Characterization of a New Phase and Its Effect on the Work Characteristics of a Near-Stoichiometric Ni\textsubscript{30}Pt\textsubscript{20}Ti\textsubscript{50} High-Temperature Shape Memory Alloy (HTSMA)

A new phase observed in a nominal Ni\textsubscript{30}Pt\textsubscript{20}Ti\textsubscript{50} (at.\%) high temperature shape memory alloy has been characterized using transmission electron microscopy and 3-D atom probe tomography. This phase forms homogenously in the B2 austenite matrix by a nucleation and growth mechanism and results in a concomitant increase in the martensitic transformation temperature of the base alloy. Although the structure of this phase typically contains a high density of faults making characterization difficult, it appears to be trigonal (-3m point group) with $a_0\sim1.28$ nm and $c_0\sim1.4$ nm. Precipitation of this phase increases the microhardness of the alloy substantially over that of the solution treated and quenched single-phase material. The effect of precipitation strengthening on the work characteristics of the alloy has been explored through load-biased strain-temperature testing in the solution-treated condition and after aging at 500 °C for times ranging from 1 to 256 hours. Work output was found to increase in the aged alloy as a result of an increase in transformation strain, but was not very sensitive to aging time. The amount of permanent deformation that occurred during thermal cycling under load was small but increased with increasing aging time and stress. Nevertheless, the dimensional stability of the alloy at short aging times (1-4 hours) was still very good making it a potentially useful material for high-temperature actuator applications. (Support by the NASA Fundamental Aeronautics Program, Supersonics Project and the analytical facilities at the Center for Advanced Research and Technology at the University of North Texas are gratefully acknowledged.)
Characterization of a New Phase and its Effect on the Work Characteristics of a Near-Stoichiometric Ni$_{30}$Pt$_{20}$Ti$_{50}$ (at.%) High-Temperature Shape Memory Alloy (HTSMA)

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High-Temperature Shape Memory Alloys are an enabling technology to a host of “smart” structures in jet engines

**Advantages of HTSMA**

- High force per volume/weight - compact, lightweight
- Solid State - eliminates hydraulics, pneumatics, mechanical systems simple, frictionless, quiet, maintenance free
- Passive control - eliminates sensors, electronics
- Can be actively controlled for high-force, precision movements
Effect of Pt on Transformation Temperatures

Work Behavior of HTSMA

10 J/cm³ is equivalent to a 44 mil rod, 25” long, lifting a 110 lb weight 0.5”

4 J/cm³ is equivalent to a 44 mil rod, 25” long, lifting a 44 lb weight 0.5”

Introduction
Experimental

- Alloys vacuum induction melted in graphite crucibles.
- Ingots homogenized and then canned and extruded.
- Compositional analysis (at.%) – 30.09Ni-19.33Pt-49.76Ti-0.46C-0.29O-0.03N-0.01Cu-0.03Fe.
- Thermal analysis (DSC/DTA)
- Microstructural Analysis (SEM, TEM, 3DAP, HAADF, HRTEM)
- Mechanical properties (hardness, load biased thermal cycling tests, etc).
**Microstructure:** Alloy aged at 500°C/1024h

**SEM**
- Fine ~0.5μm phase P (black)

**TEM**
- Fine Phase (P) in a martensite matrix (M)
DTA Scan: Ext. 13 sample annealed 500°C/1024h

- The low temperature peaks (A,A’) are due to the austenite-to-martensite and the reverse transformation.
- The higher temperature peaks (B,B’) are likely due to the fine phase P.
- Quenching from 800°C results in elimination of the fine phase P.
SADP of Fine Phase:

Zone A
[11-20] \text{trigonal} // [110] \text{cubic}
\[0001]/[111]
AC \sim 6.0 \text{A}

Zone B
[110] \text{cubic}
AC \sim 5.4 \text{A}

Zone C
[112] \text{cubic}
AC \sim 6.4 \text{A}

Zone D
[001] \text{cubic}
AC \sim 4.0 \text{A}

Zone E
<111> \text{cubic}

Zone F
<112> \text{cubic}

Zone G
<110> \text{cubic}

Structure appears to be Trigonal (\text{3m})
**HAADF Imaging** of the precipitates – contrast proportional to $Z^2$
($Z_{Pt}=78$, $Z_{Ni}=28$, $Z_{Ti}=22$)

- Observation of precipitate in the “cubic” [110] orientation.
- HAADF contrast dominated by dumbbell-like motif represents two closely positioned Pt rich columns.
- 2D projection has oblique symmetry $a \sim 3.7\text{Å}$, $b \sim 6.9\text{Å}$, $\gamma \sim 100^\circ$.
- Fourier transform consistent with diffraction pattern $G$, [110]cubic.
Hypothesis: Fine Phase P is

- Trigonal based on a B2 crystal structure where Ni and Pt substitute each other on the Ni sub-lattice.
- In addition, there is an ordering of Pt on the Ni sub-lattice of B2 structure.
3D Atom Probe Analysis:
Fine phase is rich in Ni and slightly depleted in Pt

Alloy Soln. Treated 800°C/30min + WQ + Aged 500°C/(0-1024h)

Transformation Temperatures

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Load Biased Thermal Cycling in Compression to Determine Shape Memory Response Under Load (For Actuator Type Applications)

- Definition of properties determined from load-biased thermal cycling under a constant load.

- Indicated for each curve is the Applied stress level and the equivalent work output ( = transformation strain x applied stress).
Transformation Strain vs. Stress after Aging for Various Times at 500 °C

- Aging increases the amount of transformation strain.
Work output (proportional to transformation strain) increases with increasing stress and is independent of aging time.
Permanent Deformation vs. Stress after Aging for Various Times at 500°C

- Aging at times longer than 4 hr causes an increase in the amount of dimensional instability (equivalent to permanent deformation) that occurs with each load-biased thermal cycle.
A new phase has been identified in a Ni$_{30}$Pt$_{20}$Ti$_{50}$ alloy. The new phase is Ni rich and slightly Pt lean (lower Z contrast). The crystal structure appears to be Trigonal (3m). Atom positions are based on the B2 structure but with ordering of Pt on Ni sites. Aging increases the transformation temperatures for the material—Enhancing the optimum use temperature of the material. Aging also results in an increase in the transformation strain, and hence work performed at a given stress level, compared to the precipitate-free material. Unfortunately, aging does increase the amount of permanent deformation that occurs at a given stress level, however the effect is minimal at aging times of 1-4 hrs.

For use in high-temperature actuator applications or adaptive structures – the optimum condition for the Ni$_{30}$Pt$_{20}$Ti$_{50}$ (at.%) alloy is a solution treatment and water quench followed by aging 1-4 hrs at 500 °C.