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

Compositional Control is IMPORTANT!!!
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>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;</td>
<td>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;</td>
<td>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;</td>
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<td>As Extruded</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.

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

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

450C/24h
Ppts.
Av. Size
~ 500nm

200nm
50nm
200nm
50nm
500nm
200nm
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 Finish

Unrecovered Strain

Optimization of Properties

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

340°C UCT Training Increases Transformation Temperature

After Training Cycles, Transformation is Stable


10 Cycles @172MPa

340°C UCT

Sample Temperature (°C)

True Strain (%)
$\text{Ti}_{49.2}\text{Ni}_{18.8}\text{Pd}_{32}$ 350C/100hr

10 Cycles @172MPa

360ºC UCT

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

10 Cycles @172MPa

380°C UCT

Precipitates Coarsen/Grow

10 Cycles @ 172 MPa

400°C UCT

Precipitates Grow Faster

10 Cycles @172MPa

420°C UCT

Precipitates Grow Faster

10 Cycles @172MPa

440°C UCT

Aging Continues To Decrease Transformation Temp

10 Cycles @172MPa

460ºC UCT

Sample Temperature (°C)

True Strain(%)
Dynamic Creep Begins

10 Cycles @172MPa

480°C UCT

Dynamic Creep Dominates

10 Cycles @172MPa

500°C UCT

Dynamic Creep Dominates


10 Cycles @172MPa

520°C UCT
Higher UCT: Increases Tf Strain, Decreases Stability

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

Dynamic Creep
Precipitate Coarsening

Ti Rich Material: Tf Temps Don’t Change

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