Additive Manufacturing of High Gamma Prime Alloys

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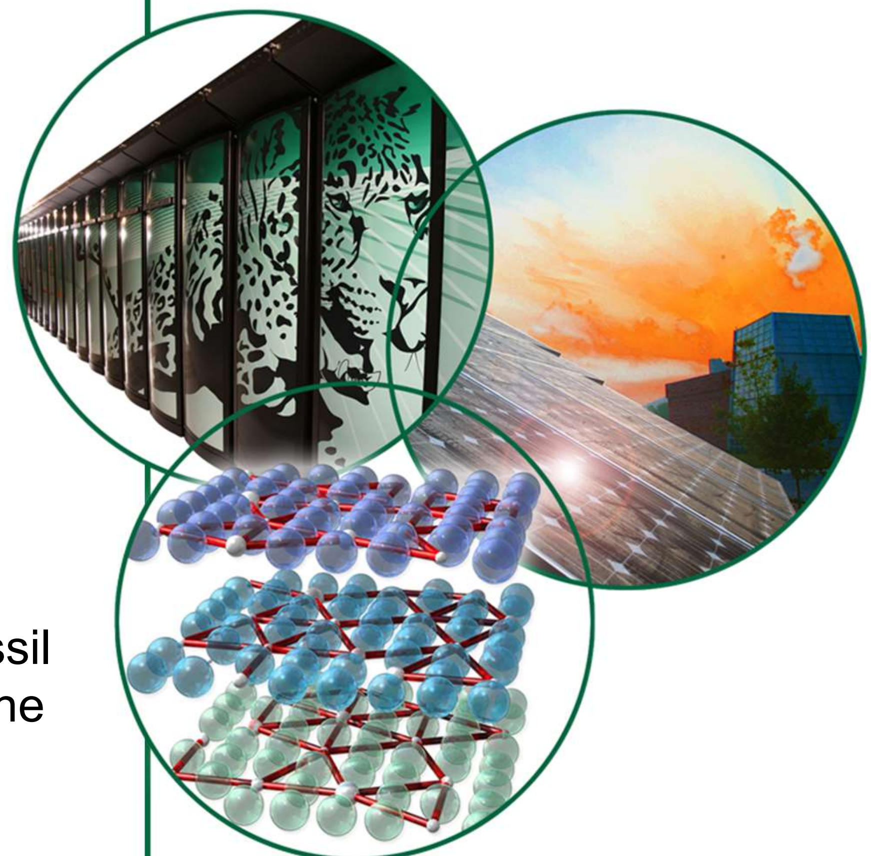
Oak Ridge National Laboratory

Crosscutting Research Review Meeting

ORNL project FEAA127



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Project Objectives

- Optimize additive manufacturing (AM) fabrication processes for:

  - Chromia forming 282: (57Ni-20Cr-10Co-8.5Mo-2.1Ti-1.5Al)

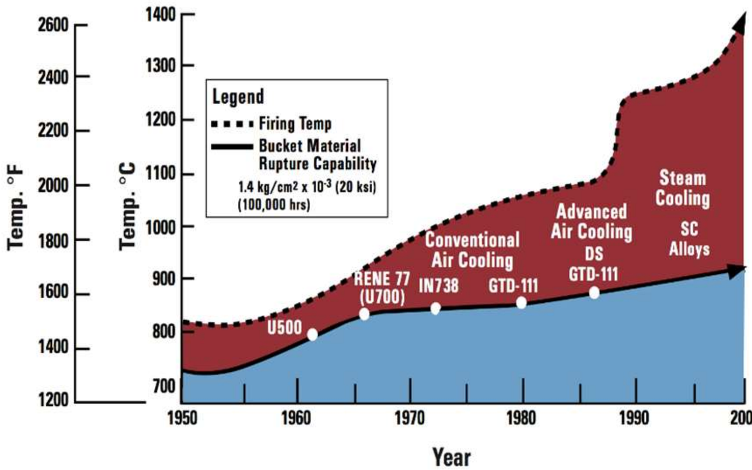
  - Alumina forming Nimonic 105 (Ni-20Co-5Mo-15Cr-4.5Al-1Ti)

- Improving understanding of the process-microstructure-property relationships
- Generate data (Tensile, Fatigue, Creep, Oxidation) relevant for FE applications
- Compare two AM techniques, electron beam melting (EBM) and selective laser melting (SLM).
- Effect of annealing/HIP'ing on microstructure and mechanical properties
- Collaboration with other 282 related programs such as A-USC

Why Additive of Ni-base Superalloys?

- Component cooling designs have existed since the 70s
- Additive manufacturing provides the empowerment for the next evolutionary phase in high temperature component design

Siemens = AM for critical rotating parts



AM Enabled Combined Cycle Efficiency Increase to 62.2 from 60.1

GE gas turbine breaks efficiency record through metal AM optimisation

December 4, 2017

more...

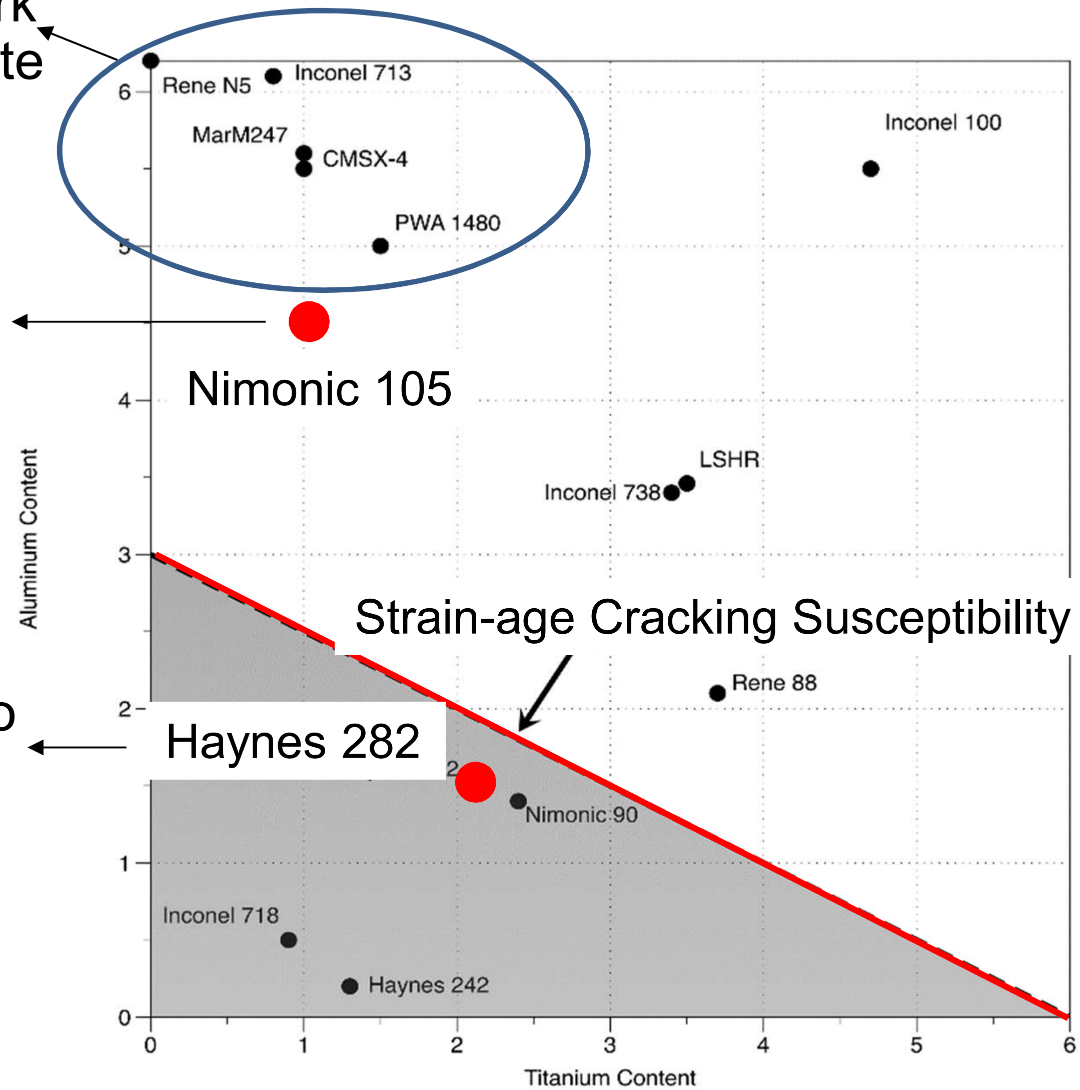
The GE Power-produced 9HA.02 gas turbine is now said to offer 64% efficiency in combined cycle power plants (Courtesy GE Power)

Alloy 282 Shows Unique Combination of High Strength and Fabricability

Extensive processing work funded by AMO to fabricate crack-free blades

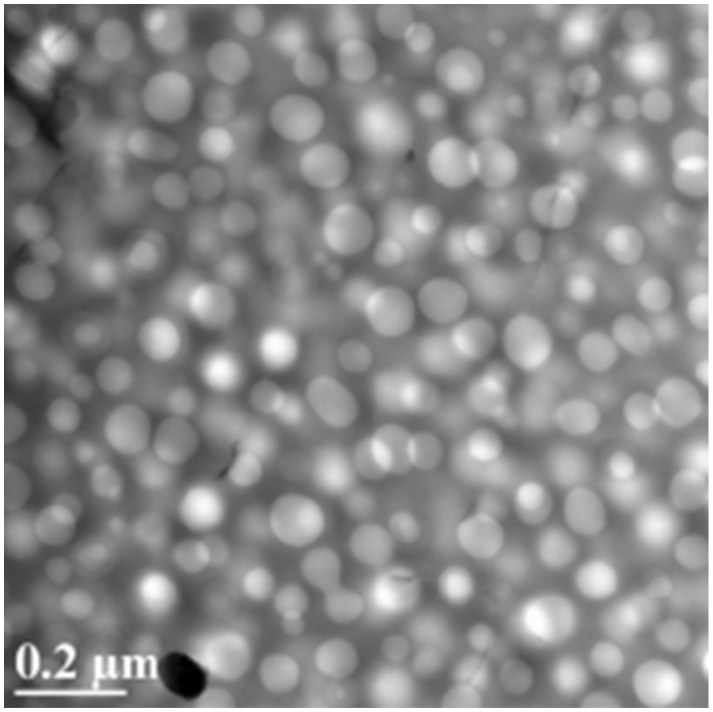
More challenging but easier than many other high γ /γ’ alloys

Easier to process due to “low” Al and Ti content



Creep Strength Depends on the γ' Precipitates Stability

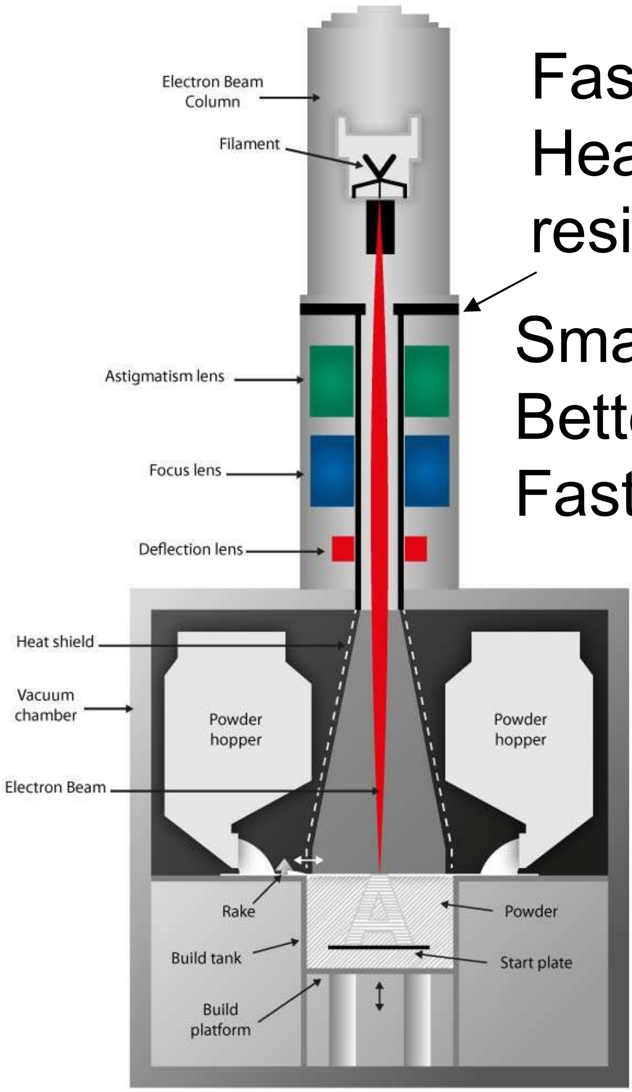
- Optimum γ' precipitate size is ~25nm in wrought 282 after solution annealing at 1121 to 1149ºC and two-step aging 2h at 1010ºC + 8h at 788ºC (Haynes recommendation)
- ~19% γ' vol. fraction after aging
- Recent work has shown that one step 4h 800ºC heat treatment led to similar properties (Bruce Pint's talk tomorrow on 282 code case)
- Best heat treatment for AM 282?



2810h, 750ºC

Alloy 282 Made by EBM and SLM

Ebeam (Arcam S12)



Faster
Heated bed = lower residual stress

Smaller beam size =
Better resolution
Fast cooling rate

EOS 250 machine

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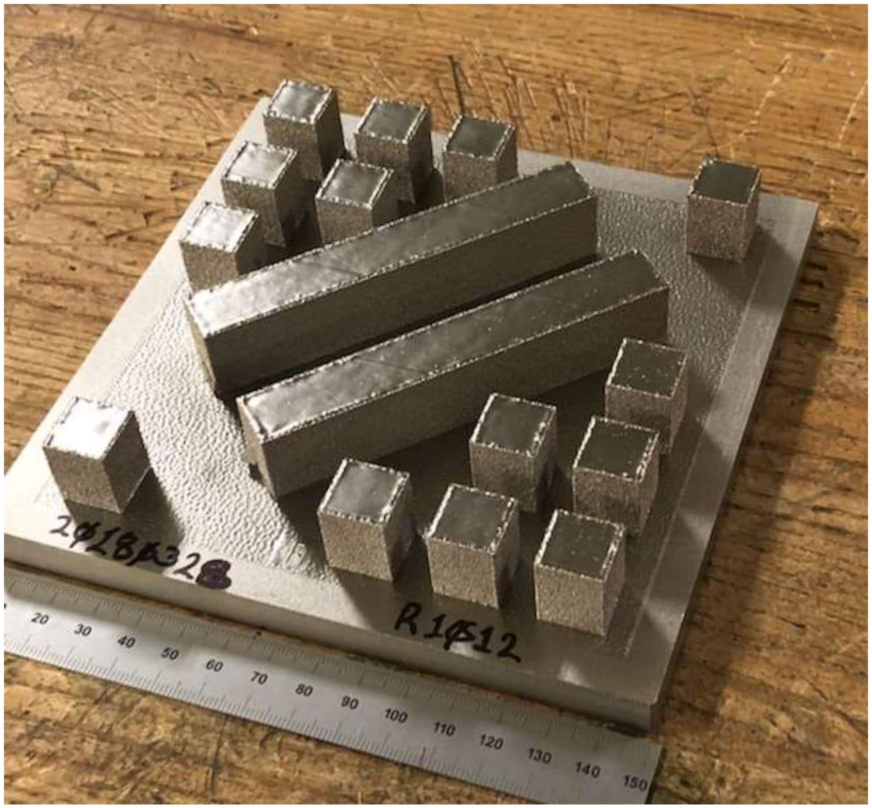
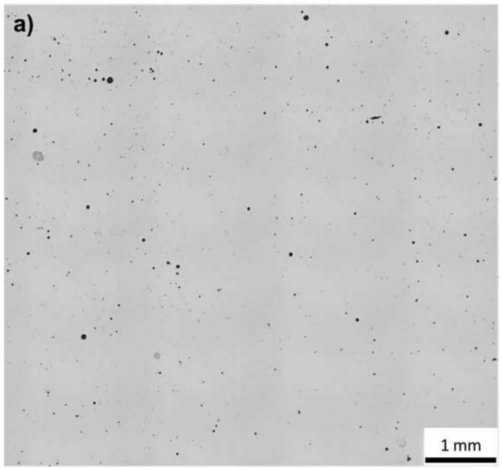
Ongoing Fabrication of Small Cubes and Bars for Microstructure Characterization

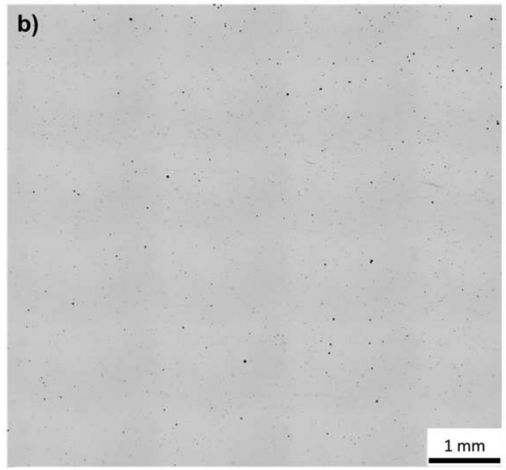


EBM build

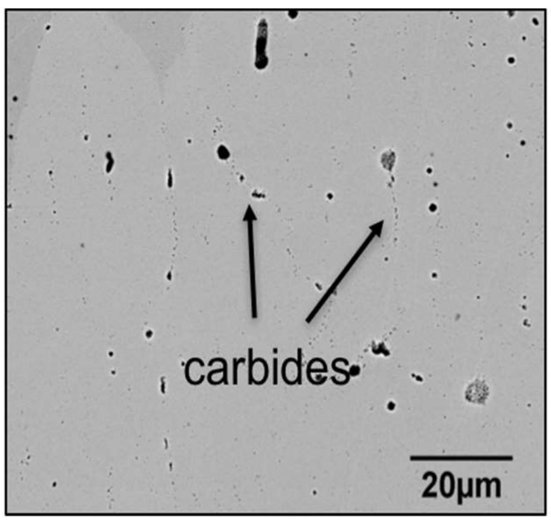
- After parameter optimization based on defect and density, rods and plates will be fabricated for extensive testing
- Testing along and perpendicular the build direction
- SLM rods were provided by Siemens for characterization

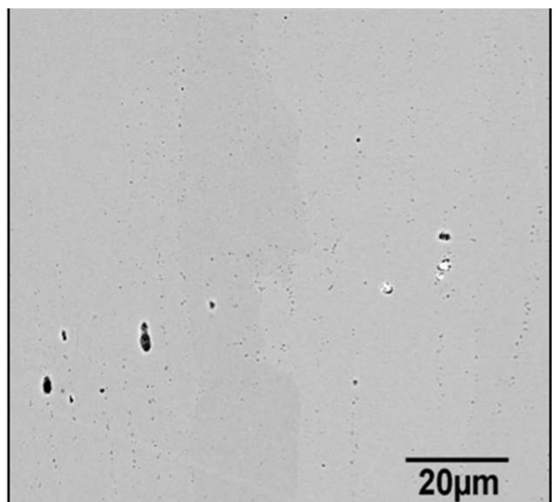
Previous work on As Built EBM 282: Limited Number of Voids + $M_{23}C_6$ Carbides





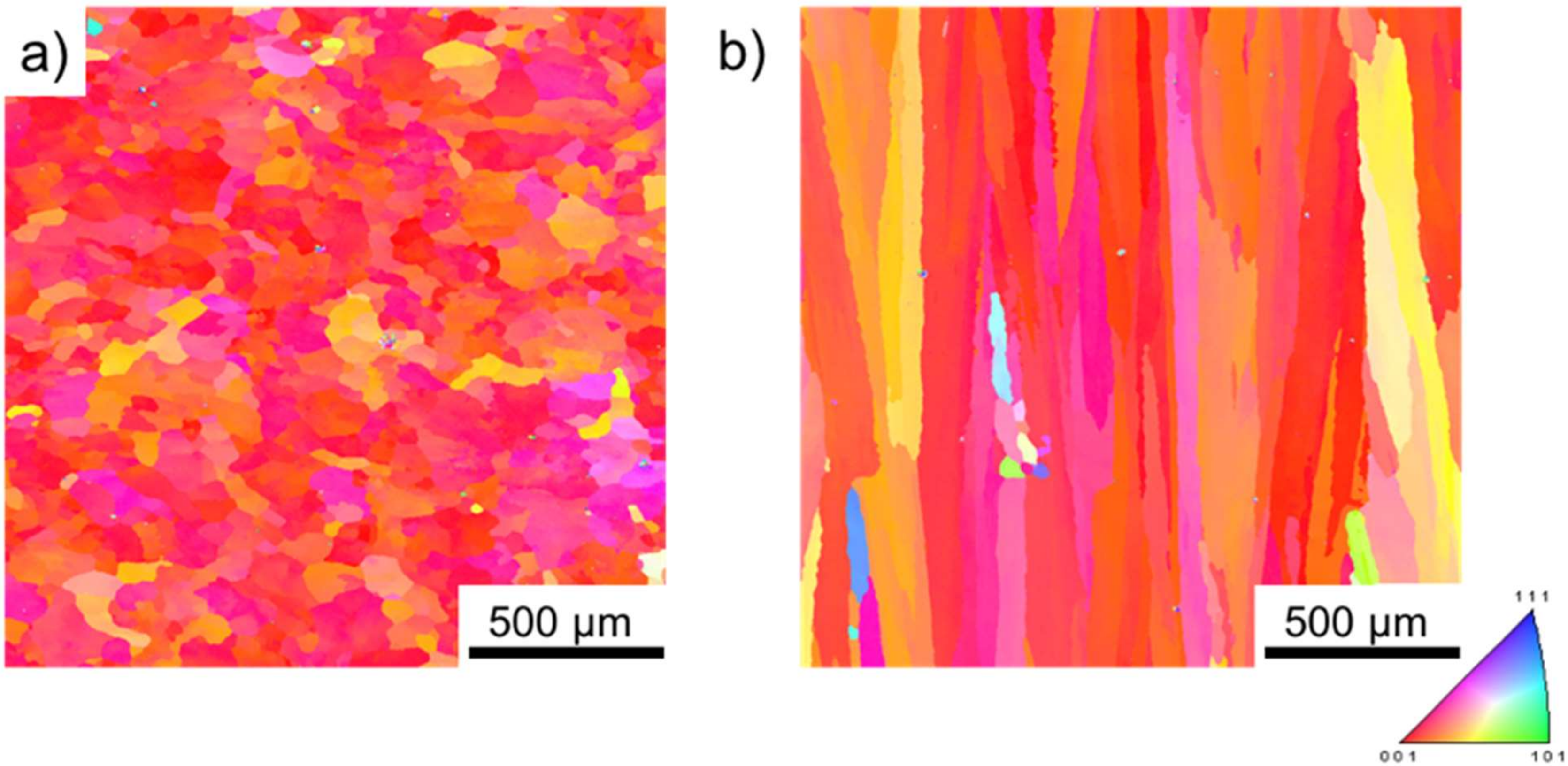
Density from 97.9% to a high of 99.5% depending on build parameters



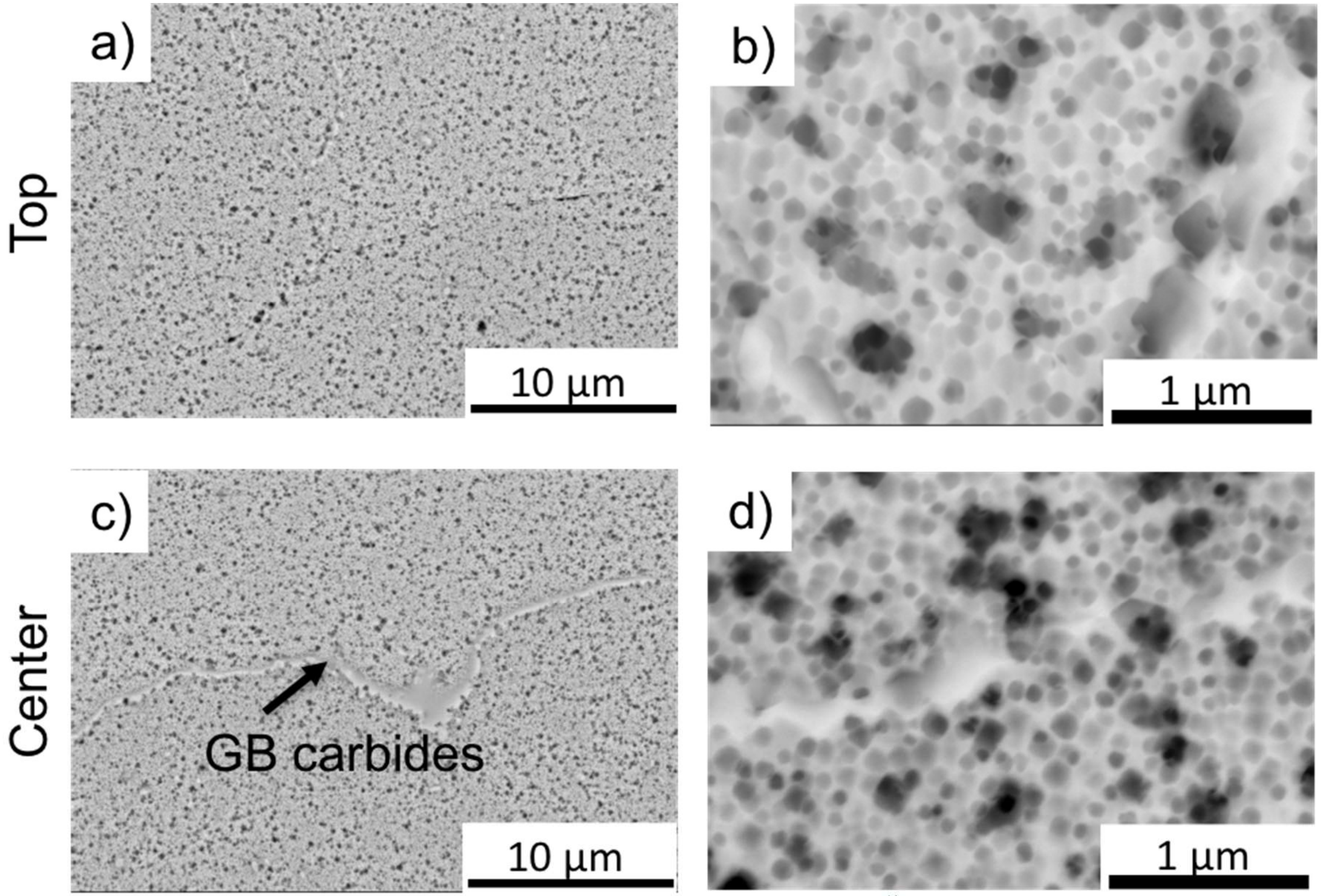


Carbides not expected in wrought 282 before aging treatment

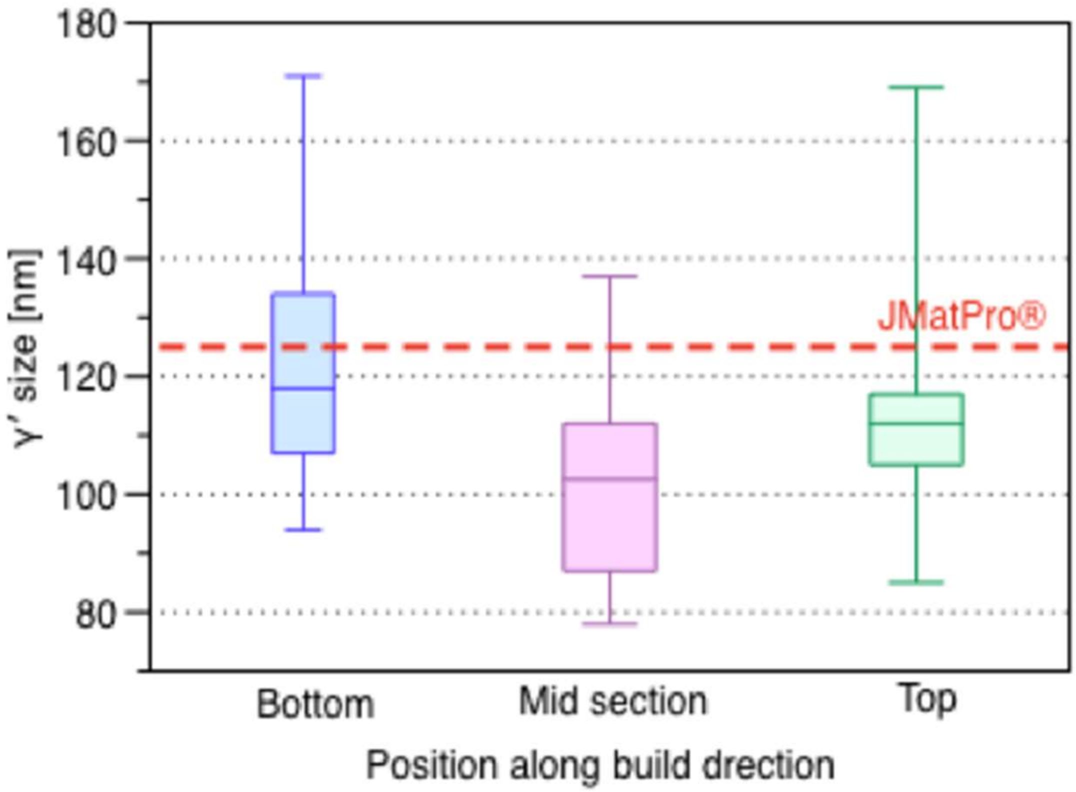
As Built EBM 282: Elongated Grains with [001] Crystallographic Orientation Aligned with the Build Direction



As Built EBM 282: ~110nm γ' precipitates



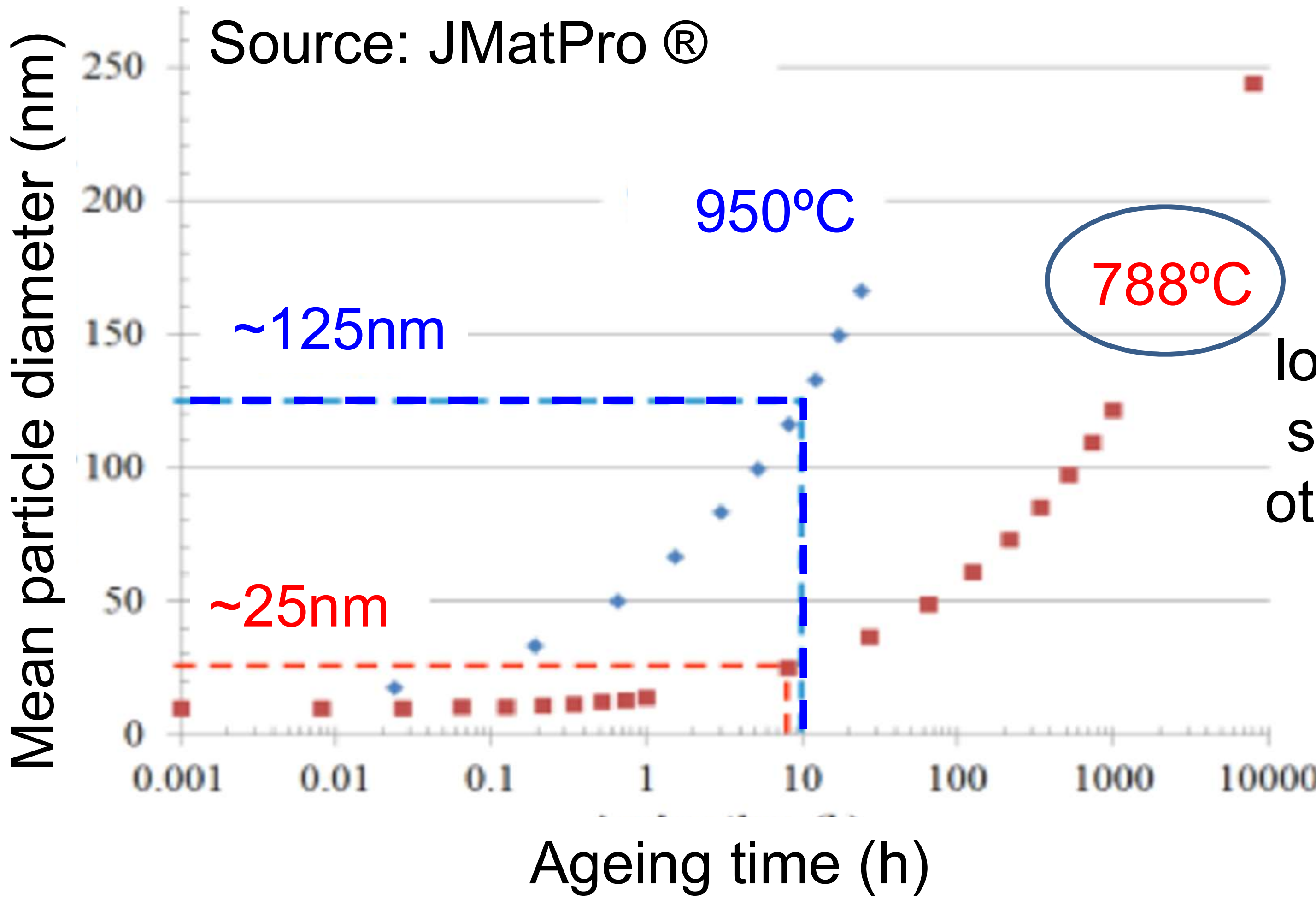
As built EBM 282: γ' Larger than optimized γ' size after annealing of Wrought 282



Optimum Gamma prime size is ~25nm in wrought 282 after annealing

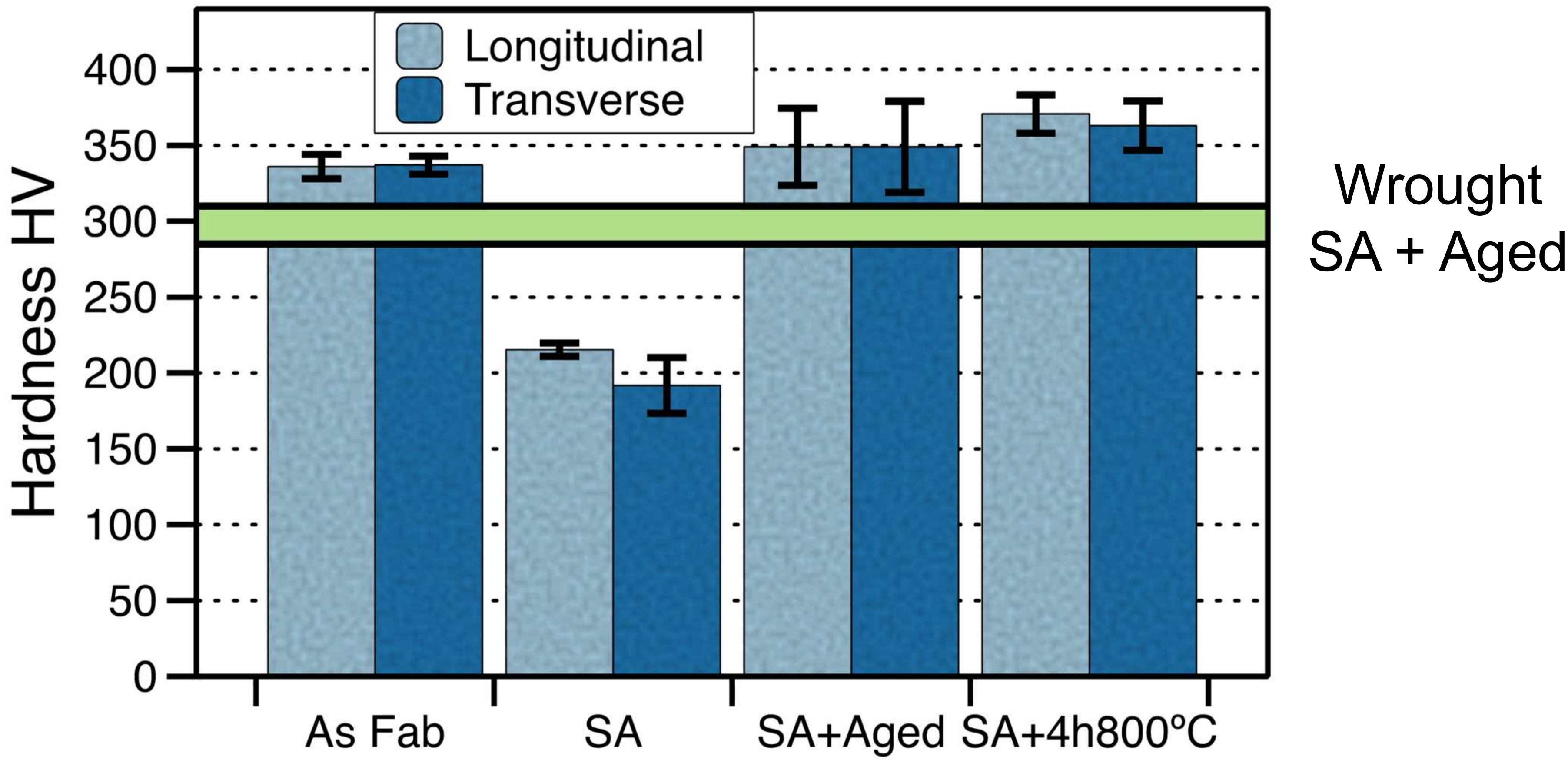
Based on image analysis measurements

Build Temperature Estimated to be around 950ºC Based on JMatPro Model



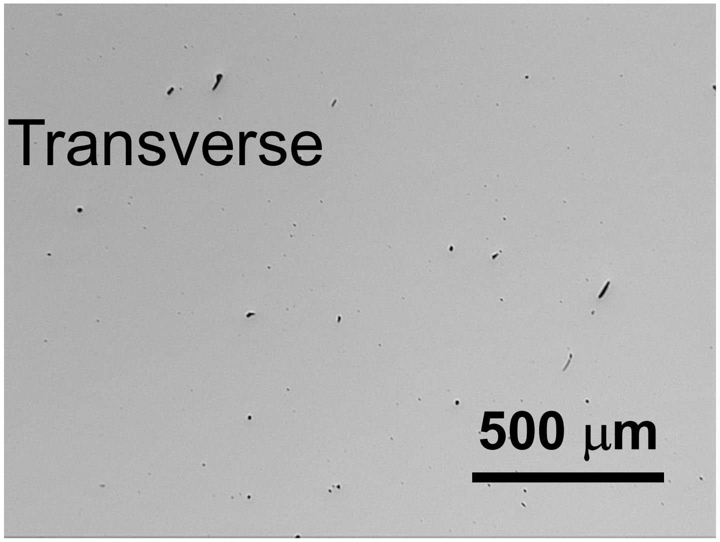
low powder sintering + other issues

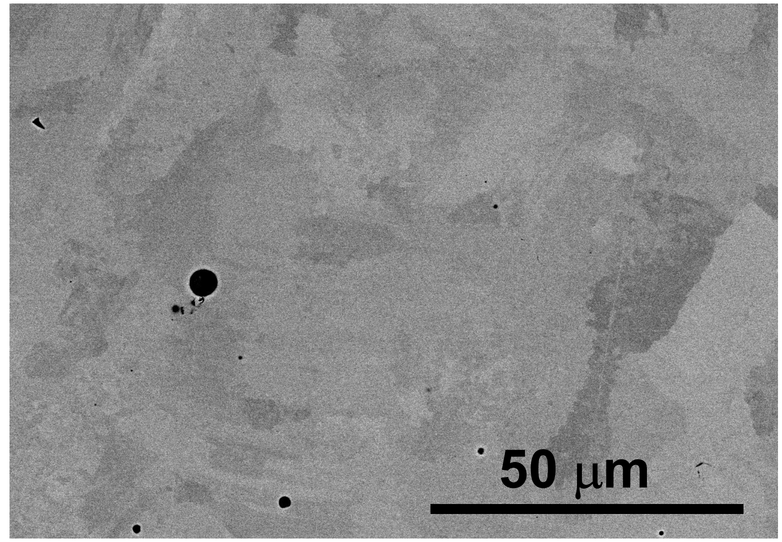
Ongoing Work to Optimize EBM 282 Heat Treatment

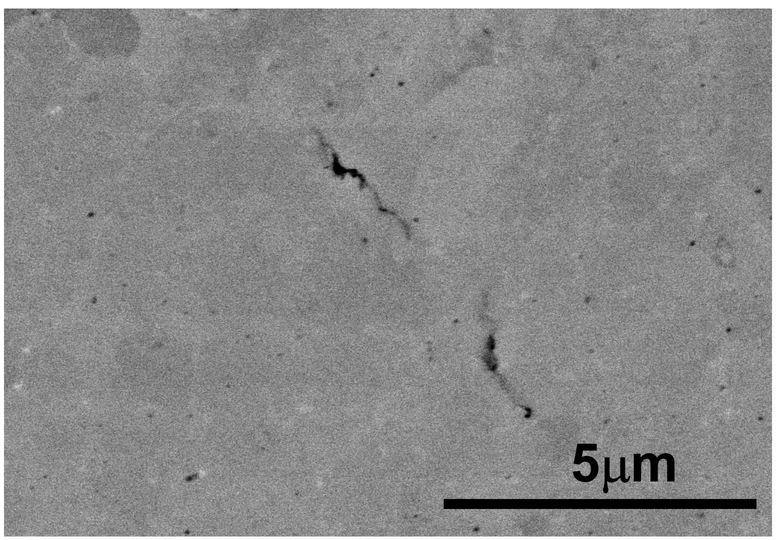


- Solution Anneal leads to γ' dissolution
- Next step γ' characterization

As built SLM 282 : Few Voids + Defects Grain size ~5-50um

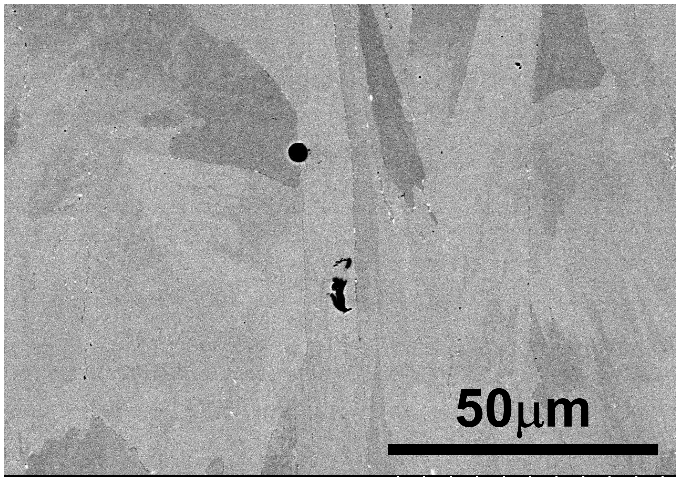




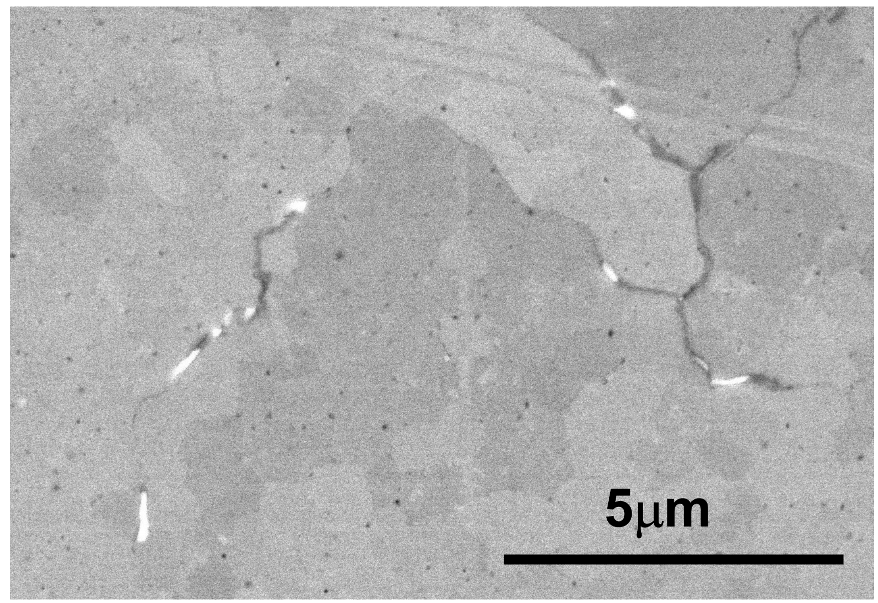


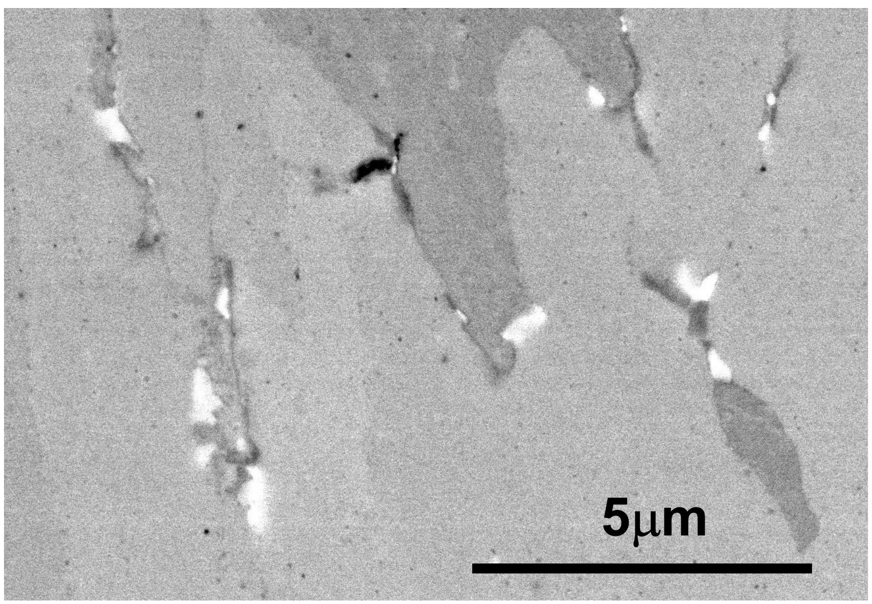
- Few small carbides +Local segregation.
- No precipitates at GB
- Need TEM for gamma prime characterization

Precipitates formation at GB after 2h at 1010ºC + 8h at 788ºC

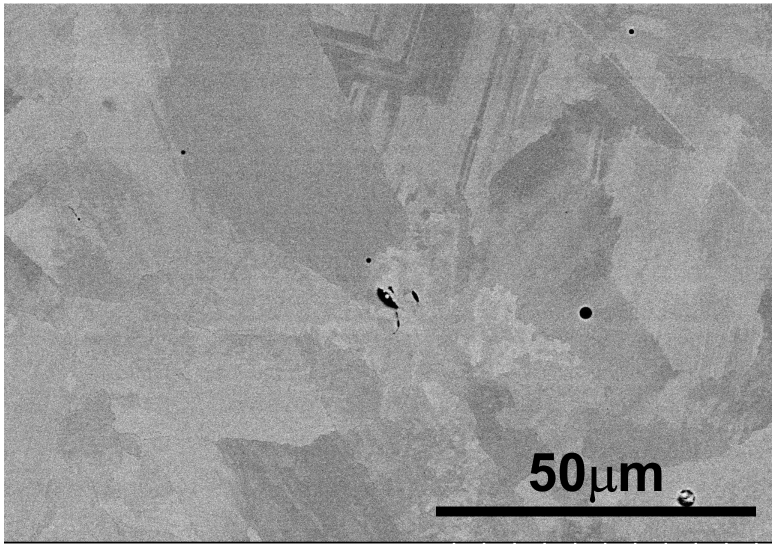


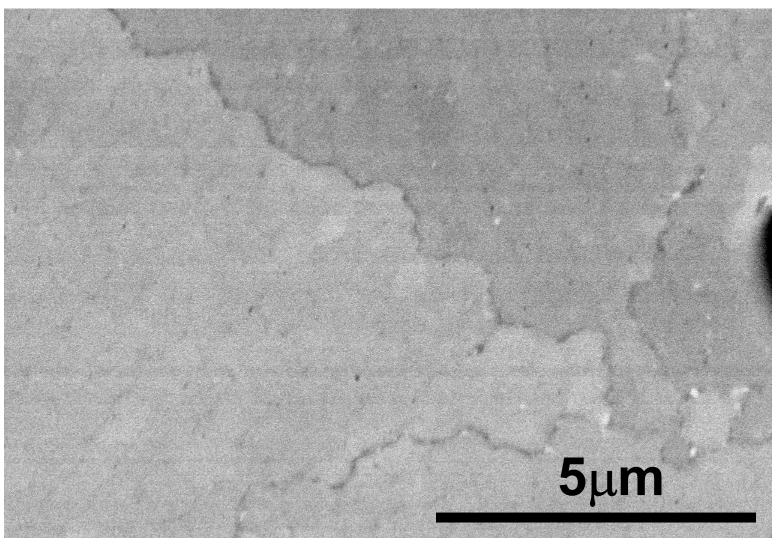
Formation of precipitates at GB
Similar defect structure



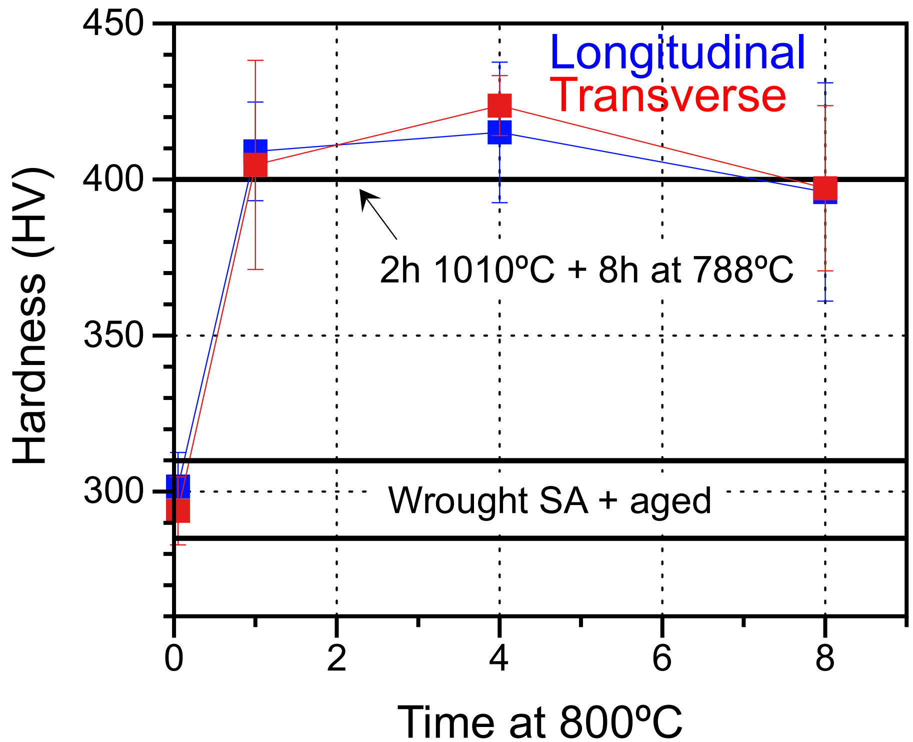


Very High Hardness After Standard Aging or Annealing at 800ºC



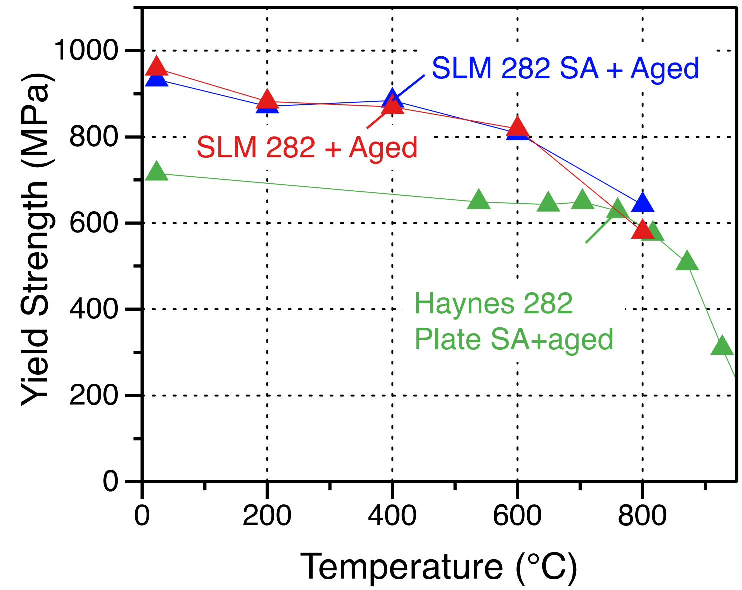


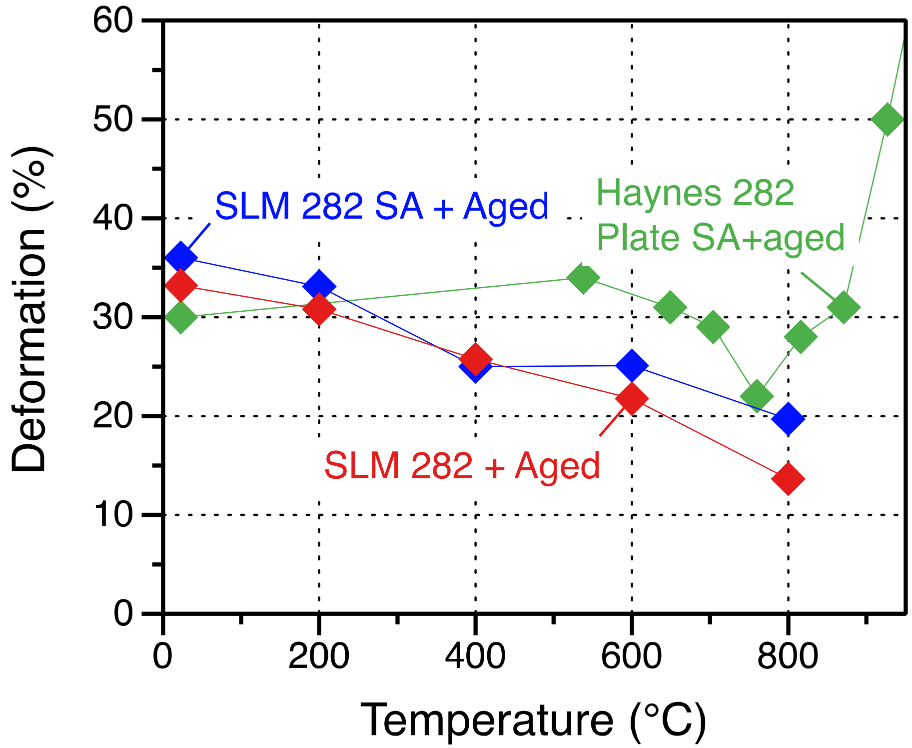
- Similar microstructure and hardness after 1h to 8h at 800ºC
- Optimized HT for SLM 282?

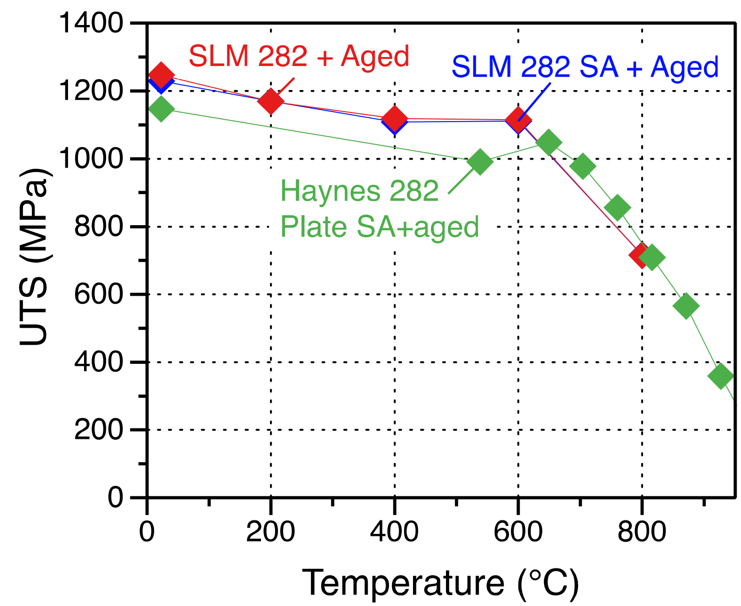


High Strength for SLM 282 after Standard HT

- No effect of solution anneal on tensile properties
- Slightly lower ductility compared to wrought 282?







Conclusion

- Initial microstructure characterization and Hardness measurement for EBM 282 shows high strength is achievable with appropriate heat treatment
- High strength for aged SLM 282. Because of fast cooling, solution anneal might not be necessary
- Next step is to optimize heat treatment (HIP'ing?) and conduct extensive characterization (tensile, fatigue, creep and oxidation)
- Fabrication of actual turbine components
- Working on modeling γ' evolution during processing
- Aiming at better properties than properties of wrought 282?