AM of Nickel Components & Joining of Dissimilar Metal Welds

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2020 HIGH PERFORMANCE MATERIALS PROJECT REVIEW MEETING

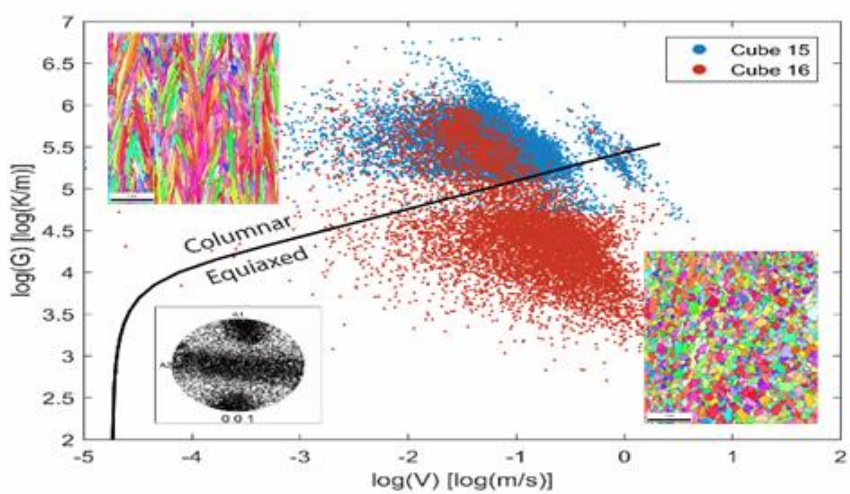
Additive Manufacturing Could Have A Significant Impact on Fossil Energy Power Generation

- New more efficient and/or less expensive components of complex shape
- Control of microstructure for superior properties
- Graded chemistry and microstructure for dissimilar metal welds
- New domestic supply chain for FE components
- New alloys specific to future FE needs i.e. Hydrogen economy
- New approach to qualify alloys/components

Establishing process-microstructure-properties relationship for Ni-based AM Components

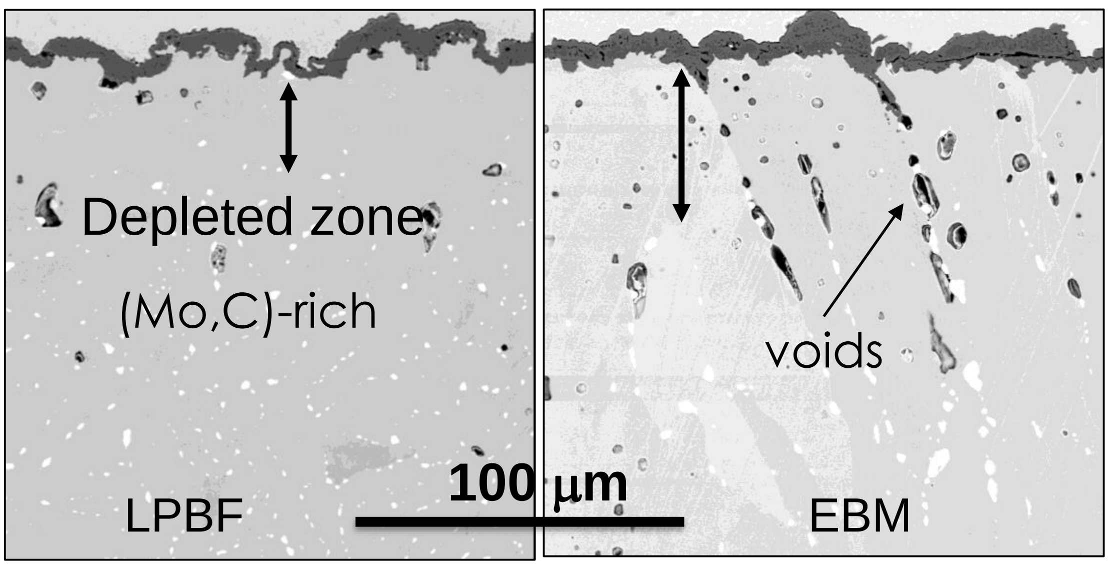
- Many process parameters can impact the microstructure
  - Optimize parameters (low defects density) and generate data **relevant for FE applications**
  - (**Local**) Control of the microstructure for superior properties
- Develop approach and physics-based tools for process-microstructure-properties correlation

- Hastelloy X, Ni-22Cr-19Fe-9Mo
- Haynes 282, Ni-20Cr-10Co-8.5Mo 2.1Ti-1.5Al
- Nimonic 105, Ni-20Co-15Cr-5Mo 4.5Al-1.2Ti

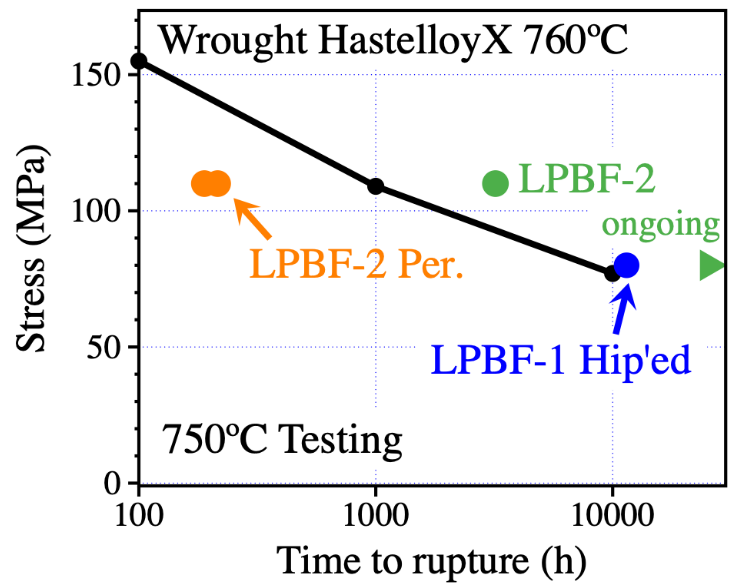


Large database generated for AM Hastelloy X

- Tensile (~90 tests), Creep (>40k cumulative hours), oxidation (>50k cumulative hours), Mechanical Fatigue
- Electron beam melting (EBM), Laser powder bed fusion (LPBF) , Directed Energy Deposition (DED)
- As printed, annealed and hot isostatic pressed (HIP)



Oxidation in air, 950°C, 1000h



Creep along and perpendicular to build direction

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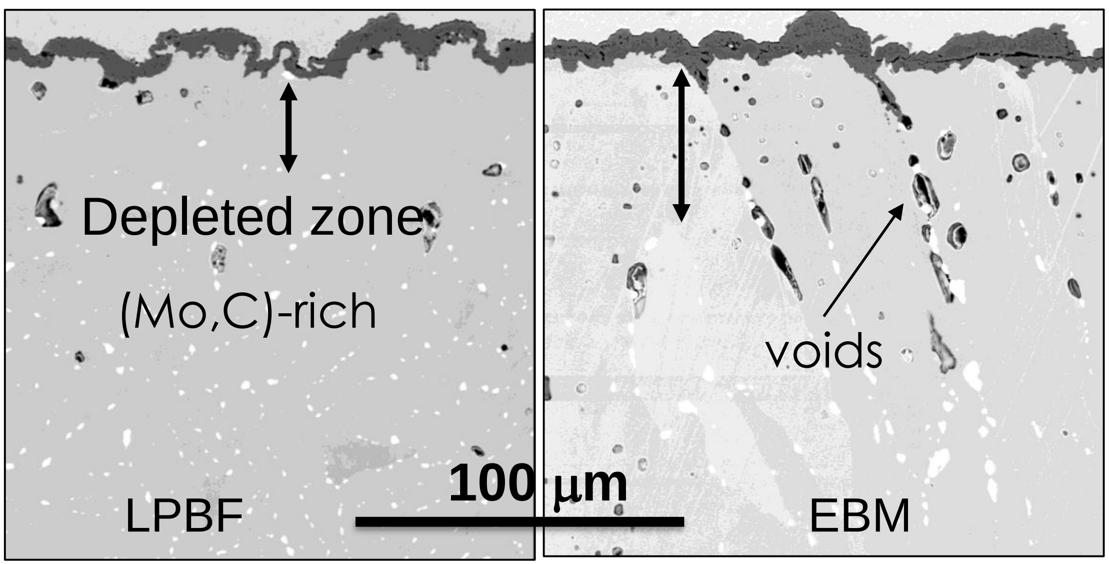
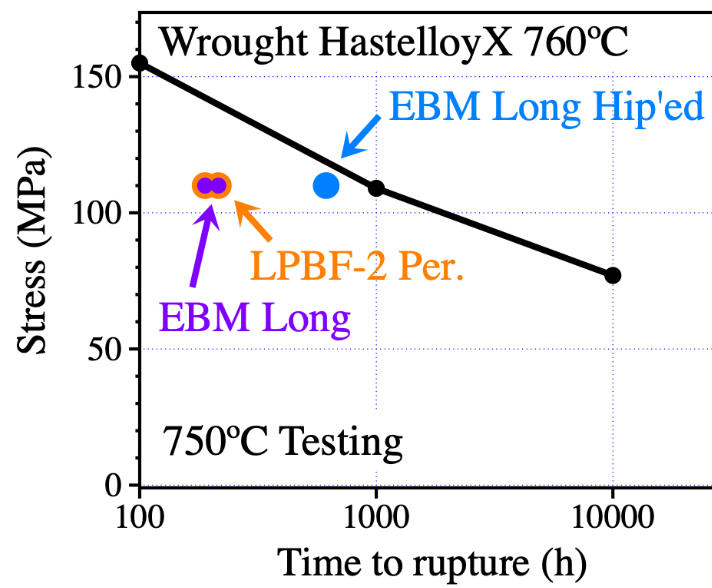
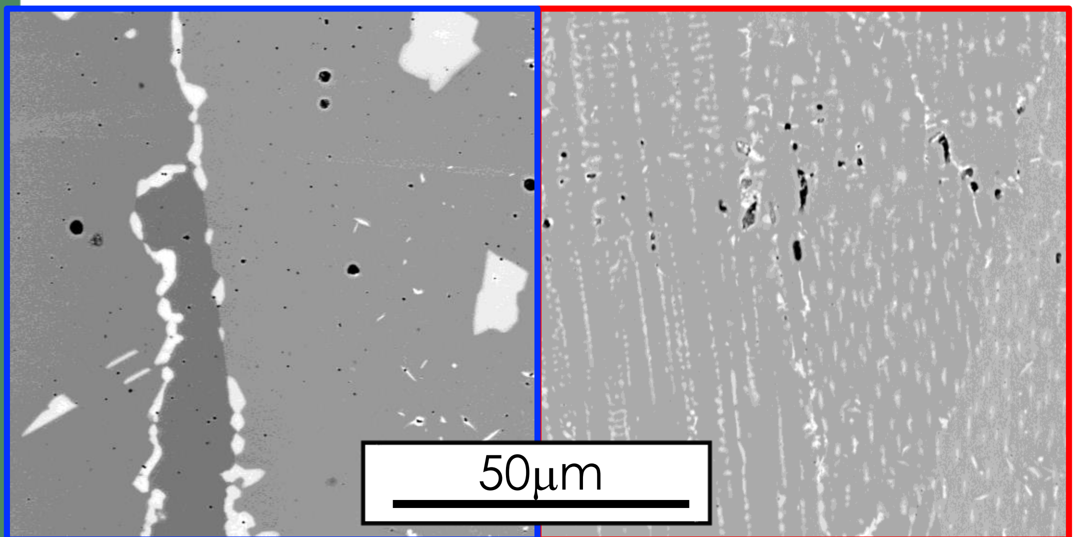


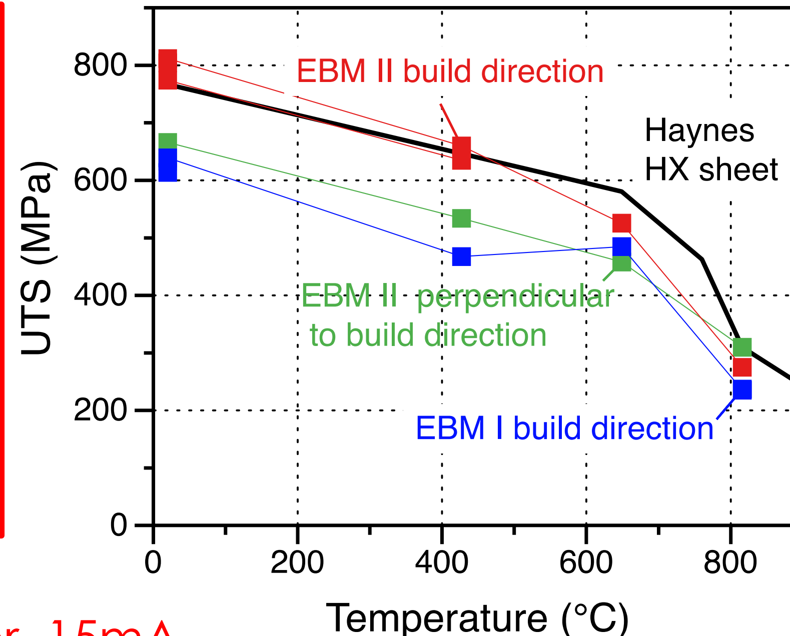
Oxidation in air, 950°C, 1000h



Parameter Optimization for Superior EBM Hastelloy X Properties



1050°C. 75um layer, 8mA   900°C. 50um layer, 15mA



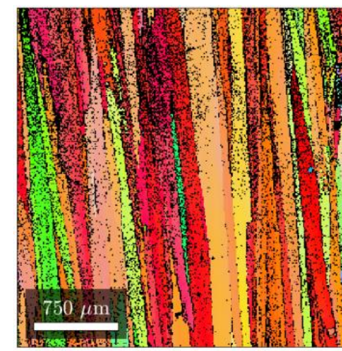
- LPBF Hastelloy X exhibits superior strength but lower ductility compared with EBM Hastelloy X
- Variation in printing parameters can have a strong impact on the microstructure beyond defects density

New Point Net Beam Strategies to Control Thermal Gradients, Solidification Rates and Microstructures

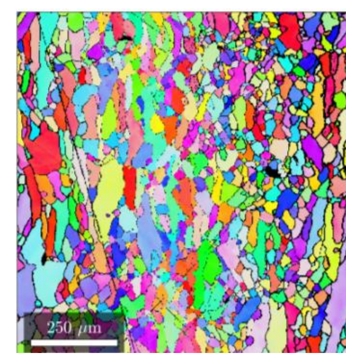
Random

EBM 282, Ni-20Cr-10Co-8.5Mo-2.1Ti-1.5Al

Flood

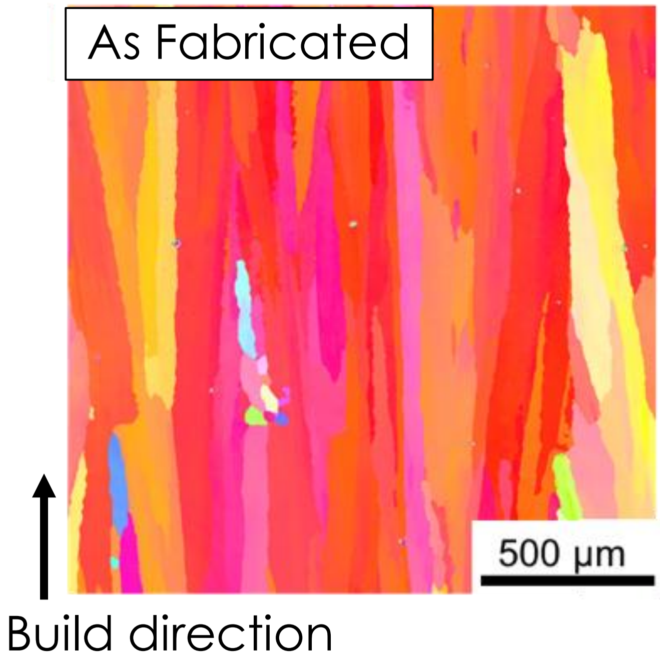


Square

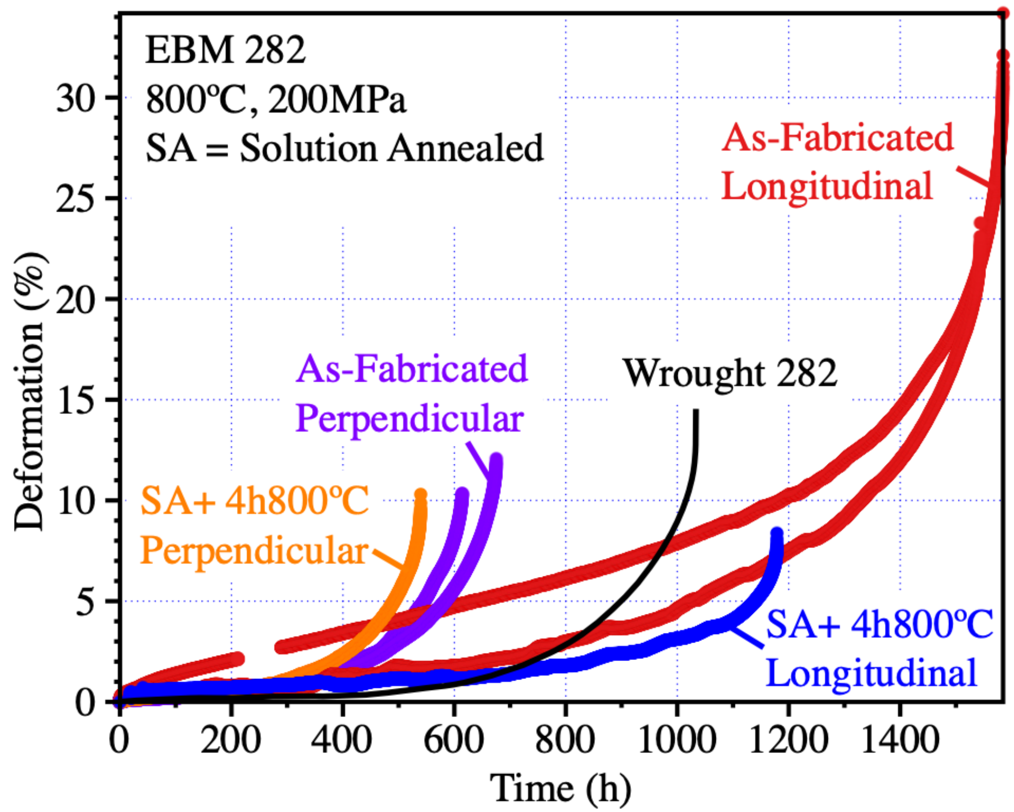


Investigating deep convolutional neural networks for quantifying patterns in point net beam strategies

Superior Creep Properties For As Fabricated EBM 282 But Lower Properties Perpendicular to the Build Direct

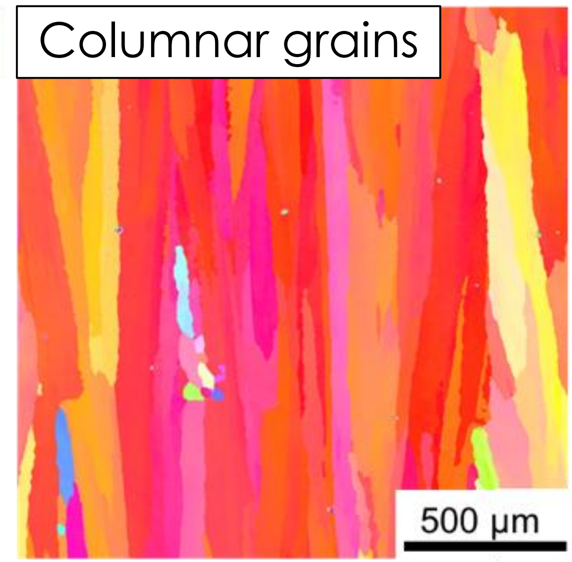


- Columnar grains with strong texture due to "standard" raster beam strategy
- As fab 100nm gamma prime acceptable

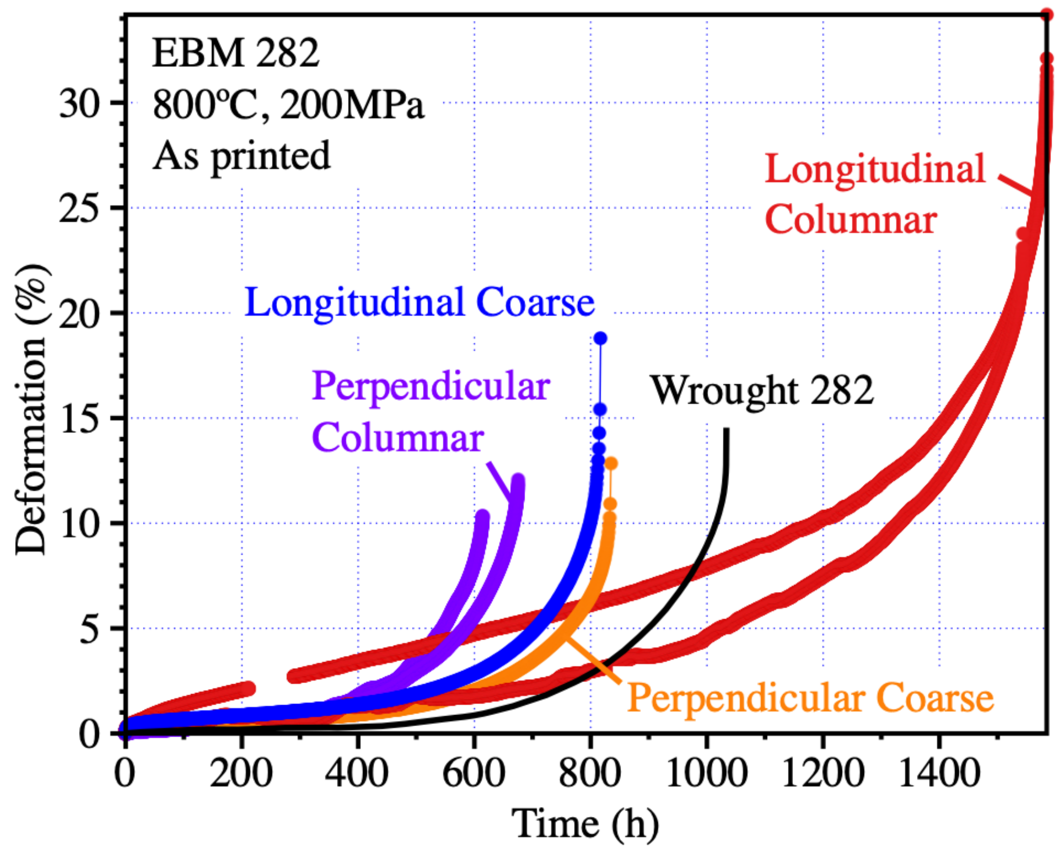


Tensile properties (not shown) were similar along and perpendicular to the build direction

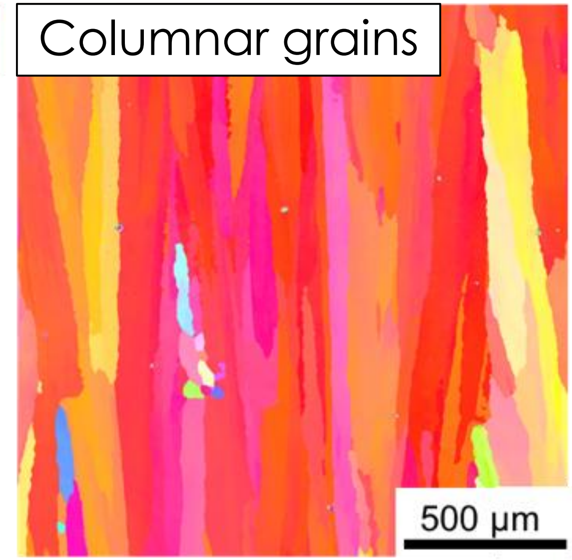
Controlling the Microstructure to Reduce EBM282 Creep Anisotropy at 800°C

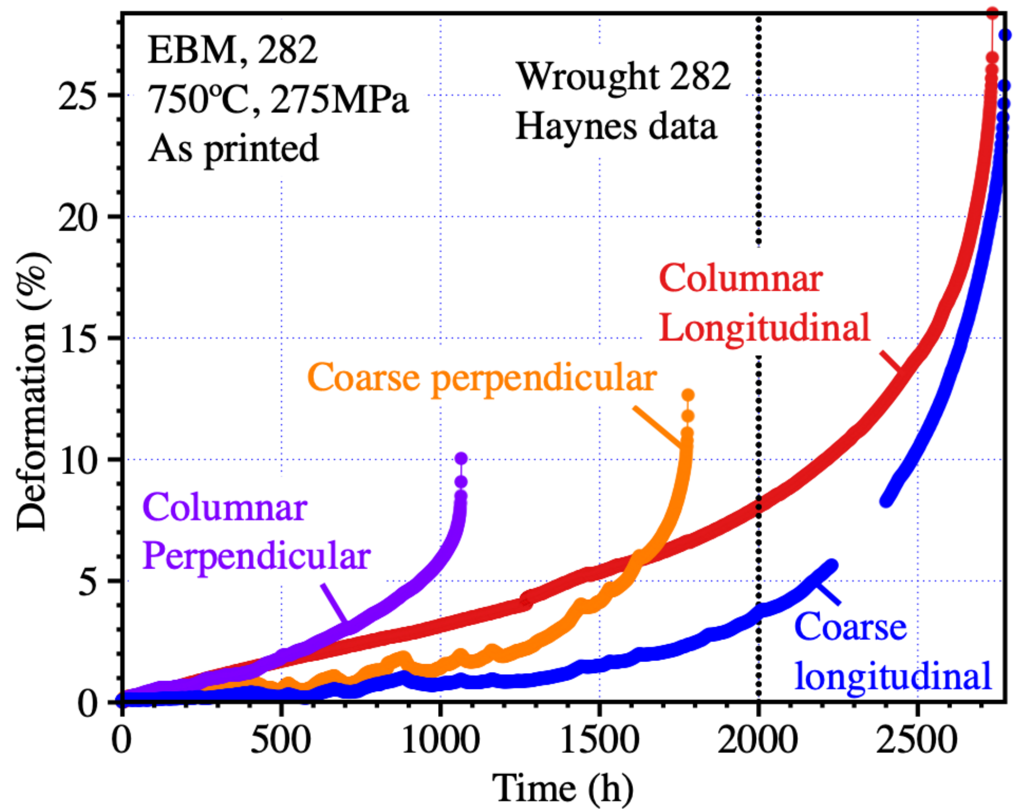


Coarse grain via flood beam strategy

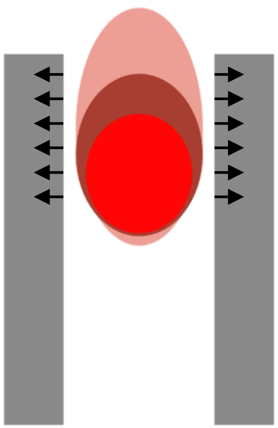


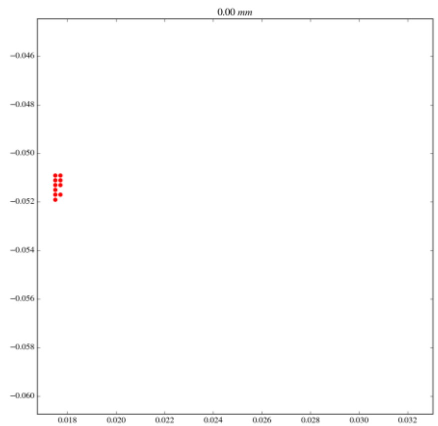
Controlling the Microstructure to Reduce EBM282 Creep Anisotropy at 750°C

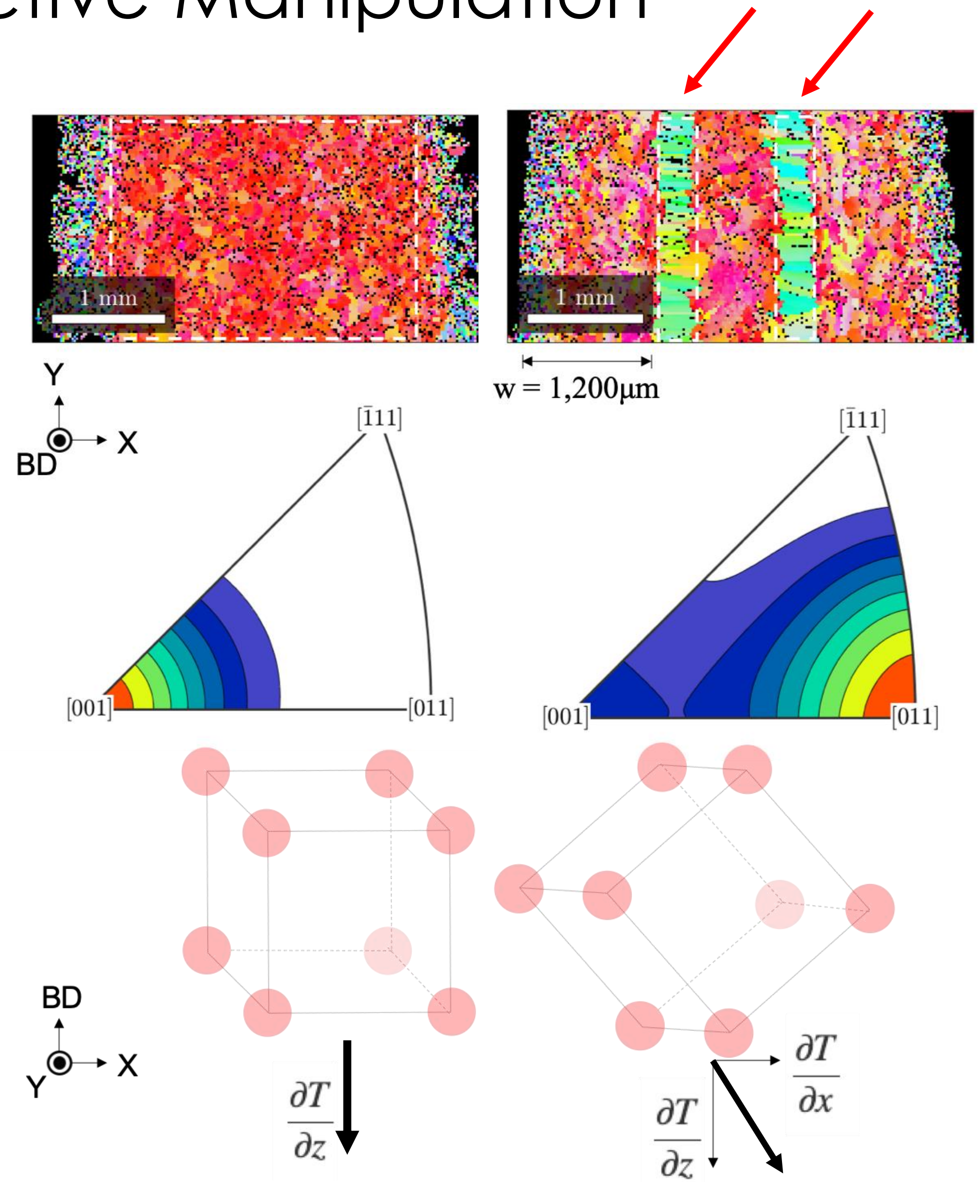




Mesoscale Texture Control Through Conductive Manipulation



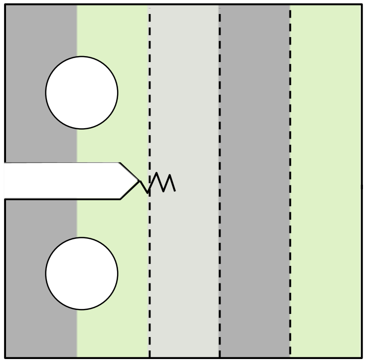


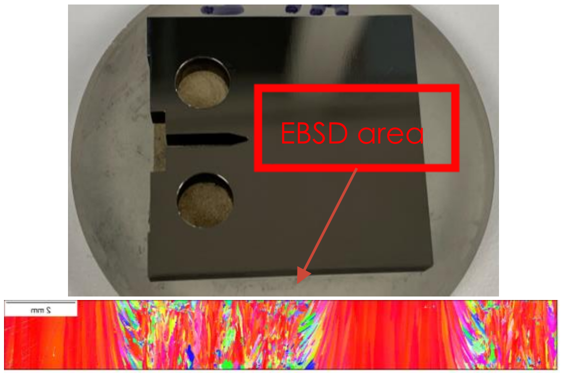


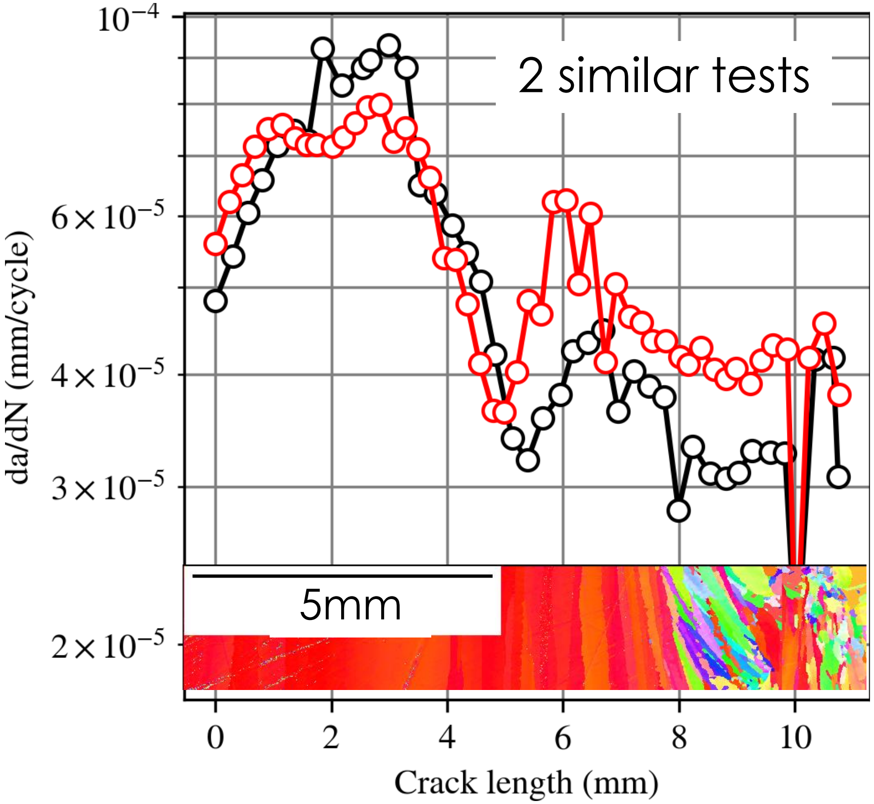
Additional lateral conduction in melted metal compared to unmelted powder

P. Fernandez Zelaia et al. Materials & Design 2020

Variation of fatigue crack growth in EBM282 Composite Microstructure







Constant ΔK=20ksi*in$^{0.5}$ tests
Paris Law: $da/dN = C(\Delta K)^n$
Hence da/dN = f(***microstructure*** ***alone***)

- 2X da/dN change across microstructures
- Local control of the component microstructure to improve its performance

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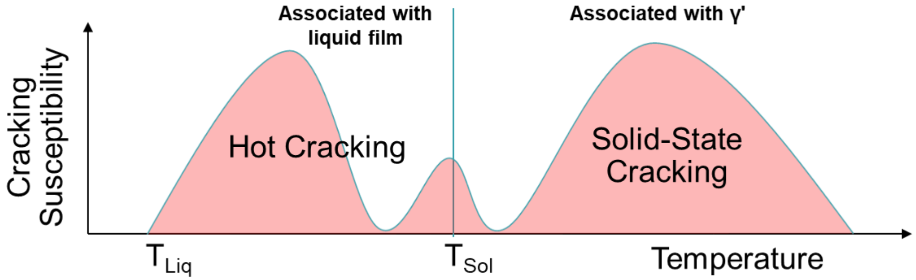
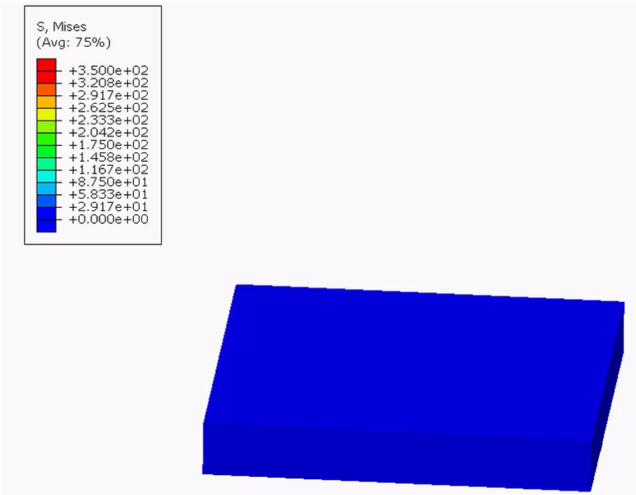
Understanding Crack Formation in High Gamma Prime Alloys for Crack-free Components

Crack Formation Modeling (EERE-AMO/FE)

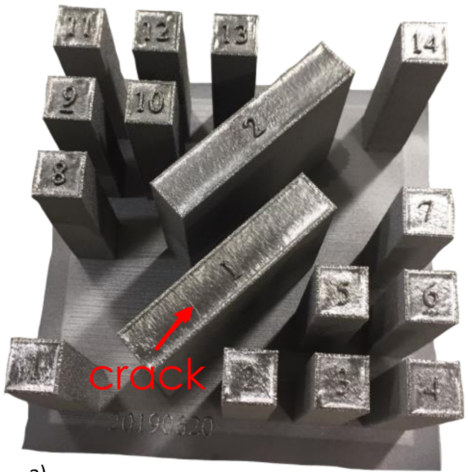


Modelling requires:

- Thermal profile during printing
- Transient evolution of Microstructure
- Stress magnitude and distribution

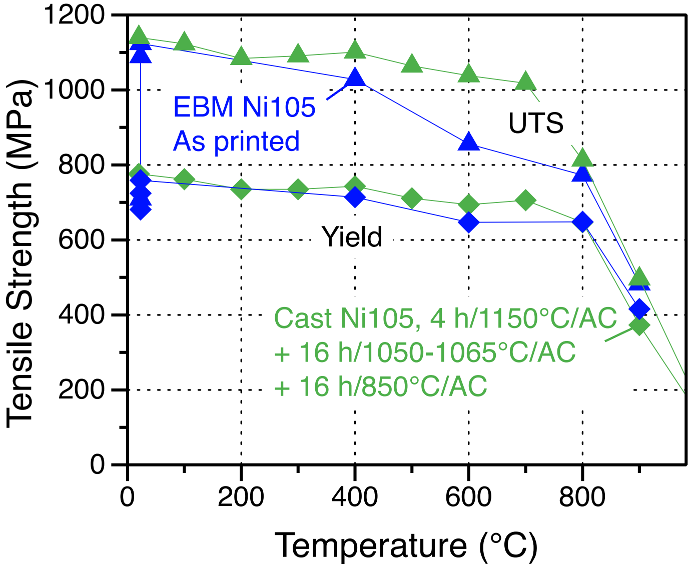


Looking at new alloys relevant for FE such as Alloy Ni105 or ABD-900



a)

Very different crack pattern compared to CM247



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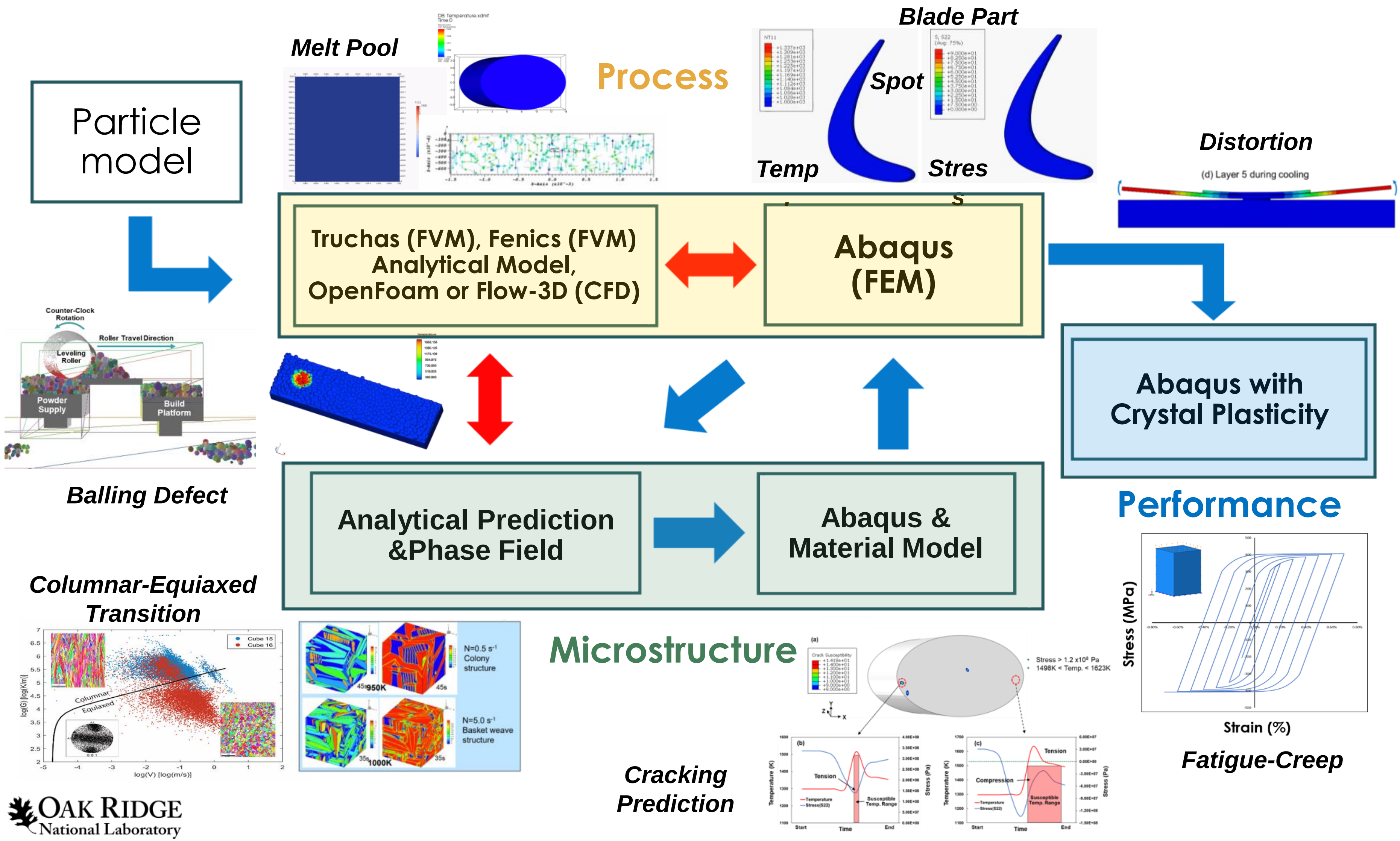
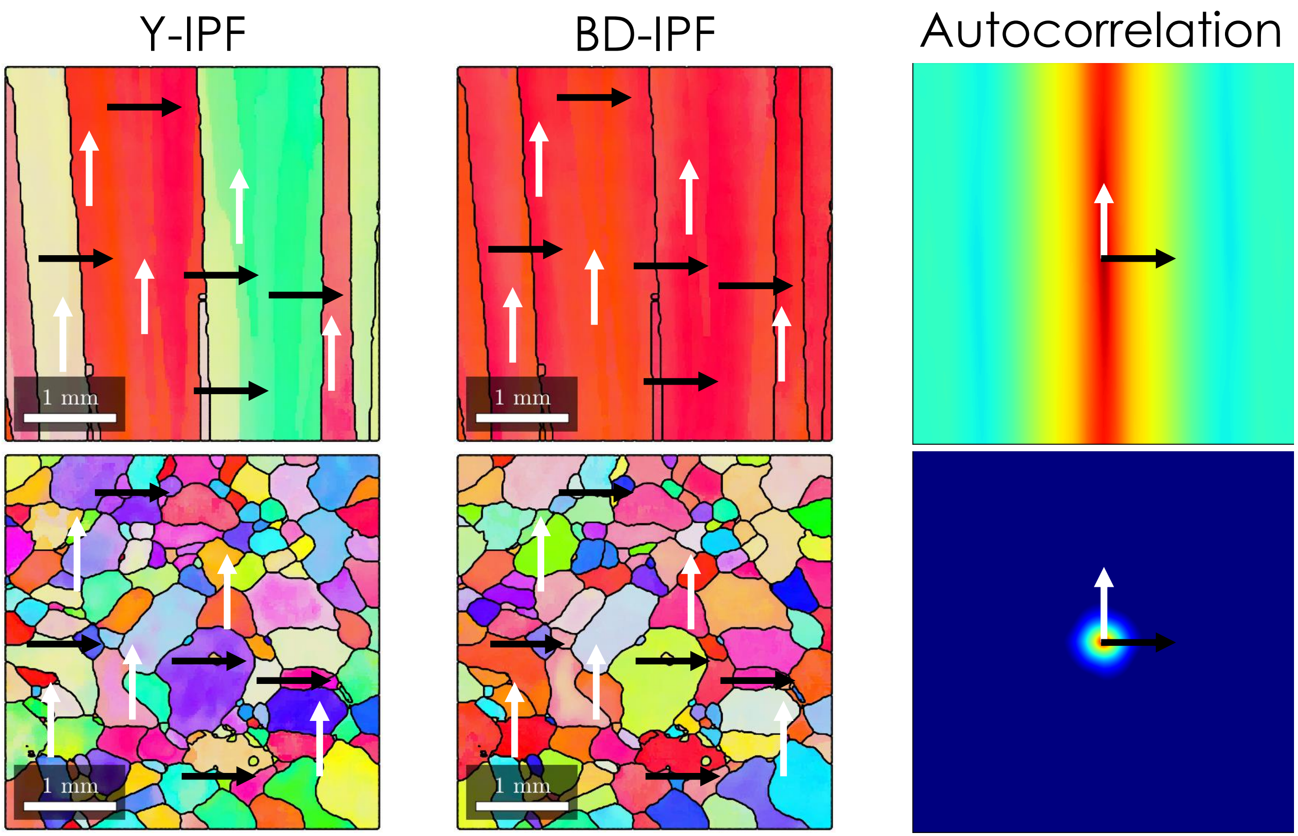
Various Physic-Based Models For Process-Microstructure-Properties Correlation. EERE-AMO/FE Collaboration



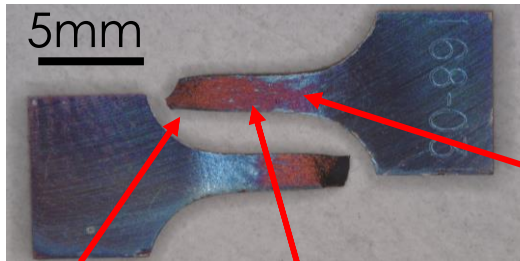
Machine learning approach: autocorrelation functions using EBSD map For Microstructure Quantification



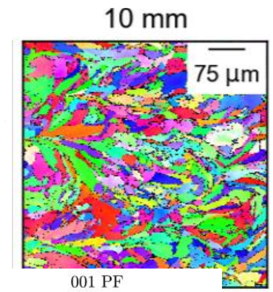
- Throw in many random vectors & Compute frequency of “similarity” of heads and tails
- Similarity metric considers absolute orientation – not simply “coloring” from one IPF map.

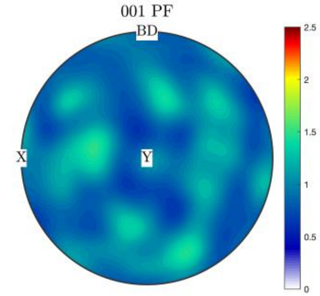
Extract maximum constitutive information from experiments utilizing correlation statistics

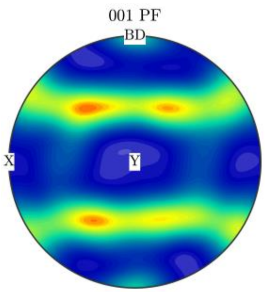
Laser powder bed fusion 316L 600°C tensile

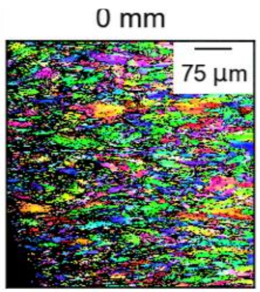


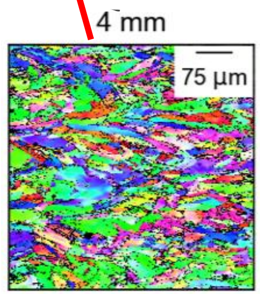
Collaboration with EERE/VTO

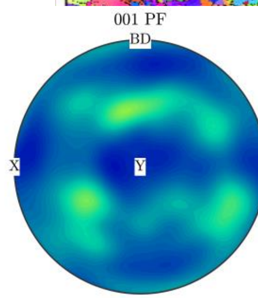




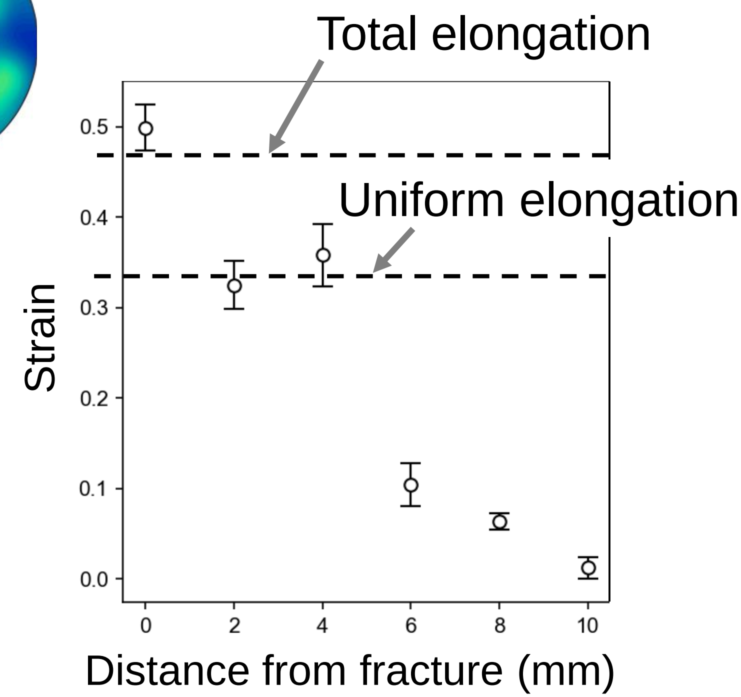








- Deformation gradations in tensile specimens
  - High strain – strong deformation texture
  - Low strain – inherit random texture from AM
- Synthetic microstructure to calibrate the model

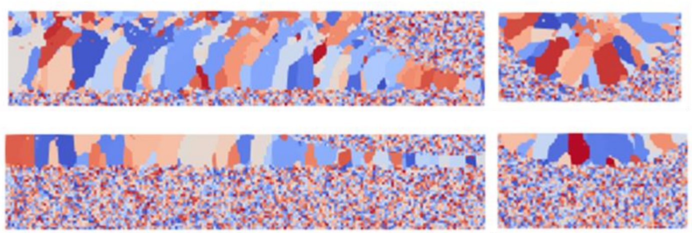


Synthetic Microstructure to Accelerate Process-Microstructure-Performance Correlation

Process-Microstructure

Using Kinetic Monte Carlo Model

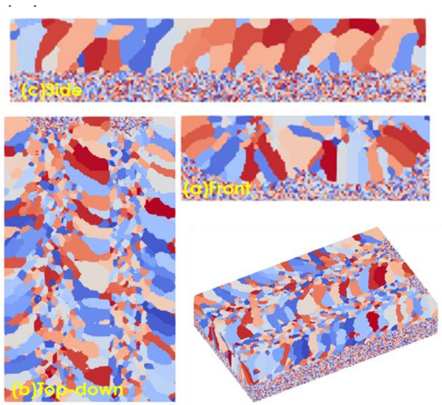
1.Melt Pool Shape

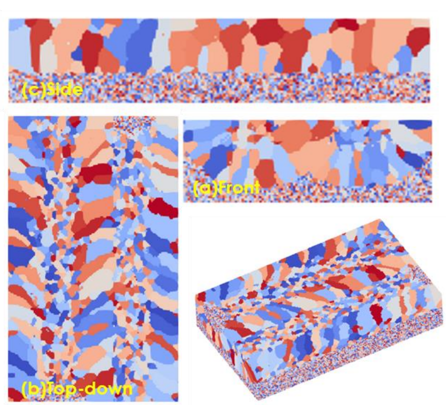


2.Scan pattern & 3.Geometry

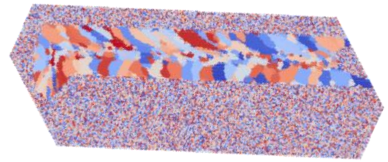
Unidirectional

Bidirectional

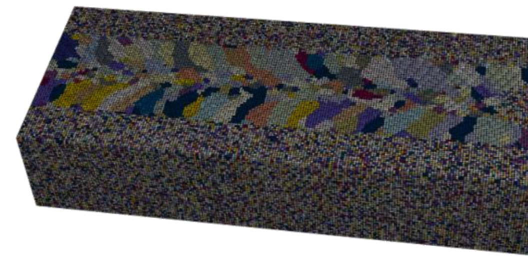




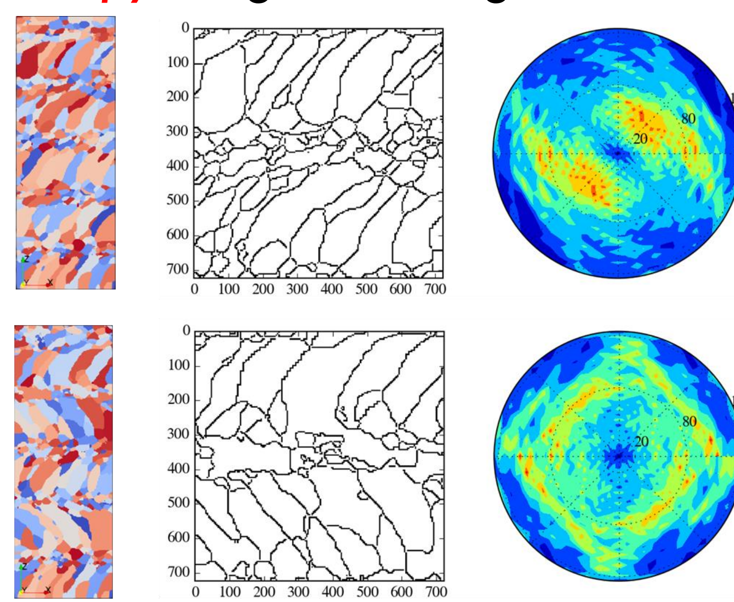
Microstructure-Performance



Conversion from KMC to FEM



Statistical analysis of microstructural anisotropy using chord length distribution



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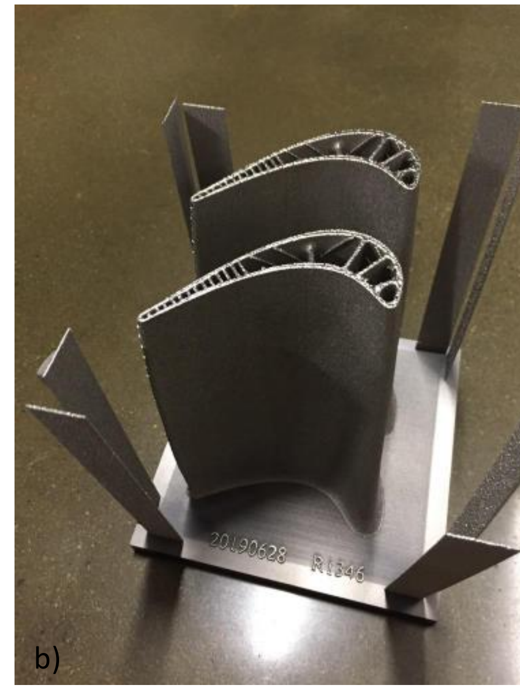
Fabrication of AM Components Relevant for FE Applications

HX fuel injector

170mm to

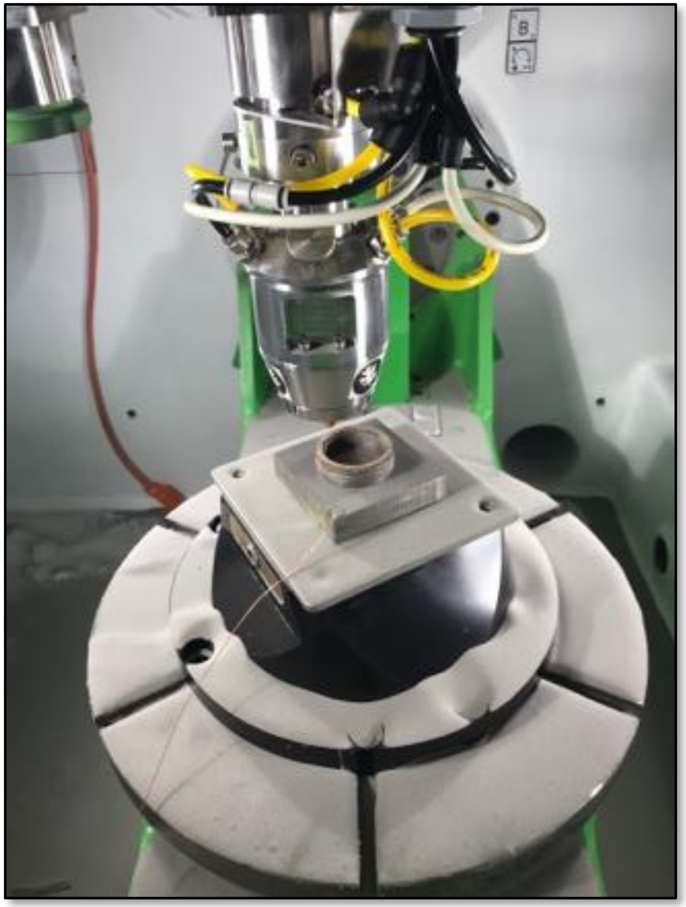
282 concentric reducer



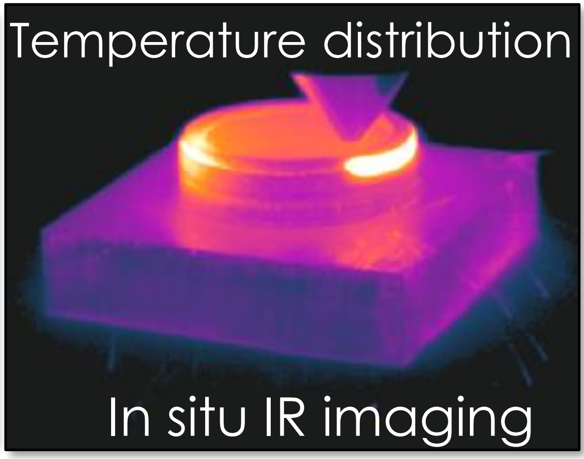
Ni105 blade

Coated 282 combustion components

Functionally Graded Transition Joints to Enable Dissimilar Metal Welds

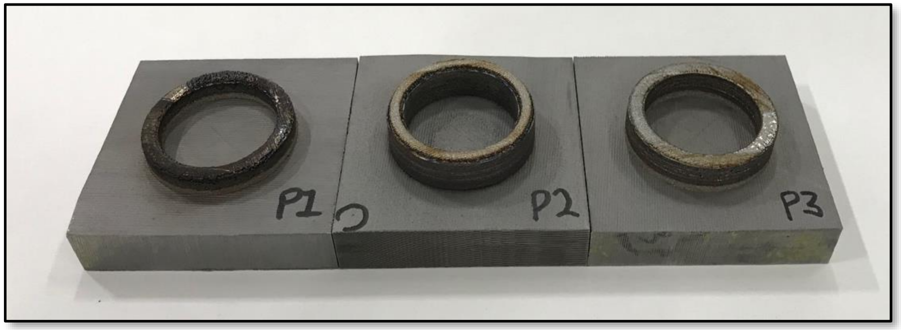


BeAM blown powder directed energy deposition system



- Goal: To produce transition joint from SS347H to Gr. 91
- Initial work on SS316 & ANA-2 (Fe-8Cr-2Mn) powders due to better powder flowability
- Key is to optimize the microstructure in the transition zone

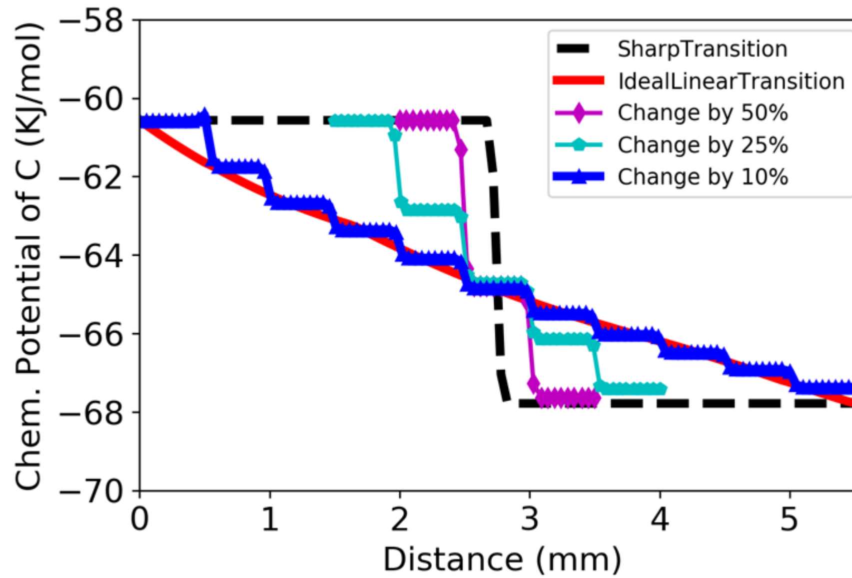
Thermodynamic and FEA Simulations to Optimize Transition Zone



100%SS/100%F

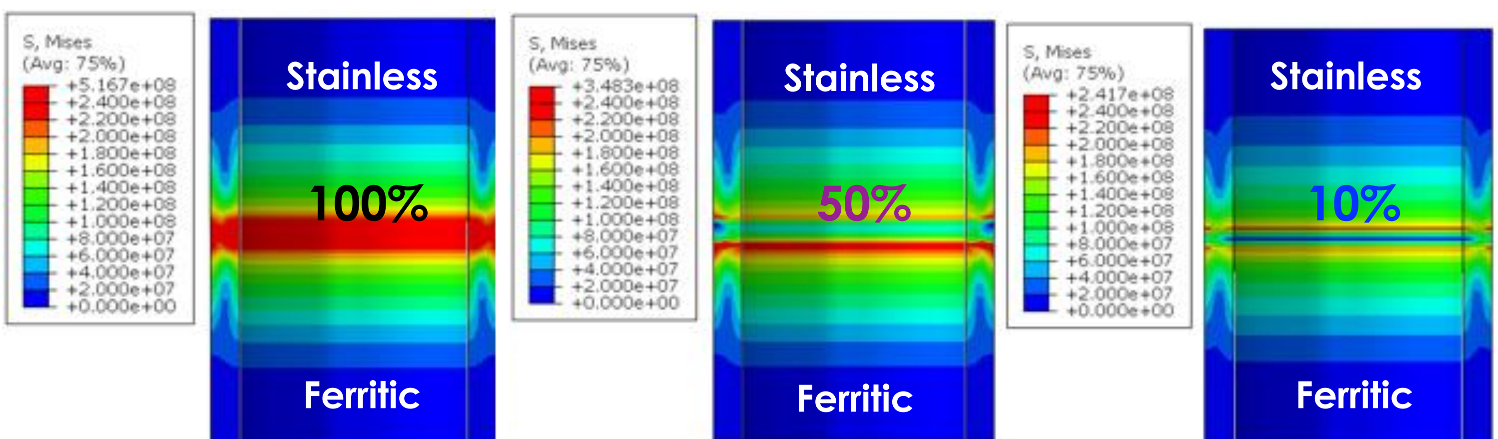
100%SS/50%SS-50%F-100%F

100%SS/70%SS-30%F/50%SS-50%F/30%SS-70%F/100%F



- Minimize change of C chemical potential
- Minimize stress due to mismatch in coefficient of thermal expansion

Mises Stress



Conclusion: Great AM Opportunities for FE

- AM allows the fabrication of complex parts with local control of the microstructure for superior component performance
- Continuous development of physics-based models and data analytics tools for establishing process-microstructure-properties correlation
- Broad range of opportunities due to AM versatility: graded microstructure for weld and coatings, large scale additive manufacturing to help with domestic supply chain, unique microstructure resistant to H embrittlement