Review

Thermomechanical fatigue of Boeing 60-NiTi

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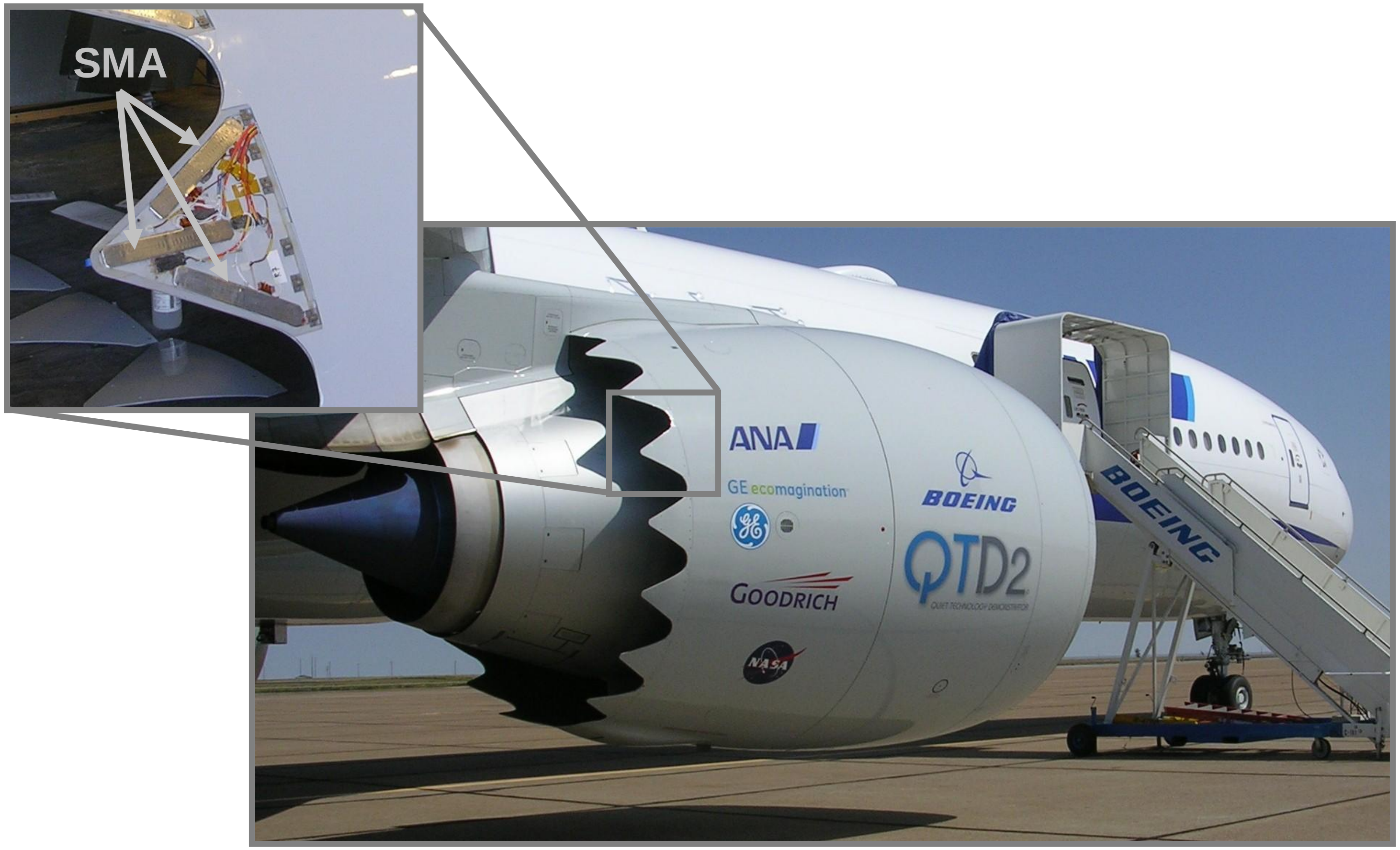
Fatigue in Aircraft

Fatigue behavior evaluation of SMA bending components in opposition to elastic composite structure of complex geometry



Fatigue in Aircraft

- Fatigue failure corresponds to approximately 80 percent of failures of components during a service life

- Boeing flight cycles design limits usually between 20000 and 75000 cycles

- Localization of fatigue: weak section, high loads, large strains

- How does the FAA set fatigue criteria? Any safety factor?

- How is fatigue assessed? Is crack propagation accepted and monitored?

Thermomechanical fatigue characterization

- In the context of the future application of the Variable Geometry Chevrons, the thermomechanical fatigue behavior of the SMA beams providing actuation to the chevrons has to be addressed.

- Identification of the loading conditions of the SMA components led to the definition of a series of uniaxial isobaric thermally induced fatigue tests.

Experimental Setup (1)

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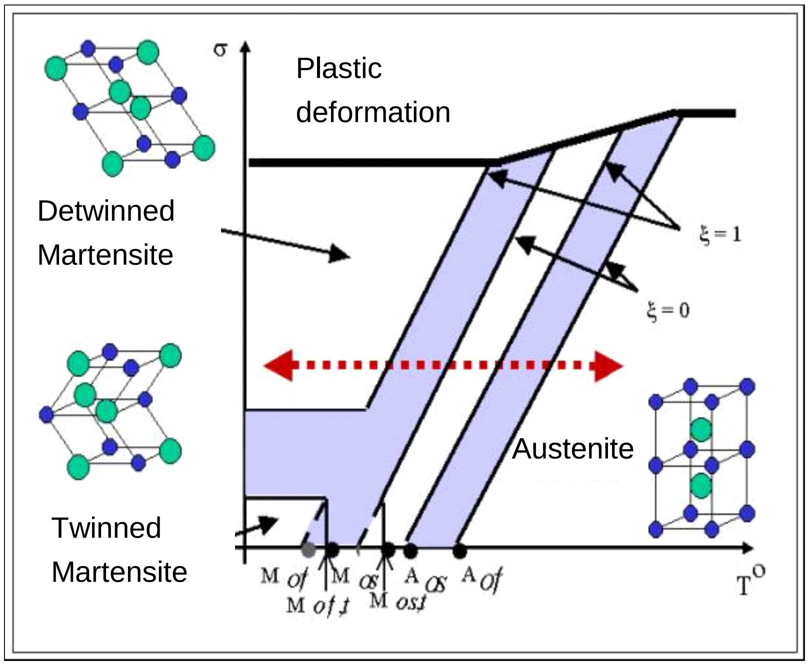
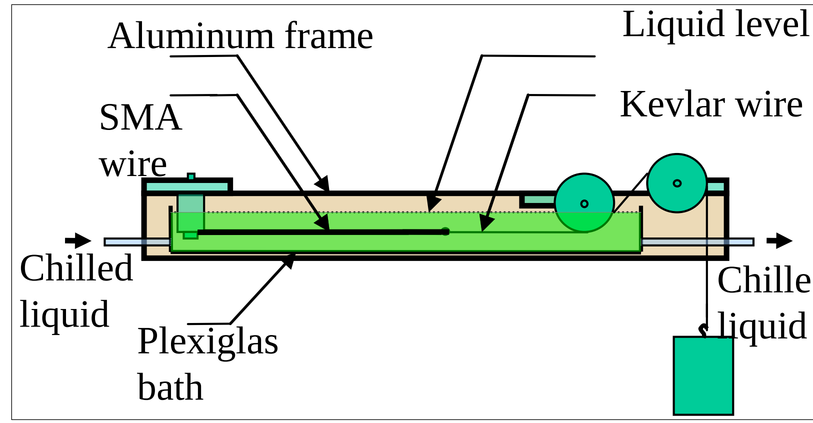
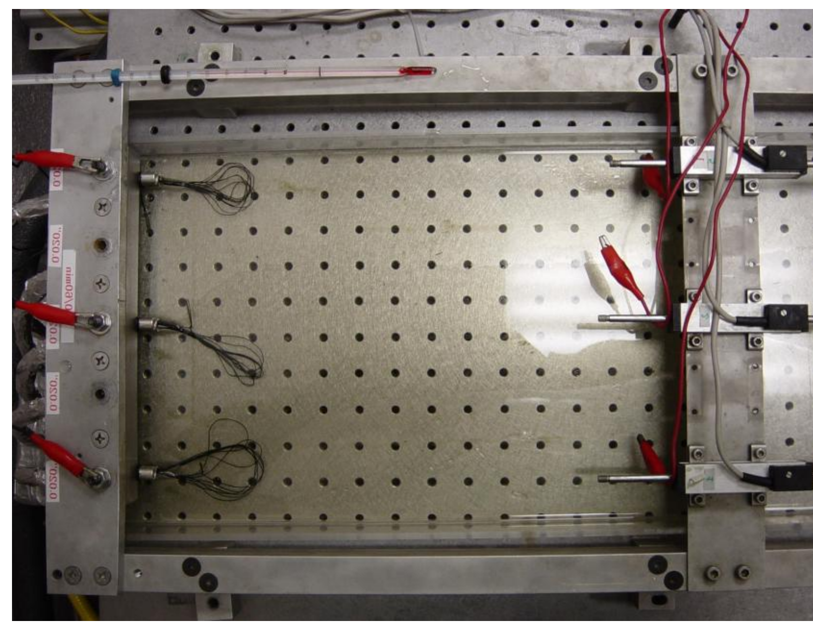
Experimental Setup (2)

Texas A&M University

Uniaxial isobaric fatigue testing for SMA actuators under constant applied load



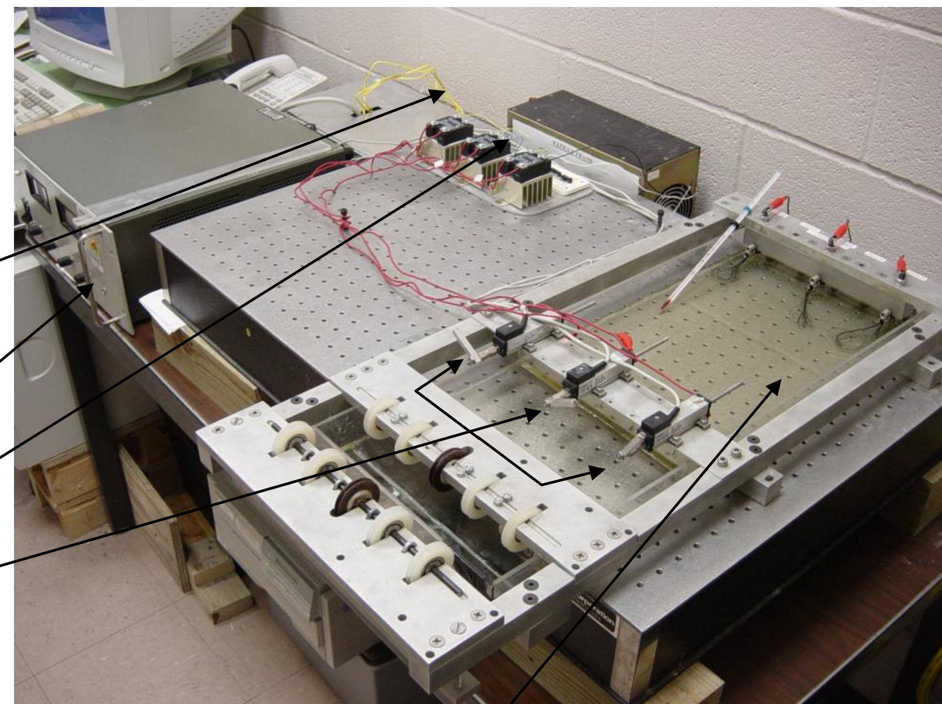




- Thermally induced transformation cycles
- Constant load
- Complete and partial phase transformation cycles

Experimental Setup (3)

- Thermal actuation:
  - Resistive heating in SMA specimens using DC power supply
  - Cooling is achieved using forced convection of a waterless coolant (ethylene and propylene glycol)



Experimental Setup (4)

- Capacity to provide resistive heating and active cooling with forced fluid convection (waterless coolant)

- Thermal loading cycles are achieved at a frequency close to 0.2Hz

- The relatively elevated cycling frequency doesn't allow generation of hysteresis loops in a quasi-static sense. The advantage of such design is the capacity to produce thermomechanical fatigue data in 48 to 72 hours.

- Measurement of displacement of SMA actuators is recorded through LVDT transducers and strains in the austenitic and martensitic state are used to define total, plastic and recoverable strains.

Different parameters

In order to develop and use 60-NiTi SMA at its full capacity, thermomechanical fatigue testing will be achieved with different parameters allowing to identify:

- The average fatigue life of 60-NiTi SMA actuators
- The optimum set of parameters to generate an optimized a fatigue response

The different parameters are:

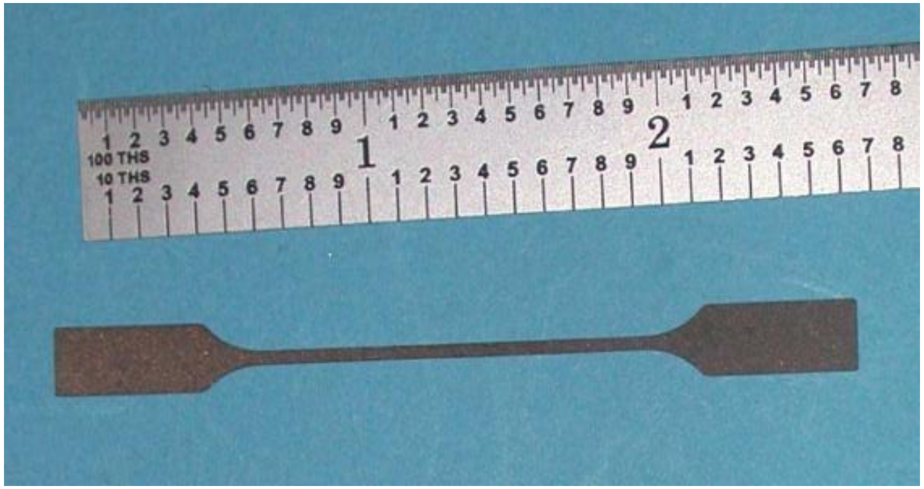
- Heat treatment
- Specimen thickness
- Applied constant stress level

Range of experiments

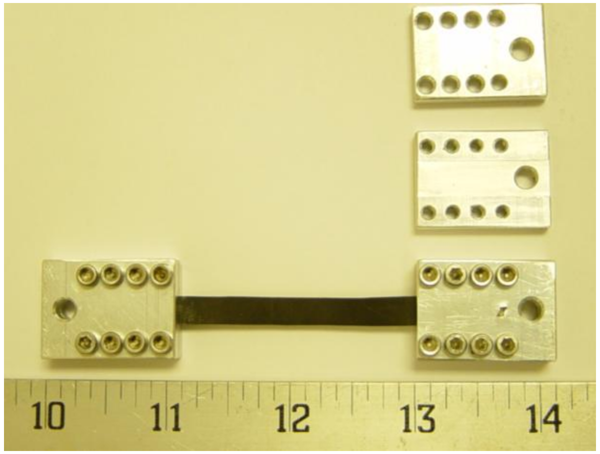
Fatigue Test Matrix		Applied stress		
Heat treatment	Cross section (mils^2)	50 MPa	150 MPa	250 MPa
1 hr.@ 850 C furnace cool, 1 hr.@ 450 C water quenched	50 x 5	6	6	6
	50 x 15	6	6	6
1 hr.@ 850 C furnace cool, 24 hrs.@ 450 C water quenched	50 x 5	6	6	6
	50 x 15	6	6	6

Specimens and Clamping

▪ Specimens are cut into thin dogbones with corner radii to remove stress concentration at the grips



▪ Grips designed to allow testing for dogbone specimens



Specimen details (1)

Run order	Specimen #	Heat treatment	Thickness (mils)	Applied stress (MPa)
1	*SP# 6 HT2*	*A2*	*10*	*226*
2	*SP# 4 HT2*	*A2*	*5*	*107*
3	*SP# 3 HT1*	*A1*	*5*	*204*
4	*SP# 7 HT1*	*A1*	*15*	*243*
5	*SP# 5 HT2*	*A2*	*5*	*103*
6	*SP# 5 HT1*	*A1*	*10*	*90*
7	*SP# 3 HT2*	*A2*	*15*	*142*
8	*SP# 7 HT2*	*A2*	*5*	*250*
9	*SP# 2 HT1*	*A1*	*10*	*250*
10	*SP# 4 HT1*	*A1*	*15*	*203*
Heat Treatments		A1	1 hr @ 850 C, 1 hr @ 450 C	
		A2	1 hr @ 850 C, 20 hrs @ 450 C	

SP# 1 HT1	Damaged during preliminary testing
SP# 1 HT2	Damaged during preliminary testing
SP# 2 HT2	Not applicable for isobaric uniaxial fatigue testing irregular cross section with major notches
SP# 6 HT1	MTS tested
SP# 8 HT2	MTS tested
SP# 5 HT1	No failure (run out at ~60K cycles)
SP# 5 HT2	No failure (run out at ~60K cycles)
SP# 4 HT1	Invalid results (computer malfunction)

Specimen details (2)

Run order	Specimen #	Heat treatment	Thickness (mils)	Applied stress (MPa)
11	*SP# 8 HT1*	*A1*	*10*	*100*
12	*SP# 9 HT1*	*A1*	*15*	*100*
13	*SP# 10 HT1*	*A1*	*5*	*100*
14	*SP# 9 HT2*	*A2*	*10*	*100*
15	*SP# 10 HT2*	*A2*	*10*	*250*
Heat Treatments		A1	1 hr @ 850 C, 1 hr @ 450 C	
		A2	1 hr @ 850 C, 20 hrs @ 450 C	

To be tested

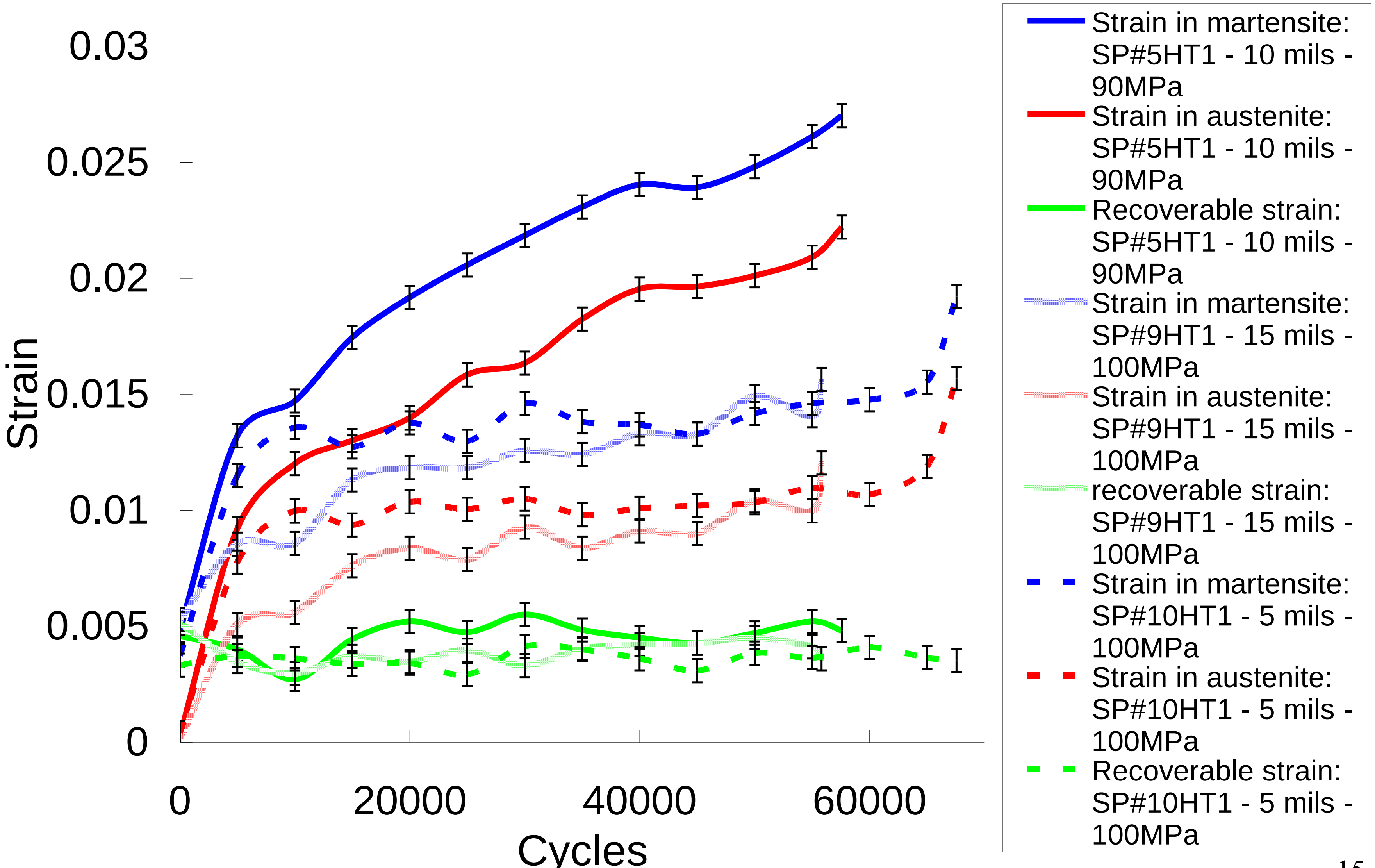
Tested

Test in progress

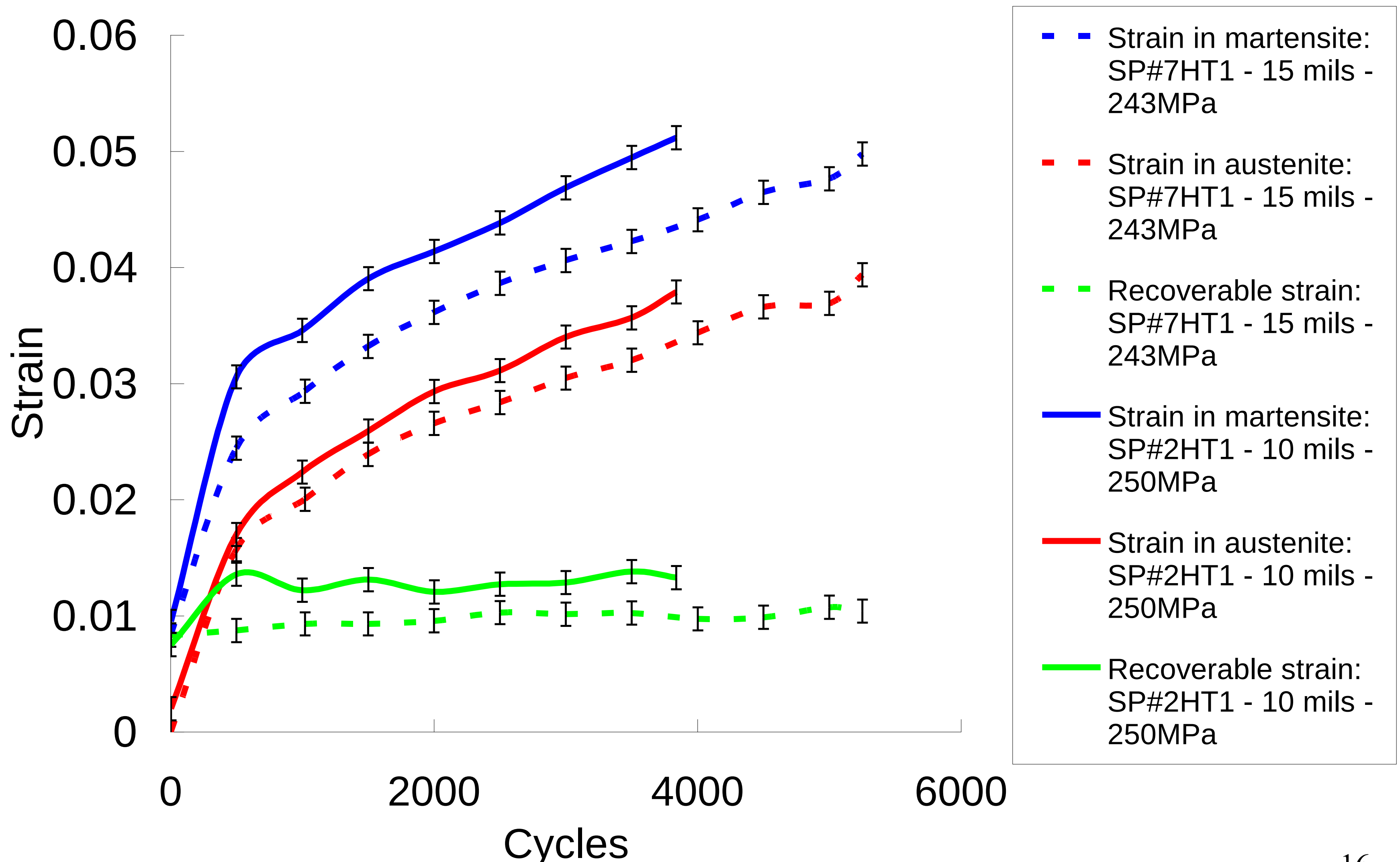
Tested

Fatigue Results
Heat Treatment #1

Strain - Life result for HT1 under 90MPa and 100MPa

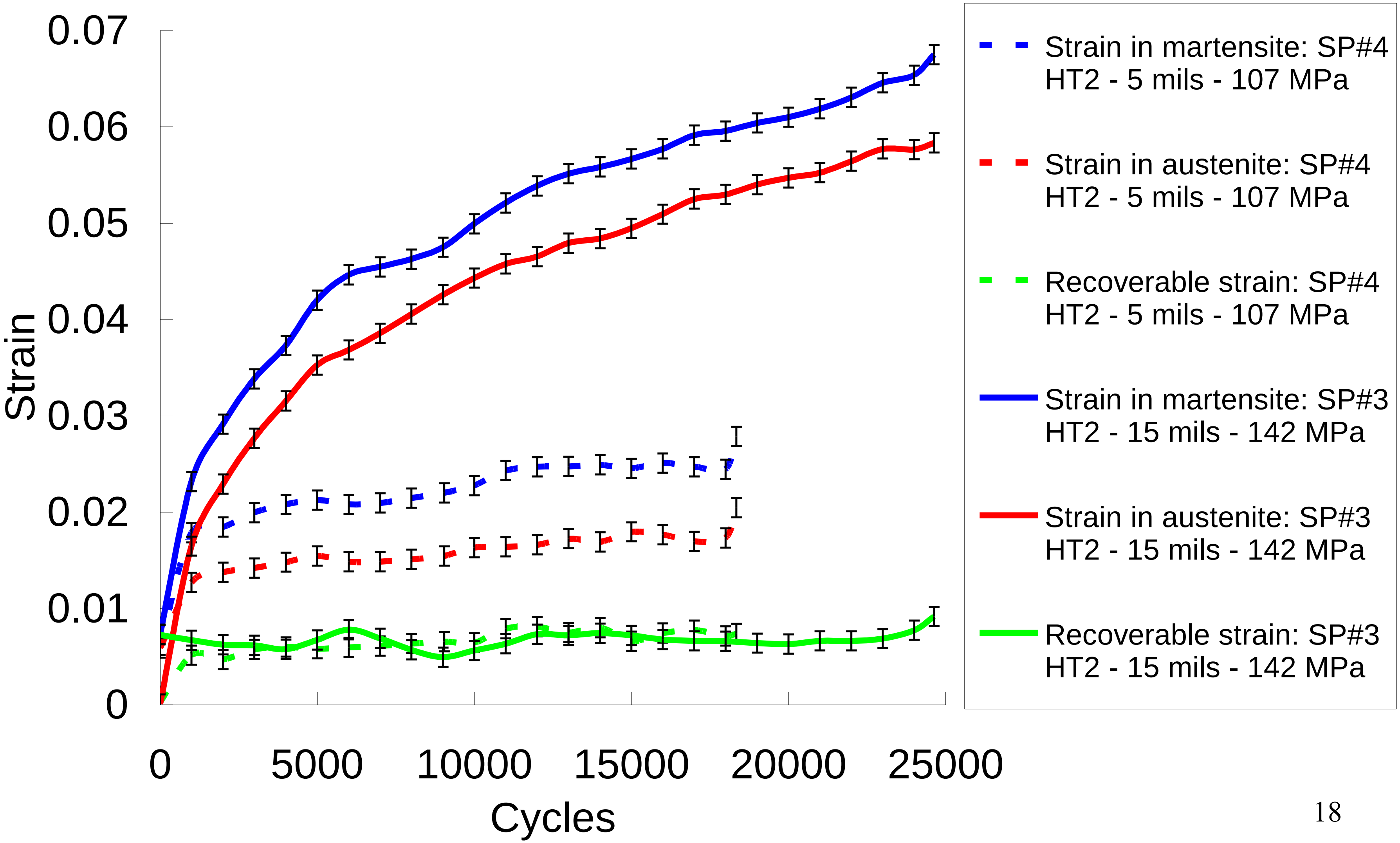


Strain - Life result for HT1 under 243MPa and 250MPa

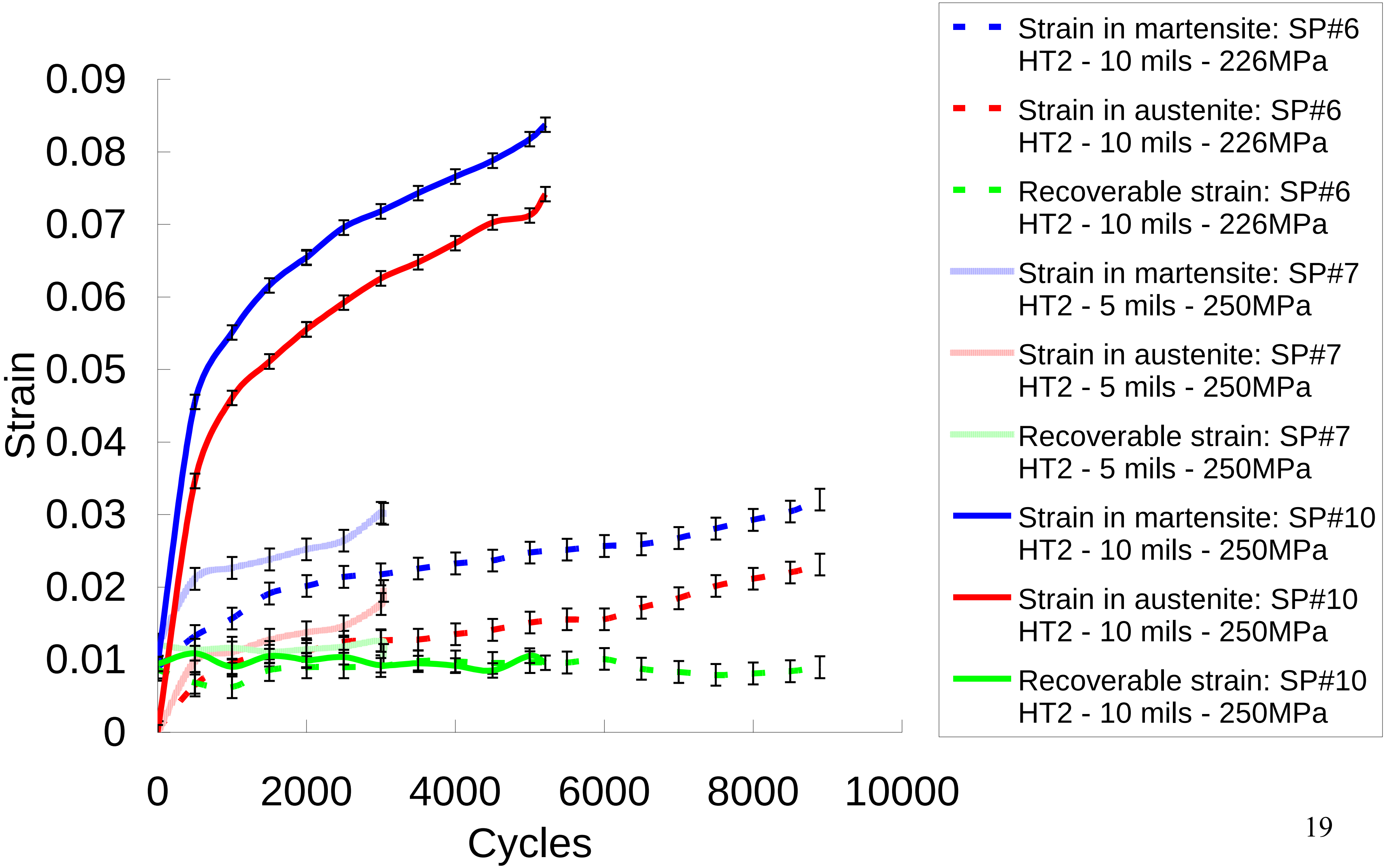


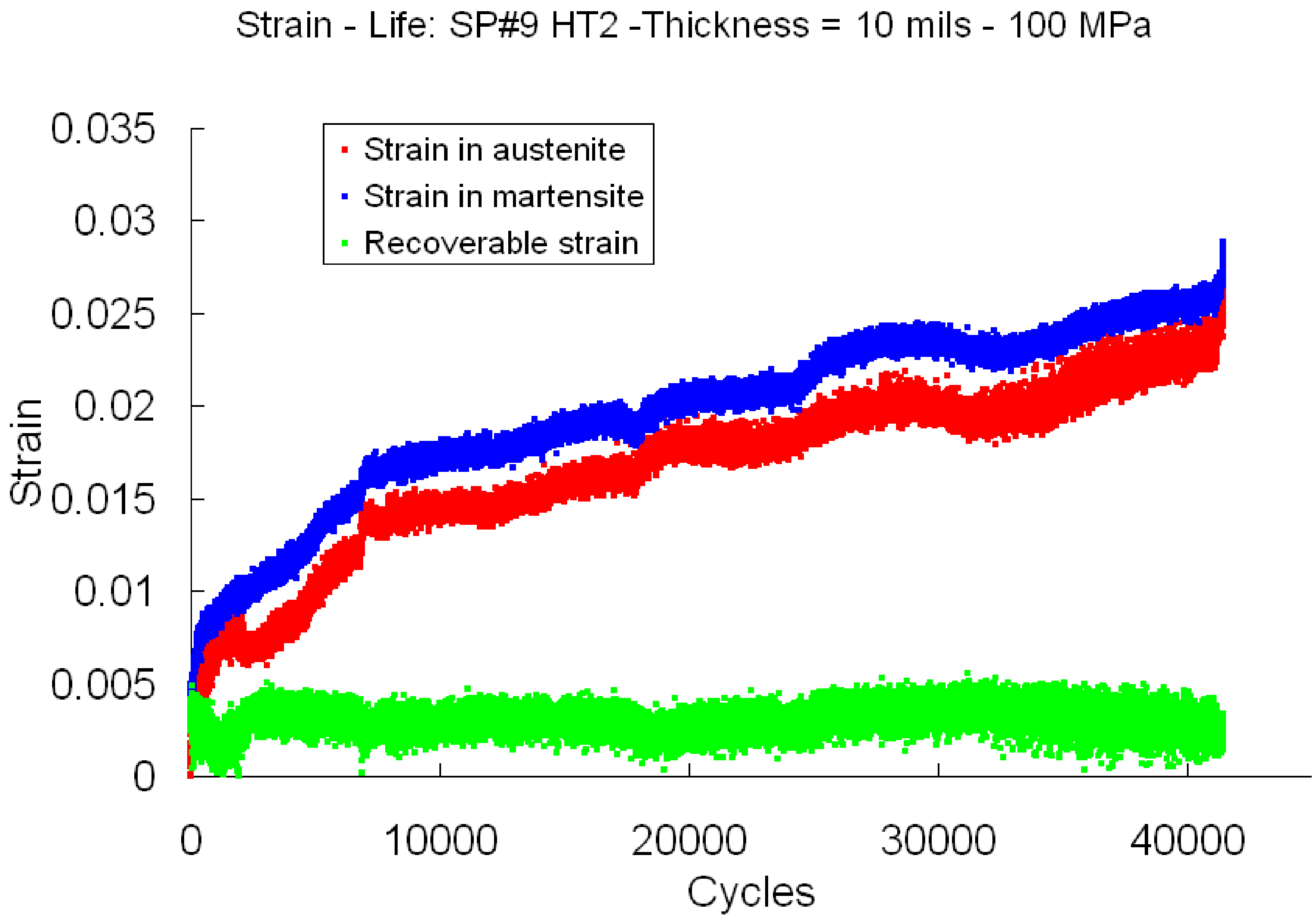
Fatigue Results
Heat Treatment #2

Strain - Life result for HT2 under 107MPa and 142MPa



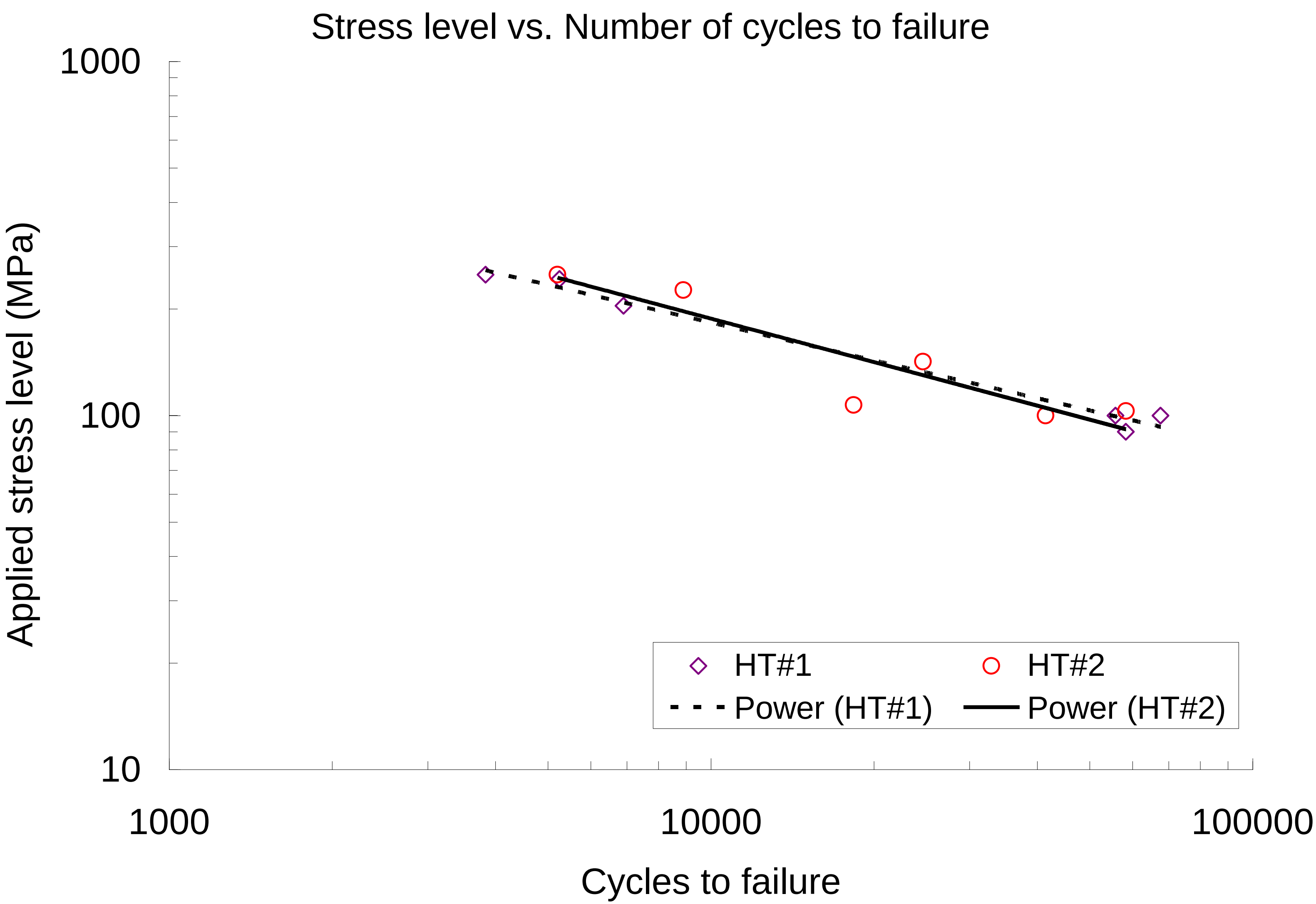
Strain - Life result for HT2 under 250MPa and 226MPa



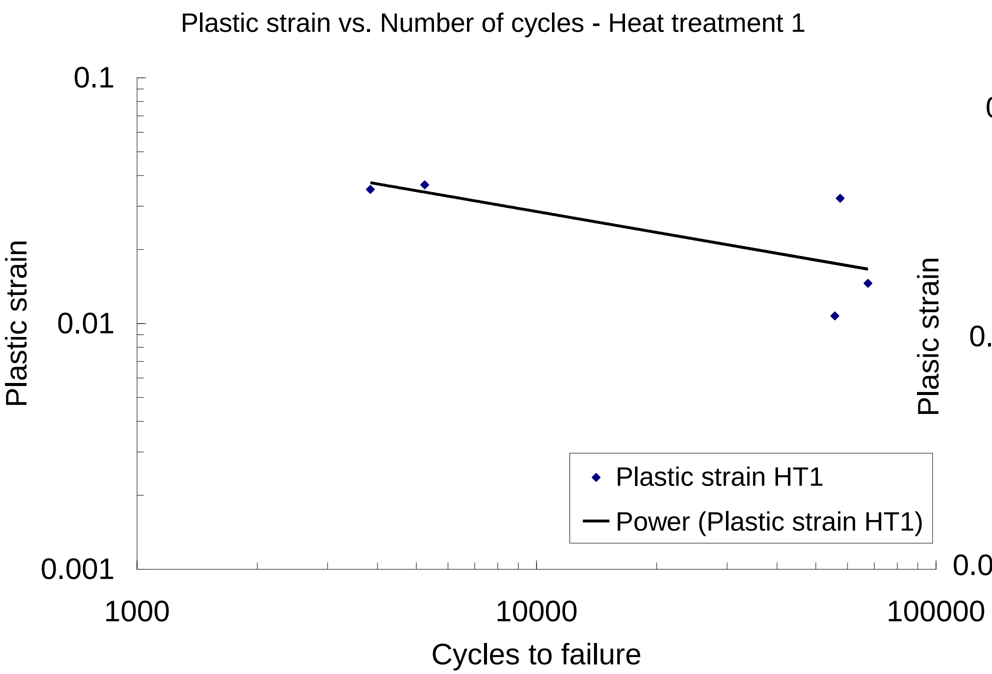

Strain - Life: SP#9 HT2 -Thickness = 10 mils - 100 MPa
Strain in austenite
Strain in martensite
Recoverable strain
Strain
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
10000
20000
30000
40000
Cycles

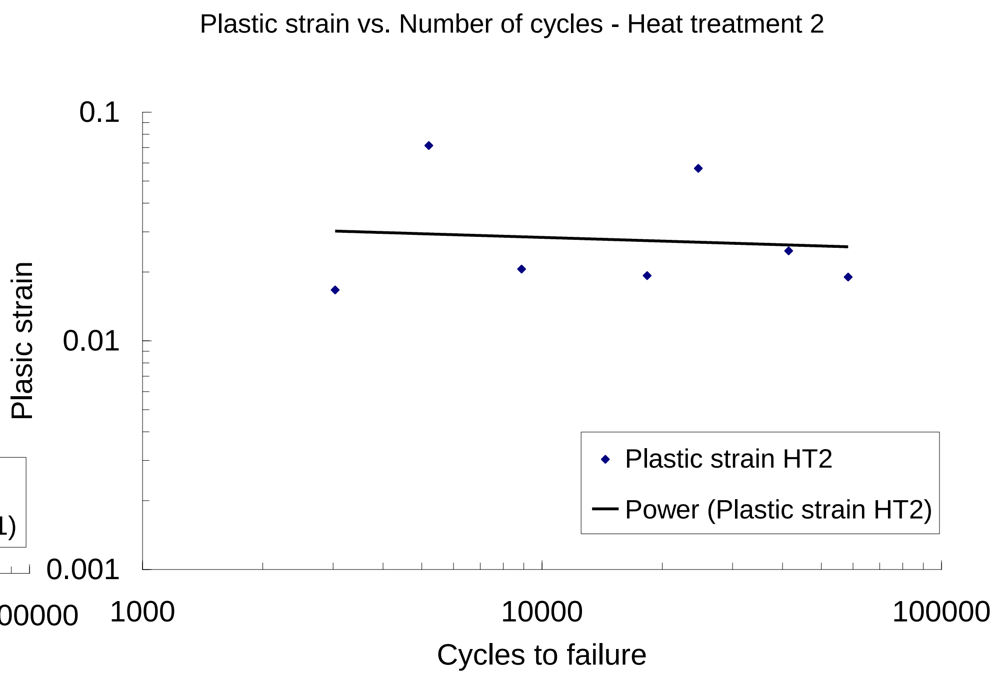
Cumulative results

Stress – Life


Stress level vs. Number of cycles to failure
1000
100
10
Applied stress level (MPa)
1000
10000
100000
Cycles to failure
HT#1
HT#2
Power (HT#1)
Power (HT#2)

Plastic strain at failure





Future Work

After the test matrix is completed, each specimen will be characterized by:

- A number of cycles to failure
- The total accumulated plastic strain
- The stabilized recoverable strain
- A shift in transformation temperatures

The next step is an in depth microstructural analysis of the ruptured specimens to analyze and understand the mechanisms of failure in order to identify an optimum set of parameters.

One of the ultimate goals is to determine some fatigue failure criteria that could eventually be implemented in the currently used 3-D SMA constitutive model.