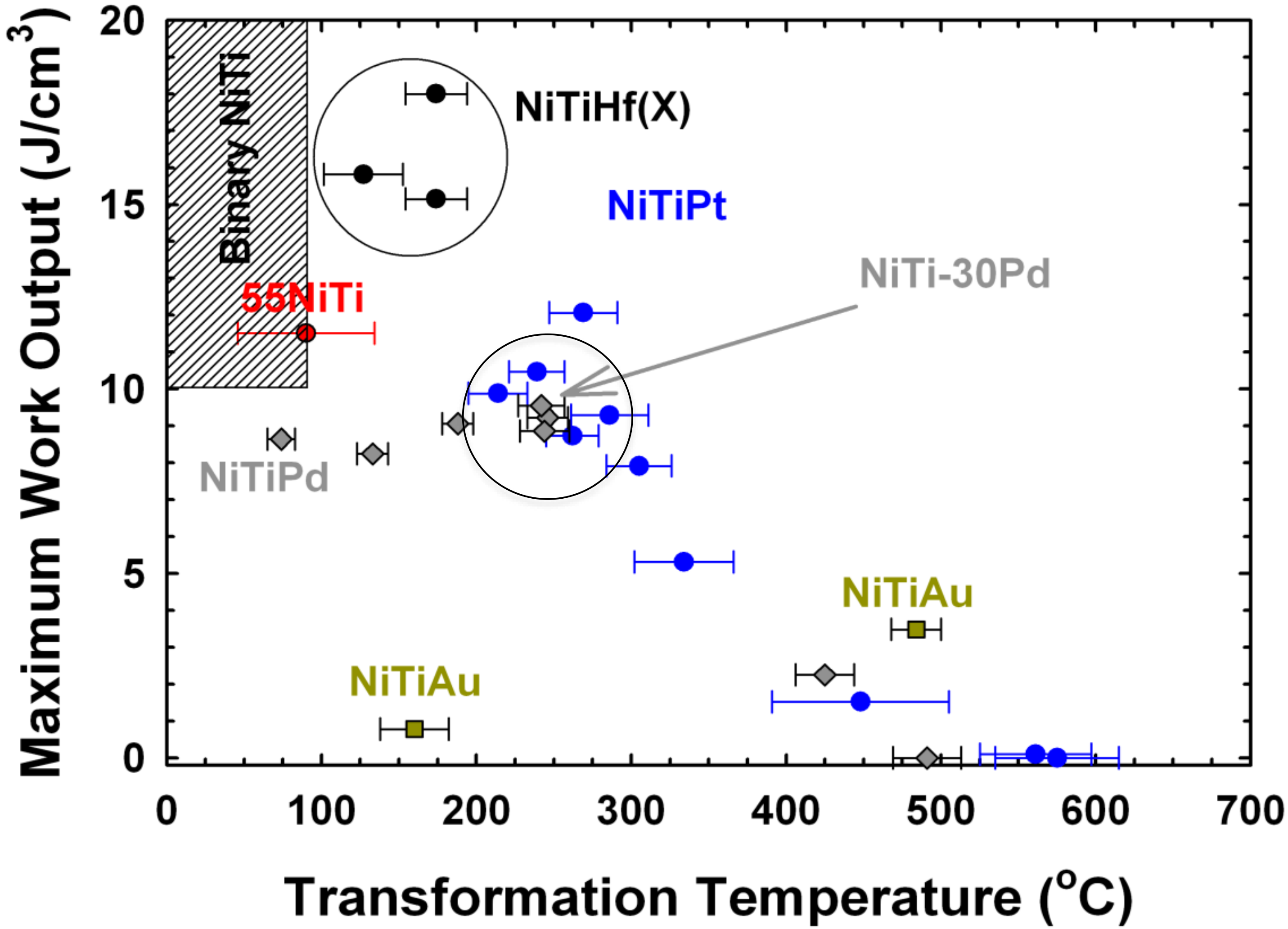
Development of Shape Memory Alloys:

NiTi –Based HTSMAs

NiTiHf

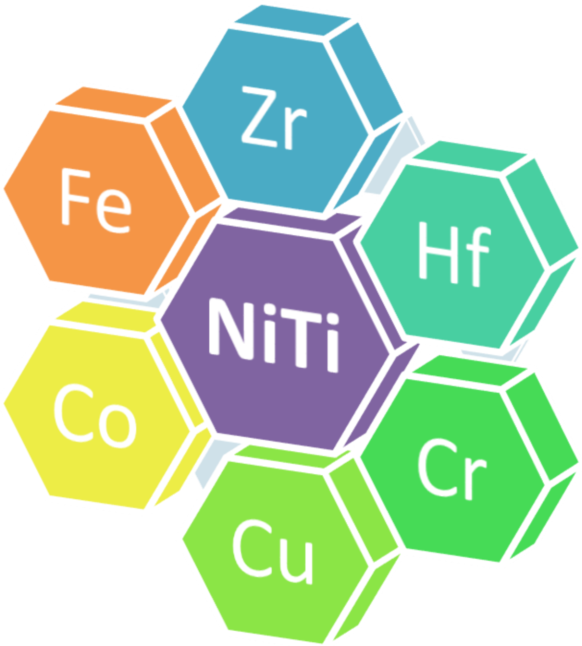


Development of Shape Memory Alloys: HTSMAs Summary



Materials – High and Low Temperature SMA

Cold — **0 °C** — **Hot**



Low Temperature SMAs

- NiTi
- NiTiFe
- NiTiCo/Cr
- NiTiCu
- NiTiHf/Zr

High Temperature SMAs

- NiTiHf
- NiTiZr
- NiTiPd
- NiTiPt
- NiTiAu

Development of Shape Memory Alloys: Challenges and Lessons Learned

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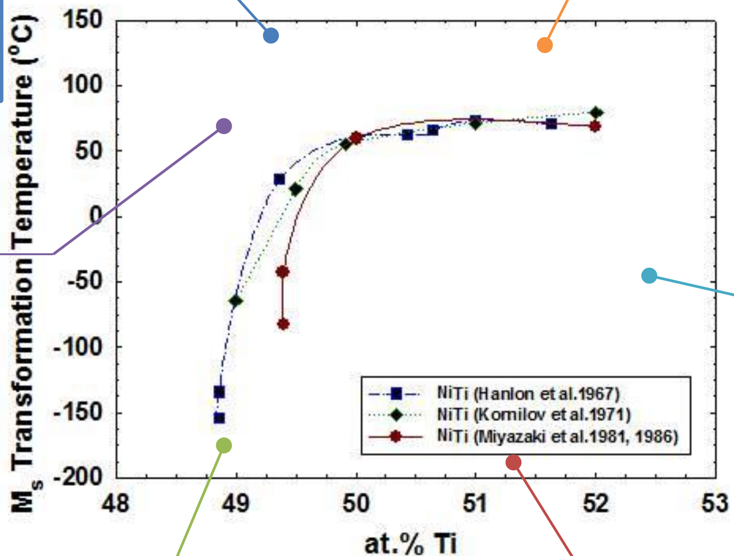

Modeling
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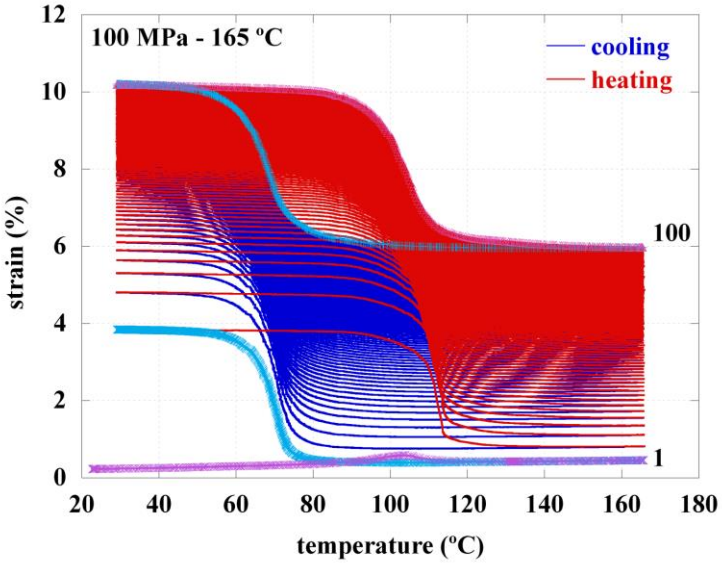
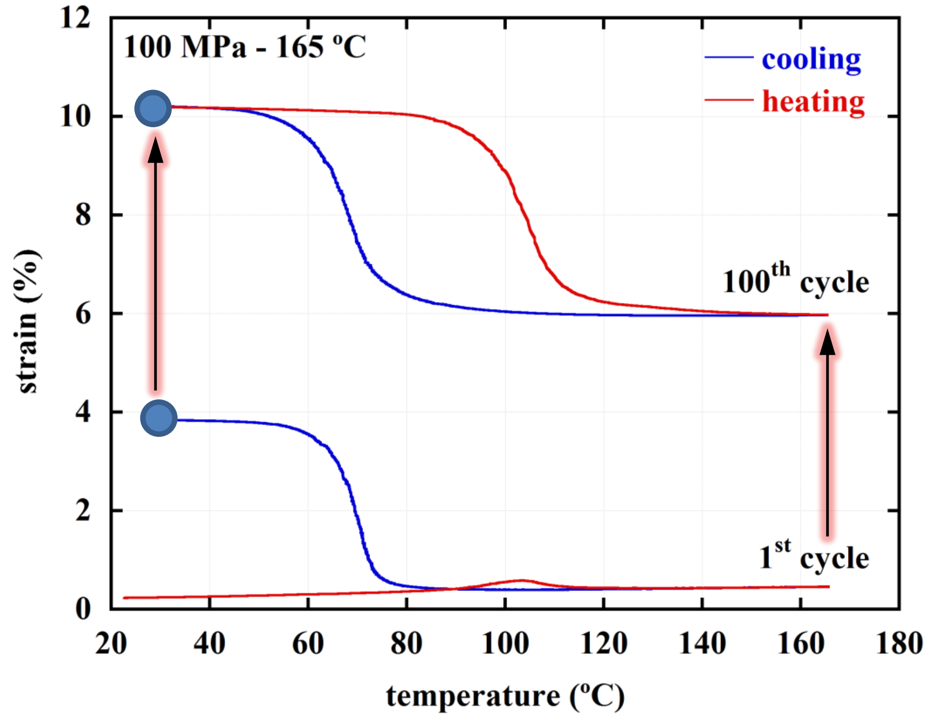
Development of Shape Memory Alloys:

How about Dimensional Stability?





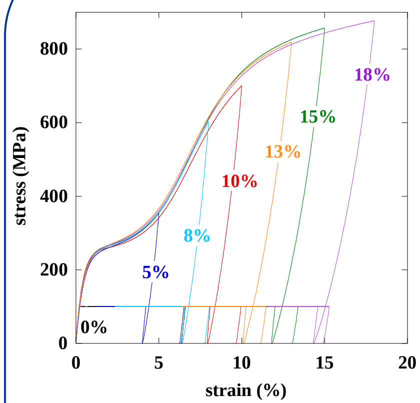
How to make the material/actuator stable?

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

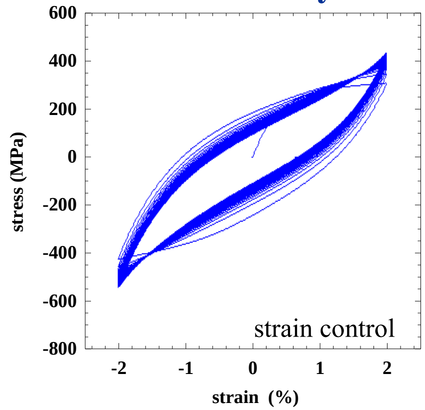
Thermomechanical Testing

Uniaxial (tension/compression)

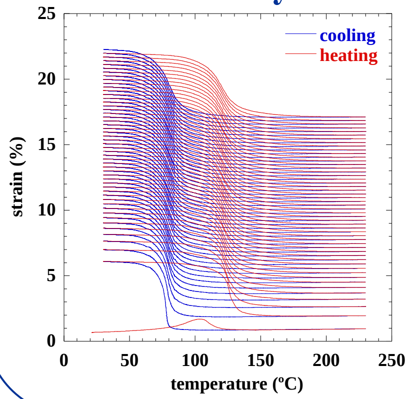
Isothermal monotonic



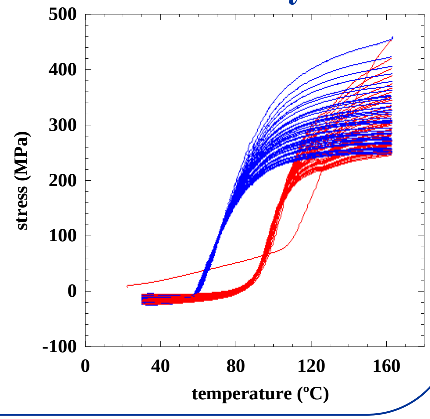
Isothermal cyclic



Isobaric cyclic



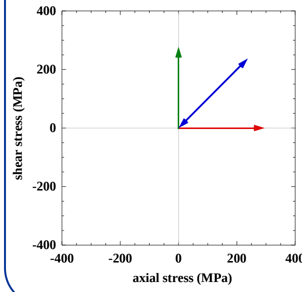
Isostrain cyclic

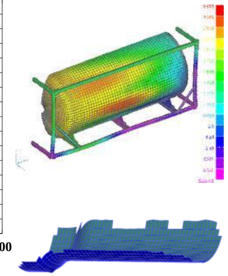


Geometries

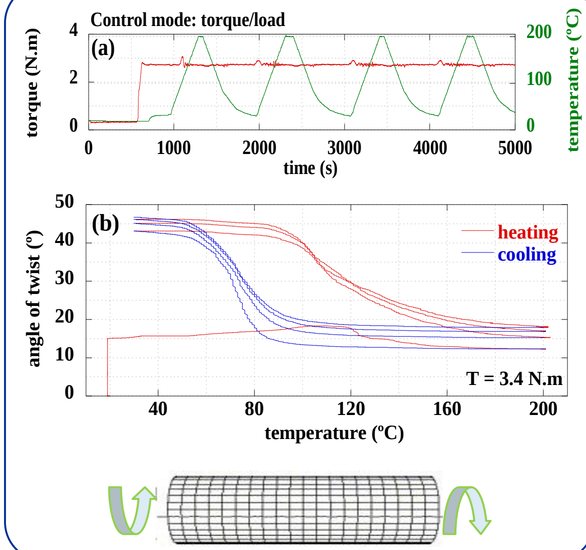
Multiaxial

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

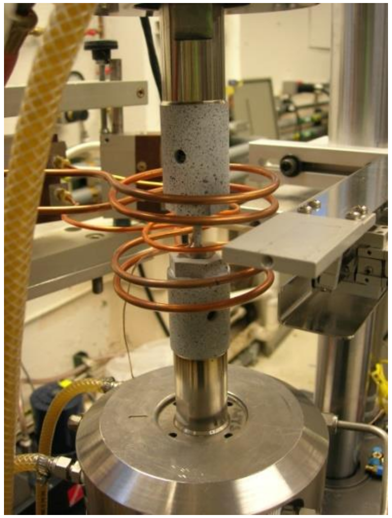




Torsion



Hot grip testing

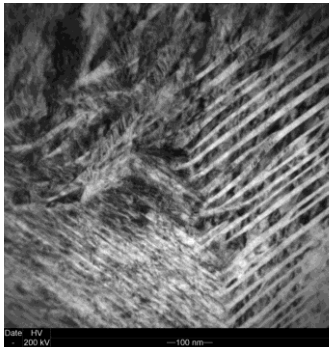


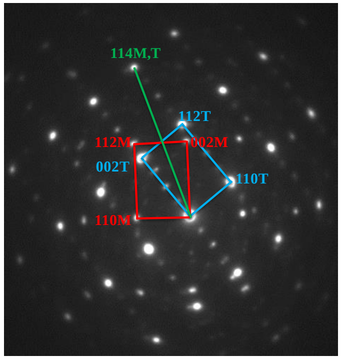
Thermomechanical Testing

Microstructural Control towards Stability

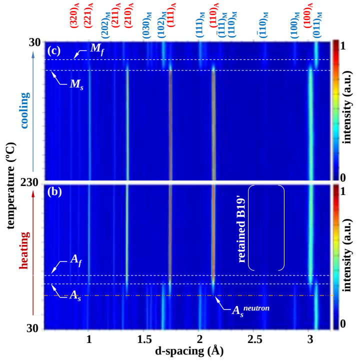
Electron diffraction

55NiTi

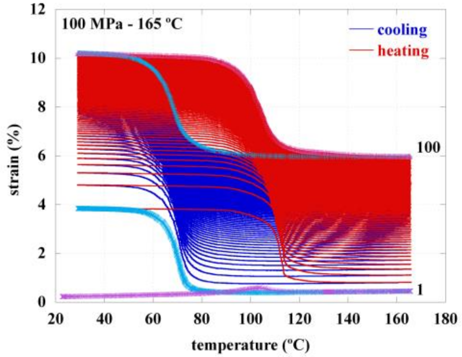




In situ diffraction



Outcome



Development of Shape Memory Alloys: Challenges and Lessons Learned

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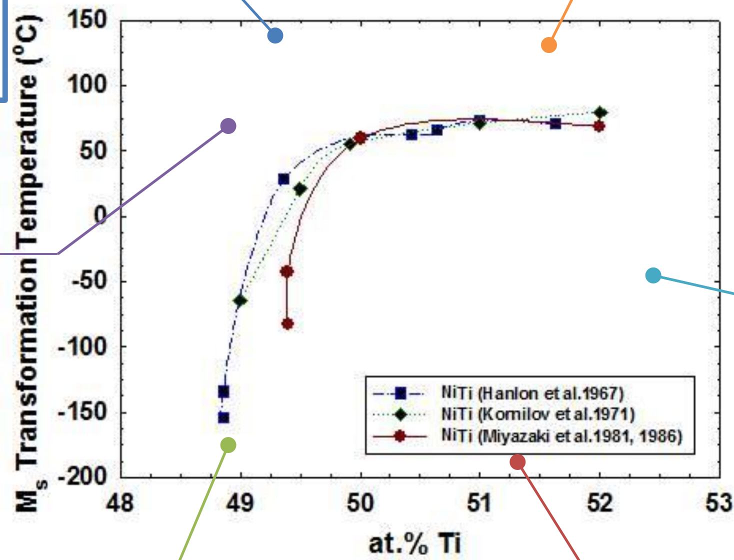

Workability/Processing
- Ductility
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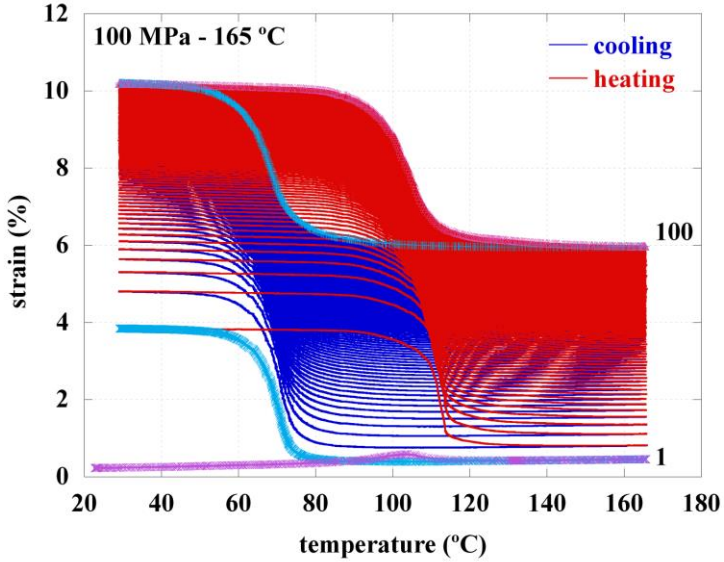
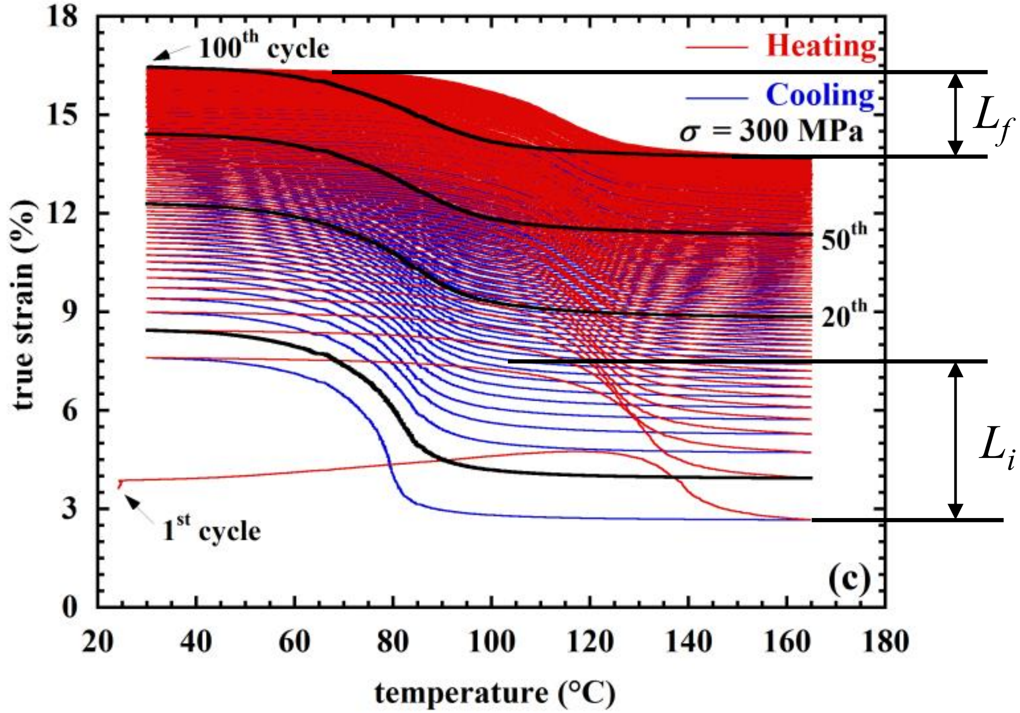
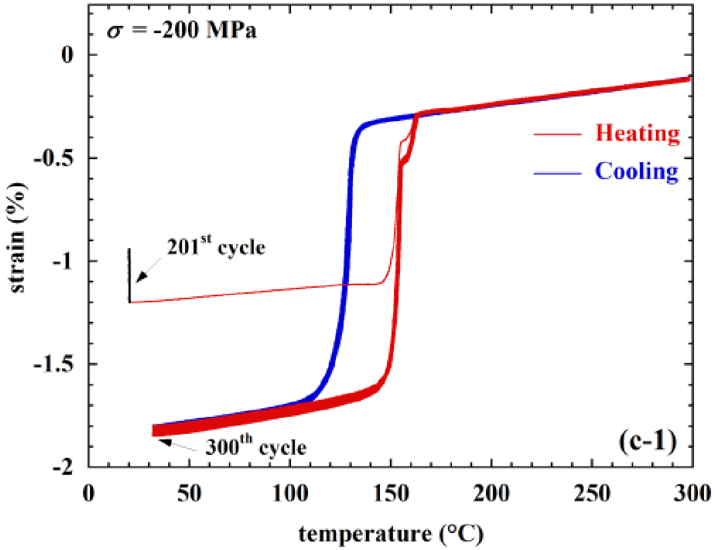
Development of Shape Memory Alloys:
How about Durability/Fatigue?



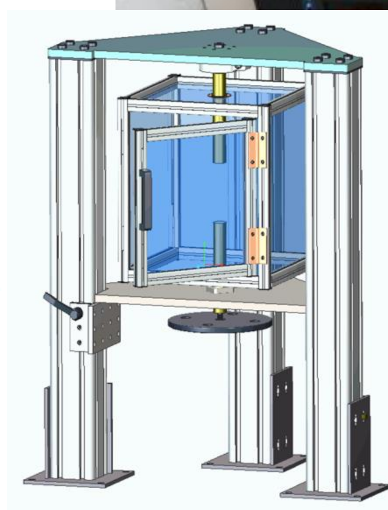


- Loss of actuation strain
- Shifts in transformation characteristics (Hysteresis, temperatures…)

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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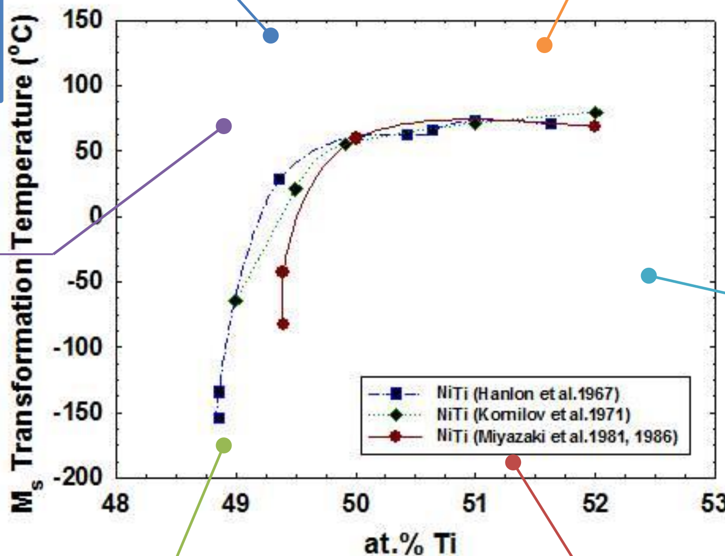

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Processing and Workability of HTSMAs

NiTiPt

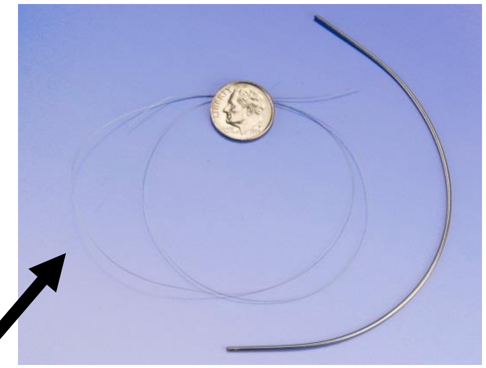
Induction Melt + Homogenization

Extrusion

Multiple-Pass Extrusion

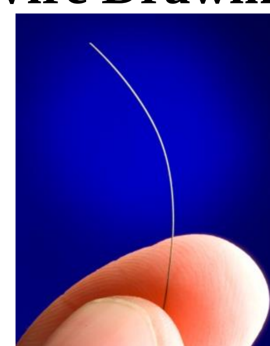
60 mil NiTi-20Pt rod

Wire Grinding



44 & 5 mil NiTiPt

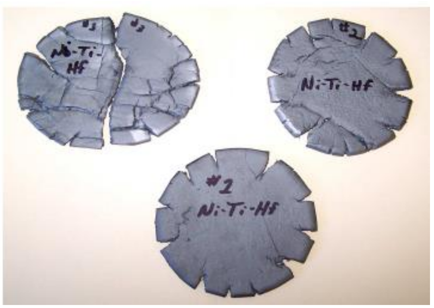
Wire Drawing



5 mil NiTiPt wire

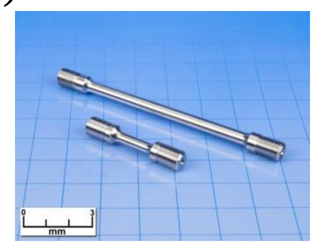
Processing and Workability of HTSMAs

NiTiHf



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

Successful hot rolled button (C. Wojcik 2008)



Successful hot extrusion (rods and tubes)

Development of Shape Memory Alloys: Challenges and Lessons Learned

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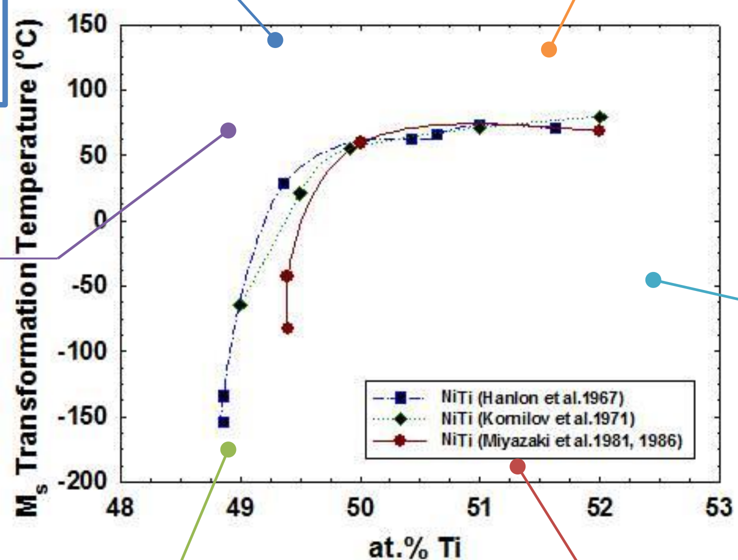

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Certification and Test Standards

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….

CONSORTIUM FOR THE ADVANCEMENT OF SHAPE MEMORY ALLOY RESEARCH AND TECHNOLOGY

CASMART

Government Academia Industry

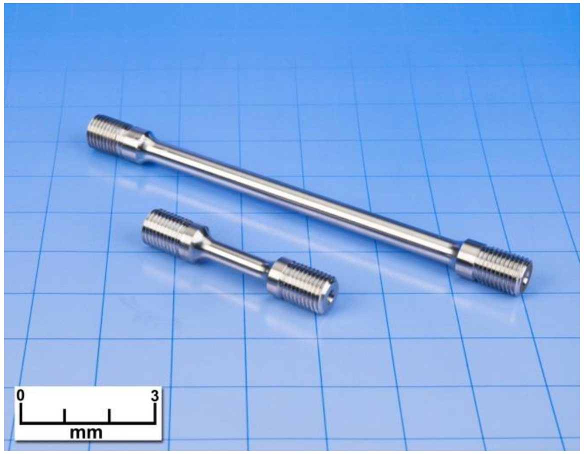
Texas A&M University
COLORADO SCHOOL OF MINES EARTH • ENERGY • ENVIRONMENT
UNIVERSITÄT DES SAARLANDES
NORTHWESTERN UNIVERSITY 1851
MICHIGAN STATE UNIVERSITY
University of Central Florida
UNIVERSITY of NORTH TEXAS

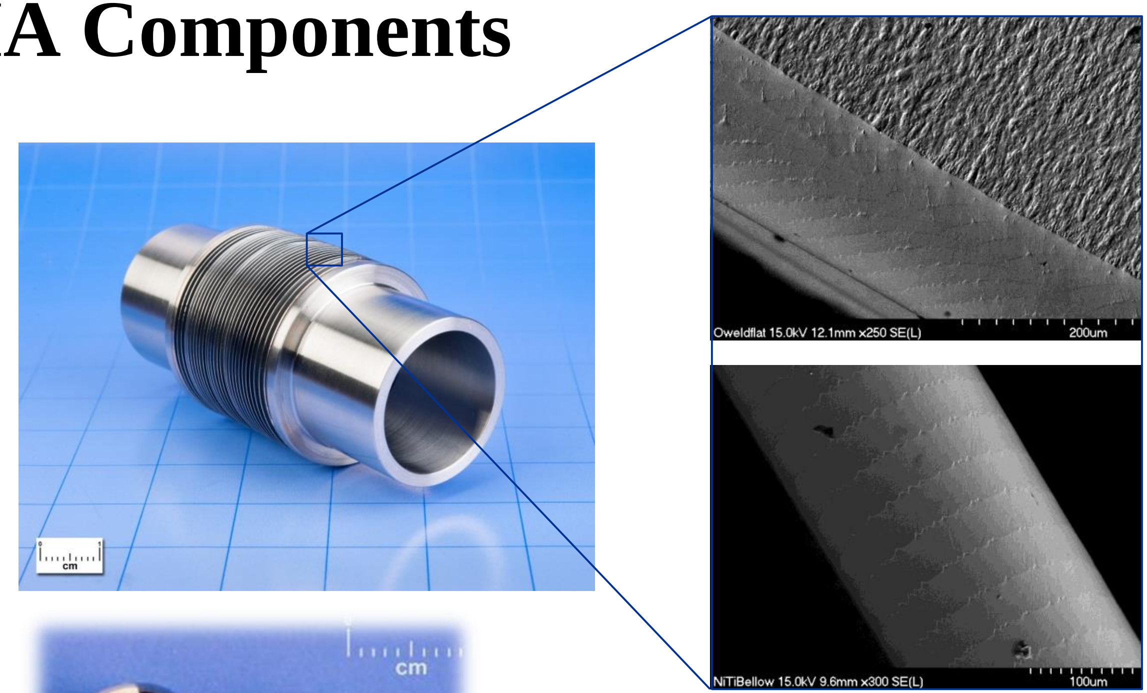
ATI Wah Chang
DYNALLOY, Inc. Makers of Dynamic Alloys
FORT WAYNE METALS Turning knowledge into solutions.
JM Johnson Matthey

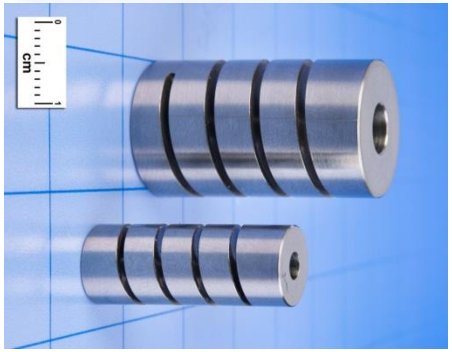
NASA
Sandia National Laboratories
GM
BOEING
Rolls-Royce

Applications of SMAs

Some SMA Components

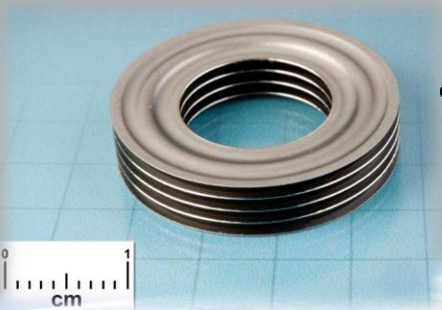






Shape Memory Alloy Applications

Space

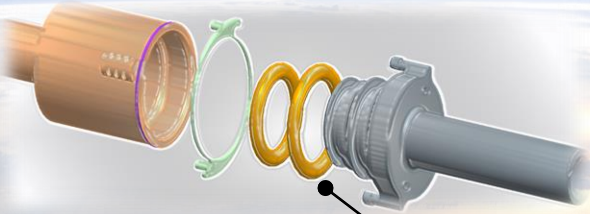


SMA Bellows

- Dynamic sealing
- Fluid handling
- Flexibility (structure alignment)

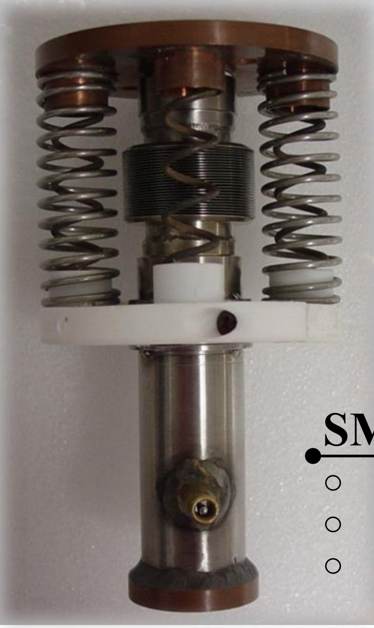
SMA Spring Tire

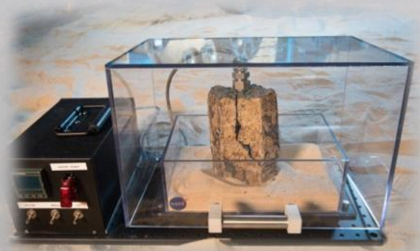
- Superelastic technology
- Lunar rovers
- Terrestrial tires



SMA Docking Coupling

- Cryogenic transfer coupling
- Orbital propellant depots
- Propellant handling/protection





SMA rock splitters

SMA Thermal Switch

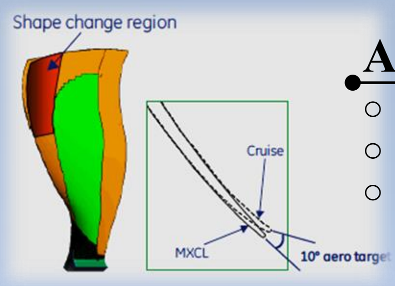
- Thermal management
- Clean & spark-free operation
- Passive or active control

SMA Bearings

- Corrosion resistant
- Non-galling properties
- High yield

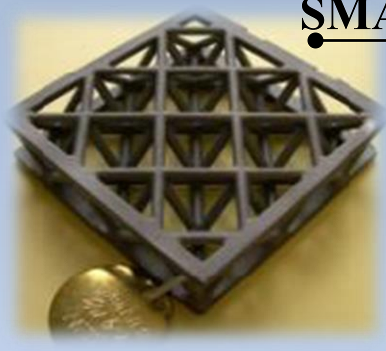
Shape Memory Alloy Applications

Aeronautics



Adaptive Fan Blade

- Embedded SMA actuators
- Aerodynamic efficiency
- Specific fuel consumption reduction

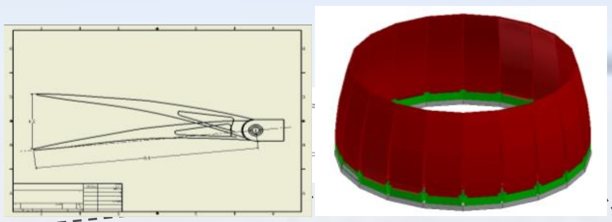


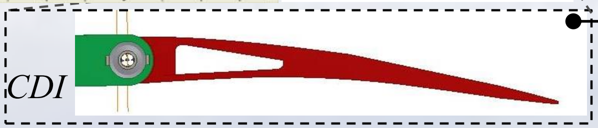
SMA Cellular Structures

- 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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