INL/EXT-15-35715-Revision-0

Alloy 617 Isochronous Stress-Strain Curves

Jill Wright, Nancy Lybeck

July 2015

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http://www.inl.gov

Prepared for the
U.S. Department of Energy

Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Alloy 617 Isochronous Stress-Strain Curves

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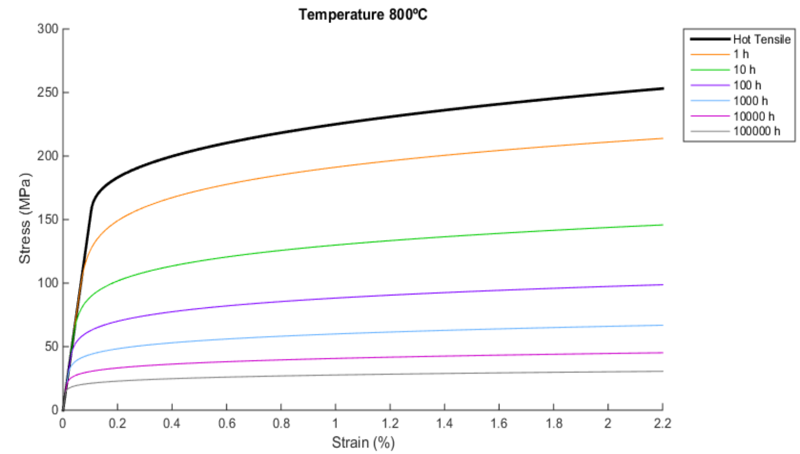
Advanced Reactor Technologies
Advanced Materials R&D Program Review
July 14-15, 2015

Work Package AT-15IN160101
Subtask: Isochronous Stress-Strain Curves

Subtask Relevancy

- **Isochronous stress-strain curves are an integral part of the Code Case**
  - Required in applying the Subsection NH design procedures.
  - Provide designers with strain caused by stress under elevated temperature assuming average properties



Technical Approach/Results/Accomplishments

- **Developed hot tensile curves based on the INL Alloy 617 tensile data**
- **Fit a creep model to INL generated creep curves (up to 3% creep strain)**
- **Determined the stress and temperature dependence of the parametric constants in the creep model**
- **Shifted the hot tensile and isochronous curves to represent the average behavior based on a larger data set**

Expected Deliverable & Schedule

- **Contribute to Appendix T of the Alloy 617 Code Case**
- **Draft Code Case to be completed August 31, 2015**

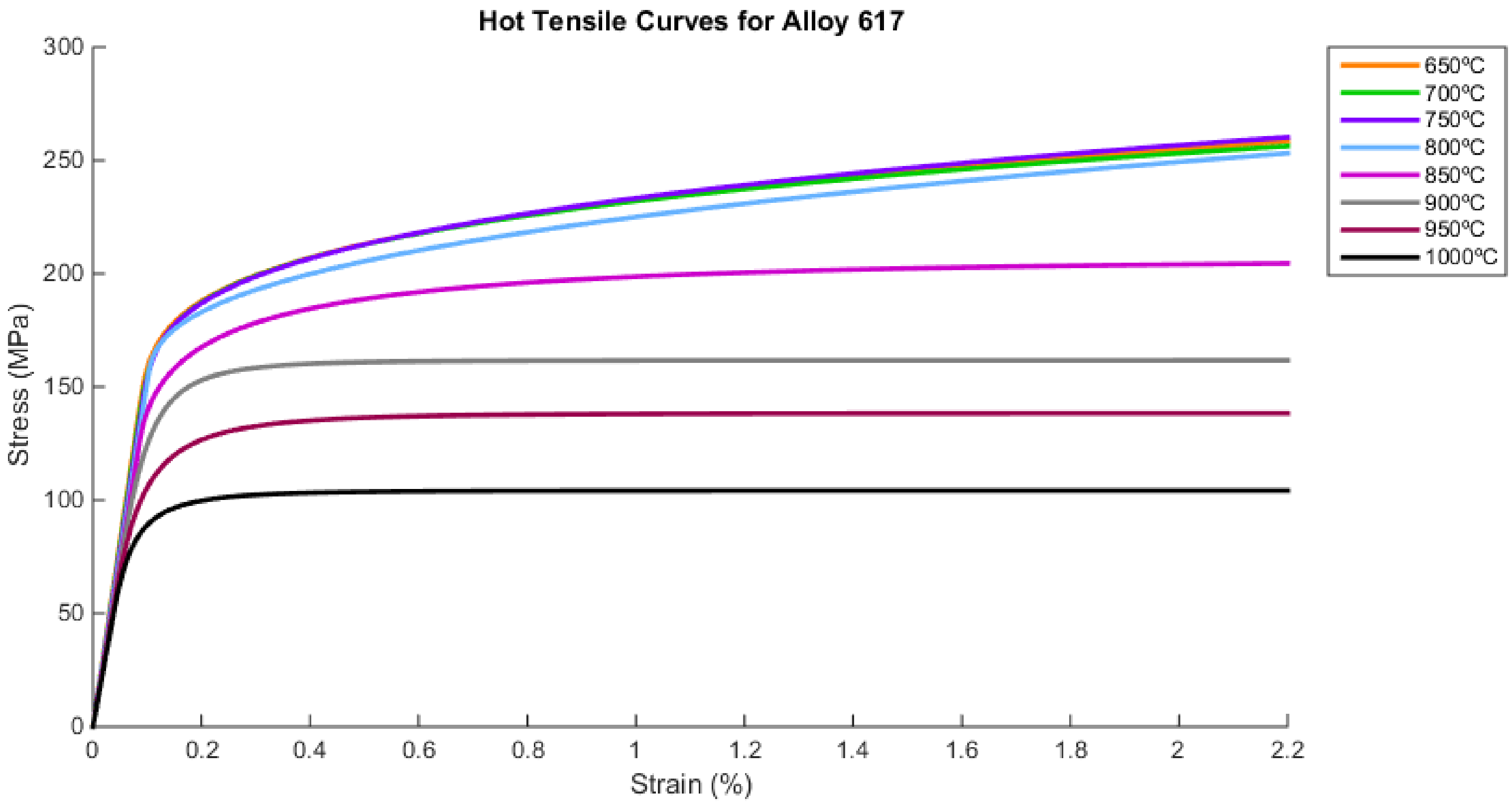
Introduction

- **Isochronous stress-strain curves (ISSC) and hot tensile curves are needed up to 2.2% strain for Alloy 617**
  - 427 – 950°C in 25°C increments
  - 800 – 1800°F in 50°F increments
- **Hot tensile curves provide an upper bound for isochronous stress-strain curves**
- **Isochronous curves are not needed for temperature ranges where creep is negligible**

HOT TENSILE CURVES

What is a Hot Tensile Curve?

- Hot tensile curves represent tensile behavior of an average strength heat of the alloy for various temperatures
- Experimental tensile curves are used to match the shape



Hot Tensile Curves: Ramberg-Osgood

- **Used for lower temperatures where creep is not significant**

$$\varepsilon = \varepsilon_E + \varepsilon_p$$

$$\varepsilon_E = \frac{\sigma}{E}$$

$$\varepsilon_p = a(\sigma - \sigma_L)^m \qquad \sigma > \sigma_L$$

ε **= strain**

σ **= stress**

E **= elastic modulus**

σ_L **= proportional limit**

- **The parameters a and m are chosen so the curve goes through the experimentally determined 0.2% offset yield strength and the 2% offset flow stress for the specified temperature.**

Hot Tensile Curves: Voce

- **Used for higher temperatures where creep is significant**

$$\varepsilon = \varepsilon_E + \varepsilon_p$$

$$\varepsilon_E = \frac{\sigma}{E}$$

$$\varepsilon_p = \frac{1}{b}\left[\ln\left(\frac{\sigma_L - \sigma_{UTS}}{\sigma - \sigma_{UTS}}\right)\right]^2 \qquad \sigma > \sigma_L$$

ε = strain

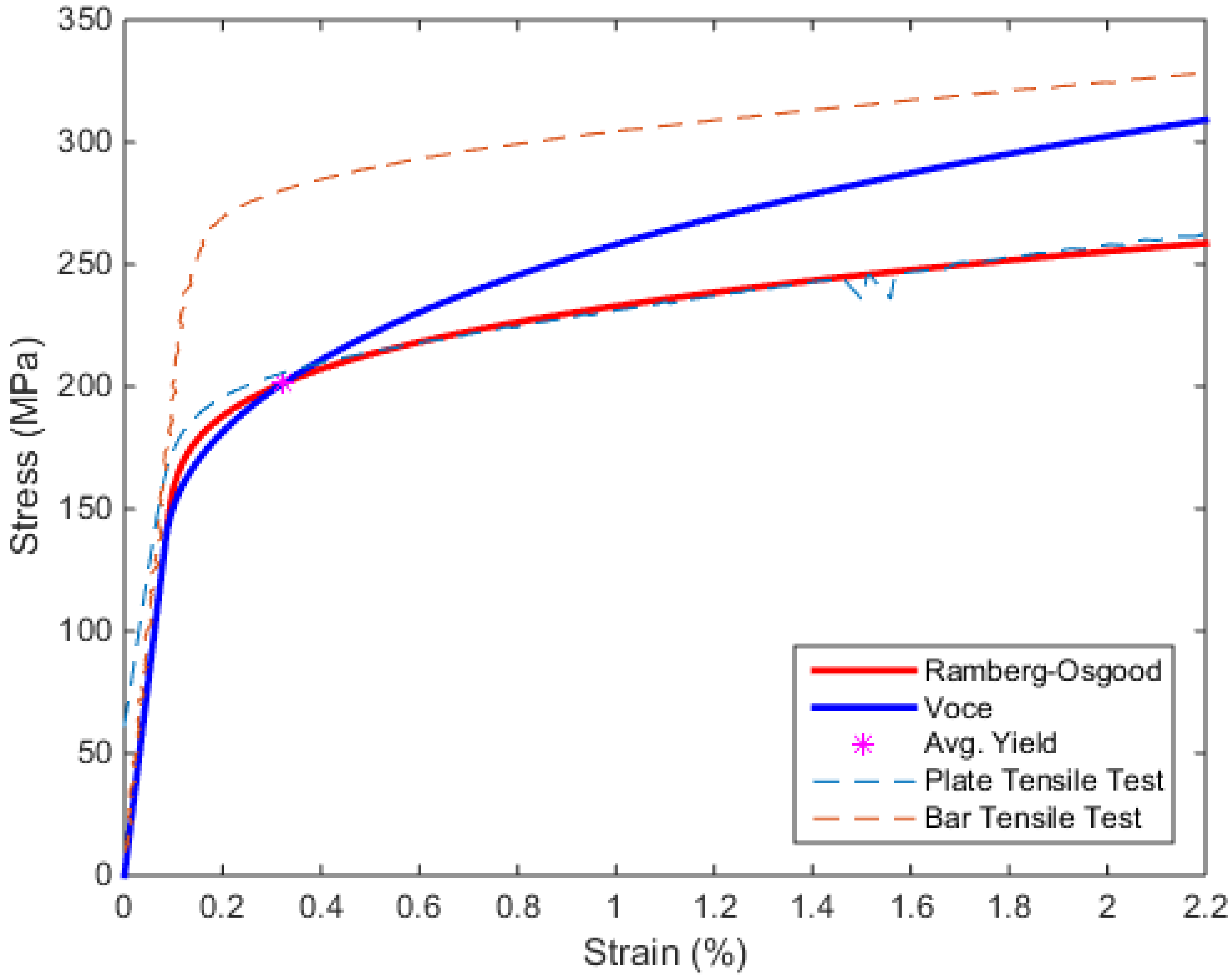
σ = stress

σ_{UTS} = ultimate tensile strength

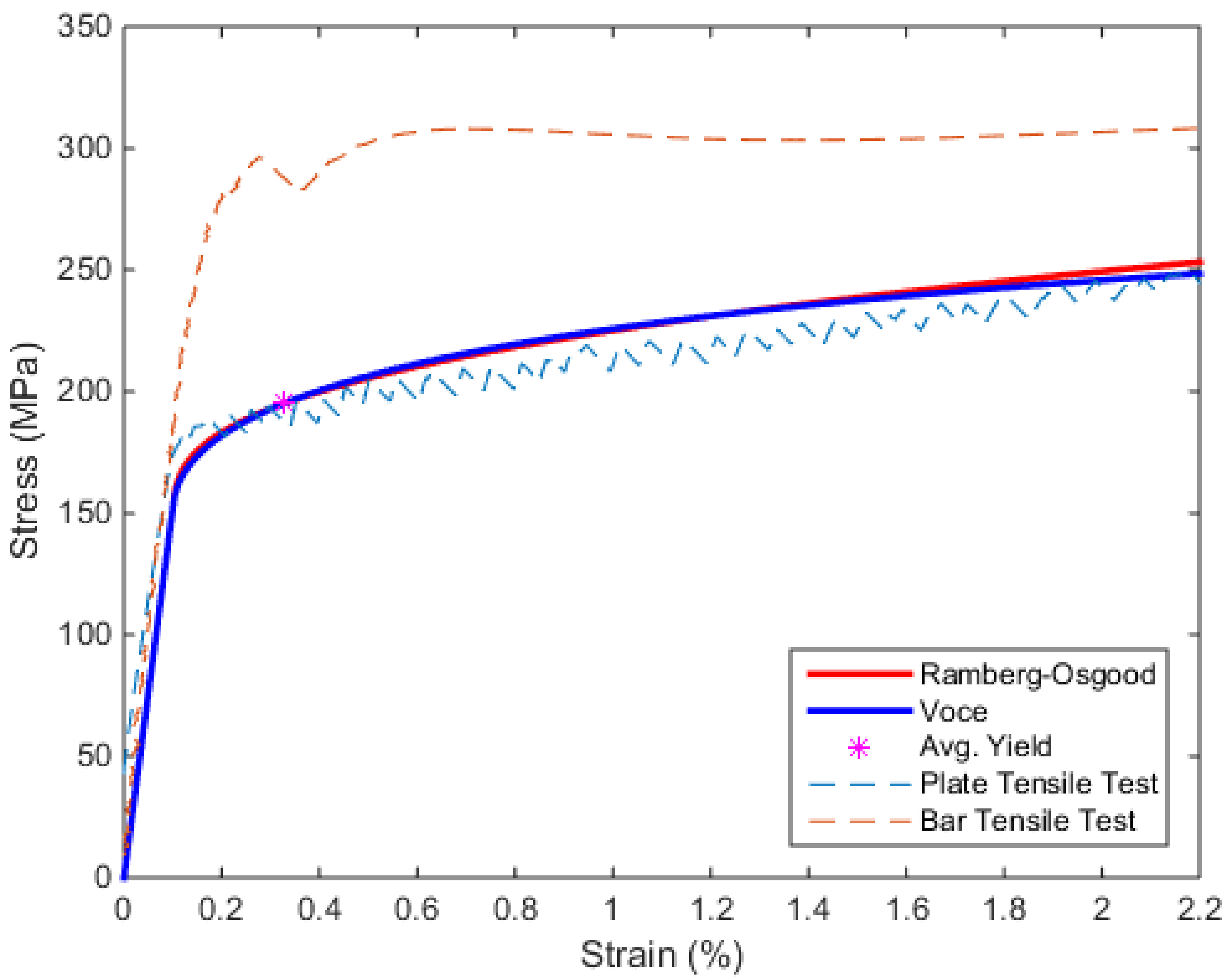
σ_L = proportional limit

- **The parameter b is chosen so the curve goes through the experimentally determined 0.2% offset yield.**

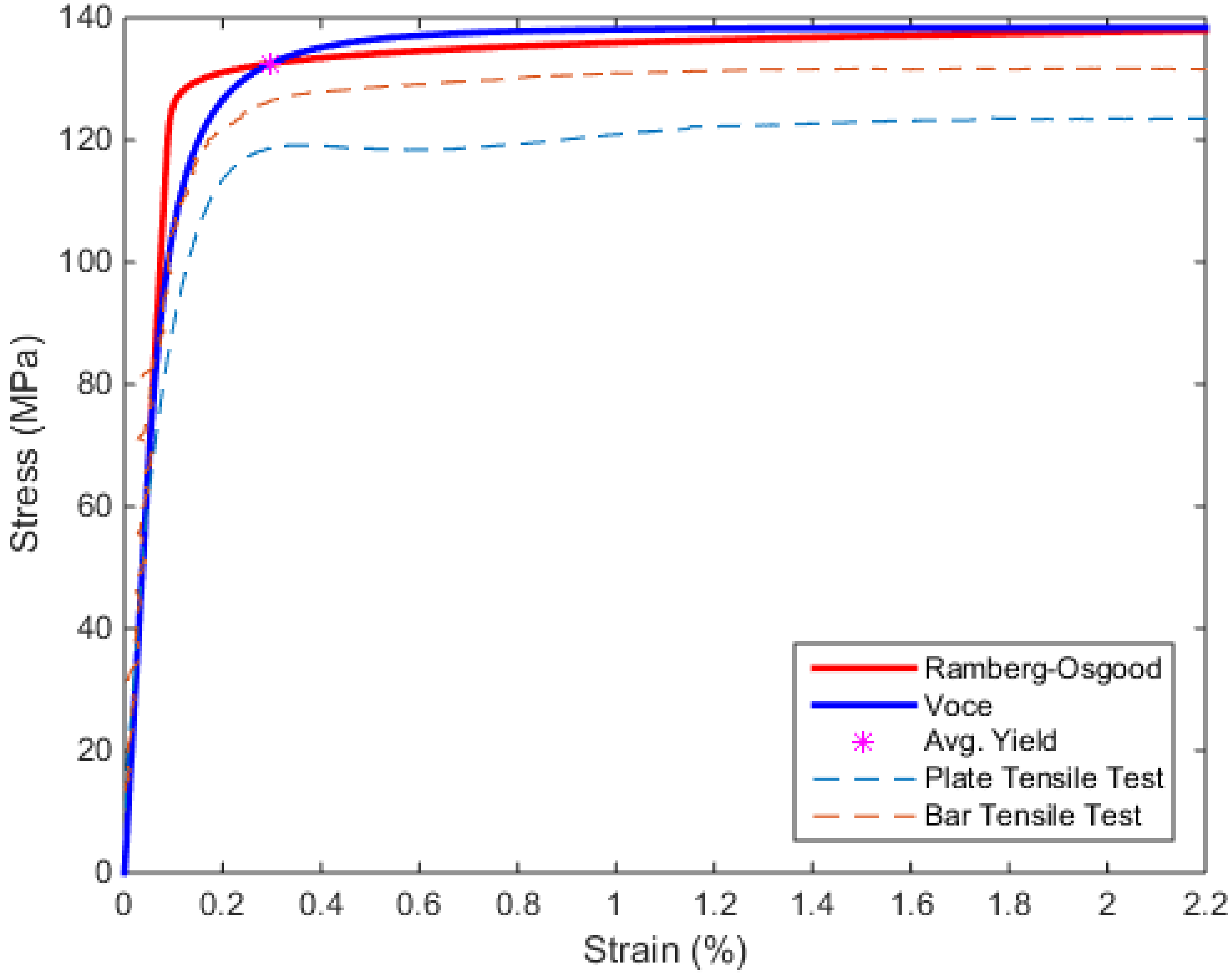
650ºC Hot Tensile Curve



800ºC Hot Tensile Curve



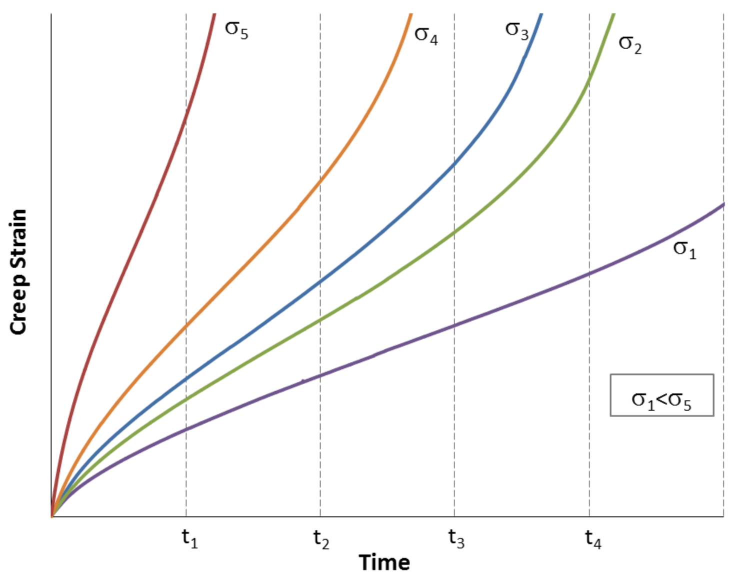
950ºC Hot Tensile Curve

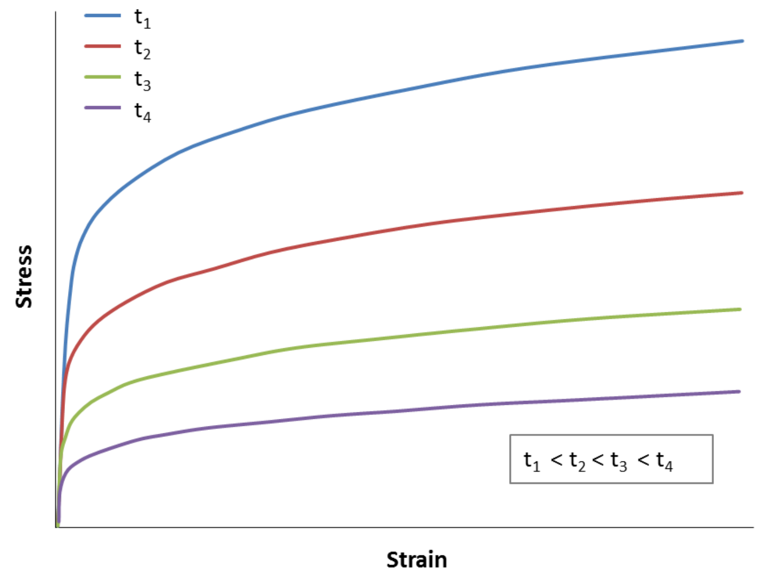


ISOCHRONOUS CURVES

What is an Isochronous Stress Strain Curve?

- **Isochronous curves are constant-time stress-strain curves for a given temperature**





Model

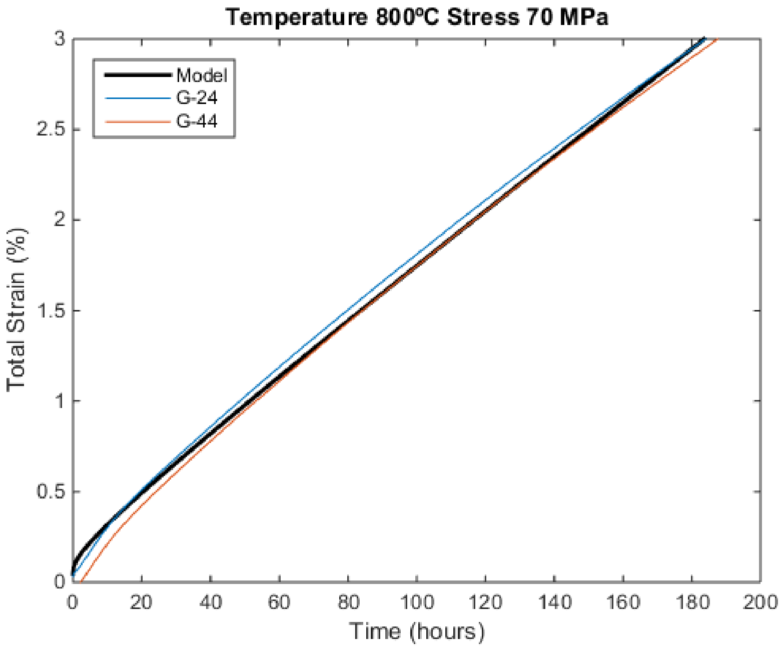
- The creep strain equation selected has been used by Swindeman (1998) and Booker (1990)

$$\varepsilon_c = at^{1/3} + mcr\,t$$

a = primary creep strain constant

mcr = minimum creep rate

- The equation was fit to all INL creep curves up to 3% strain for temperatures ≥ 800ºC
- The 750ºC creep curves entered tertiary creep too quickly, and the model did not provide a good fit to the data



Parametric Model

- **Based on these results, the stress and temperature dependence of the minimum creep rate was determined using the equation**

$$mcr = a\left(\frac{\sigma}{E}\right)^{b} e^{-c/RT}$$

σ = stress

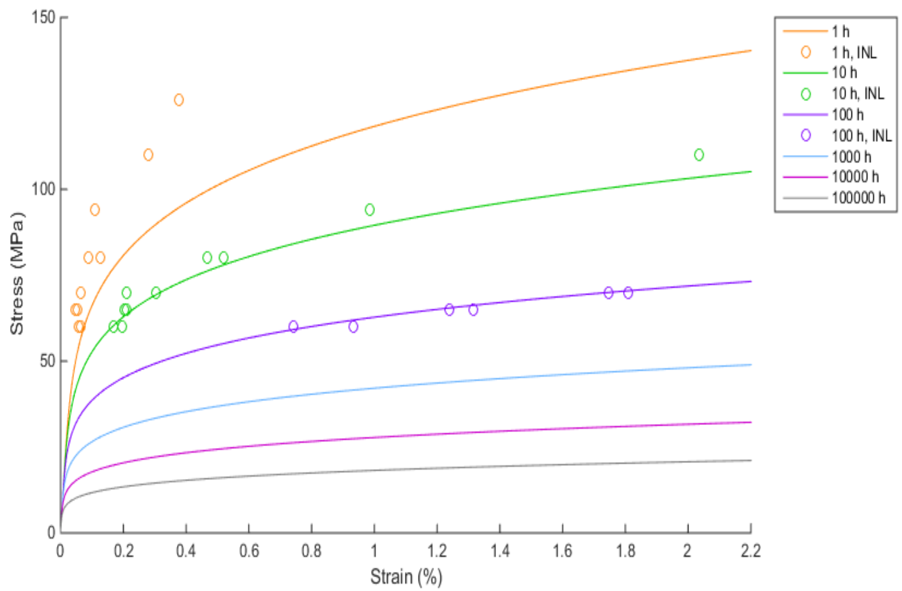
E = elastic modulus

R = universal gas constant

T = absolute temperature

a, b, and c are determined optimally

- **The stress and temperature dependence of the primary creep strain constant was quantified using the same equation form**
- **The isochronous curves can then be generated for each time/temperature combination**

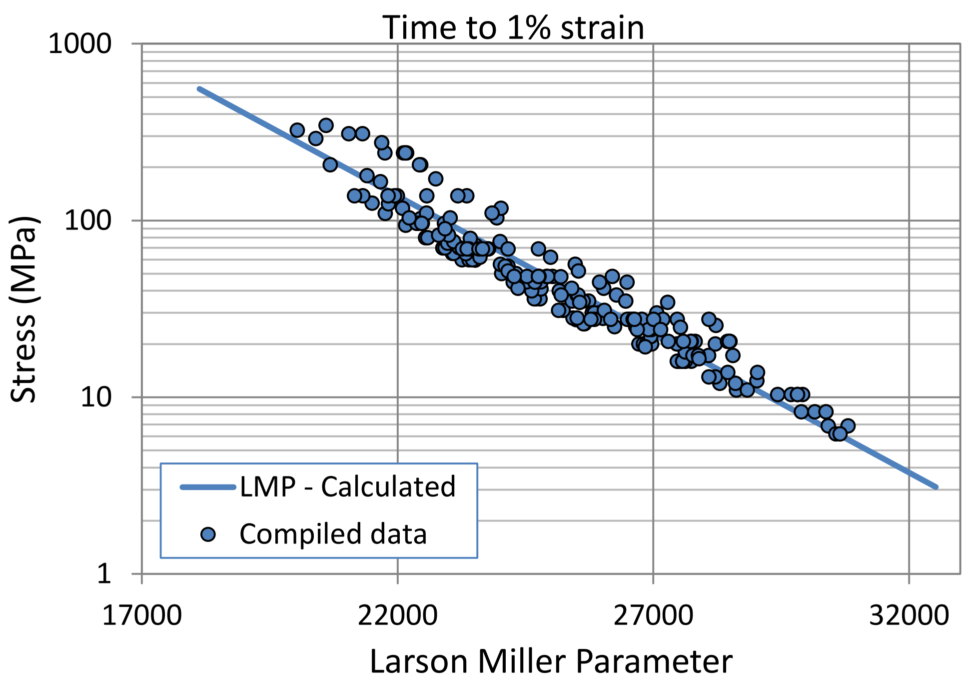


Shifting Isochronous Curves

- **Generate isochronous curves for the INL heat of Alloy 617**
- **Calculate the average stress value at 1% strain using the Larson-Miller equation for time to 1% strain (based on multiple heats)**

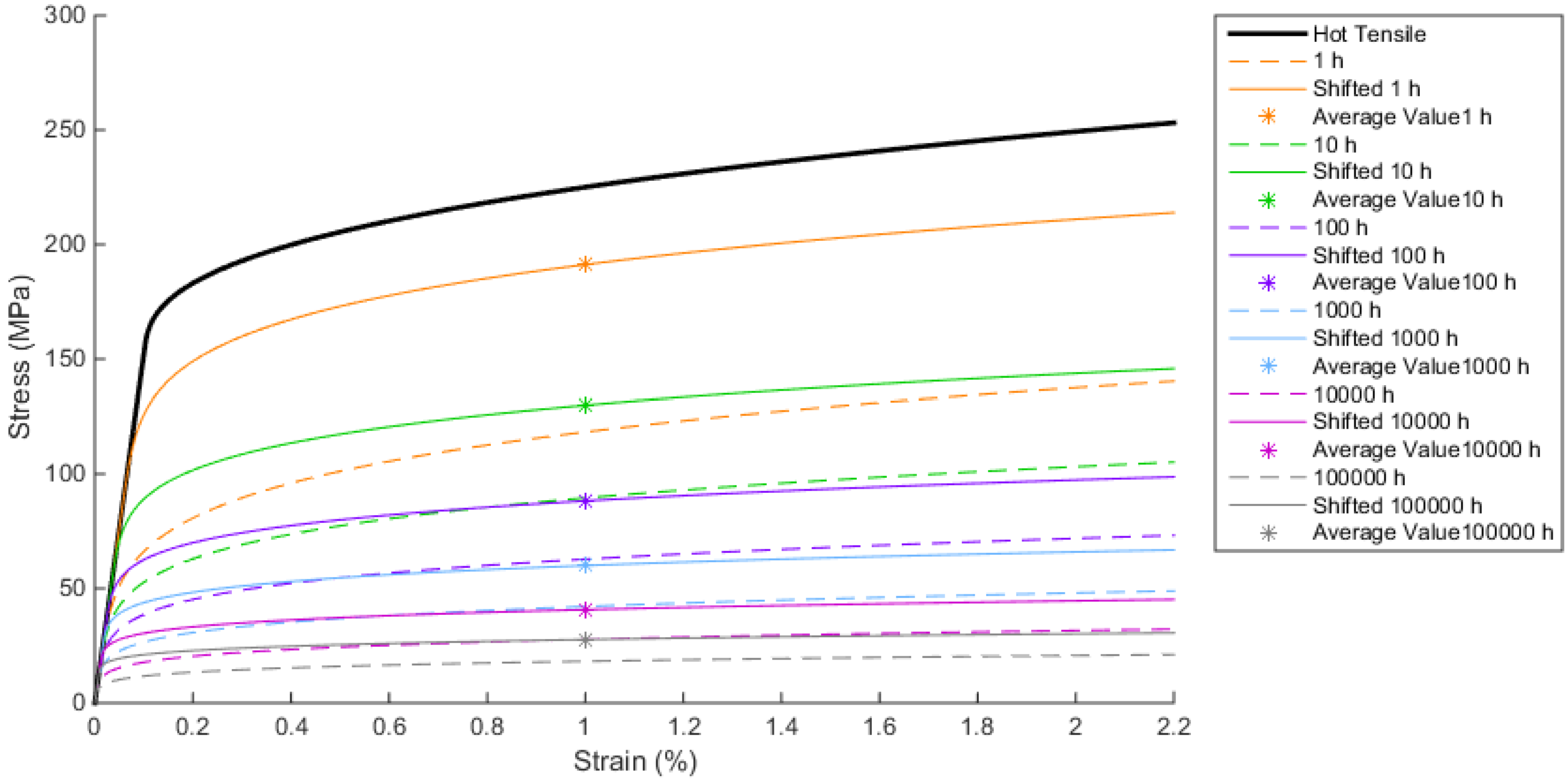
$$\boldsymbol{LMP} = 35663.0735 - 6388.5288\ log_{10}(\sigma)$$

$$log_{10}(t_{1\%}) = \frac{LMP}{T} - 19.64334$$



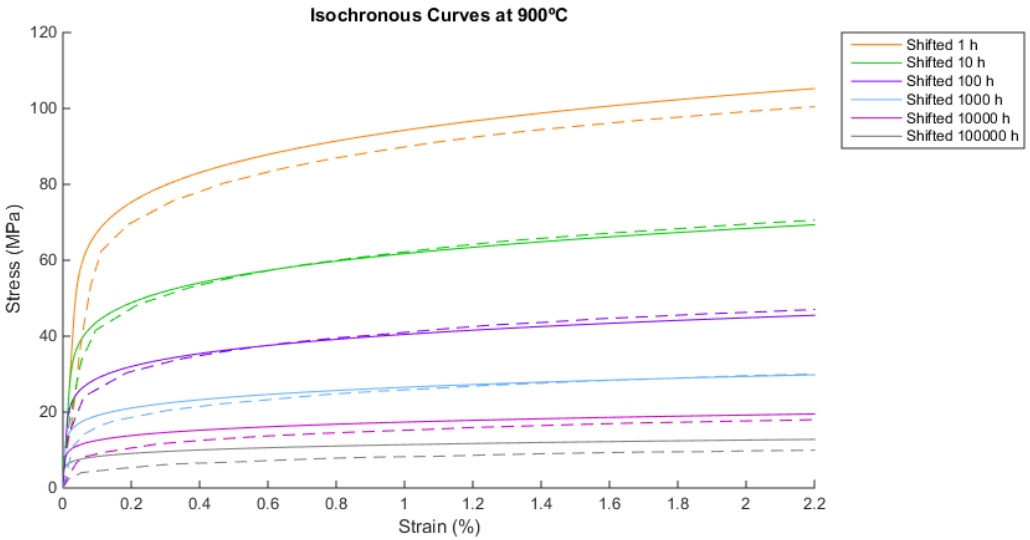
Shifting Isochronous Curves

- Shift the isochronous curves along the elastic stress-strain curve to go through the average stress value at 1% strain
- Exclude curves that exceed the hot tensile curve in the 2% strain range

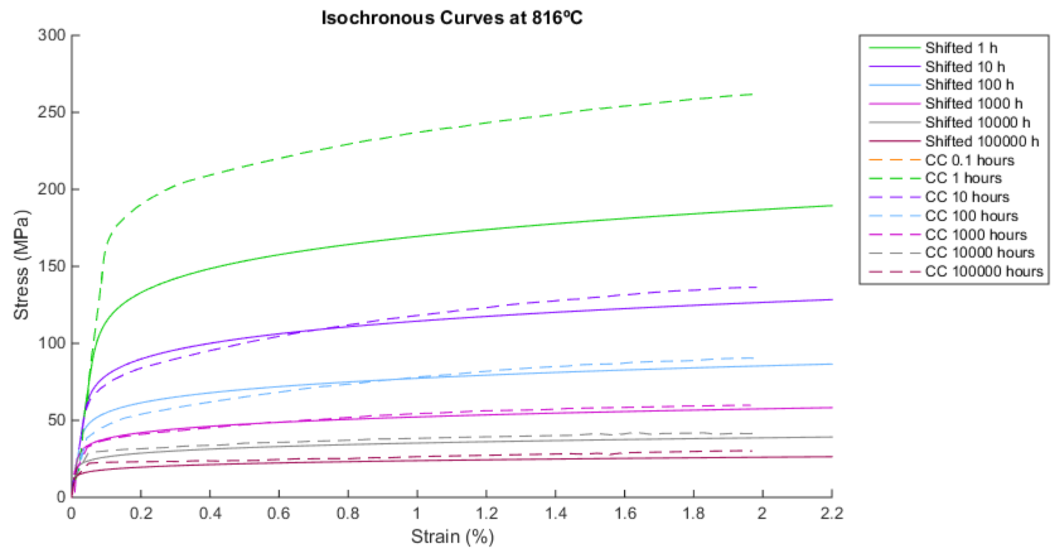


Comparing Isochronous Curves

- **German Isochronous Stress Strain Curves**

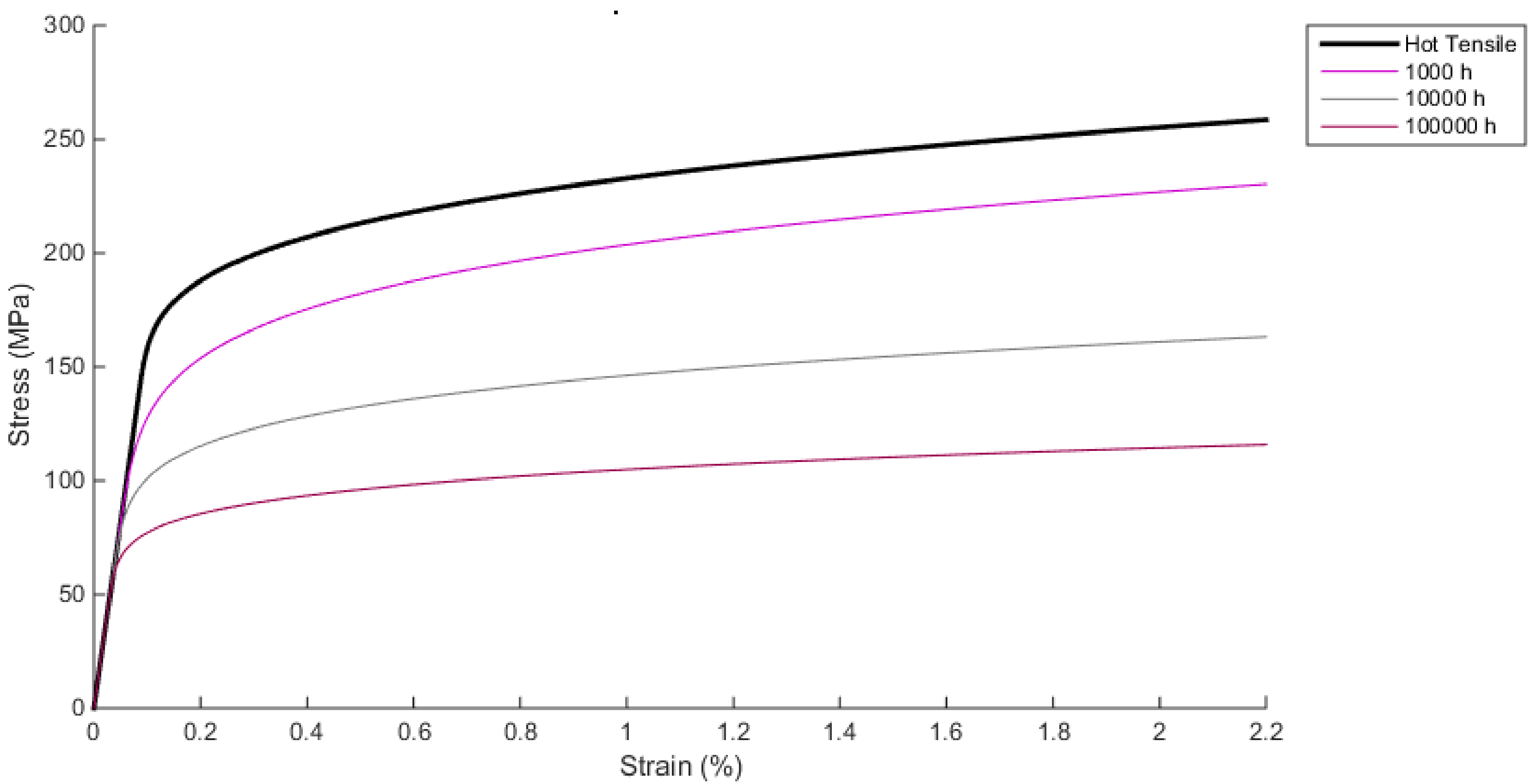


- **1990s Draft Code Case**

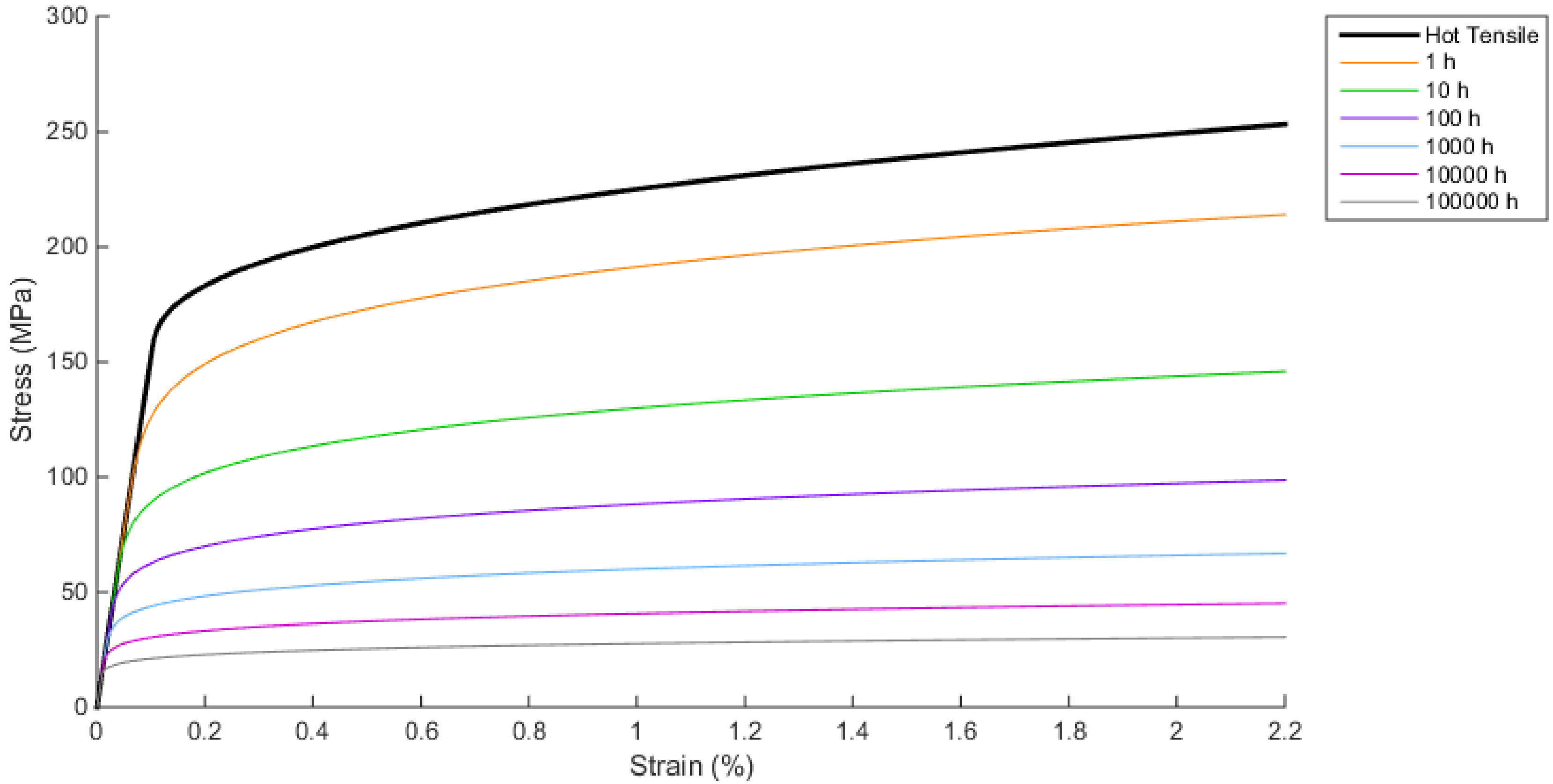


PROPOSED APPENDIX T FIGURES

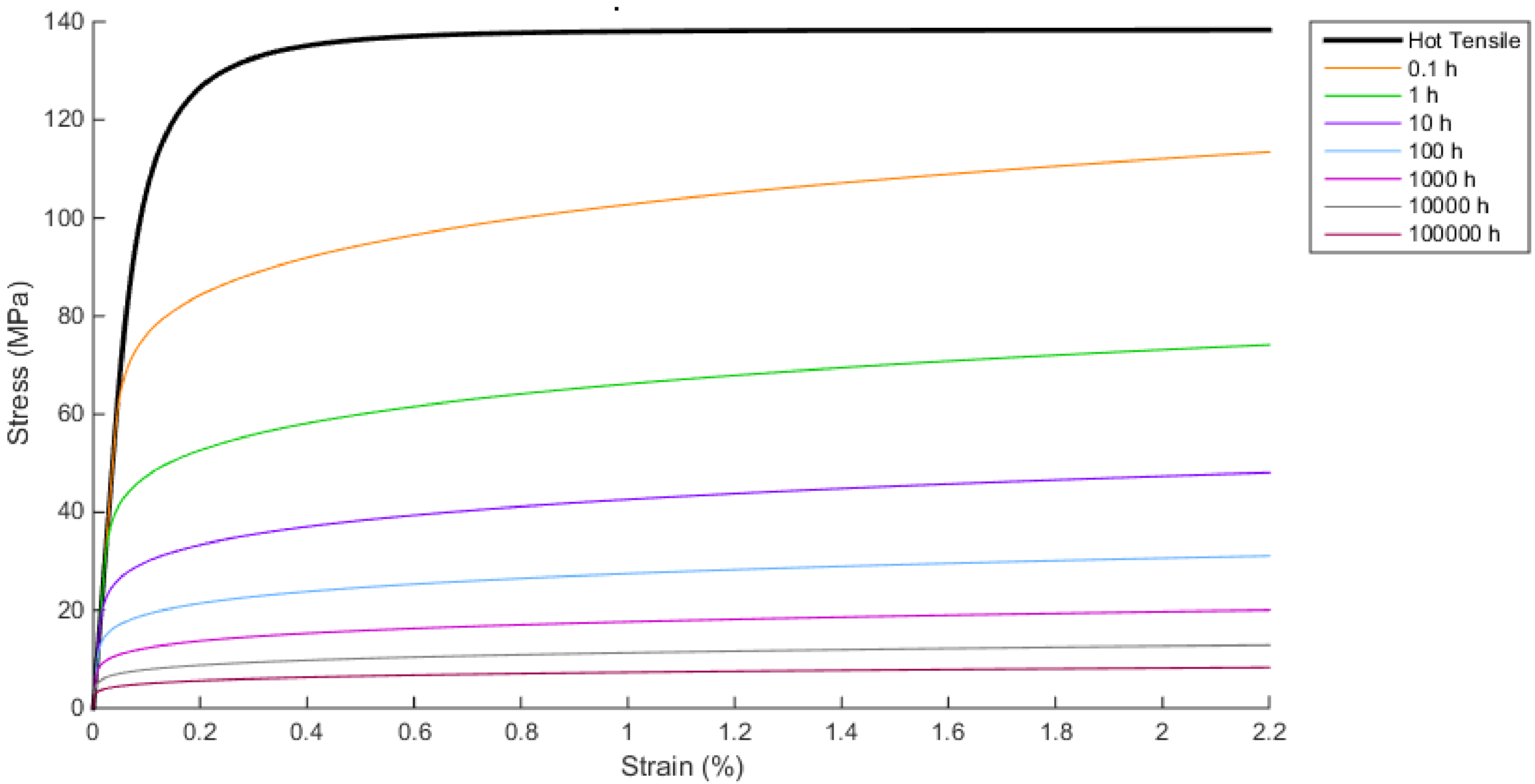
650ºC Results



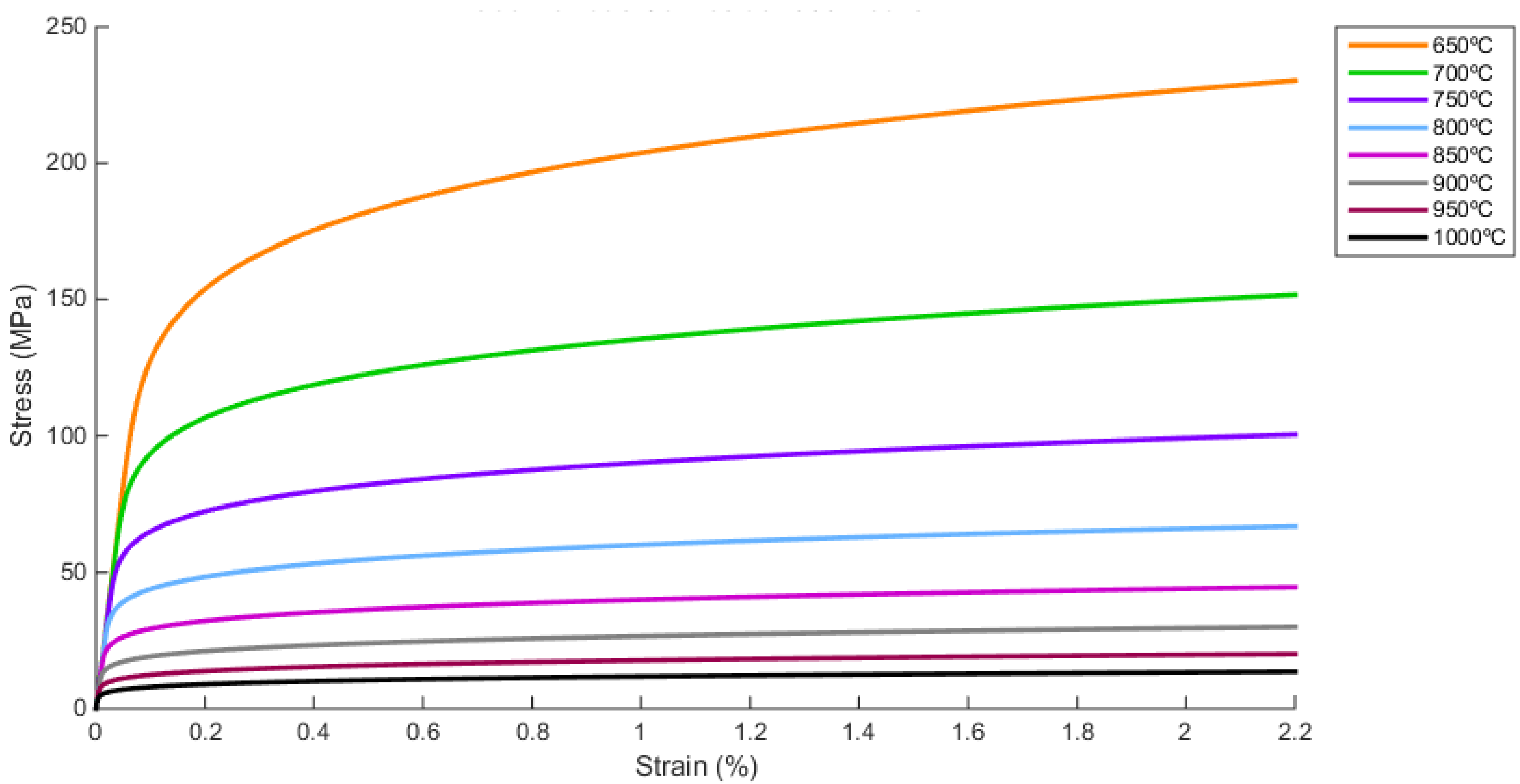
800ºC Results



950ºC Results



1000 hour Results



Conclusions

- **Hot tensile curves were generated**
  - Ramberg-Osgood equation from 650-800ºC
  - Voce equation above 800ºC
  - The curves were shifted to reflect the average behavior of Alloy 617
- **Isochronous curves were generated from 650-1000ºC**
  - 2-parameter creep strain model was used
  - The curves were shifted to reflect the average behavior of Alloy 617 at 1% strain
- **Work will continue**
  - Refine curves as needed
  - Generate curves for conventional units
  - Develop curves for lower temperatures where ISSC are required but no creep data is available