

Probabilistic Life Assessment and Aged Materials Testing for Service Feedback of Gas Turbine Components

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for the US Department of Energy

Aged Materials Data – Incorporated into Design

Materials availability

- Acquisition of gas/steam/HRSG/Boiler materials
- Prepare metallography and demonstrate feasibility of image segmentation



Data Collection

- Insight into grain size, defects, gamma prime coarsening for correlation to properties
- Indentation and mechanical testing for property envelope



Analytics for correlations

- First feasibility for Bayesian model for process-structure-property linkages
- Correlation of gamma prime size to mechanical properties



PSP Linkages

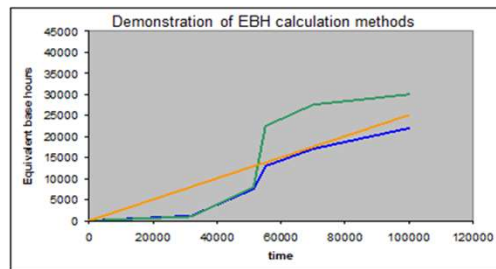
- Develop linkages and correlate for unknown sample
- Augmentation of microstructure database for rotor steels and blade 4 alloys for time temperature dependence



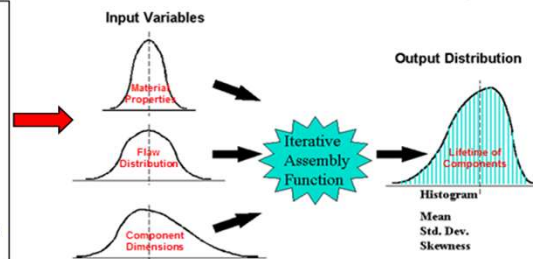
Validation

- Machine learning to predict material properties from insitu-metallography images for rotor steels and superalloys
- Go Forward Plan

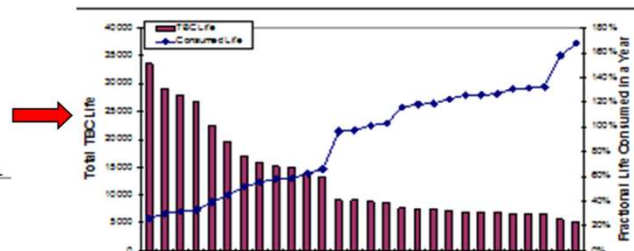
Tracking damage mechanisms



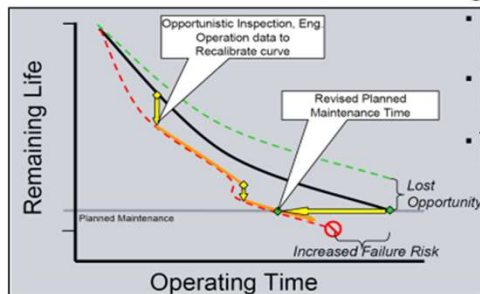
Constitutive modeling



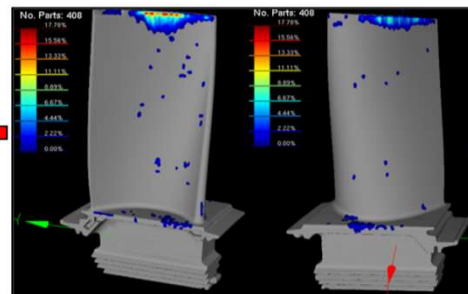
Coating remaining life



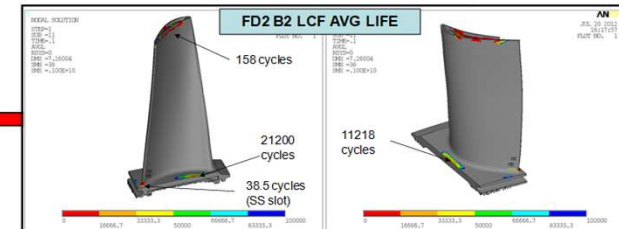
Service/Maintenance Scheduling



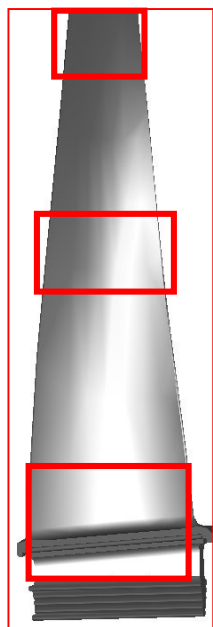
Correlation to service



Superalloy remaining life



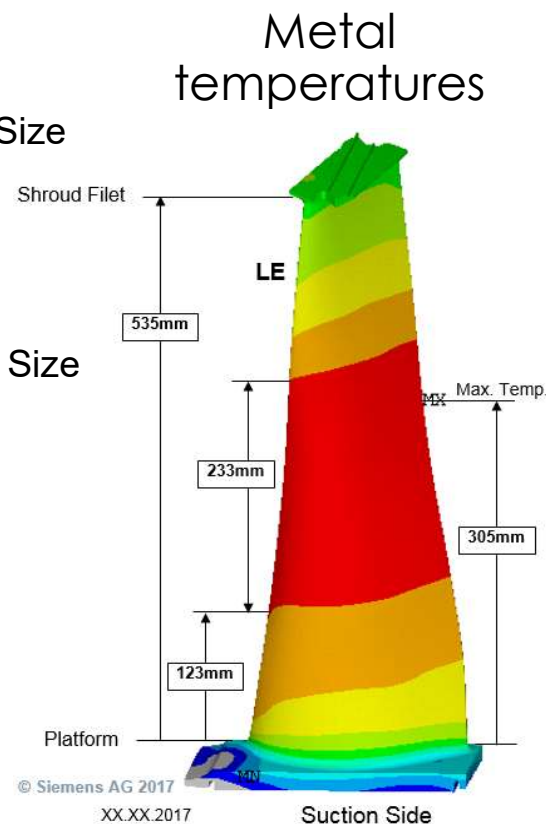
- Properties in production cast parts have variability and uncertainty that is not typically characterized or considered in design.
- Location variation



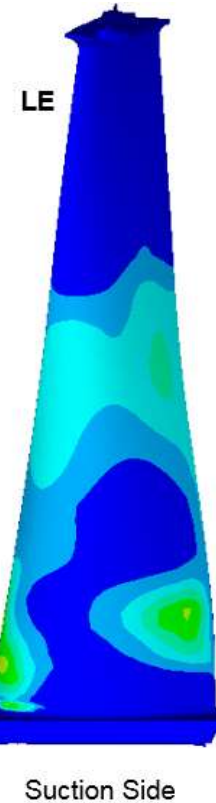
Upper Airfoil
-Thinnest Section Size
-Fine Grain

Mid Airfoil
-Thicker Section Size
-Coarser Grain

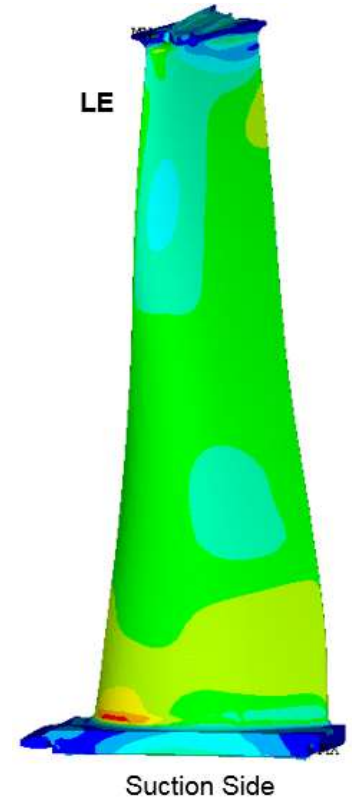
Lower Airfoil
-Thickest Section Size
-Coarse Grain



Creep strain



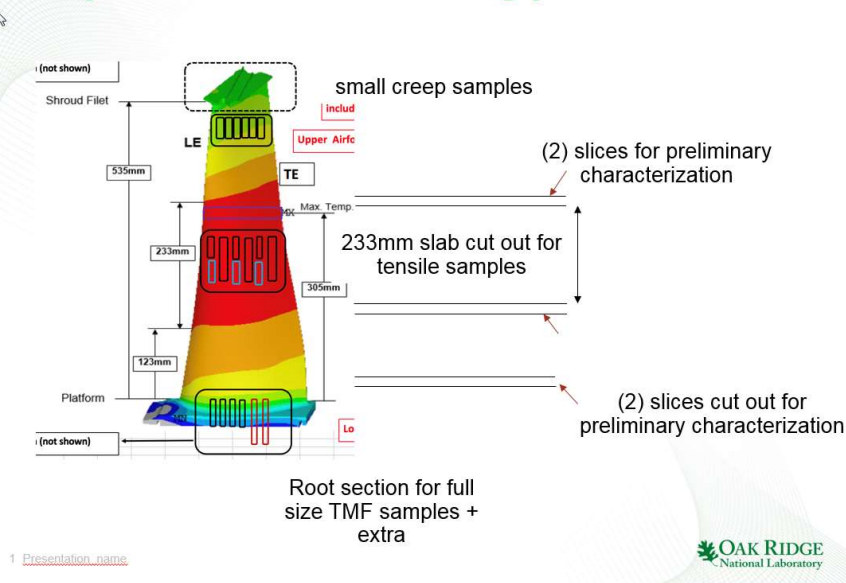
Von Mises stresses



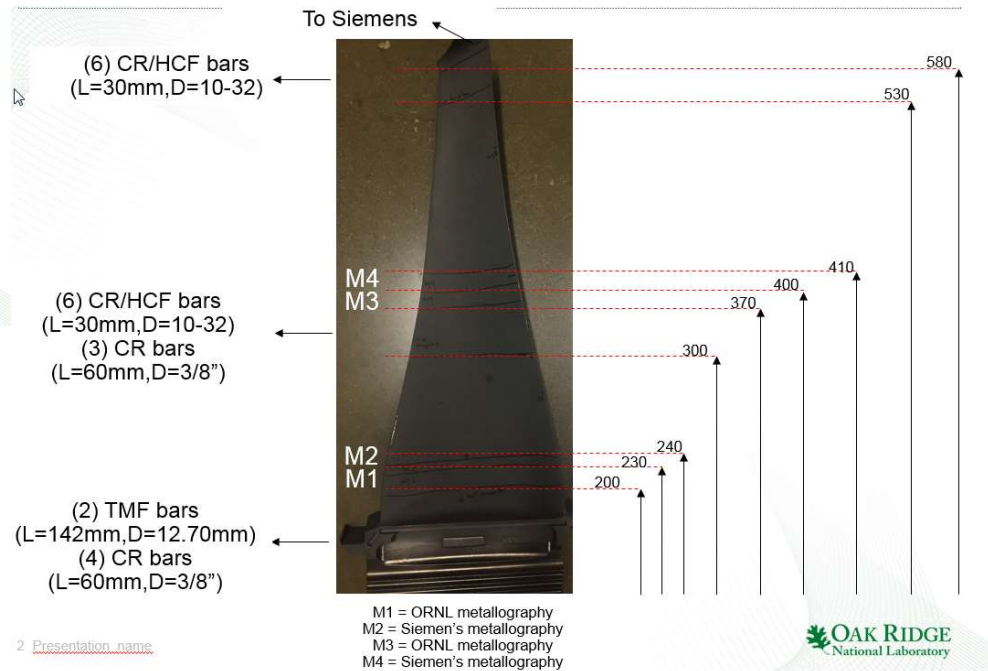
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- Data Generation to establish Process-Structure-Property Correlations

Proposed Blade Sectioning plan



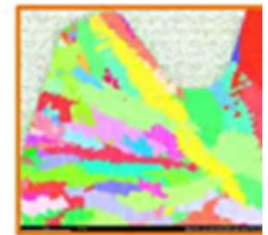
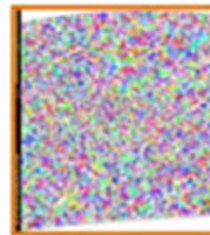
Need to understand and modeling the parameters that influence the operability of turbine components over their lifetime



Studies to be extended to Haynes 282 (for A-USC/Gas turbine applications)

Microstructure Characterization

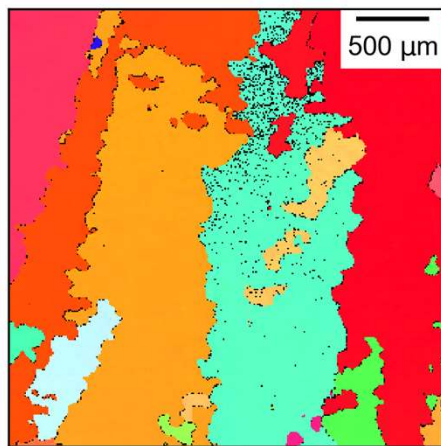
- Characterization work also ongoing at Munich Siemens facility
- Confirm fine recrystallized structure in one blade
- Characterization of root section



Microstructure Characterization

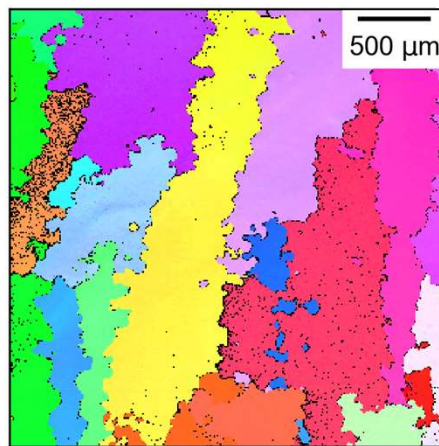
- Microscopy performed on three blades
 - As-fabricated
 - 78khrs cumulative service hours (3 intervals)
 - 33khrs + repair + 33khrs + repair + 12khrs, sent to ORNL
 - 49khrs cumulative service hours
 - pulled, over-aged, dimensionally out of tolerance sent to ORNL
 - Recrystallized microstructure due to HT or service (?)
 - over-aged to make metal easier to repair (lower strength), standard HT to return to service (solution, primary, secondary)

As-Fabricated



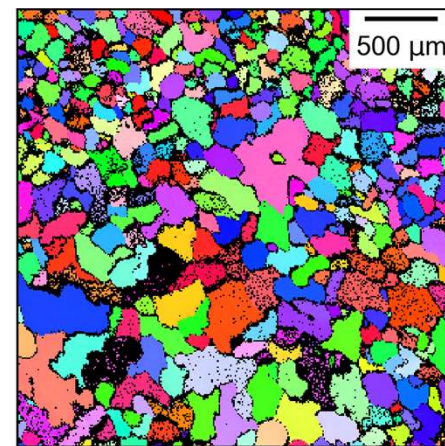
1-5mm grains

49khrs + HT



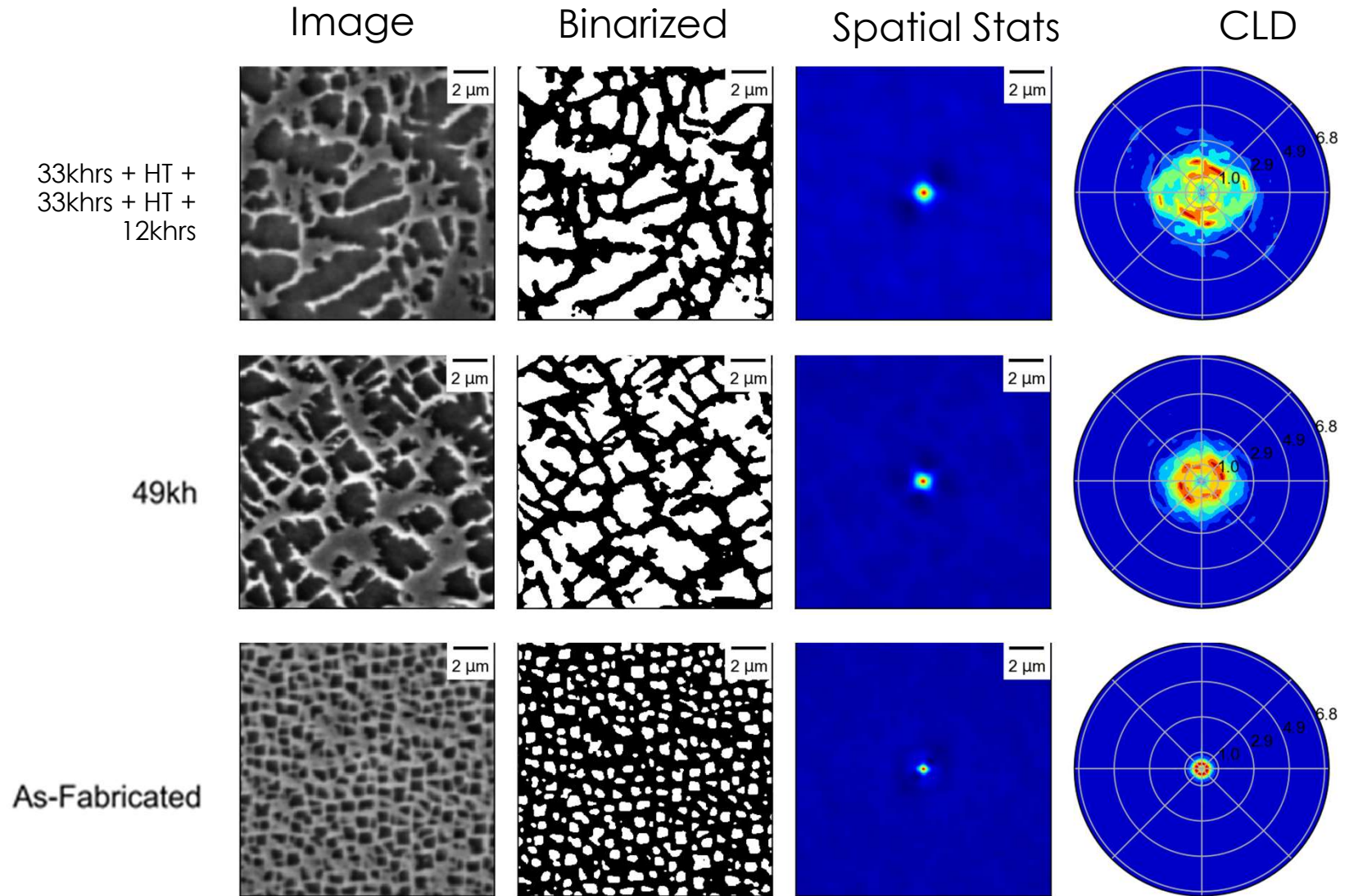
~1-5mm grains

33khrs + HT + 33khrs + HT + 12khrs



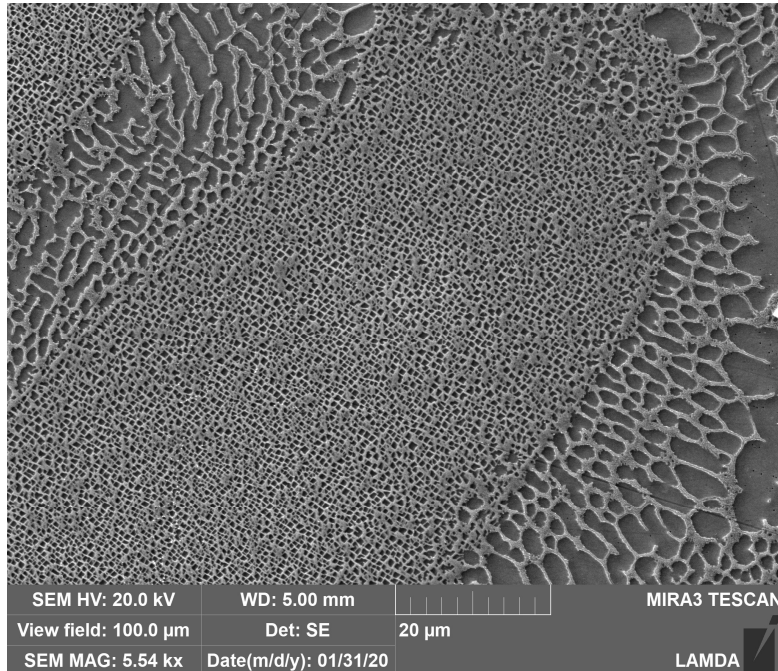
100-500μm grains

Microstructure Characterization – blades

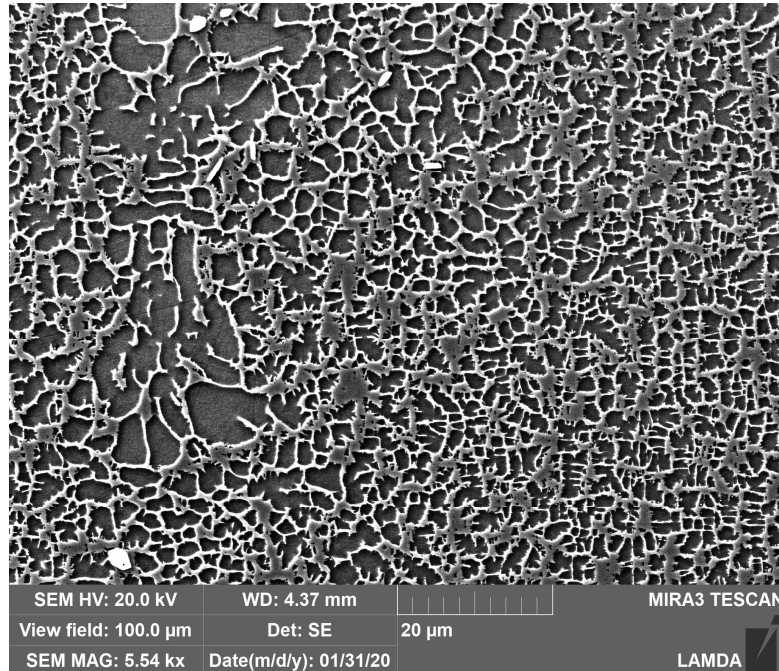


Microstructure Characterization – blades

As-fab



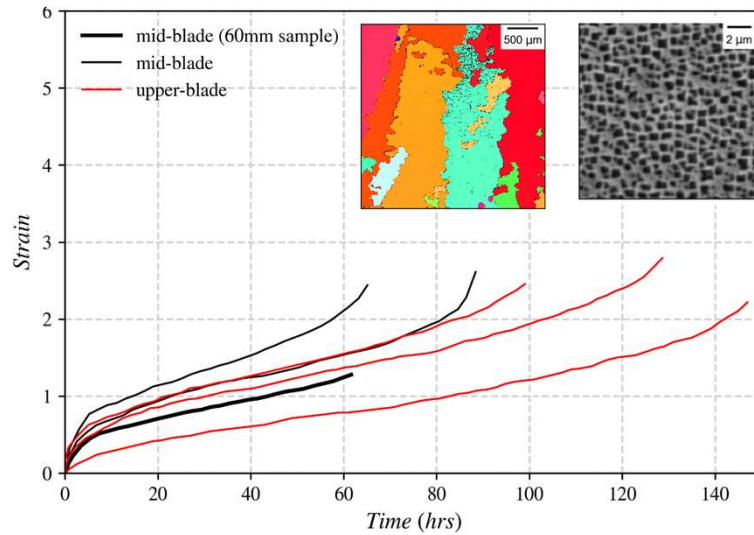
49khr



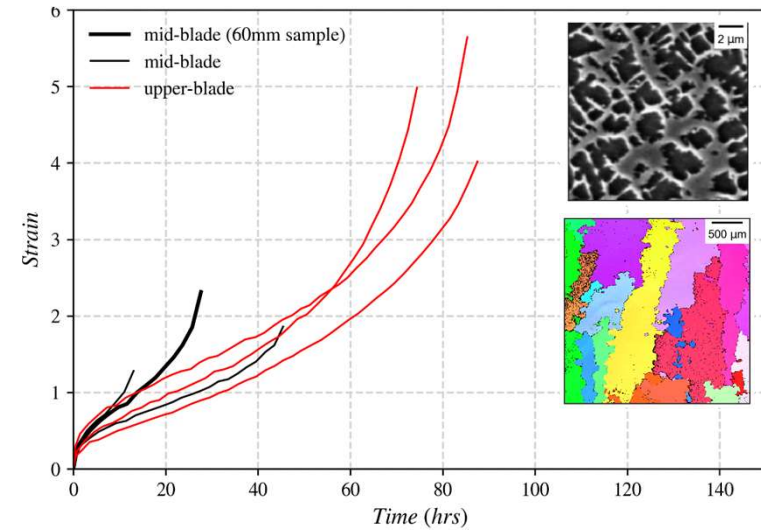
- Moderate coarsening of gamma-prime
 - Initial **325nm**
 - 49khrs + HT **2.35 μm**
 - 33khrs + HT + 33khrs + 12khrs **2.64 μm**

Fine scale precipitate tends to coarsen
Eutectic unaffected

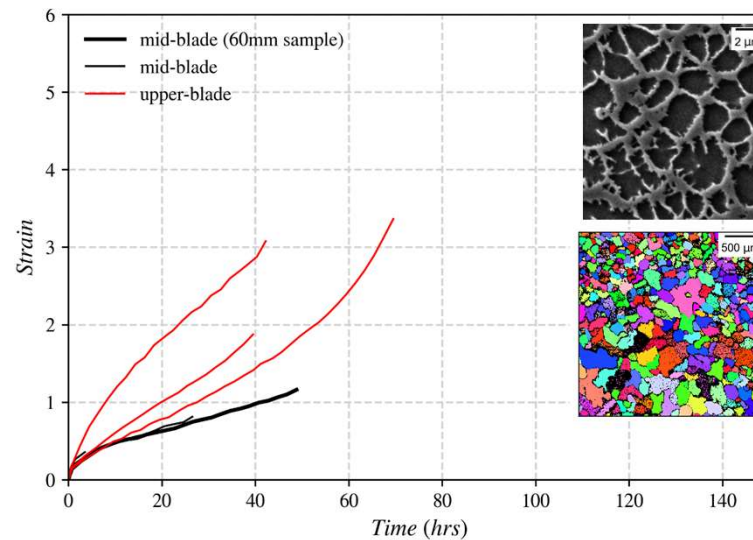
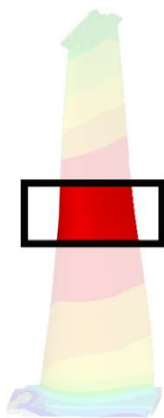
Preliminary Creep results (760C 690MPa)



As fabricated



49K hours service + HT



33khrs + HT + 33khrs + HT + 12khrs



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Preliminary Creep results (760C 690MPa)

- Exposure drives an increase in gamma prime size which drives down remaining life
- Repairs occasionally performed impose additional HT cycle
 - Recrystallization either due to service or these repairs
- Smaller grain size results in debit on creep life
- Consistently upper blade exhibits longer life
 - Need to characterize returned samples, perhaps lower temperatures inhibit coarsening...?