Precipitation Strengthenable NiTiPd High Temperature Shape Memory Alloys

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Opportunities for SMA Actuators

NiTiPd is expensive
=> Actuators most likely wire based

Can be drawn to fine wire

Shape set to form springs, etc.

Vortex Generator

Access Panel Fasteners

Flow Control

In-Cabin Locks and Fasteners
High temperature shape memory alloys (HTSMAs) formed by alloying with Au, Hf, Pd, Pt, or Zr.

Ni-rich alloys: stability, bandwidth

Tf Temps drop drastically with Ni content for Ni-rich alloys

Compositional control with such precision is difficult

Aging can be used to regain Tf temps.

\( M_s \): Martensite Start, \( M_p \): Martensite Peak

NiTi - F. Sczerzenie, Proc of SMST 2004
Prior State of the Art

Low Temp, Ni-rich, dimensionally stable
Very high ppt volume

Current Alloys

High Temp, Ti-rich, poor dimensional stability

* Need to optimize chemistry and precipitation to achieve high temp (~200ºC) alloy with good work output
Approach

- Produce range of alloys having target Ti contents of 50.5, 49.7, and 49.2 at%
  - Vacuum Induction Melting (VIM) in graphite crucible
- Age samples at various times and temperatures
- Determine microstructure as extruded and aged
- Load biased test in tension in series w/2 cycles per stress (MPa) level:
  - No-load, 50, 100, 200, 300, 400MPa, No-load
- Load biased cycle temperatures:
  - Ext 181: (50.5Ti) 30°C to 400°C
  - Ext 182: (49.7Ti) 30°C to 350°C
  - Ext 183: (49.2Ti) 30°C to 350°C
- Determine effect of aging on actuator type properties

## Compositions and Heat Treats

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<thead>
<tr>
<th>Ext 181</th>
<th>Ext 182</th>
<th>Ext 183</th>
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<tr>
<td><strong>Ti&lt;sub&gt;50.5&lt;/sub&gt;Ni&lt;sub&gt;17.5&lt;/sub&gt;Pd&lt;sub&gt;32&lt;/sub&gt;</strong></td>
<td><strong>Ti&lt;sub&gt;49.7&lt;/sub&gt;Ni&lt;sub&gt;18.3&lt;/sub&gt;Pd&lt;sub&gt;32&lt;/sub&gt;</strong></td>
<td><strong>Ti&lt;sub&gt;49.2&lt;/sub&gt;Ni&lt;sub&gt;18.8&lt;/sub&gt;Pd&lt;sub&gt;32&lt;/sub&gt;</strong></td>
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*Solutionized 1050C/24hr/WQ before aging.*
Microstructure: As Extruded

50.5Ti: No Precipitates

49.7Ti: No Precipitates

49.2Ti: Precipitates (1-3nm)

Microstructure: 50.5Ti

As Extruded

350C/100hr

Ti rich: No Precipitates

Microstructure: 49.7Ti

As-Ext
No Ppts.

400C/24h
Ppts.
Av. Size
~ 400nm

350C/66h
Ppts.
Av. Size
~ 50nm

450C/24h
Ppts.
Av. Size
~ 500nm
Microstructure: 49.2Ti

As-Ext
Ppts.
Av. Size
~ 2nm

350C/66h
Ppts.
Av. Size
~ 60nm

400C/24h
Ppts.
Av. Size
~ 120nm

450C/24h
Ppts.
Av. Size
~ 250nm
Transformation Strain

Work Output

Austenite Start

Austenite Finish

![Graph showing the effect of applied stress on different Ti compositions](http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvMet/research/shape_memory.html)
Optimization of Properties

[Graph showing transformation strain and transformation temperature over aging time at different temperatures for 50.5Ti, 49.7Ti, and 49.2Ti.]

As-Ext

- Ppts.
  - Av. Size
  - ~ 2nm

350°C/66h

- Ppts.
  - Av. Size
  - ~ 60nm

400°C/24h

- Ppts.
  - Av. Size
  - ~ 120nm

450°C/24h

- Ppts.
  - Av. Size
  - ~ 250nm

Microstructure: 49.2Ti

P

P

100nm

50nm

200nm

100nm
49.2Ti Dynamic Creep Overview: Shows Effect of Upper Cycle Temp

350°C/100hr/AC Sample
340°C UCT Training Increases Transformation Temperature

2 No Loads + 30 Training @172MPa

340°C UCT

Sample Temperature (°C)

True Strain (%)
After Training Cycles, Transformation is Stable

After 10 cycles at 172 MPa, the transformation is stable at 340°C UCT.
Ti$_{49.2}$Ni$_{18.8}$Pd$_{32}$ 350°C/100hr

10 Cycles @172MPa

360°C UCT

Ti$_{49.2}$Ni$_{18.8}$Pd$_{32}$ 350°C/100hr

10 Cycles @172MPa

380°C UCT

[Graph showing true strain vs. sample temperature with 10 cycles at 172MPa and a UCT of 380°C]
Precipitates Coarsen/Grow

10 Cycles @172MPa

400°C UCT

Precipitates Grow Faster

10 Cycles @172MPa

420ºC UCT

Precipitates Grow Faster

10 Cycles @172MPa

440°C UCT

Aging Continues To Decrease Transformation Temp

10 Cycles @172MPa

460°C UCT

Dynamic Creep Begins

10 Cycles @172MPa

480°C UCT

10 Cycles @172MPa

500ºC UCT

Dynamic Creep Dominates

10 Cycles @172MPa

520ºC UCT

Higher UCT: Increases Tf Strain, Decreases Stability

Sample is Momentarily at the Upper Cycle Temperature, not Aged There

Ti Rich Material: Tf Temps Don’t Change

http://www.grc.nasa.gov/WWW/StructuresMaterials/AdvancedResearch/shape_memory.html
Conclusions

1. Decreasing Ti content
   1. Increases second phase content
   2. Decreases Tf Temp
   3. Decreases Work Output
   4. Improves Dimensional Stability

2. Aging Time/Temp Effects:
   1. Low Temp
      Small ppts – increase Tf Temp, decrease Tf Strain
   2. High Temp
      Large ppts – decrease Tf Temp, increase Tf Strain

3. Optimum Transformation Strain & Temp
   1. Low Temp (350ºC) aging for short times
   2. Moderate Temp (400ºC) aging for longer times
      1. Higher Unrecovered Strain