CANFSA

Center for Advanced Non-Ferrous Structural Alloys
An Industry/University Cooperative Research Center

Understanding Influence of Heat-Treatment on Serrated Yielding in a Ni Superalloy

Fall Meeting

October 13th – 15th 2020

Student: Nathan Brown (Mines Undergraduate)

Faculty: Amy Clarke, Kester Clarke (Mines)

Industrial Mentors: Chris Gatto (Honeywell), Bruce Antolovich (ATI)

NSF COLORADO SCHOOL OF MINES IOWA STATE UNIVERSITY

Understanding Influence of Heat-Treatment on Serrated Yielding in a Ni Superalloy

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- Student: Nathan Brown (Mines)
- Advisor(s): Kester Clarke, Amy Clarke (Mines)

Project Duration

REU+MURF: May 2020 – May 2021

- Problem: Ni-based superalloys exhibit serrated yielding which results in increased strain at constant stress.
- Objective: Understand the origins of localized deformation that accompanies serrated yielding and determine/control the mechanisms responsible.
- Benefit: Improving the mechanical properties of Ni-based superalloys can lead to better performance and more efficient turbine engines.

Recent Progress

- Thermal Gradient Testing on Gleeble
- Lab training
- Investigation of mechanisms associated with serrated yielding.
- Literature review of serrated yielding in Ni-based superalloys.

Metrics

Description	% Complete	Status
1. Literature review	35%	●
2. Obtain materials	30%	●
3. Develop experimental matrix	5%	●
4. Perform experiments (Fall 2020)	10%	●

Industrial Relevance

- Ni-based superalloys are used in turbine engine disks
  - Flight-critical components
- Wrought versus powder
- Thermomechanical processing
- Mechanical response

High pressure turbine disk Approximately 50cm diameter

Approximately 1m diameter

https://jetartaviationshop.co.uk/product/raf-sepecat-jaguar-aircraft-rolls-royce-adour-jet-engine-hp-turbine-disc-aviation-art/

R.J. Mitchell, J.A. Lemsky, R. Ramanathan, H.Y. Li, K.M. Perkins, L.D. Connor, Process development & microstructure & mechanical property evaluation of a dual microstructure heat treated advanced nickel disc alloy, Proc. Int. Symp. Superalloys. (2008)

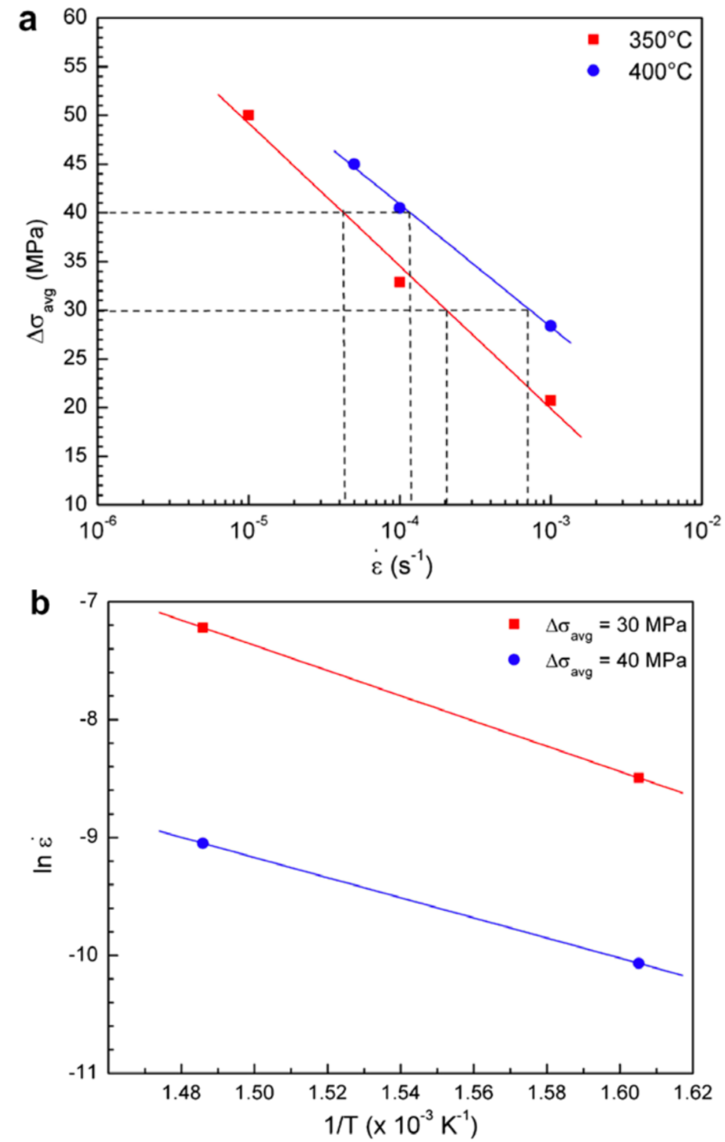
Outline

- Recent literature findings
- Equipment capabilities
- Current Work
- Next Steps
- Challenges and Opportunities

Alloy 720 LI

- Yield strength, ultimate strength, elongation, reduction in area, and work hardening rate are not affected by DSA
- Locking of mobile dislocations by substitutional alloying elements is responsible for the DSA
- Exhibits predominantly type C and type A serrations

$$Q = -R\left[\frac{\Delta \ln \dot{\varepsilon}}{\Delta 1/T}\right]_{\Delta\sigma,\varepsilon}$$



Activation energy for Ni 720 LI

K. Gopinath, A.K. Gogia, S. V. Kamat, U. Ramamurty, Dynamic strain ageing in Ni-base superalloy 720Li, Acta Mater. 57 (2009)

Activation energy calculations for discontinuous yielding in Inconel 718SPF

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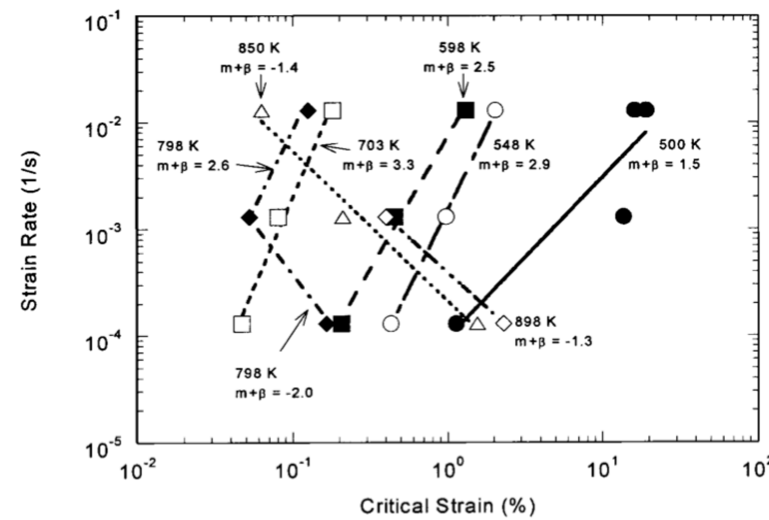
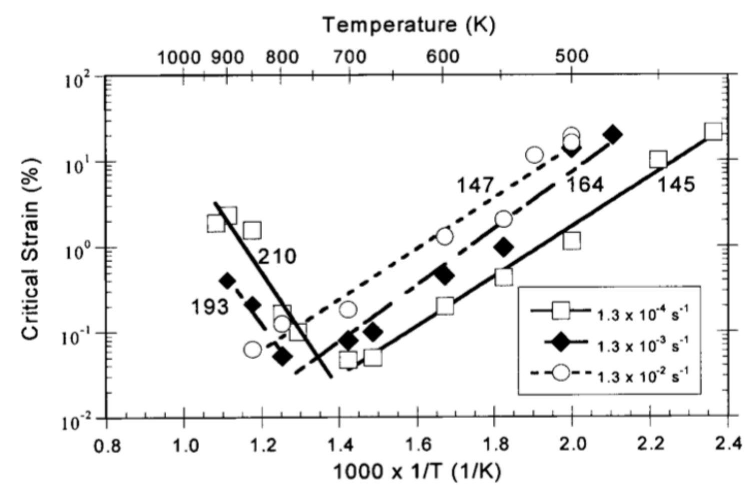
- $.5 \leq m+\beta \leq 1$
  - Interstitial solutes are responsible
- $2 \leq m+\beta \leq 3$
  - Substitutional solutes are responsible
- $Q = \text{slope} \times [m+\beta]$
- Using m+β to determine mechanisms is not always accurate
  - There are many assumptions and depend on what method was used to evaluate it.

$$\varepsilon_c^{m+\beta} = K\dot{\varepsilon}\exp(Q/RT)$$



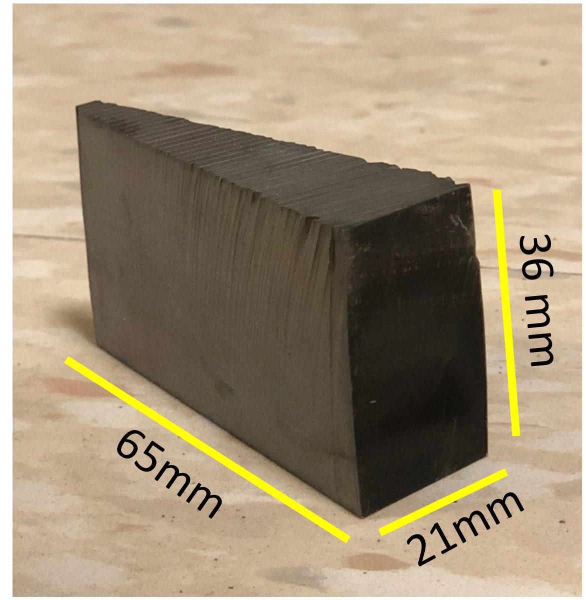
(a)



(b)

C.L. Hale, W.S. Rollings, M.L. Weaver, Activation energy calculations for discontinuos yielding in inconel 718SPF, Mater. Sci. Eng. A. 300 (2001)

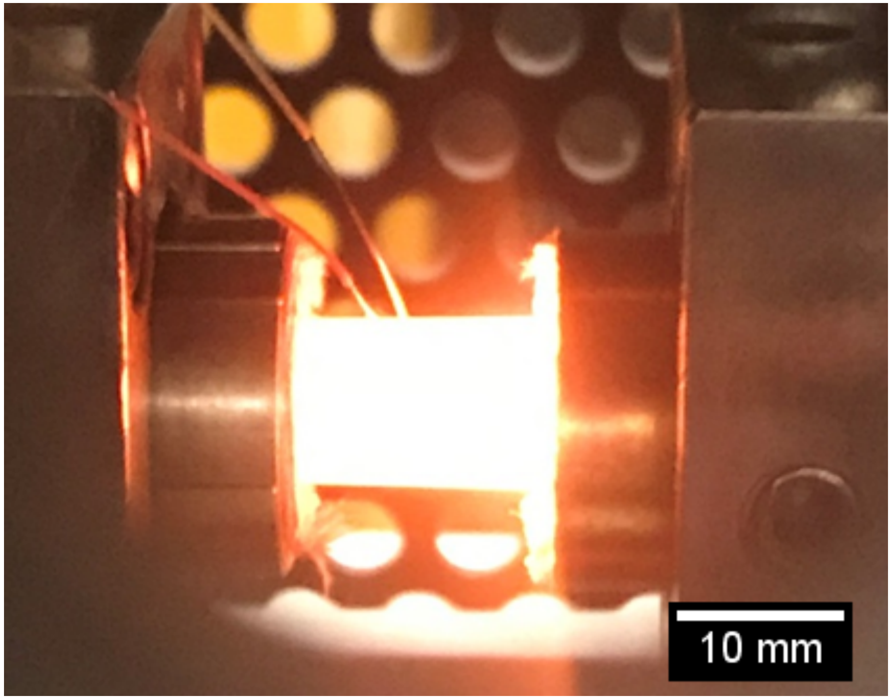
Material – Alloy 10



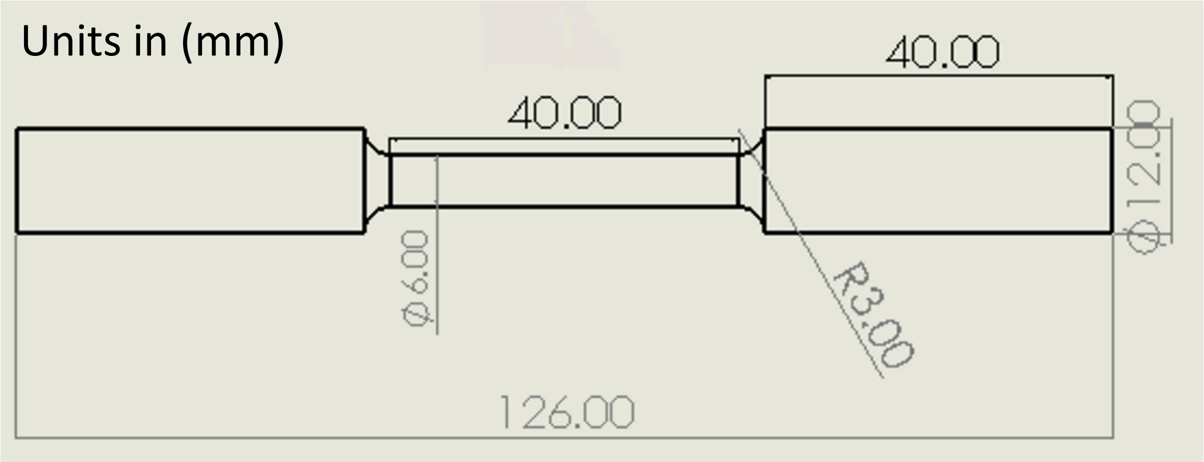
https://patentimages.storage.googleapis.com/61/bc/8c/c8c7488c13cb33/EP1658388B1.pdf

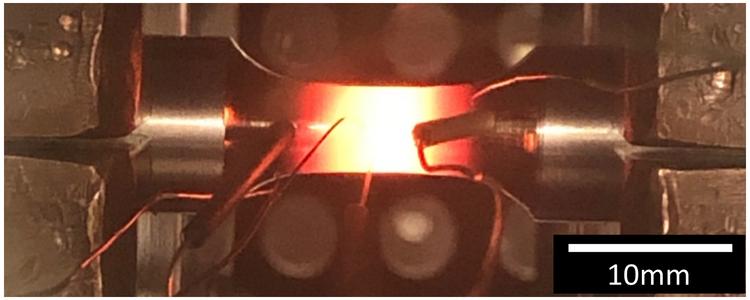
Equipment Capabilities

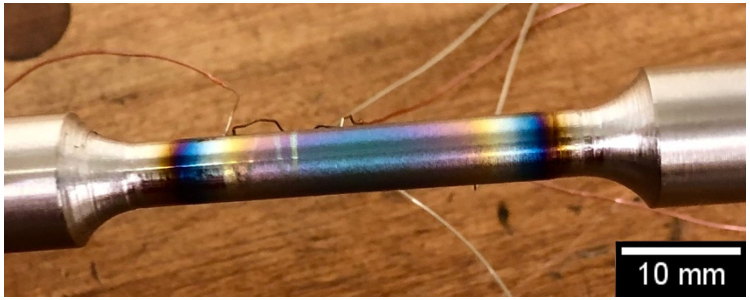
- Clamshell furnace coupled with electromechanical load frame
  - Maximum working temperature 400 ˚C
- Gleeble 3500
  - Maximum working temperature 1200 ˚C
  - Hydraulically controlled (slow strain rates)



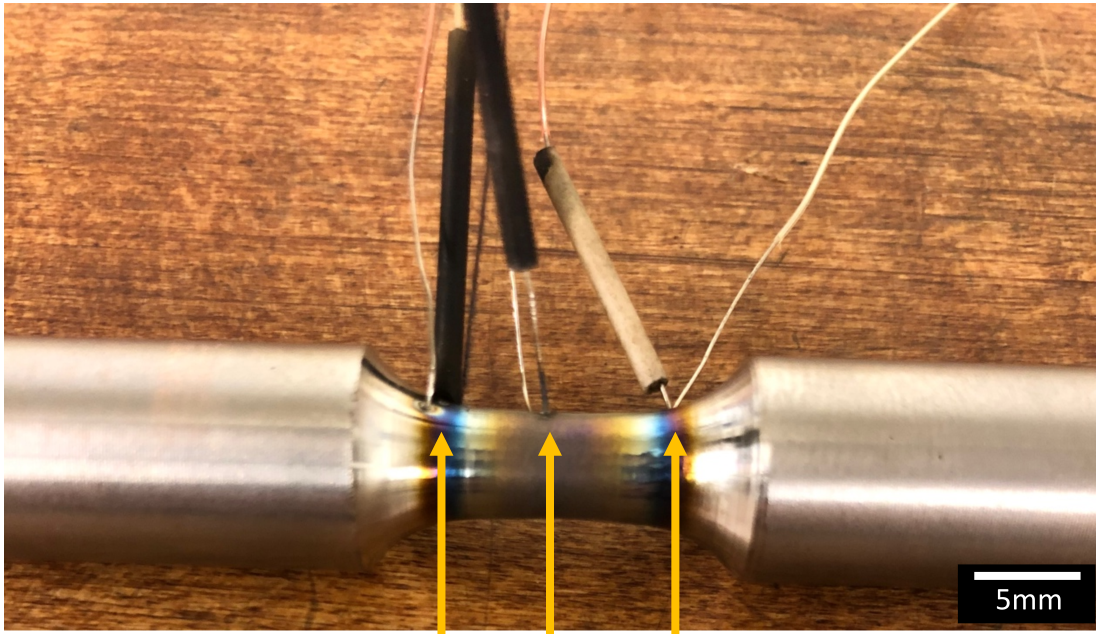
Recent Work: Sample Geometry Thermal Gradient





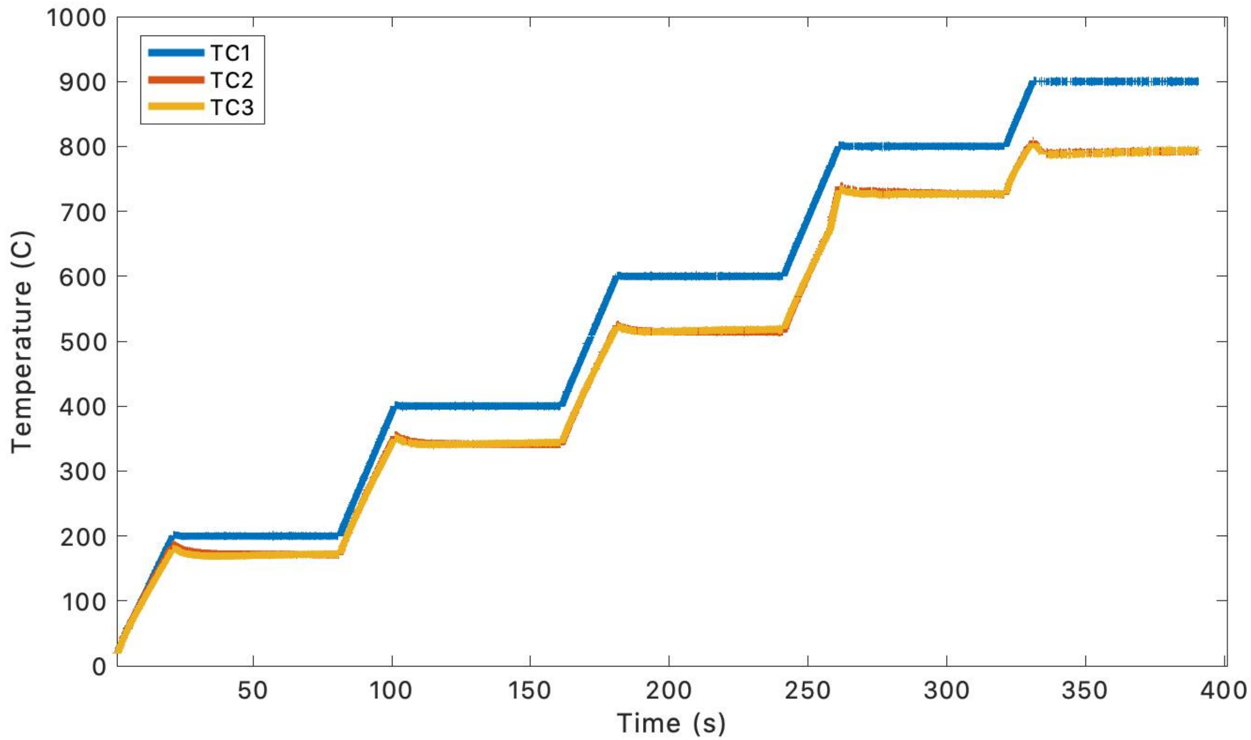


Recent Work: Sample Geometry Thermal Gradient



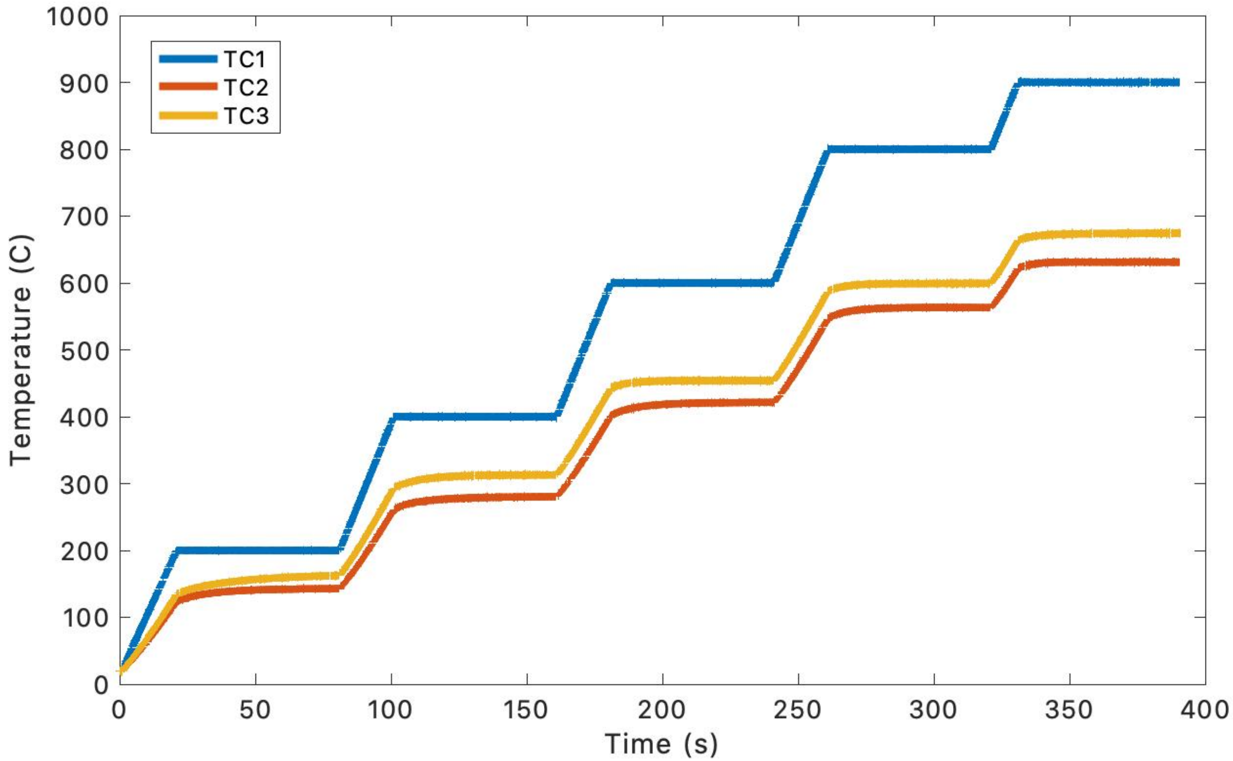
TC2 TC1 TC3

Recent Work: Sample Geometry Thermal Gradient



304 Stainless Steel 40mm Gauge Length

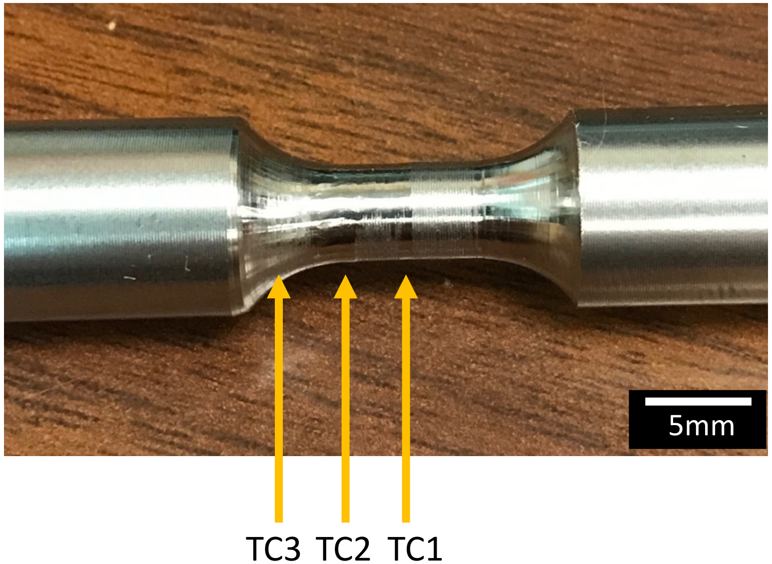
Recent Work: Sample Geometry Thermal Gradient

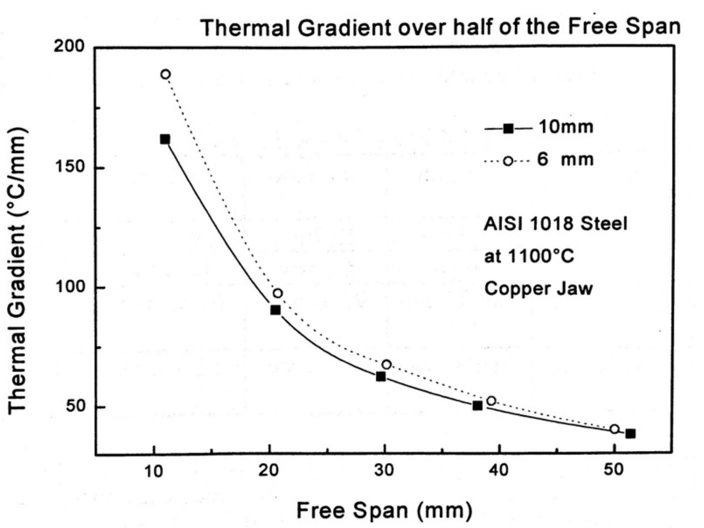


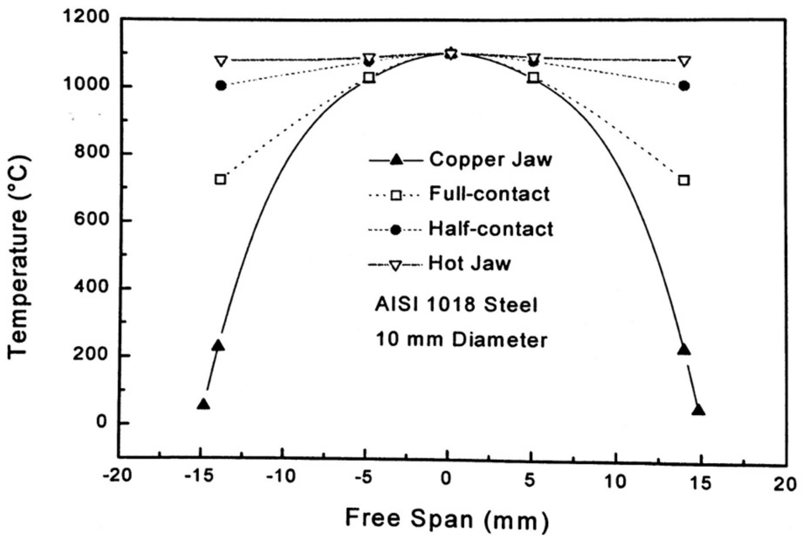
304 Stainless Steel 10mm Gauge Length

Future Work

- Free span distances
- Grip selection
- Thermocouple placement







Challenges & Opportunities

- Finalize Sample Geometry
  - Limit thermal gradient
- Start initial microstructure characterization
  - Undeformed
  - Deformed at room temperature
- Mechanical testing
  - What conditions?
    - Tensile versus compression
    - Testing until failure?
    - Strain rate

References

[1] https://jetartaviationshop.co.uk/product/raf-sepecat-jaguar-aircraft-rolls-royce-adour-jet-engine-hp-turbine-disc-aviation-art/

[2]R.J. Mitchell, J.A. Lemsky, R. Ramanathan, H.Y. Li, K.M. Perkins, L.D. Connor, Process development & microstructure & mechanical property evaluation of a dual microstructure heat treated advanced nickel disc alloy, Proc. Int. Symp. Superalloys. (2008)

[3]K. Gopinath, A.K. Gogia, S. V. Kamat, U. Ramamurty, Dynamic strain ageing in Ni-base superalloy 720Li, Acta Mater. 57 (2009) 1243–1253. https://doi.org/10.1016/j.actamat.2008.11.005.

[4]C.L. Hale, W.S. Rollings, M.L. Weaver, Activation energy calculations for discontinuos yielding in inconel 718SPF, Mater. Sci. Eng. A. 300 (2001) 153–164. https://doi.org/10.1016/S0921-5093(00)01470-2.

[5] https://patentimages.storage.googleapis.com/61/bc/8c/c8c7488c13cb33/EP1658388B1.pdf