VHTR Materials Overview

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DOE-NE Materials Crosscut Coordination Meeting
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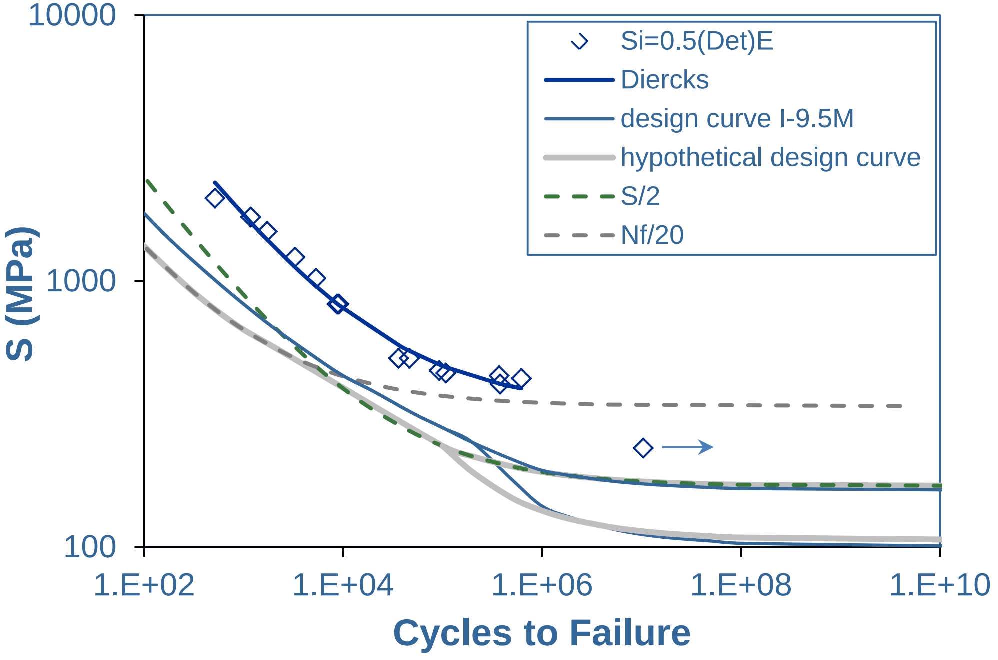
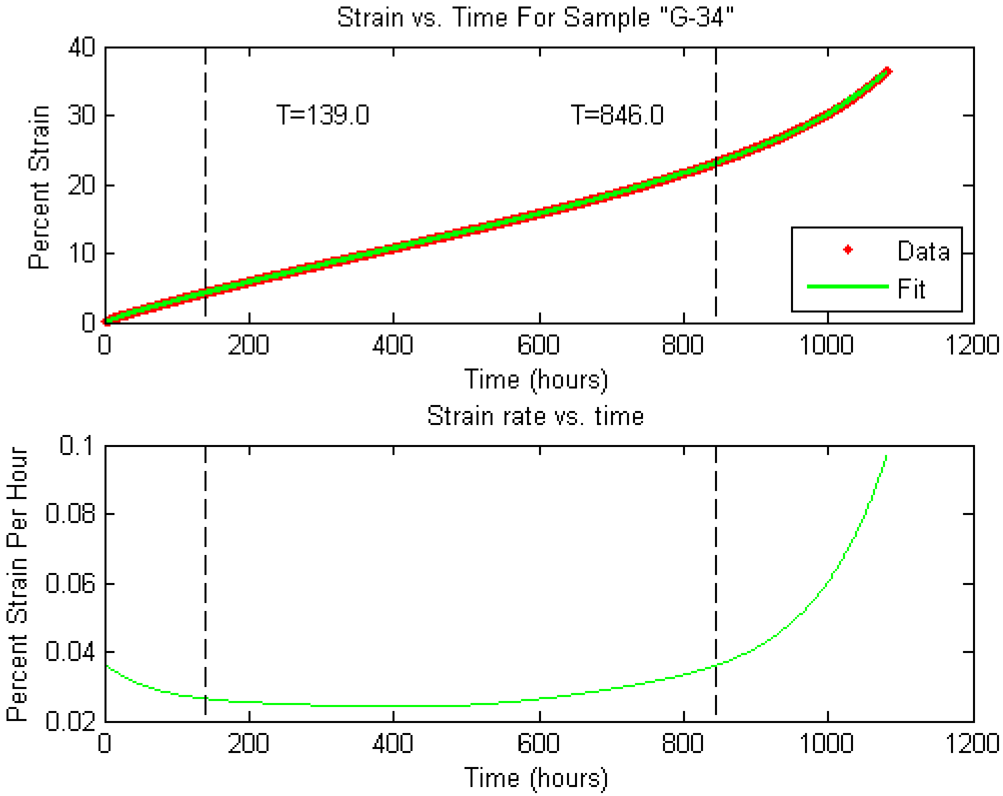
High Temperature Metals Overview

- **Focus of the program is characterization of Alloy 617 behavior and high temperature design methods for ASME Code qualification**
- **ASME Task Group on Alloy 617 Qualification has been established**
  - Two part activity
    - *Subsection NB Below 427°C data nearly complete – fatigue design curve remaining to be determined*
    - *Subsection NH above 427°C significant ongoing elevated temperature testing*
- **Support from NGNP Program, Small Modular Reactor Program and NEUP**

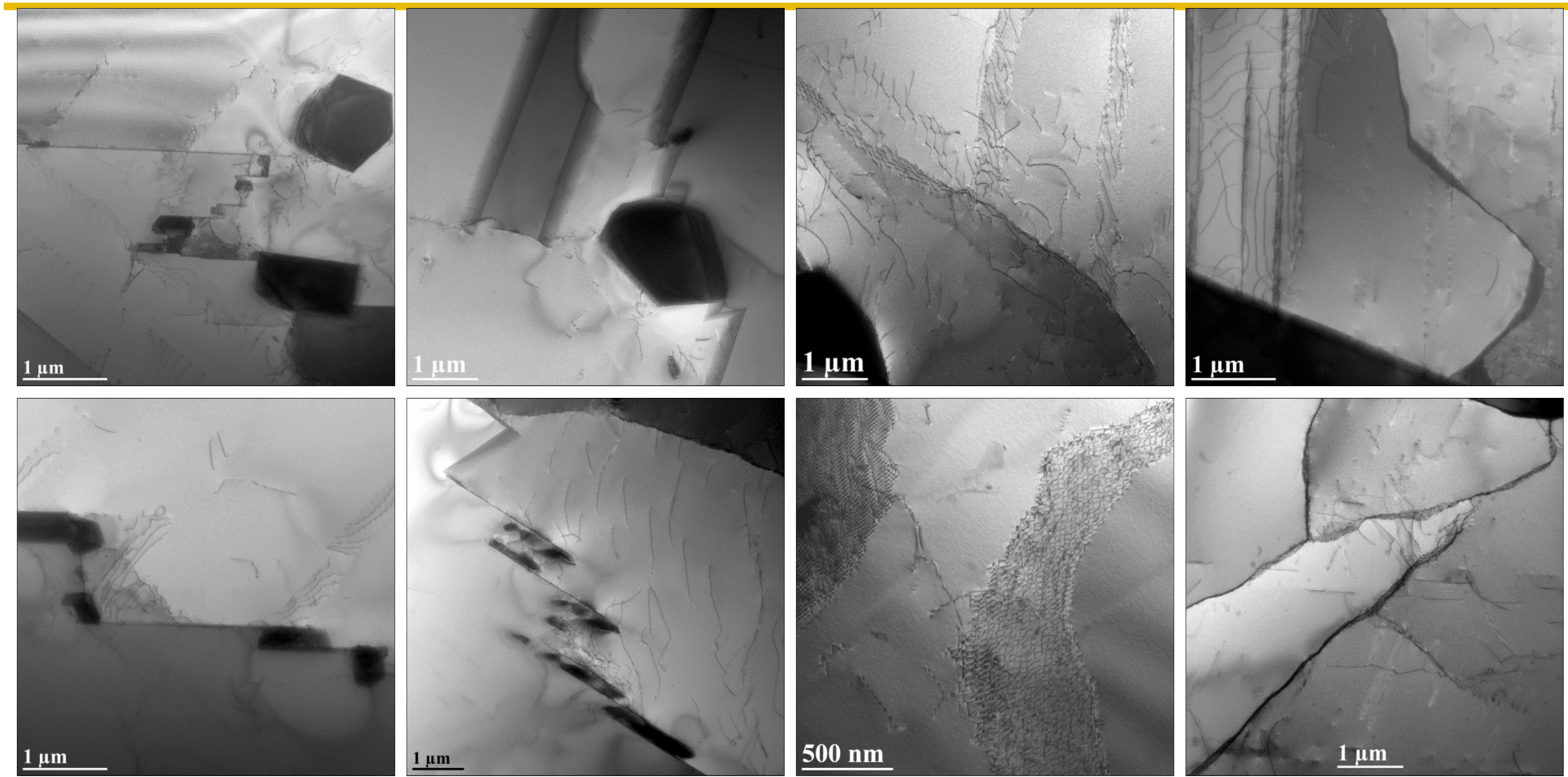
Preliminary Alloy 617 Fatigue Design Curve 427^{o}C



Creep Curve for Alloy 617 at 800^{o}C



Microstructure – TEM, 1000ºC, 20 MPa

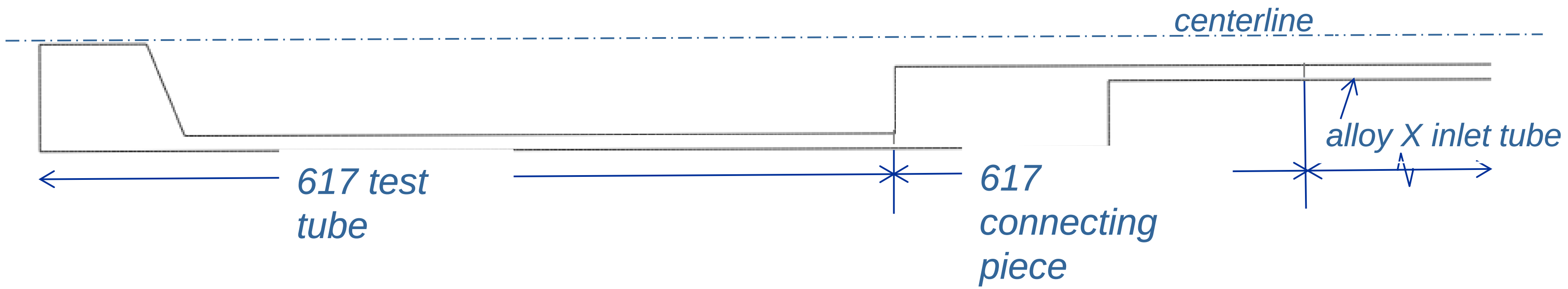


e= 2% e= 5% e= 10% e= 20%

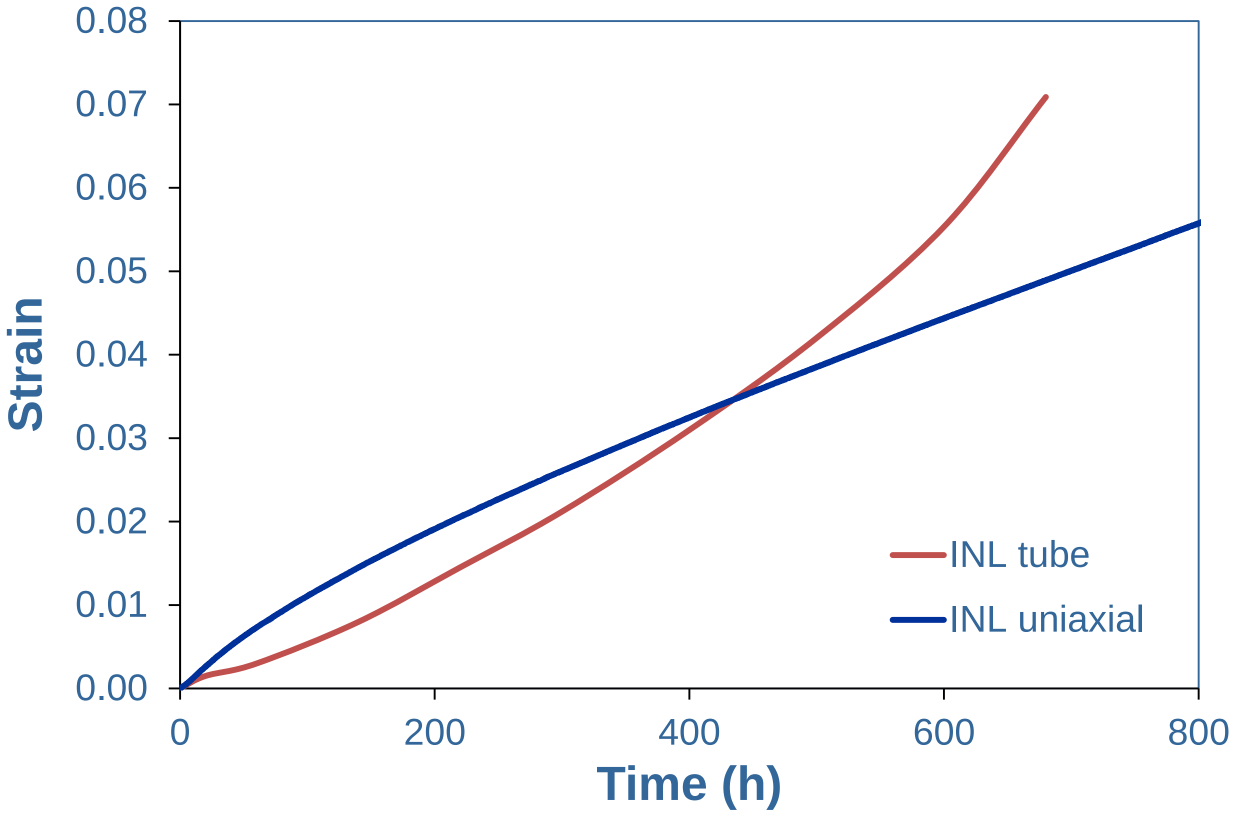
- *Minimal substructure development below 5% creep strain*
- *Extensive substructure development at 10 and 20% creep strain*
- *No porosity found during extensive examination of numerous samples*

FEM Model Pressurized Tube

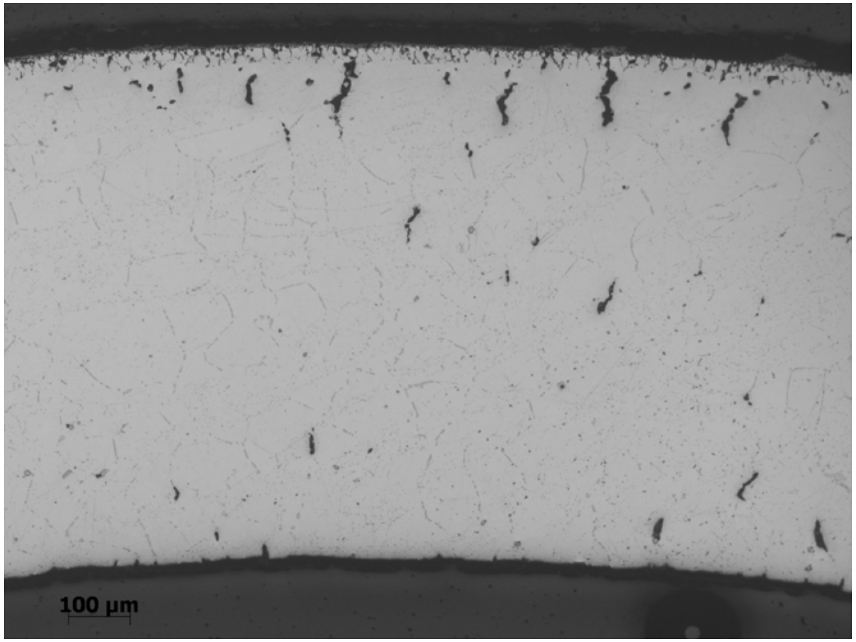
- **The model was axisymmetric, so only a half cross-section of the set-up is shown**
- **The test tube is 12mmOD with 1 mm thick walls and 50 mm long**
- **1000 psi internal applied pressure**
- **950°C**
- **Welds were not modeled**



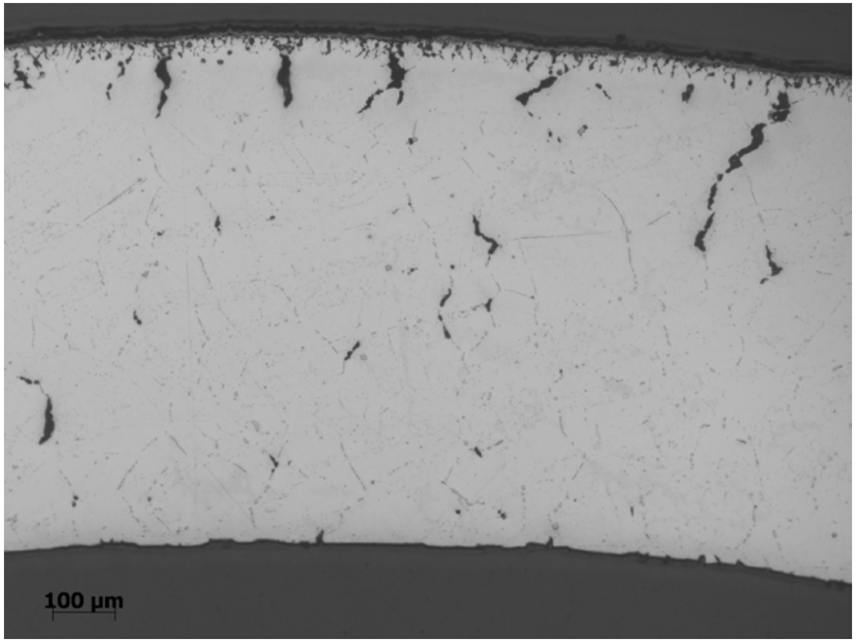
Comparison of Pressurized Tube to Uniaxial Creep



Optical Micrographs of Crept Tube

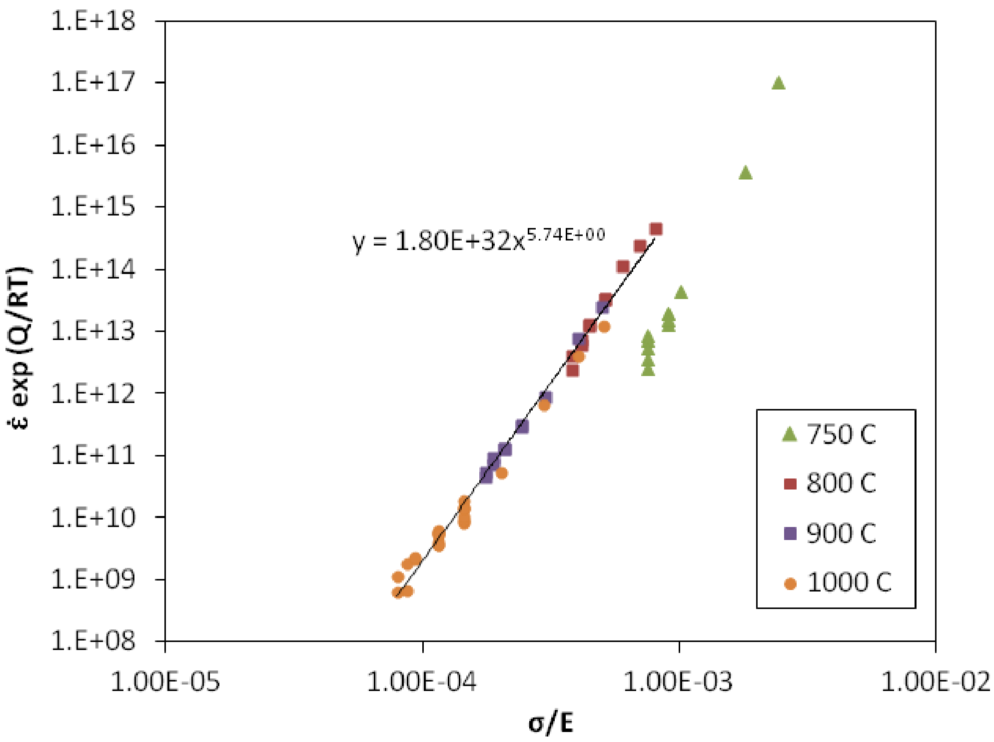


6% strain



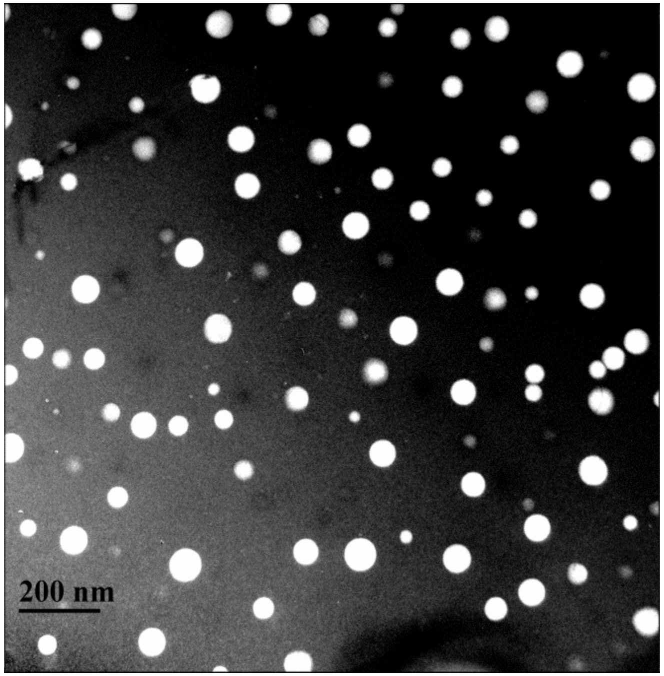
8% strain

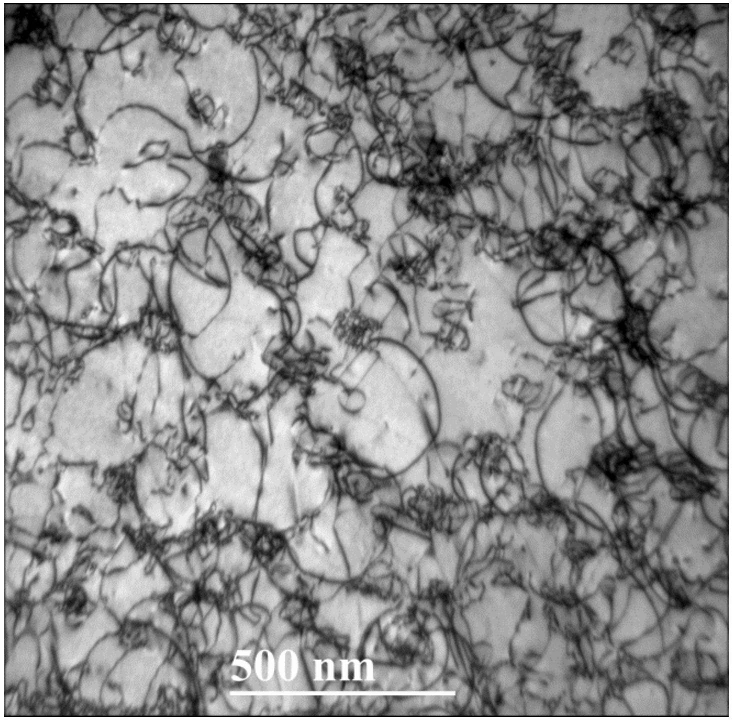
Zener-Hollaman Plot for Creep of Alloy 617



$$\dot{\varepsilon} = A\sigma^{n}e^{-Q/RT}$$

γ‘ Formation and Interaction in Creep in Alloy 617



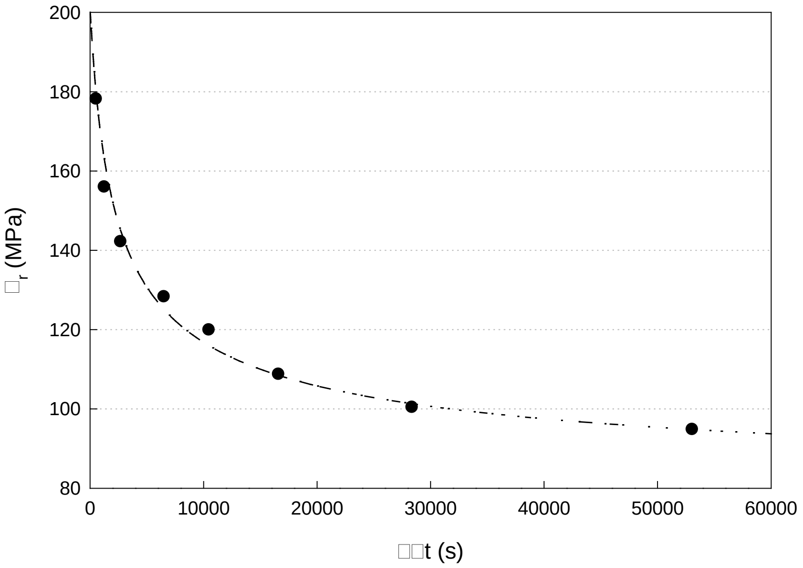


TEM darkfield image

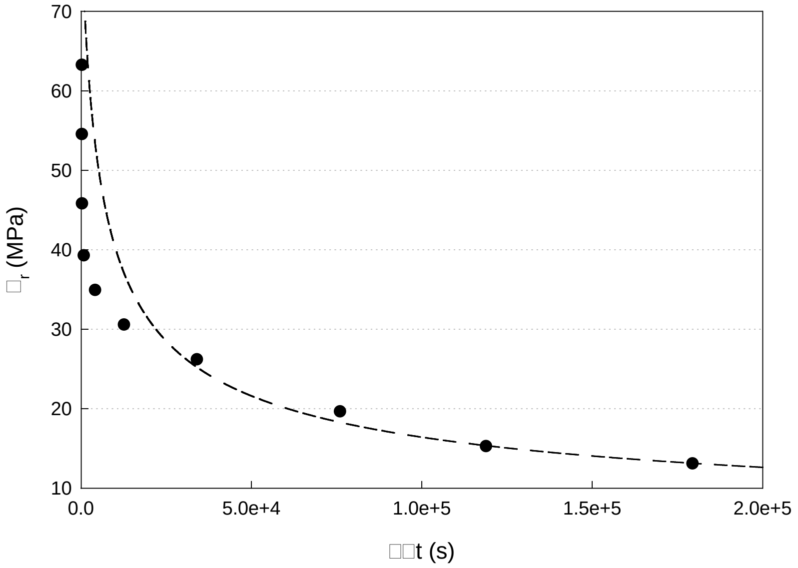
750°C and 145 MPa, ~10% creep strain, 2127 hrs

Uniaxial Creep Stress Drop Tests

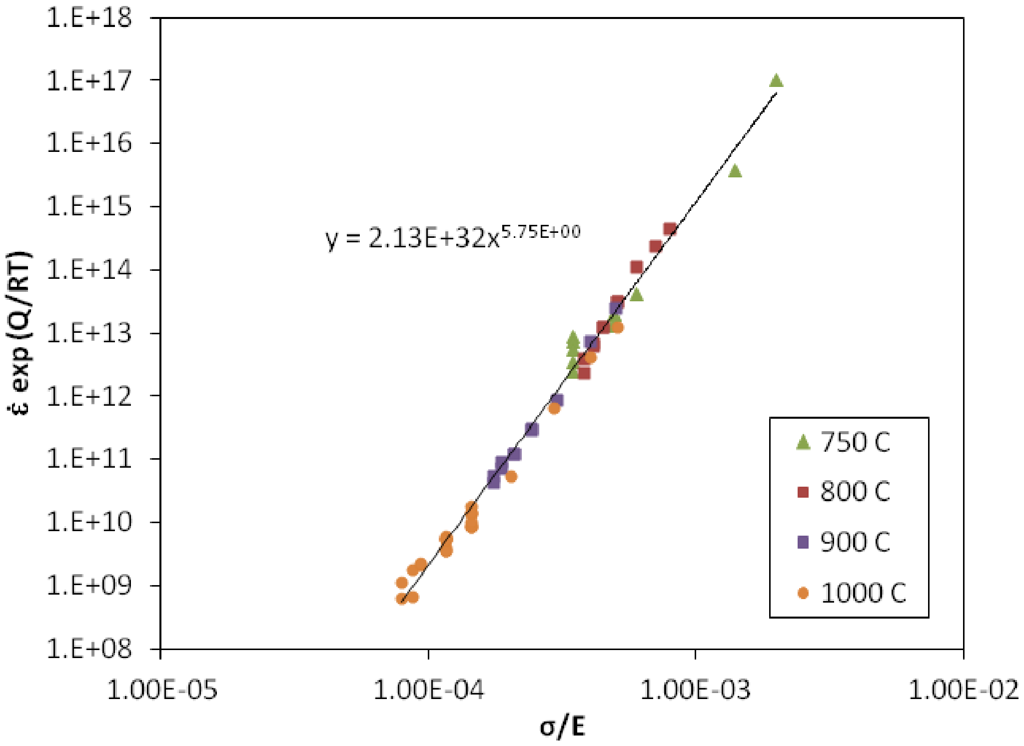
750°C



900°C

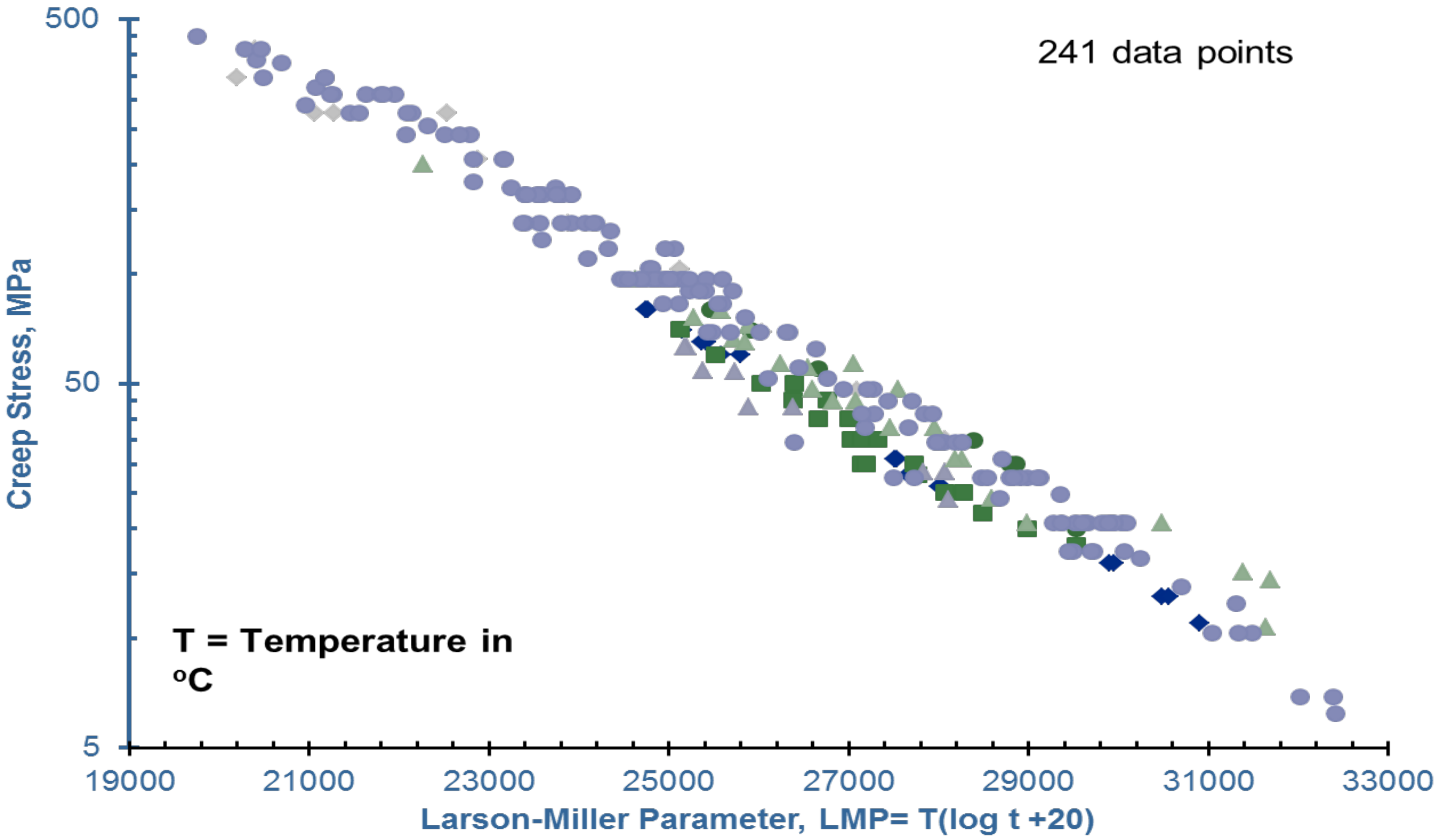


Zener-Hollaman with Threshold Stress at 750ºC

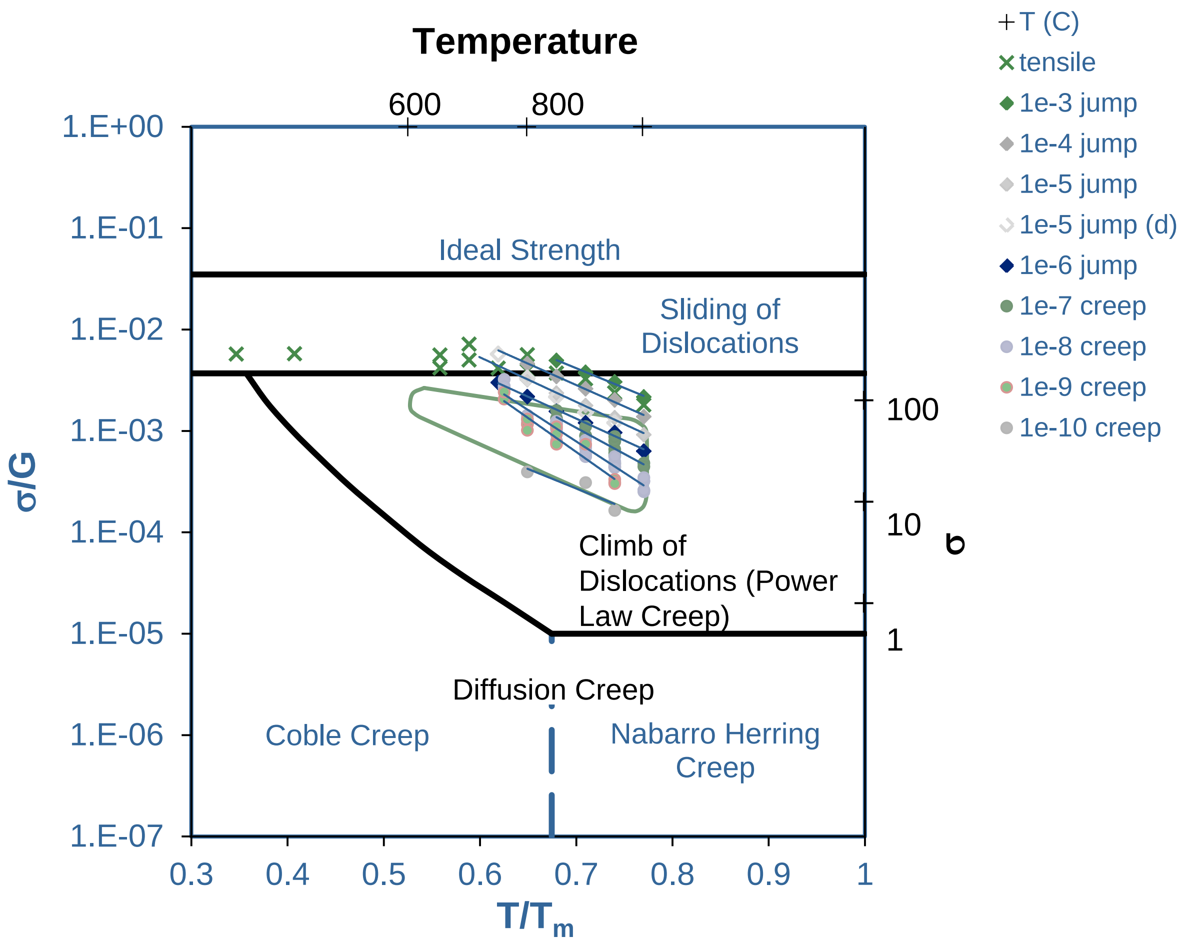


$$\dot{\varepsilon} = A\left(\sigma_{applied} - \sigma_{threshold}\right)^{n} e^{-Q/RT}$$

Larson-Miller Plot Alloy 617



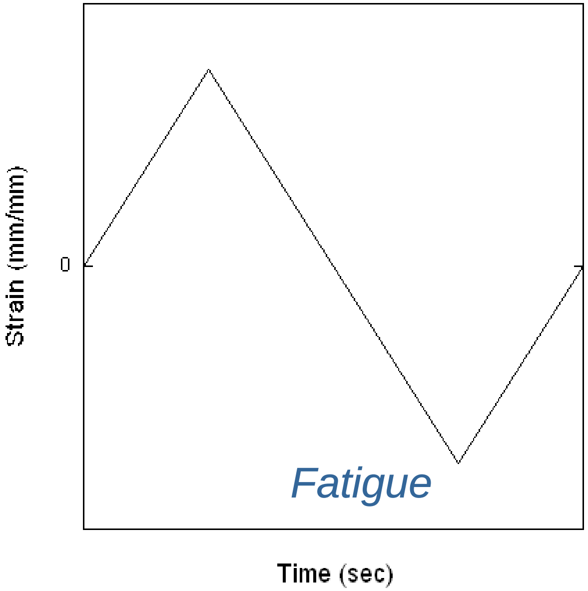
Alloy 617 Deformation Mechanism Map

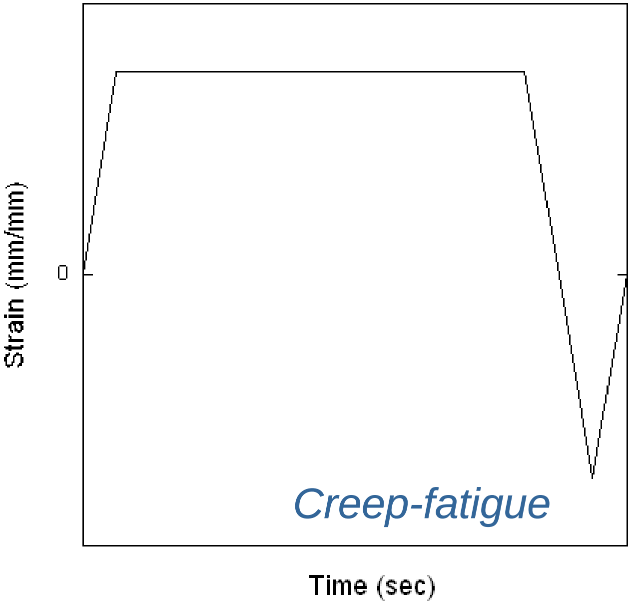


Heinz-Josef Penkalla, Hans-Helmut Over, and Florian Schubert, "Constitutive Equations for the Description of Creep and Creep Rupture Behavior of Metallic Materials at Temperatures above 800°C" Nuclear Technology, Vol. 66, Sep 1984, p. 685.

Alloy 617 Creep-Fatigue

- **950°C Creep-Fatigue (CF) behavior**
- **850°C C-F behavior**
- **950°C C-F and creep behavior of welds**





C-F (Tensile-Hold) Failure Modes

850°C ↓ Creep-fatigue interaction

950°C ↓ Creep dominated

Fatigue dominated

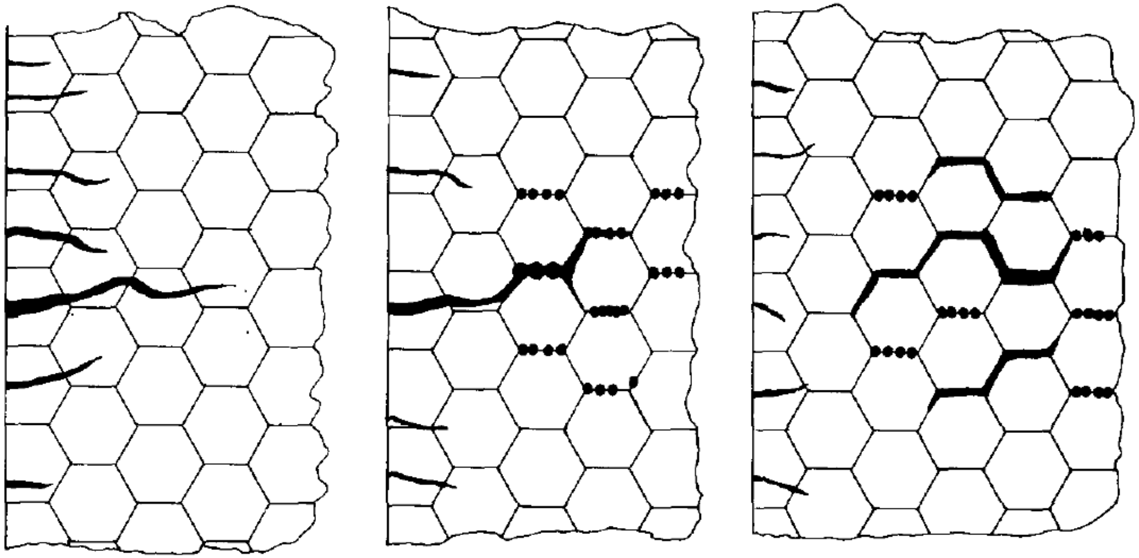
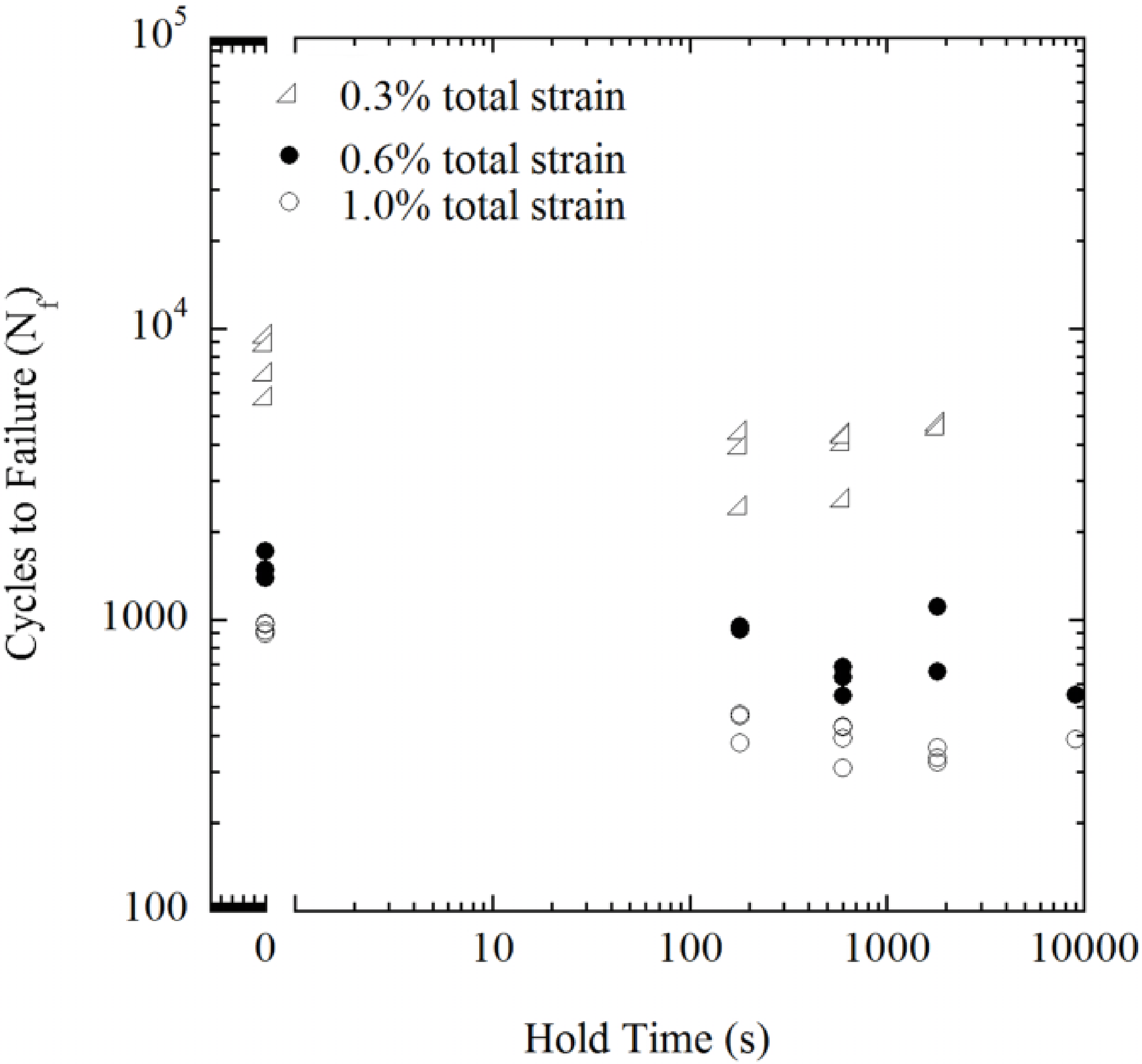
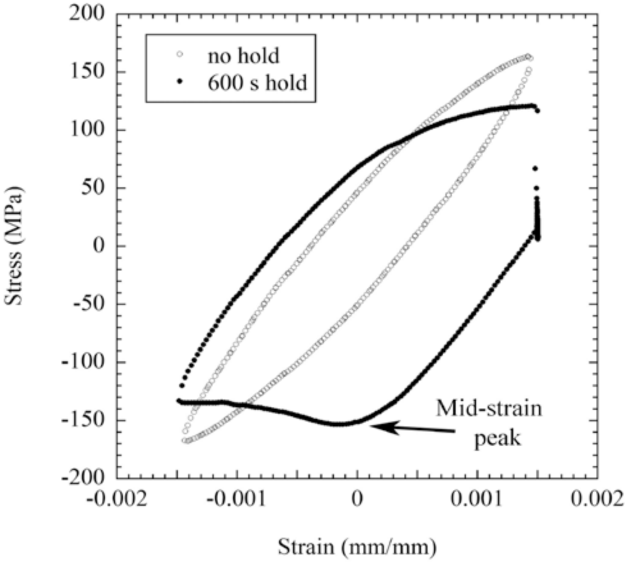


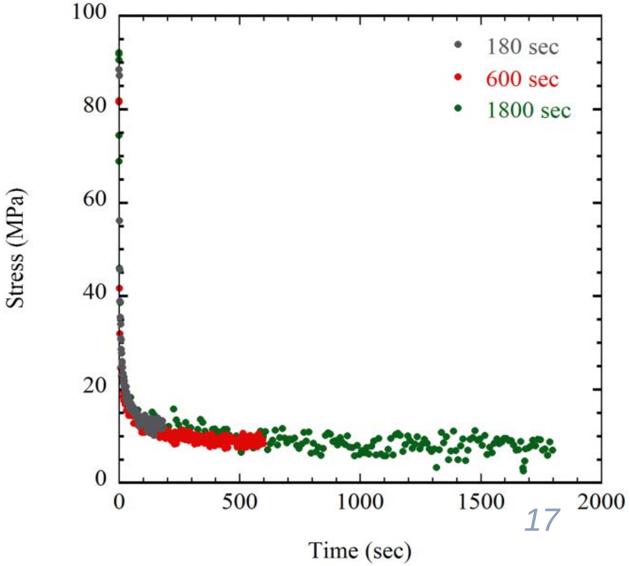
Figure from Miller, Hamm, Phillips, Materials Science and Engineering, vol. 53, p.234.

Alloy 617 950ºC C-F

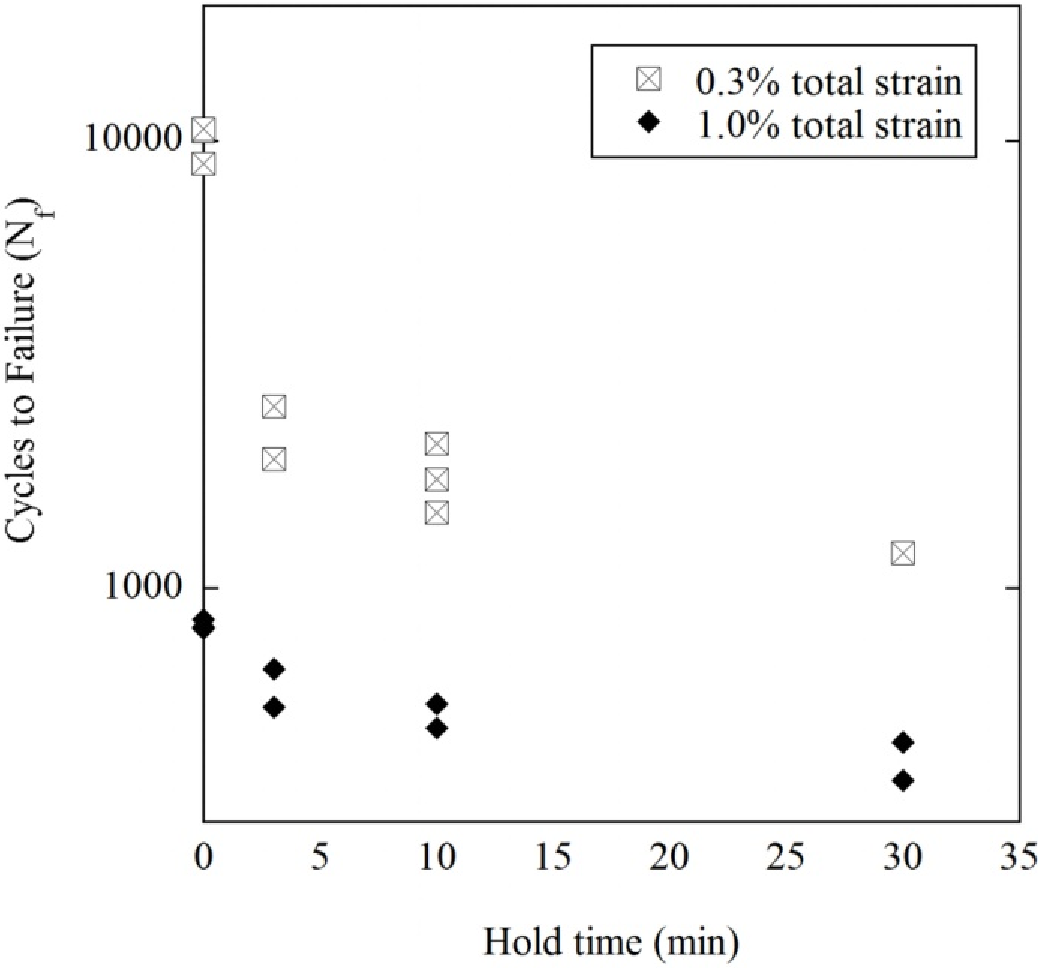


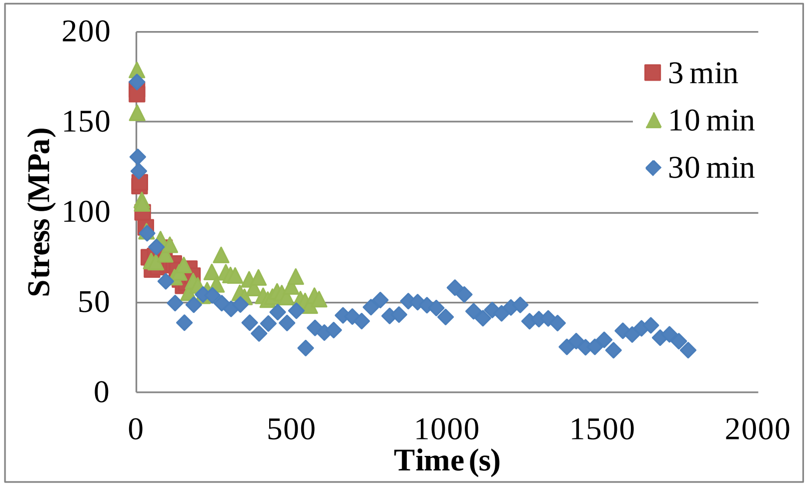


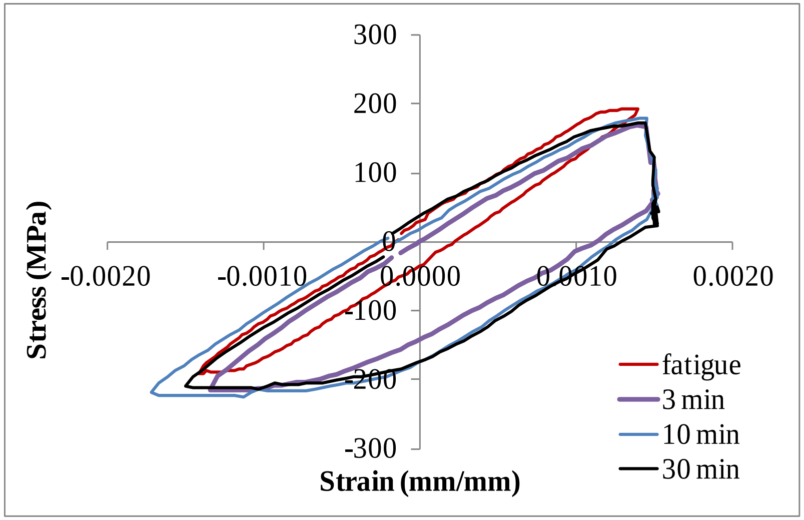
0.3% total strain



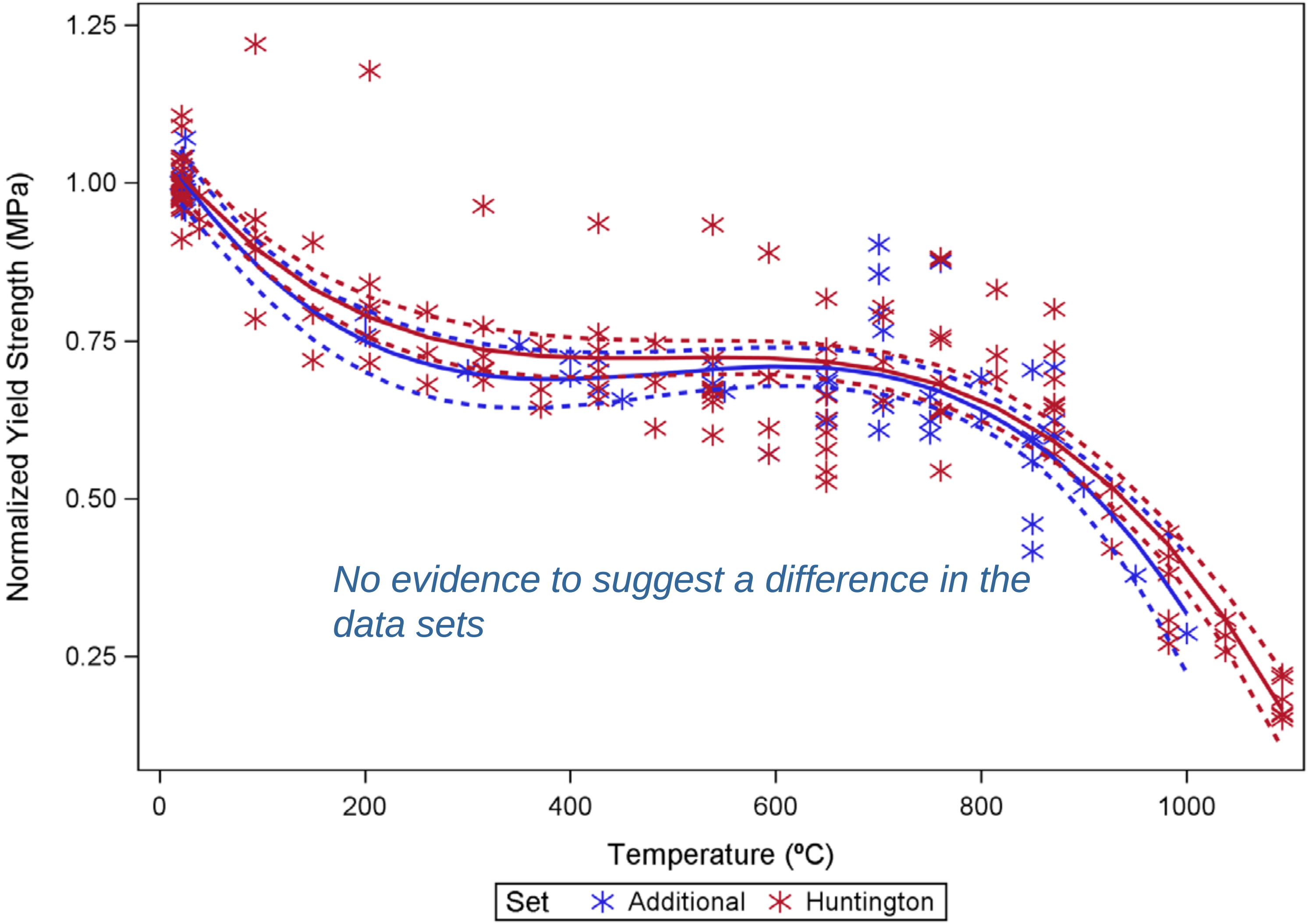
850°C CF


Cycles to Failure (N_f)
10000
1000
0
5
10
15
20
25
30
35
Hold time (min)
☒ 0.3% total strain
◆ 1.0% total strain


Stress (MPa)
200
150
100
50
0
0
500
1000
1500
2000
Time (s)
3 min
10 min
30 min

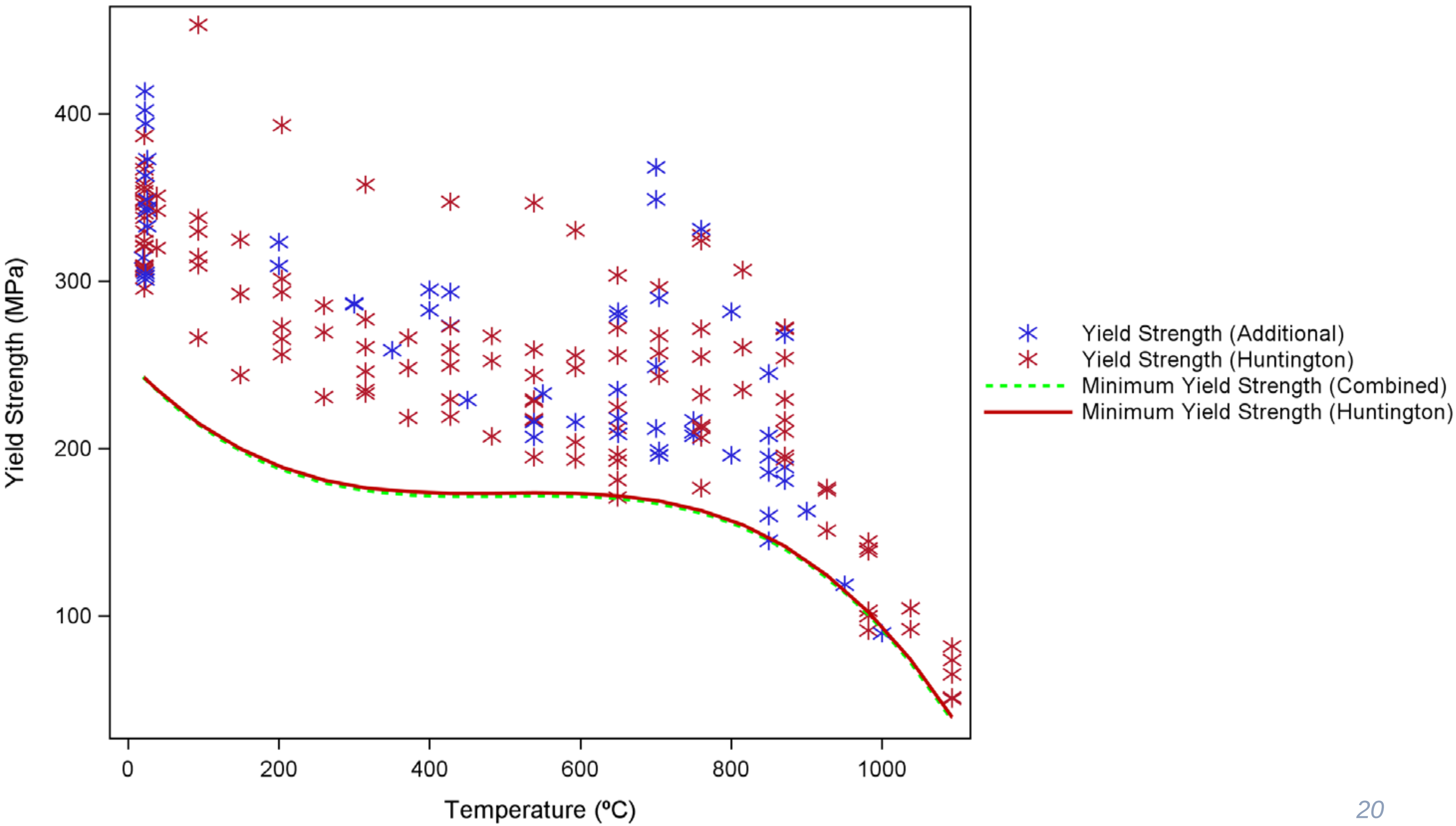

Stress (MPa)
300
200
100
0
-100
-200
-300
-0.0020
-0.0010
0.0000
0.0010
0.0020
Strain (mm/mm)
fatigue
3 min
10 min
30 min

Statistical Equivalence of New Tensile Yield Data

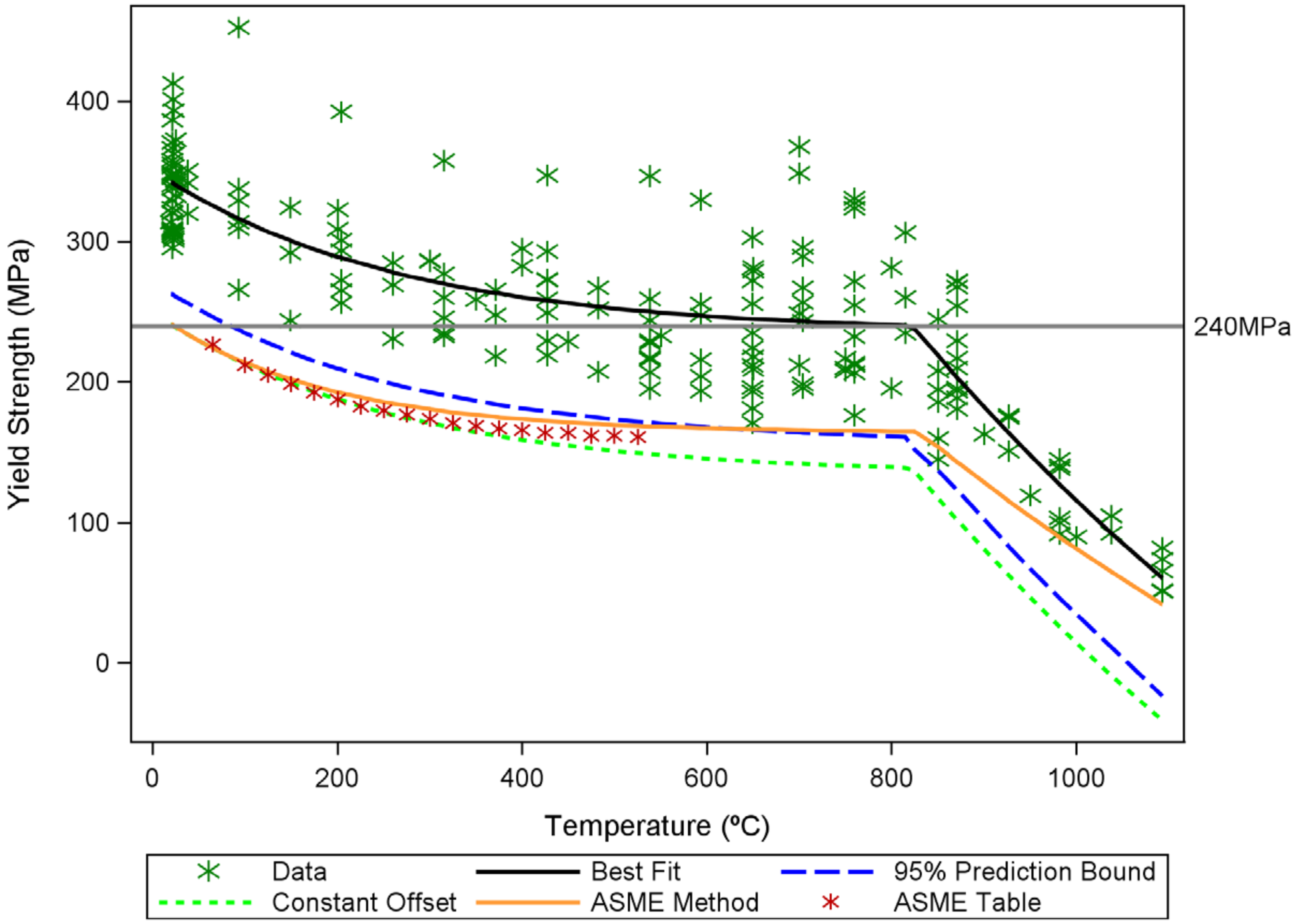


No evidence to suggest a difference in the data sets

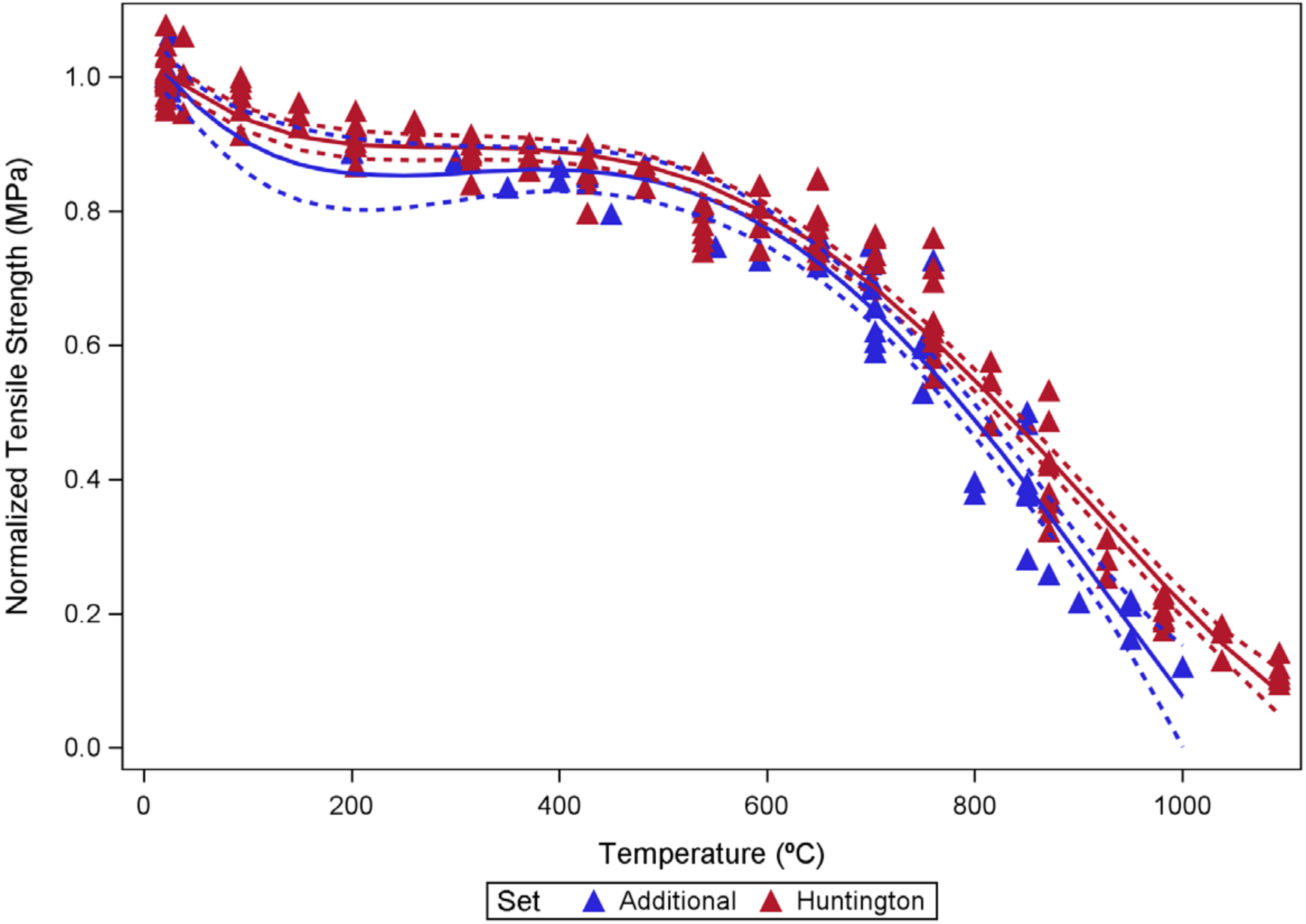
ASME Minimum Yield Strength



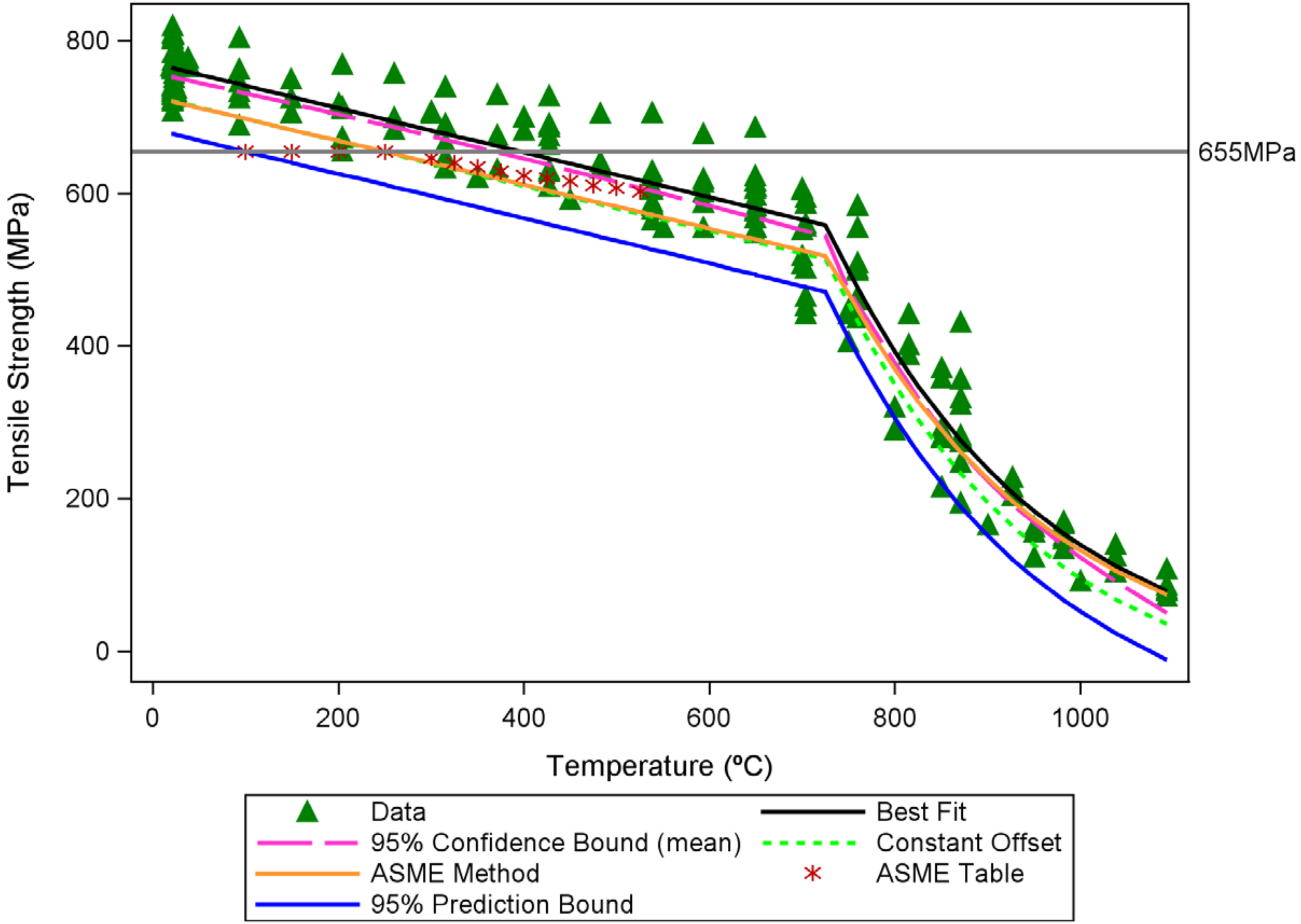
Comparison of Different Methods



Statistical Equivalence of New UTS Data

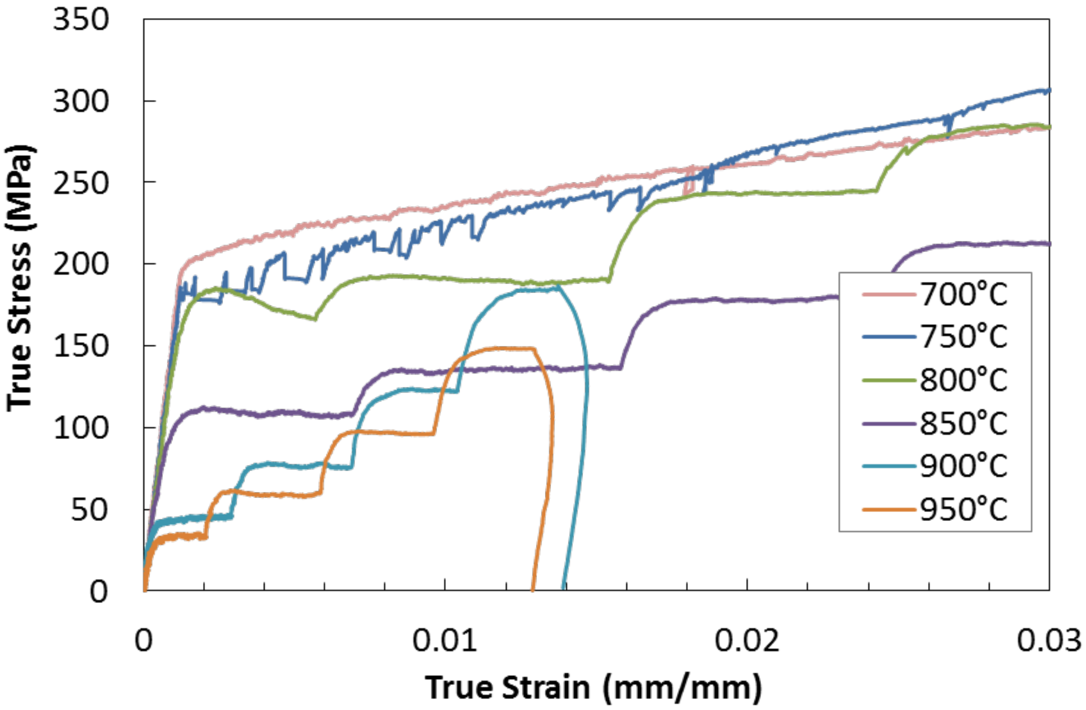


Comparison of Different Methods



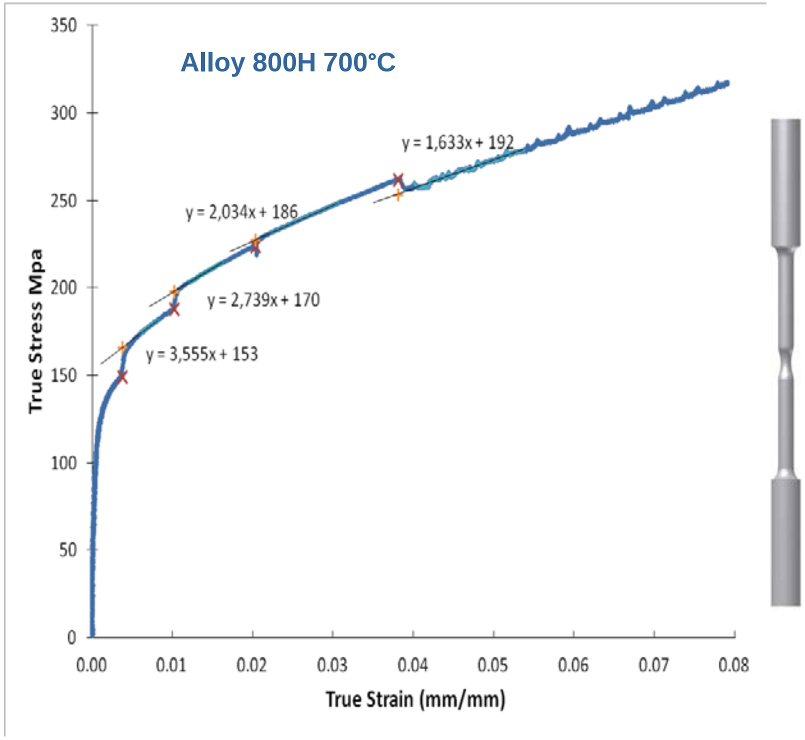
Strain Rate Jump Tests, Alloy 617

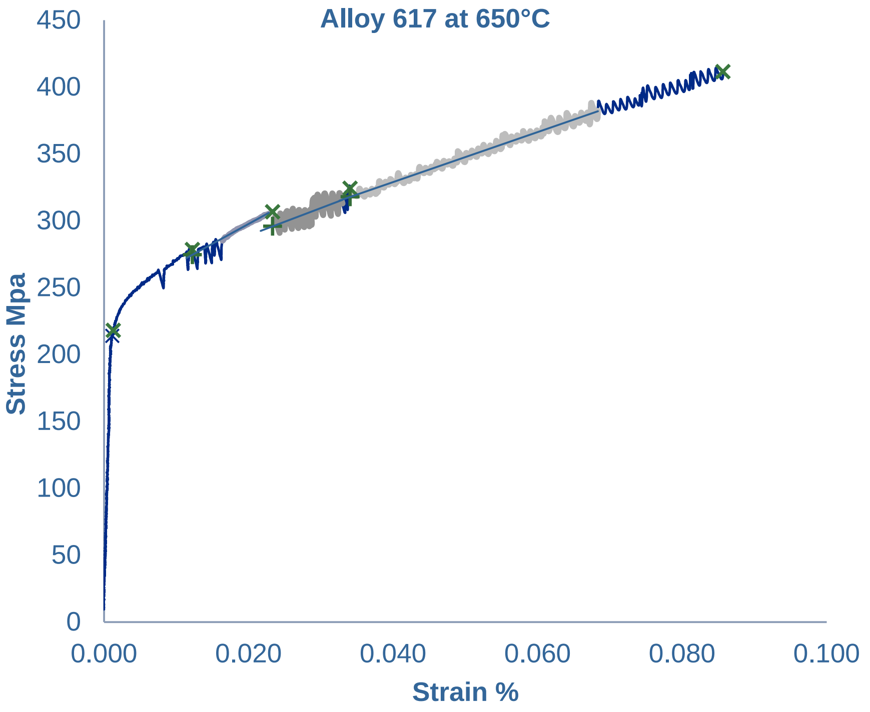
- *Above 800°C the increments of stress associated with strain rate jumps are of consistent magnitude*
- *Serrated flow associated with dynamic strain aging occurs at lower temperatures, but little strain rate sensitivity*



Negative Strain Rate Sensitivity and Serrated Flow

- **Dynamic strain aging (serrated flow) results in negative strain rate sensitivity at lower temperatures**
- **In this case the material exhibits *strain rate weakening* – the material in the neck is weaker than adjacent material and necking is exacerbated**
- **Strain rate enhanced necking results in decreased elongation**





Summary

- *ASME Code qualification of Alloy 617 is moving forward first for NB and by FY 15 for NH*
- *Preliminary fatigue design curve is under development*
- *It has been demonstrated that γ' can yield creep strengthening at 750^{o}C*
- *Creep-fatigue behavior undergoes a distinct transition between 850 and 950^{o}C*
- *Tensile properties for contemporary material compare well with historical data – although a new method of specifying minimum yield strength may be desirable*