Project 34: In-situ Observation of Phase and Texture Evolution Preceding Abnormal Grain Growth in Ni-based Aerospace Alloys

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Project 34 - In-situ Observation of Phase and Texture Evolution Preceding Abnormal Grain Growth in Ni-based Aerospace Alloys

- Student: Byron McArthur (Mines)
- Advisors: Amy Clarke, Kester Clarke (Mines)

Project Duration

PhD: Nov. 2017 to Dec. 2020

Problem: Abnormal grain growth in Ni-based superalloys, occurring as a result of forging parameters, significantly reduces mechanical properties.

Objective: Determine the mechanism of abnormal grain growth in Ni-based superalloys using ex-situ and in-situ characterization techniques.

Benefit: Improved mechanical properties for turbine disc alloys.

Recent Progress

- Preliminary literature review
- Initial forgings performed
- Beginning material characterization
- Recreated abnormal grain growth phenomena

Metrics

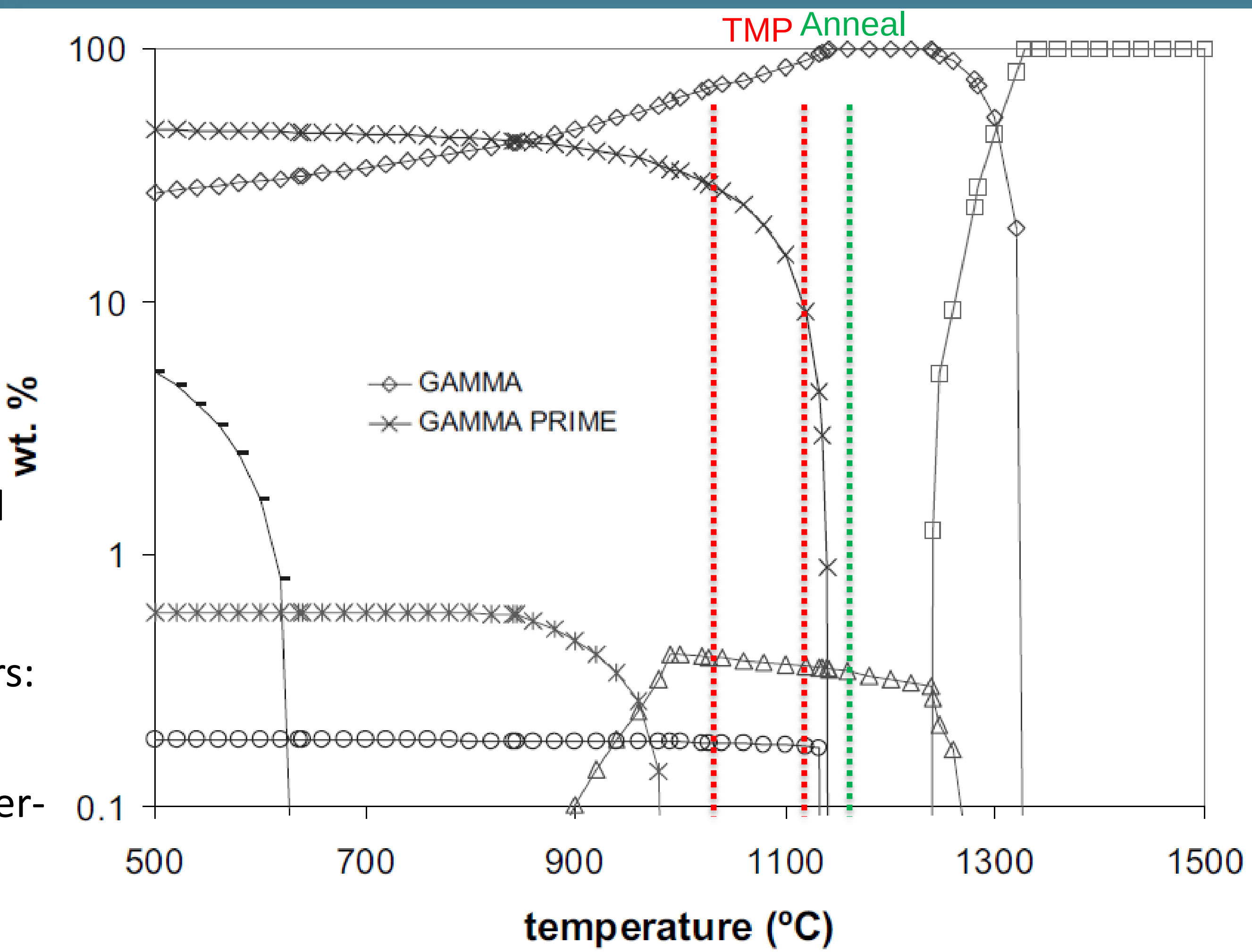
Description	% Complete	Status
1. Literature review	50%	●
2. Explore abnormal grain growth forging parameters for RR1000	15%	●
3. Ex-situ and interrupted material characterization	10%	●
4. Develop and test theory to explain abnormal grain growth phenomena	5%	●
5. Perform in-situ microscopy with a synchrotron source (HEDM) to demonstrate phenomena	0%	●

Industrial Relevance

- Turbine engine discs are flight-critical components
- Forging parameters may induce abnormal grain growth (AGG)
  - Reduction in fatigue life
- Applicable to other superalloys and material systems

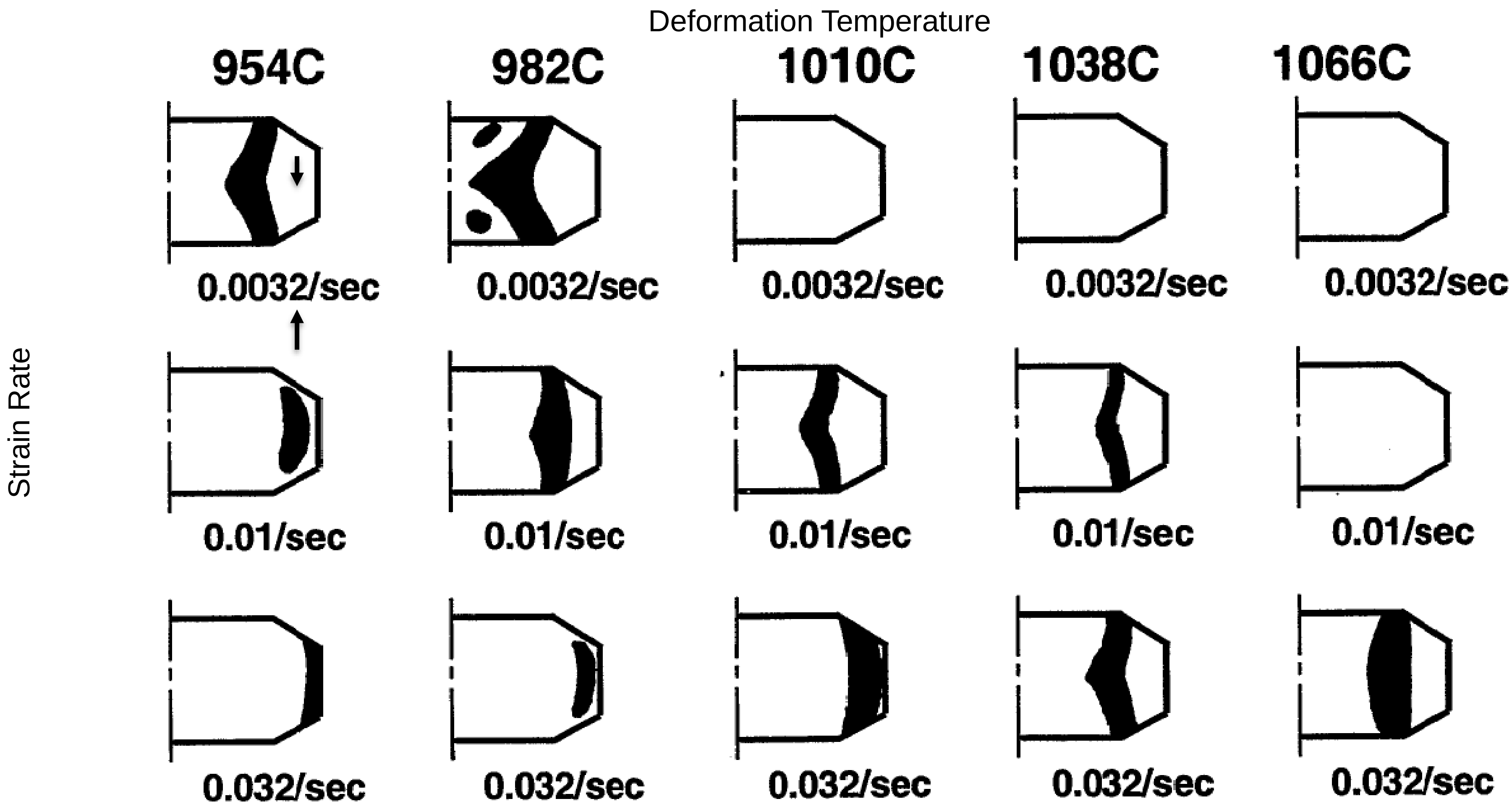
Material Overview

- Material: RR1000
  - γ - γ’
- Processing:
  - Powder-metallurgy
  - Extruded
  - TMP
    - 1035-1110°C
  - Super γ’ solvus hold
    - 1150/1170°C
    - < 1 Hr
- Critical AGG parameters:
  - $\dot{\varepsilon}$
  - Heating rate to super-γ’ solvus hold
  - TMP temperature



Hardy, M. C., Zirbel, B., Shen, G., & Shankar, R. (2004). Developing damage tolerance and creep resistance in a high strength nickel alloy for disc applications. *Superalloys 2004*, 83–90.

Occurrence of AGG (R'88DT) Double-Cone Compression



Raymond, E., Huron, E., & Srivasta, S. (2000). Control of Grain Size Via Forging Strain Rate Limits for R'88DT. *Superalloys*, 49–58.

Possible Contributions

1. γ' coherency loss
   - Dynamic recrystallization
   - Dislocation interactions
     - Orowan looping
   - Primary/secondary/tertiary γ' coherency & dissolution
2. Special boundaries
   - Mobile boundaries
   - Possible twinning contributions
3. Stored energy difference in grains
   - Local gradients in plastic deformation lead to preferential grain growth

Prior literature suggests multiple contributions

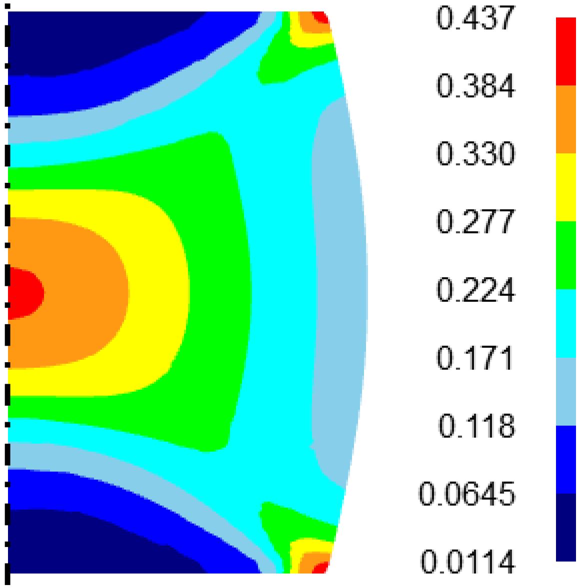
Ex-situ Experiments

- Recreate AGG in Gleeble
  - Controlled T, $\dot{T}$, ε, and $\dot{\varepsilon}$
- Obtain load-displacement curves
- Model values in DEFORM® software
  - Local strains, strain rates, temperatures
- Ex-situ characterization
  - Search for abnormal grain growth
  - Perform interrupted testing

*note: testing so far has been performed on one of two supplied material conditions

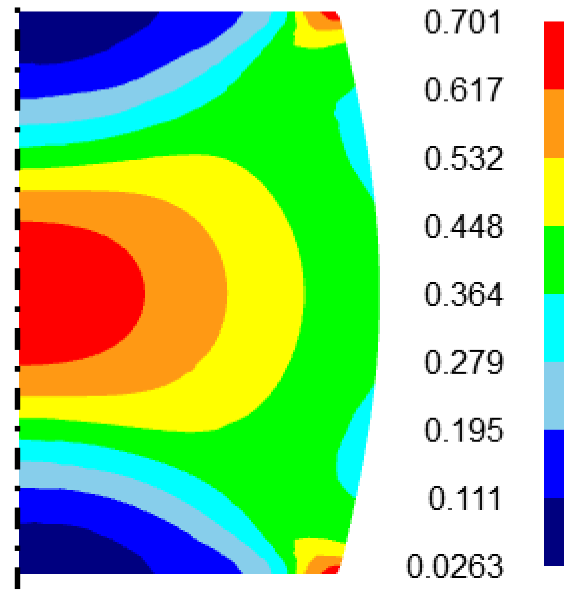
FEA Modeling - Preliminary

Local Strain Rates



Centerline

Local Strains



Centerline

Input parameters of ε= 0.33 and $\dot{\varepsilon}$=0.3. Basic material properties (to be refined)

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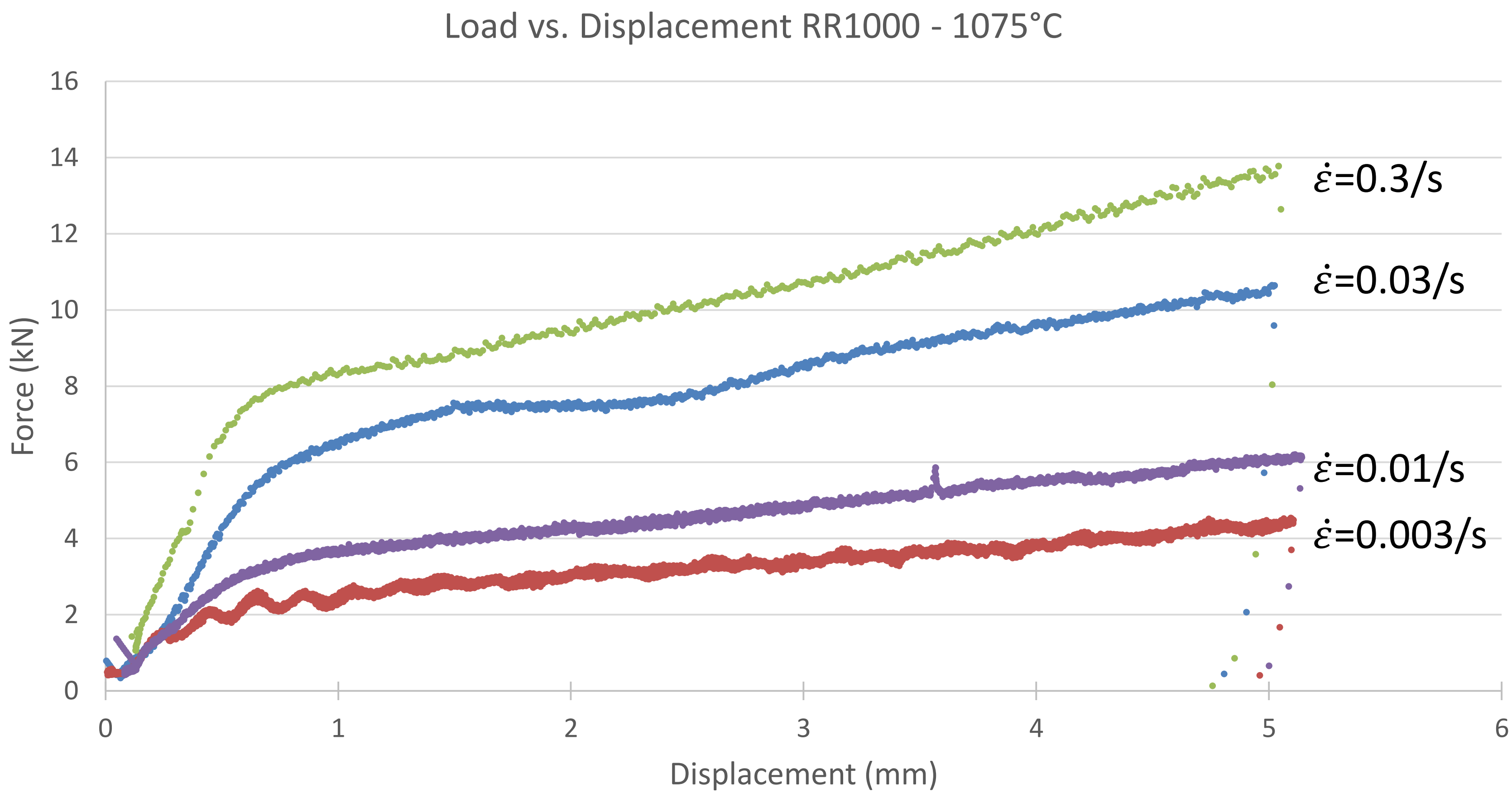
FEA Modeling - Continued

- Local strain accumulation and strain rates greatly influenced by local flow stresses and temperatures
- Accurate modeling requires high fidelity data input
- Need more Gleeble load-displacement data

Gleeble Load–Displacement Curves

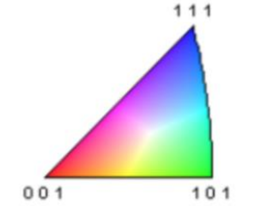


Material Characterization

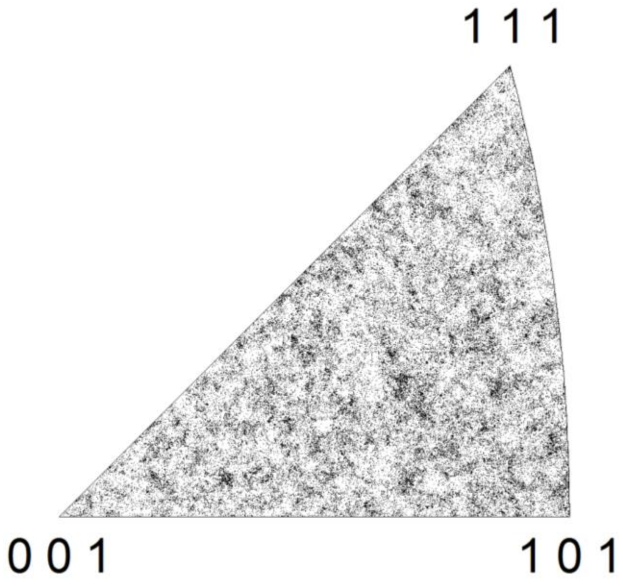
Electron Backscatter Diffraction (EBSD)

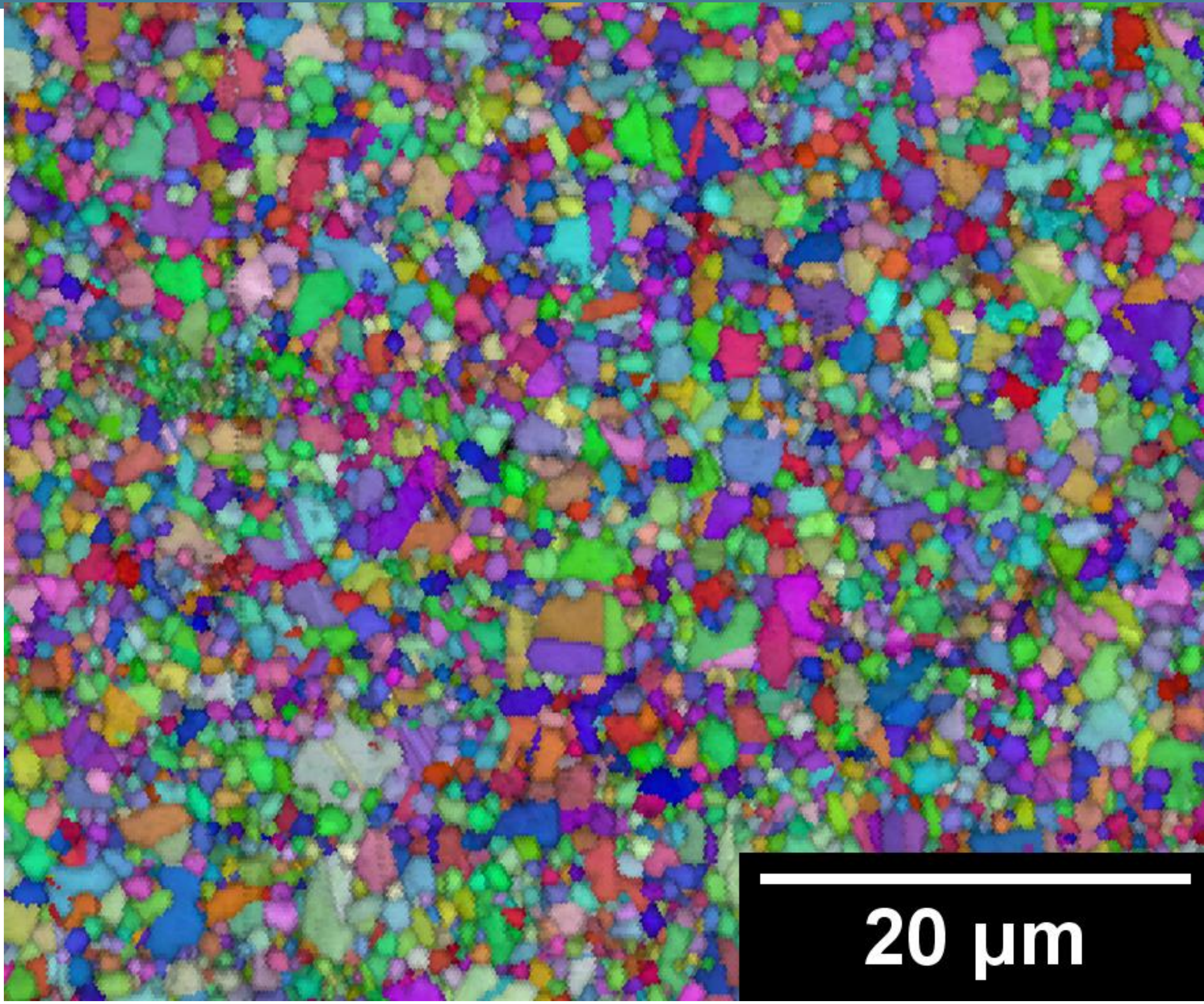
- Determine grain size distribution
- Local stored energy
  - Grain Reference Orientation Deviation (GROD)
    - Indication of dislocation density within grain
- Follow TMP processing route:
  - As received
  - Forged
  - Heat treated

As-Received Material



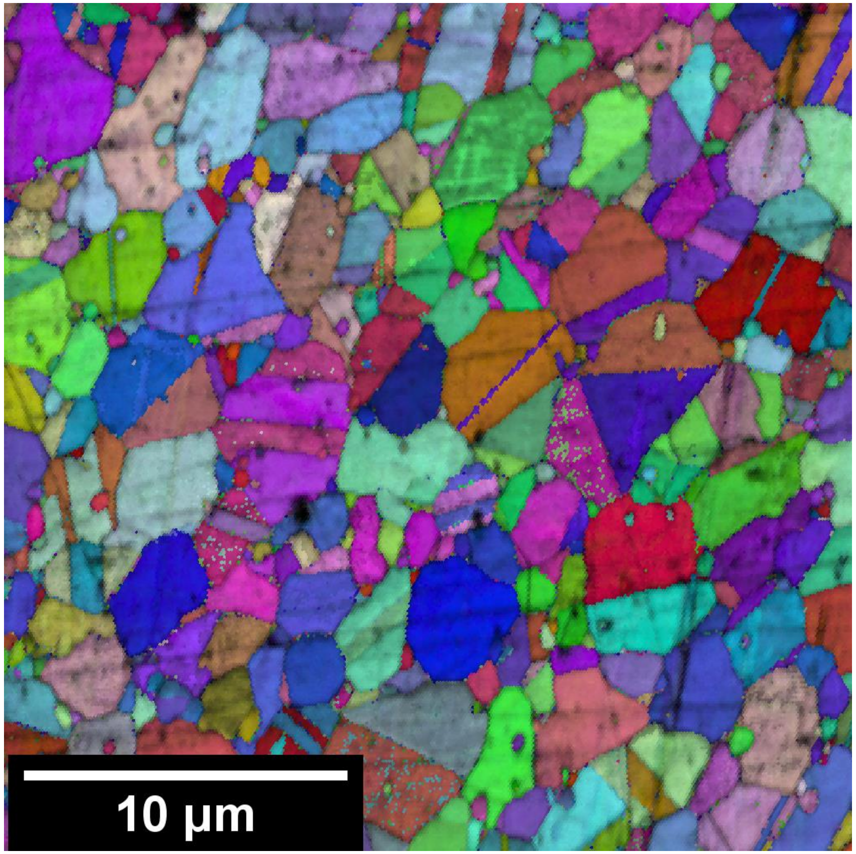
- Isotropic material
- Small starting grain size



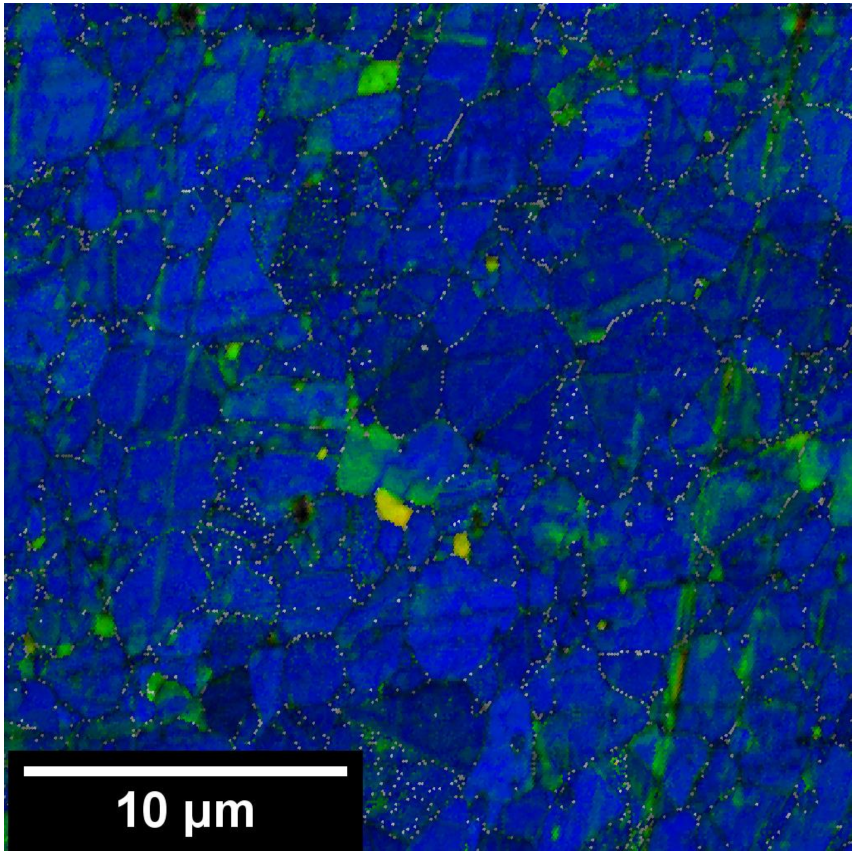


Microstructure – Post Forge, Pre HT

Orientation Map



Grain Reference Orientation Deviation



1110°C forging, $\varepsilon = 0.3, \dot{\varepsilon} = 0.003/s$

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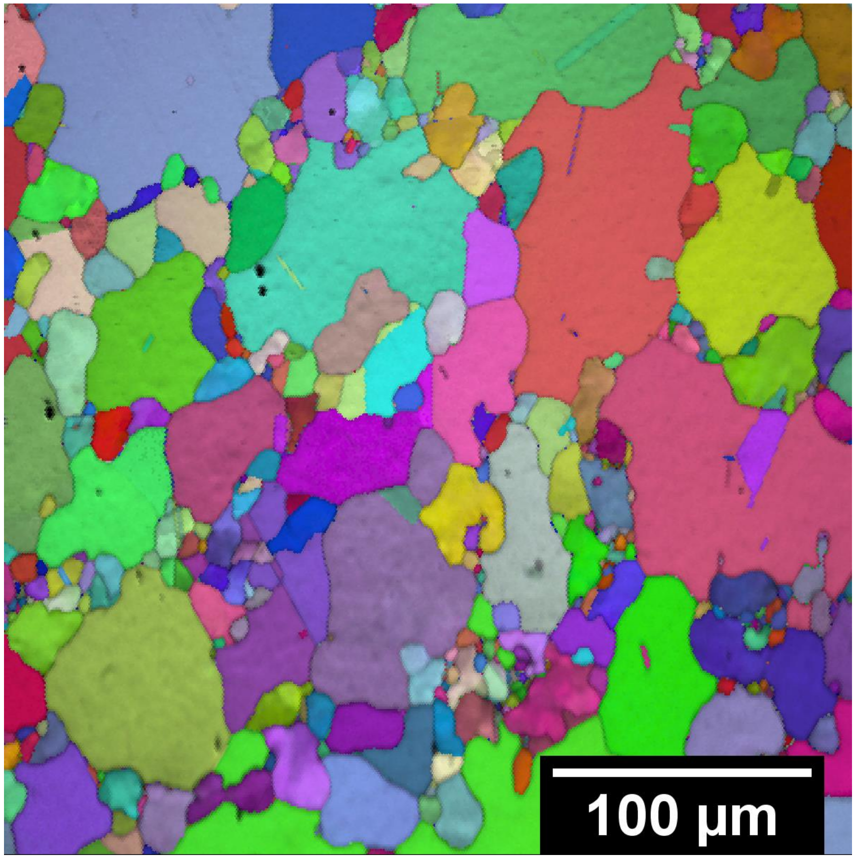
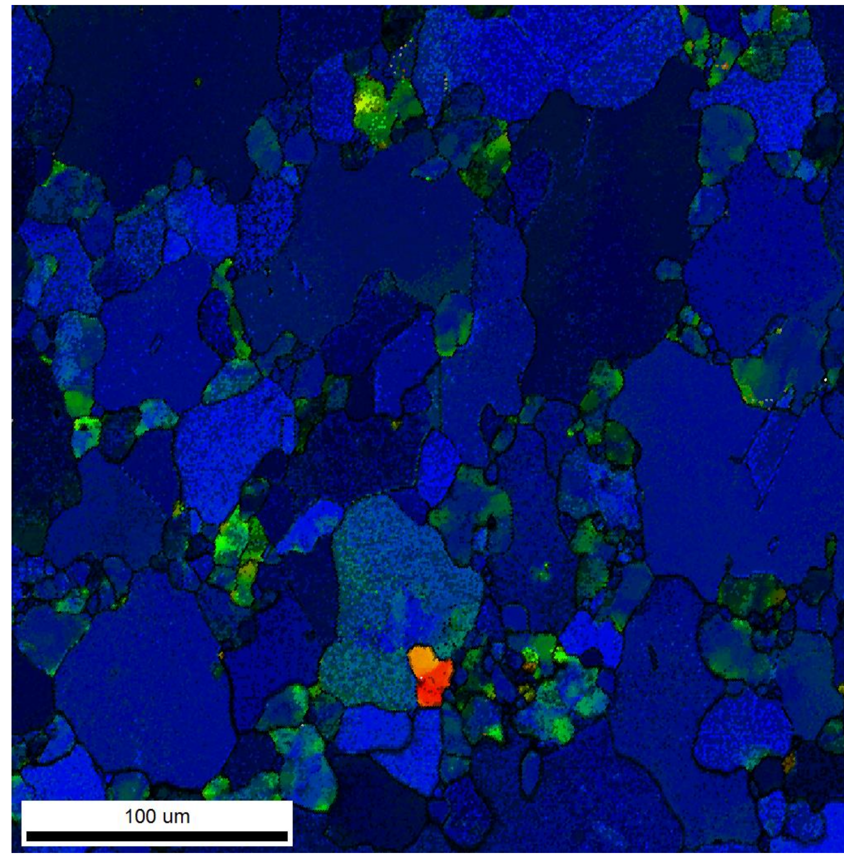
Microstructure – Post Forge & HT

Orientation Map



Grain Reference Orientation Deviation

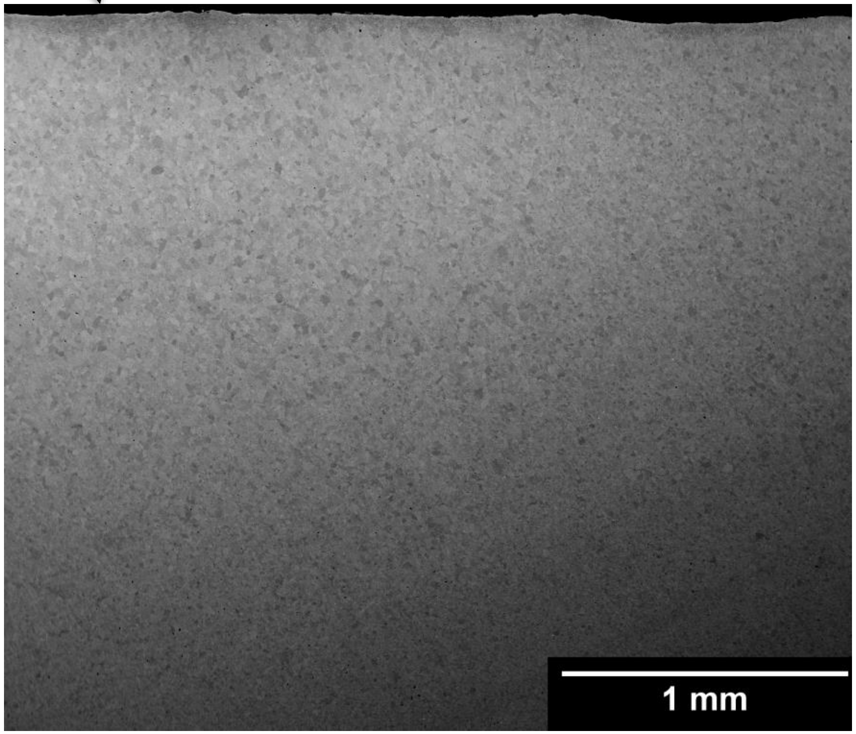


1110°C forging, $\varepsilon = 0.3, \dot{\varepsilon} = 0.003/s$, furnace heating to 1170°C for 20 minutes.

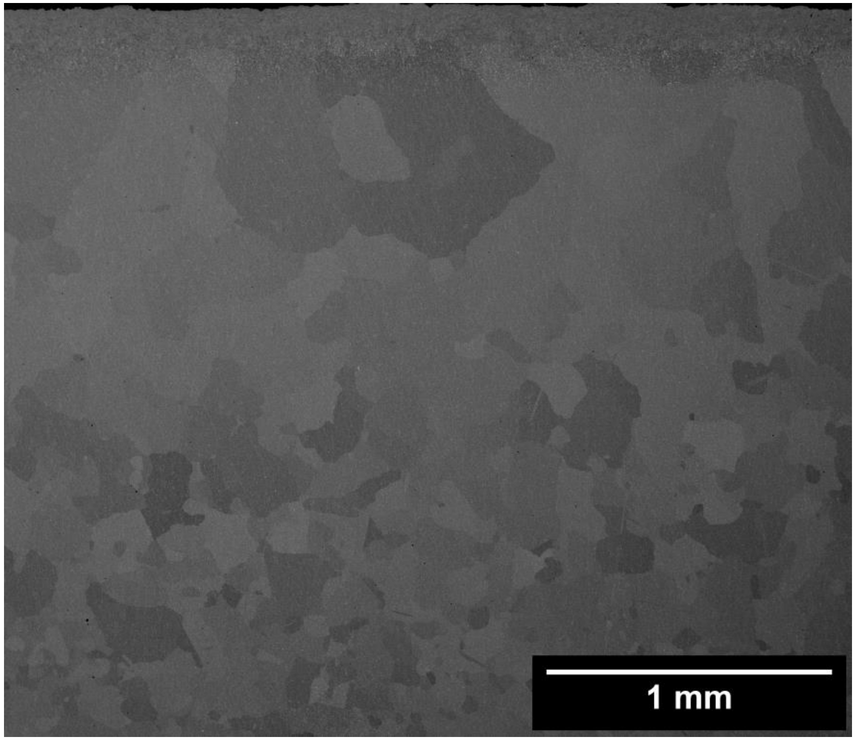
Microstructure – 1075°C Forging, 0.003 /s

Anvil-Specimen border

Forged (Pre-HT)



Forge & HT



Planned Interrupted Testing

- Utilize forged material at T and $\dot{\varepsilon}$ for AGG
- Section & polish
- Perform EBSD
  - Orientation, size distribution, and GROD
- Interrupted heat treatment in dilatometer
  - Determine AGG rate & temperature
- Repeat EBSD analysis
- Continue interrupted heat treatment and EBSD

*Free surface effects may limit validity of test

Planned Gleeble Testing

- Continue exploring forging temperature and strain rate parameters that produce AGG
- Self-impingement of large grains occurs
  - Lower input strain → fewer & larger abnormal grains (?)
- Relatively low strain rate and high forging temperature appear to produce AGG
- Use values for DEFORM® modeling

Conditions for AGG – Gleeble Work

Temperature (°C)

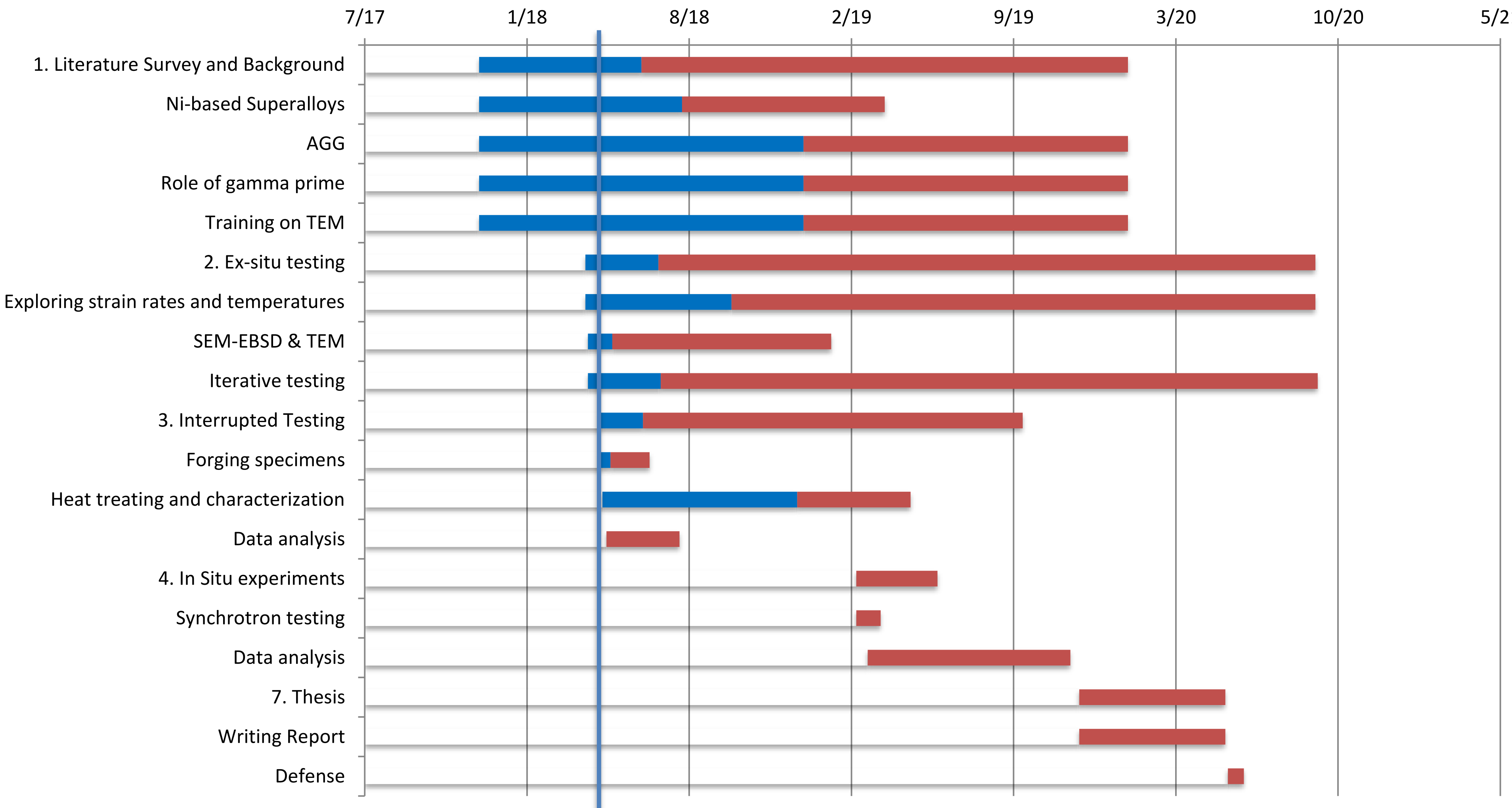
Strain Rate (s^{-1})	1035	1050	1065	1075	1080	1095	1110
0.003							
0.01							
0.03							
0.1							
0.3							

	No AGG
	Partial AGG
	Extensive AGG

Role of γ' in AGG

- The γ' acts to pin γ grain boundaries
- Various sizes form at different stages
- Forging influences the γ'
  - Coherency
  - Size
- Further analysis needed on specimens
  - TEM analysis
  - Incorporate simultaneous EDS-EBSD

Progress



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1/18
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2/19
9/19
3/20
10/20
5/2
1. Literature Survey and Background
Ni-based Superalloys
AGG
Role of gamma prime
Training on TEM
2. Ex-situ testing
Exploring strain rates and temperatures
SEM-EBSD & TEM
Iterative testing
3. Interrupted Testing
Forging specimens
Heat treating and characterization
Data analysis
4. In Situ experiments
Synchrotron testing
Data analysis
7. Thesis
Writing Report
Defense

Thank you!

Questions?

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