Computational Simulation of Fatigue Failure Risk for Additive Manufactured Metal Structures

Robert Tryon

Animesh Dey, Mike Oja

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VEXTEC Introduction




Headquarters

Nashville, TN – 20 years in business

VPS-MICRO® Software

Predicting fatigue durability and risk of metallic products and systems

Value Proposition

Supplement physical testing for increased confidence in accelerated qualification of parts

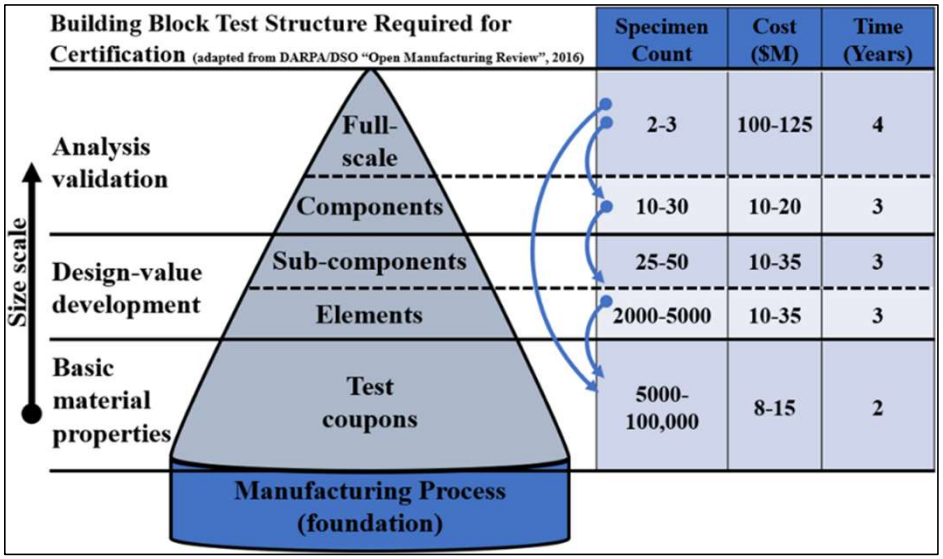
VPS-MICRO is:
Validated by US Government research programs
Utilized globally by commercial industries
Backed by 7 US Patents

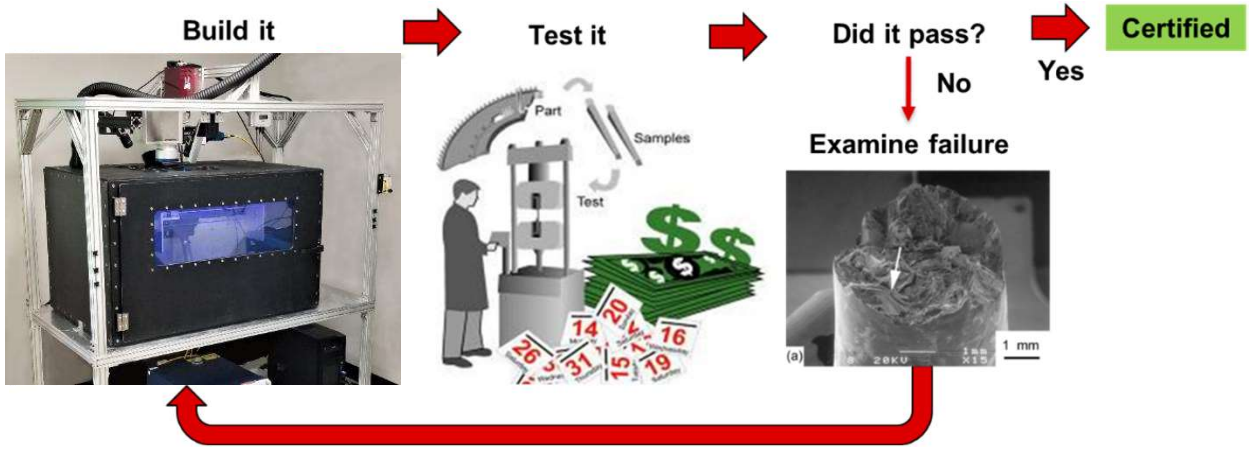
VEXTEC

Why ICME?

- **Current AM development / validation process is iterative, costly and slow**
  - Build, test, analyze, **repeat**
- **Long lead times and high development costs**
  - Design allowable databases
  - Machine manufacturer specific
  - NDE and post process inspection

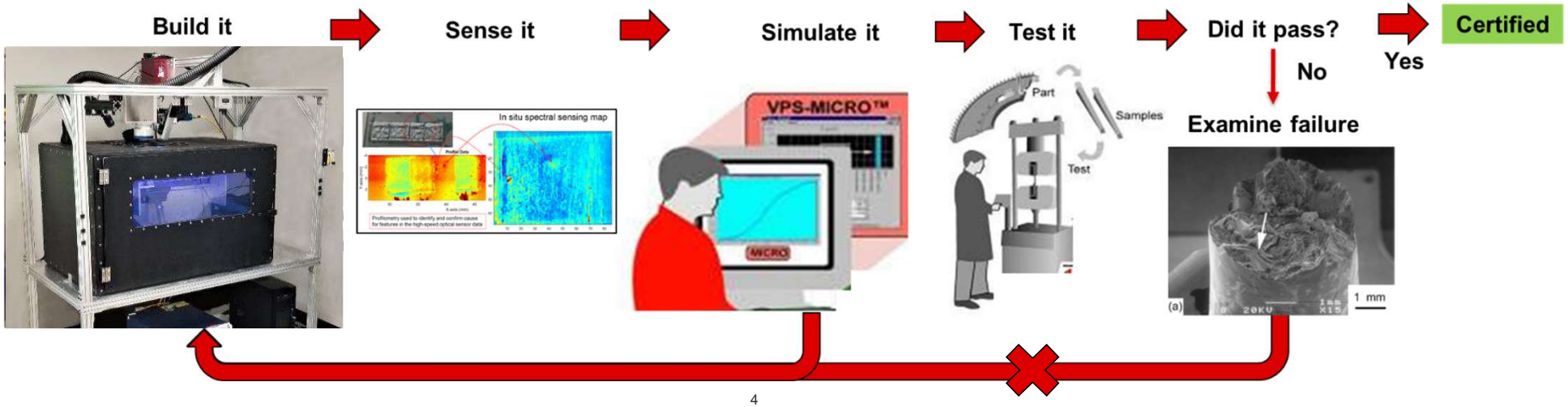
Integrated Computational Material Engineering (ICME) tools can provide up to **50% time/cost savings** for AM process development.





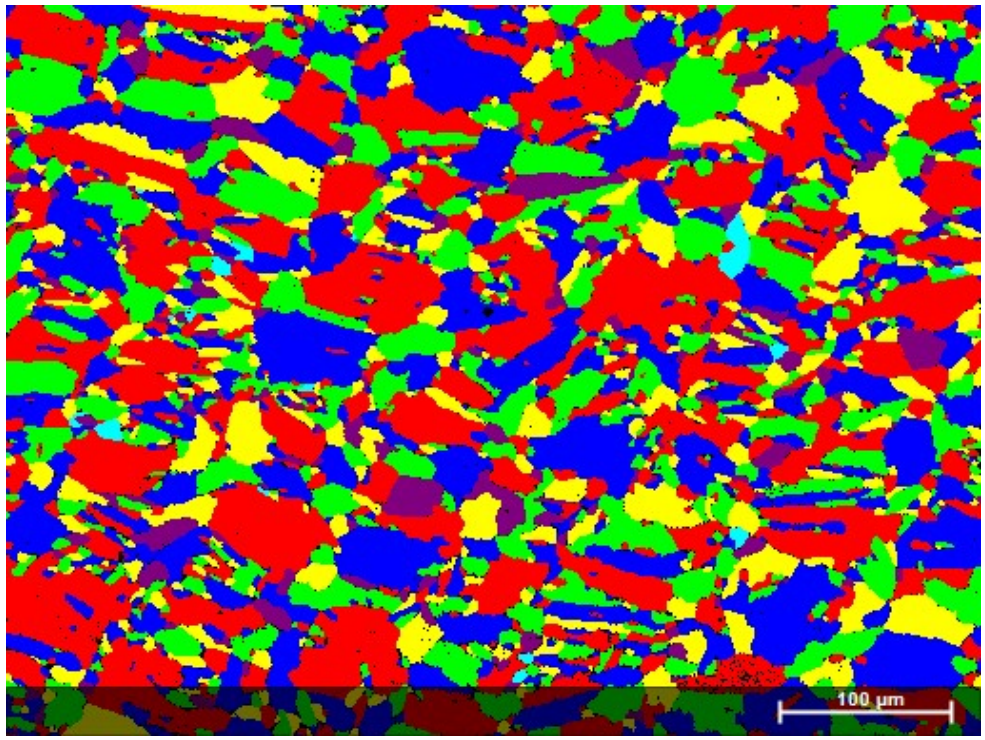
What Do We Mean by ICME-Based Certification?

- We are not changing the required elements of the certification process; we are instead simulating important aspects.
- Build and sense what is happening layer-by-layer, point-by-point, to have a high fidelity 3-D model of local properties.
- Take that model and simulate what would happen if you test it.
- Only test the part when you have high confidence it will pass the test → reducing costly repeats.

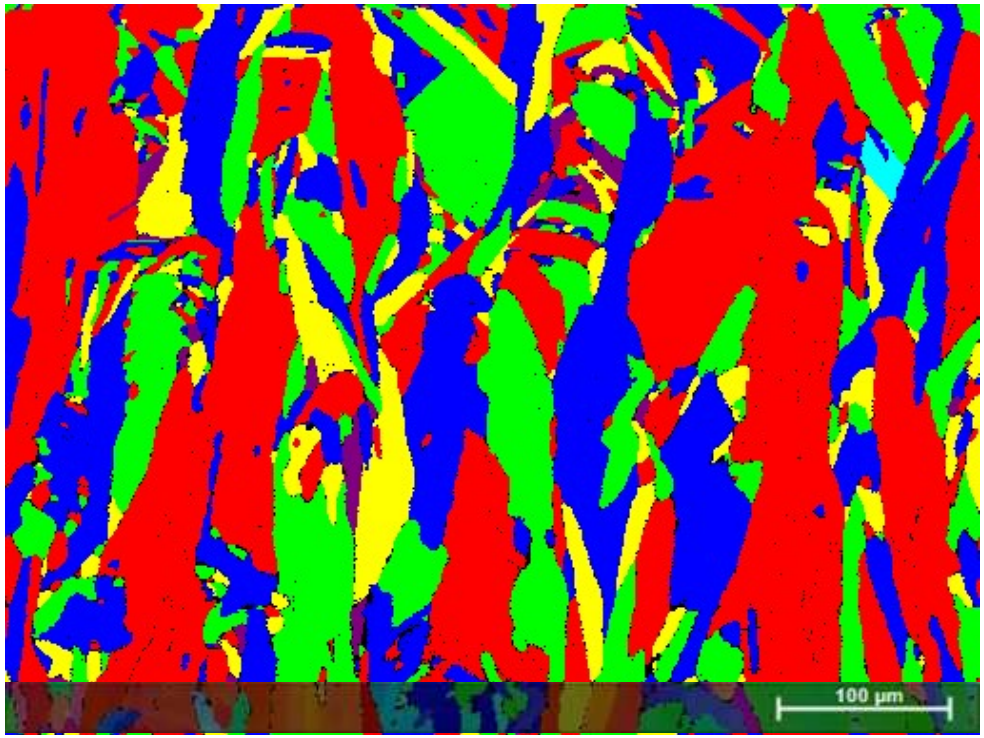


Metal AM Issues: As-Built Microstructure

Build Orientation



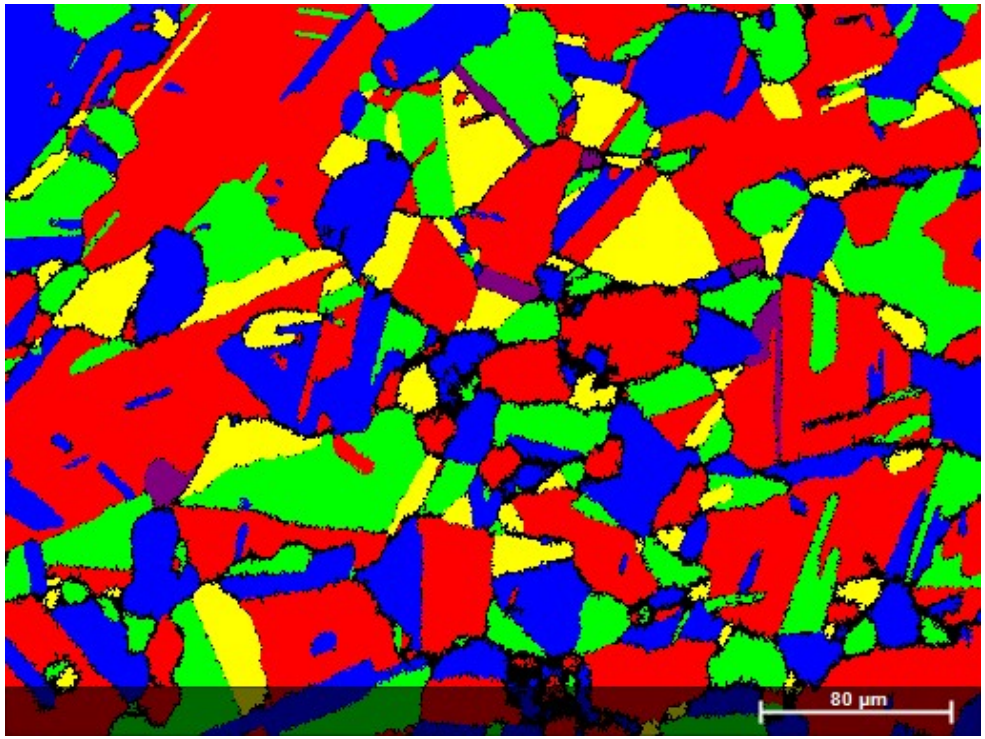
Cross Section



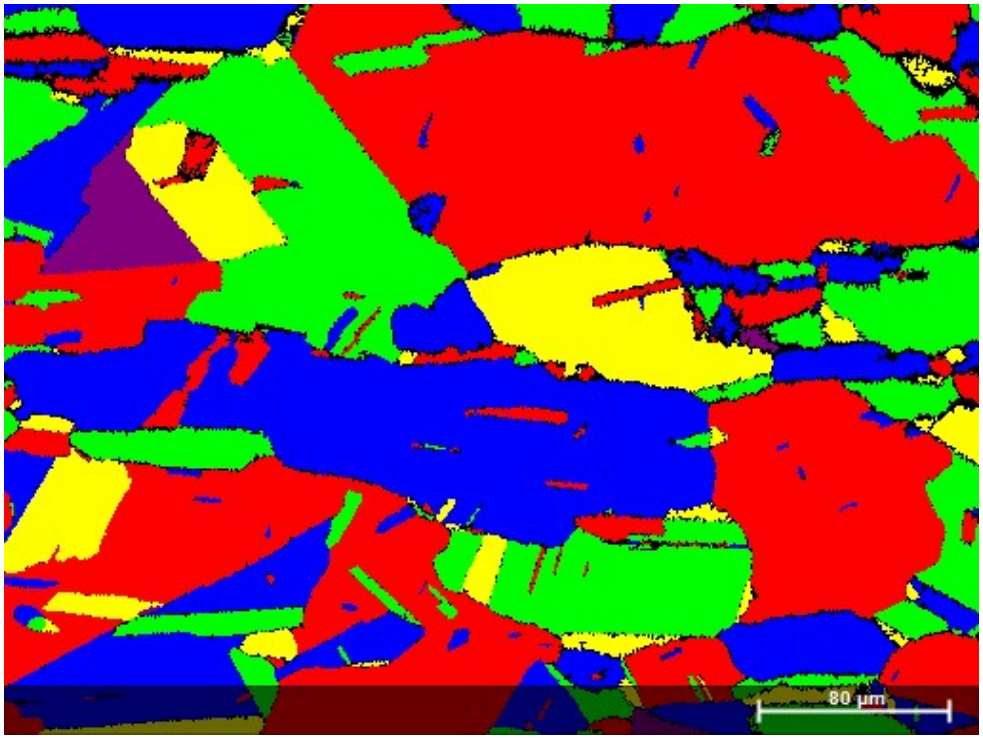
Longitudinal Section

Metal AM Issues: Post-Built Heat Treat (HIP STA)

Build Orientation

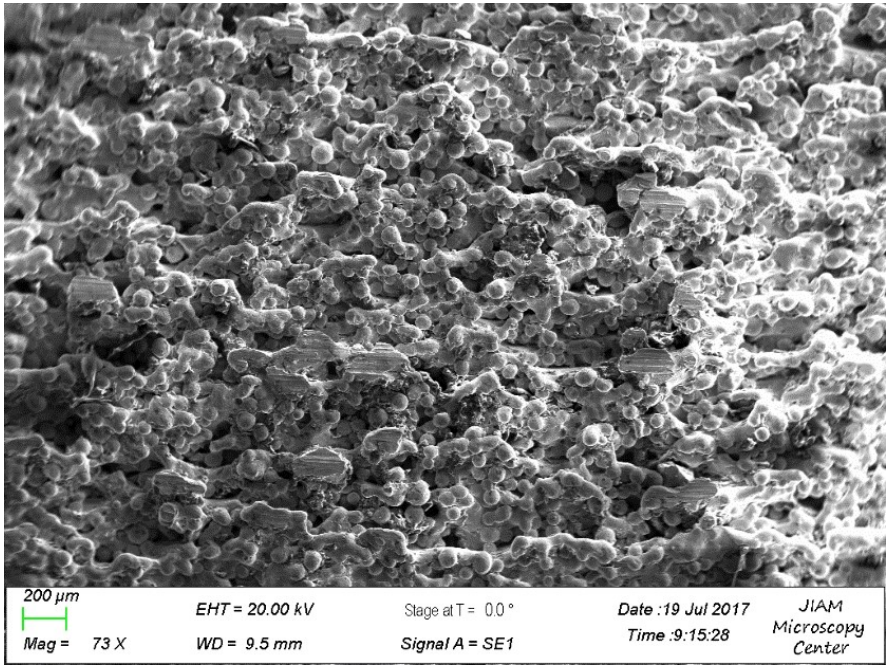


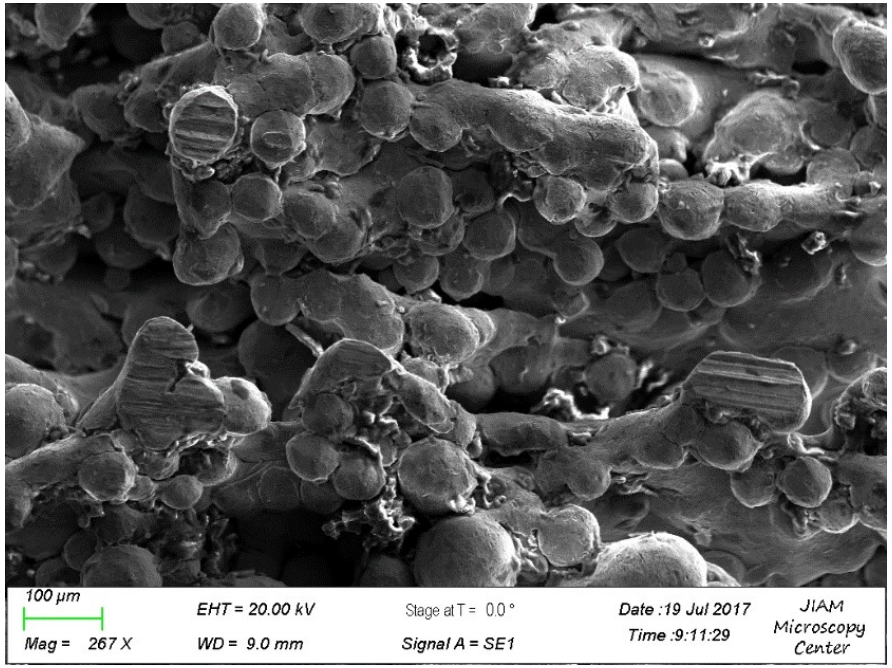
Cross Section



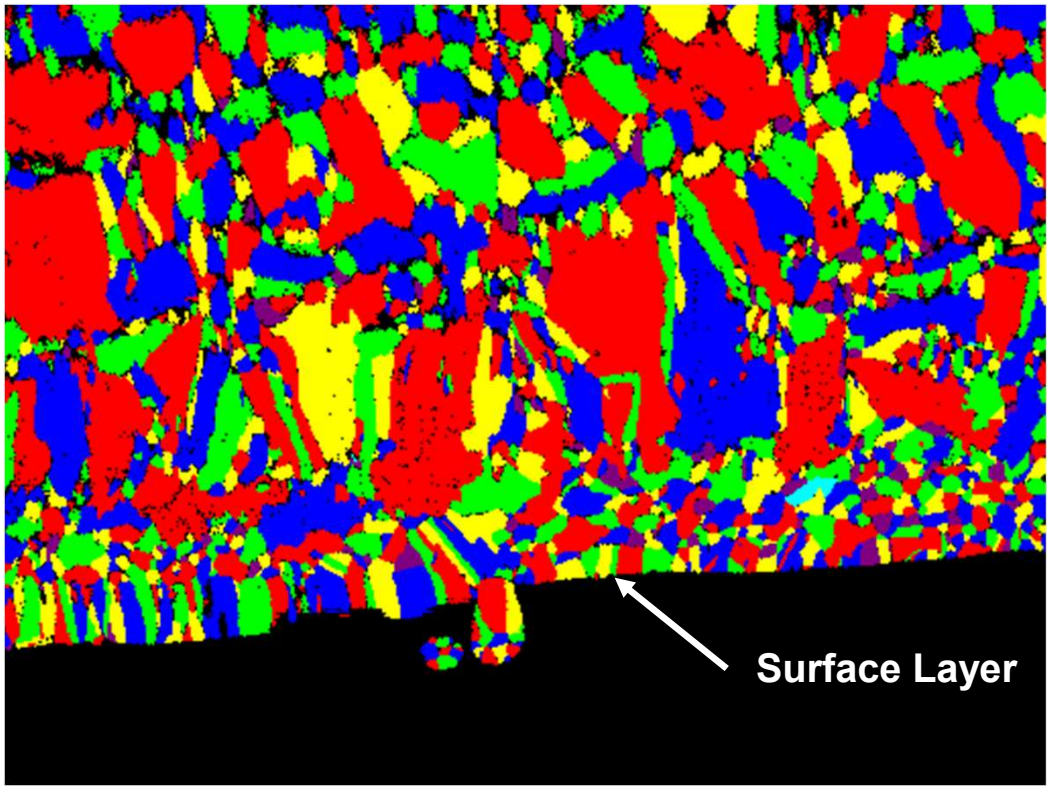
Longitudinal Section

Metal AM Issues: As-Built Surface Morphology



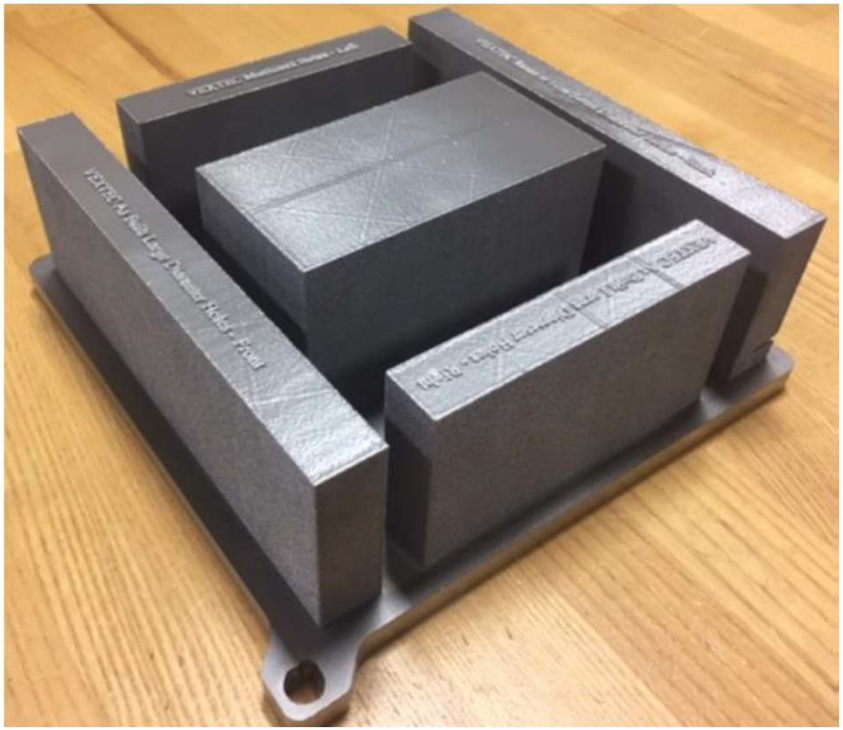


Metal AM Issues: As-Built Surface Microstructure

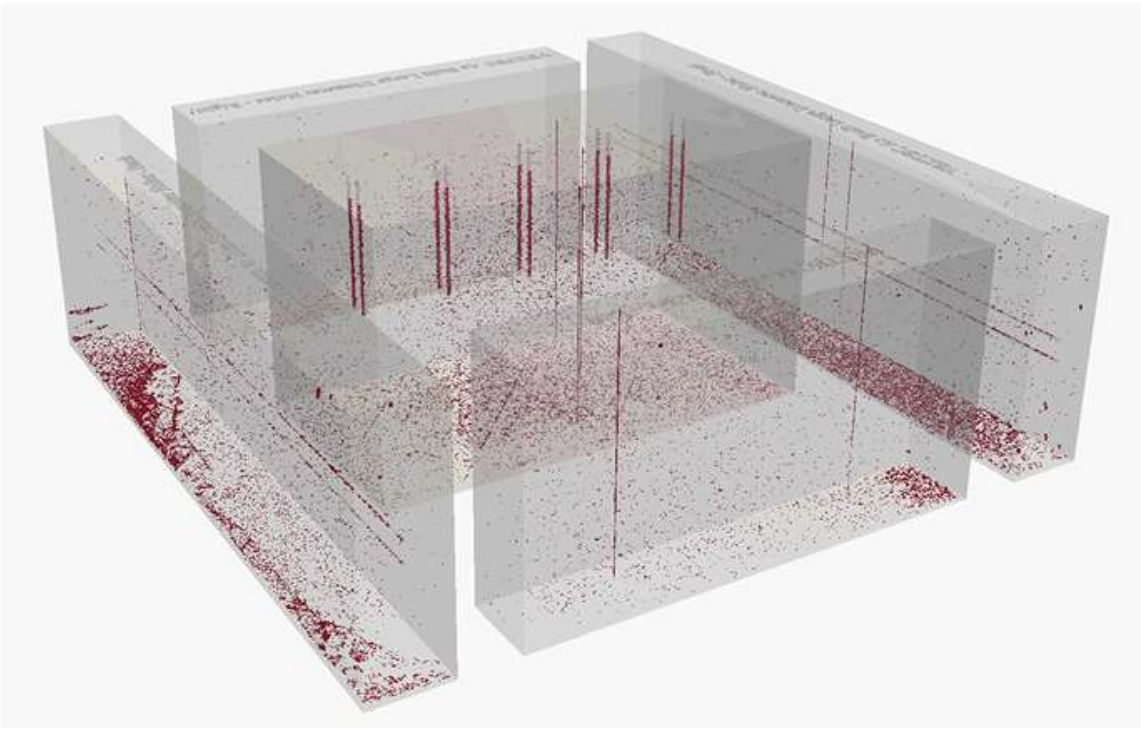


Metal AM Opportunity: As-Built Defect Sensing

Build Blocks

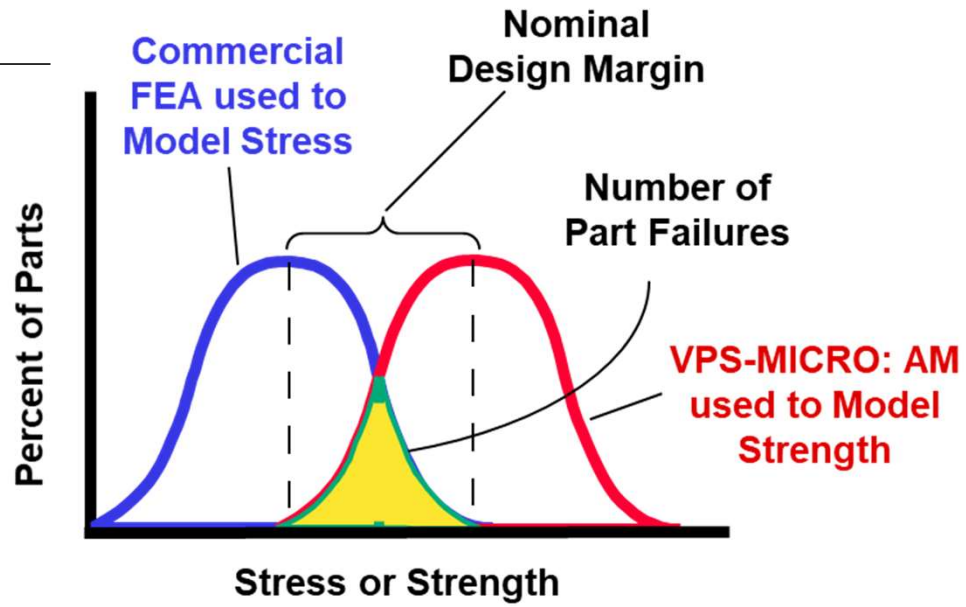


Defect Size and Location

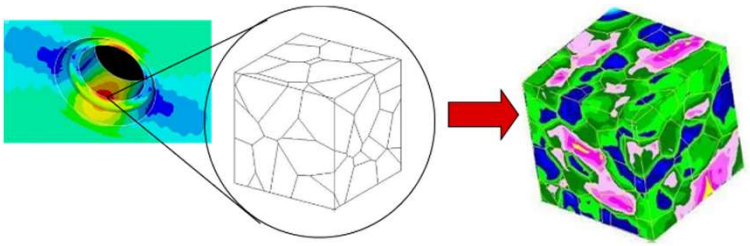


Modeling Method

- Just as FEA uses a digital representation of the part to model the stresses, VPS-MICRO uses a digital representation of the material to model strength.
  - Fatigue strength is the big cost driver and is governed by the material microstructure.
  - VPS-MICRO addresses fatigue strength.
  - VPS-MICRO creates digital models of the material microstructure.
  - VPS-MICRO simulates effect of surface roughness.

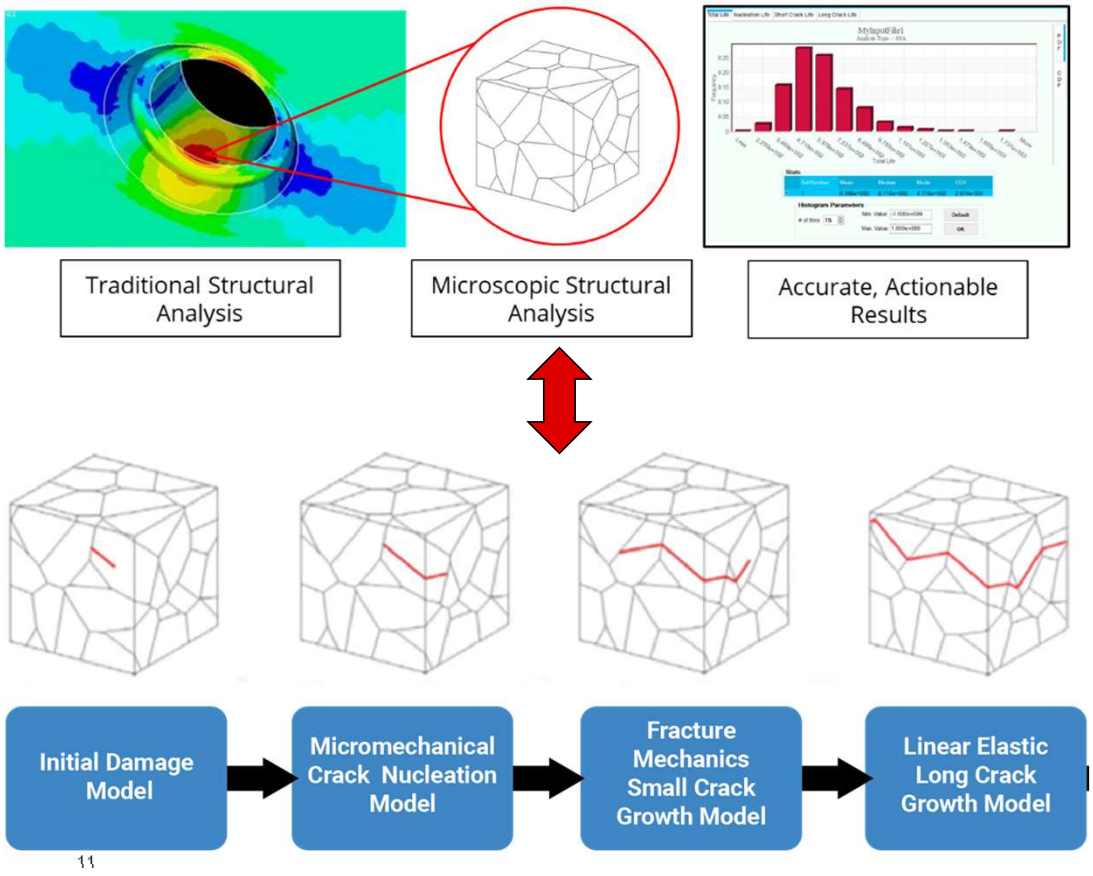


With AM, the need for analysis software is even more urgent because of the difficult-to-test-for internal surface roughness of complex geometries.



Commercial Software Solution: VPS-MICRO

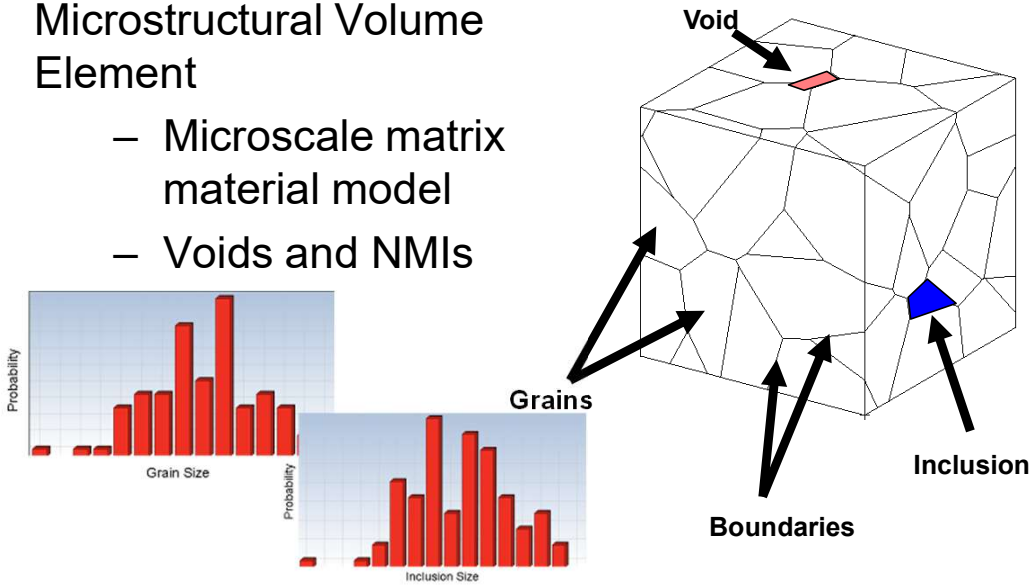
- VPS-MICRO links microstructure to macrostructural FEA to:
  - Predict scatter in fatigue.
  - Predict complex part failure rates.
  - ID allowable microstructural tolerances in manufacturing process .
- VPS-MICRO uses physics-of-failure modeling to analytically predict the cause and extent of fatigue failure.



Microstructural Definition

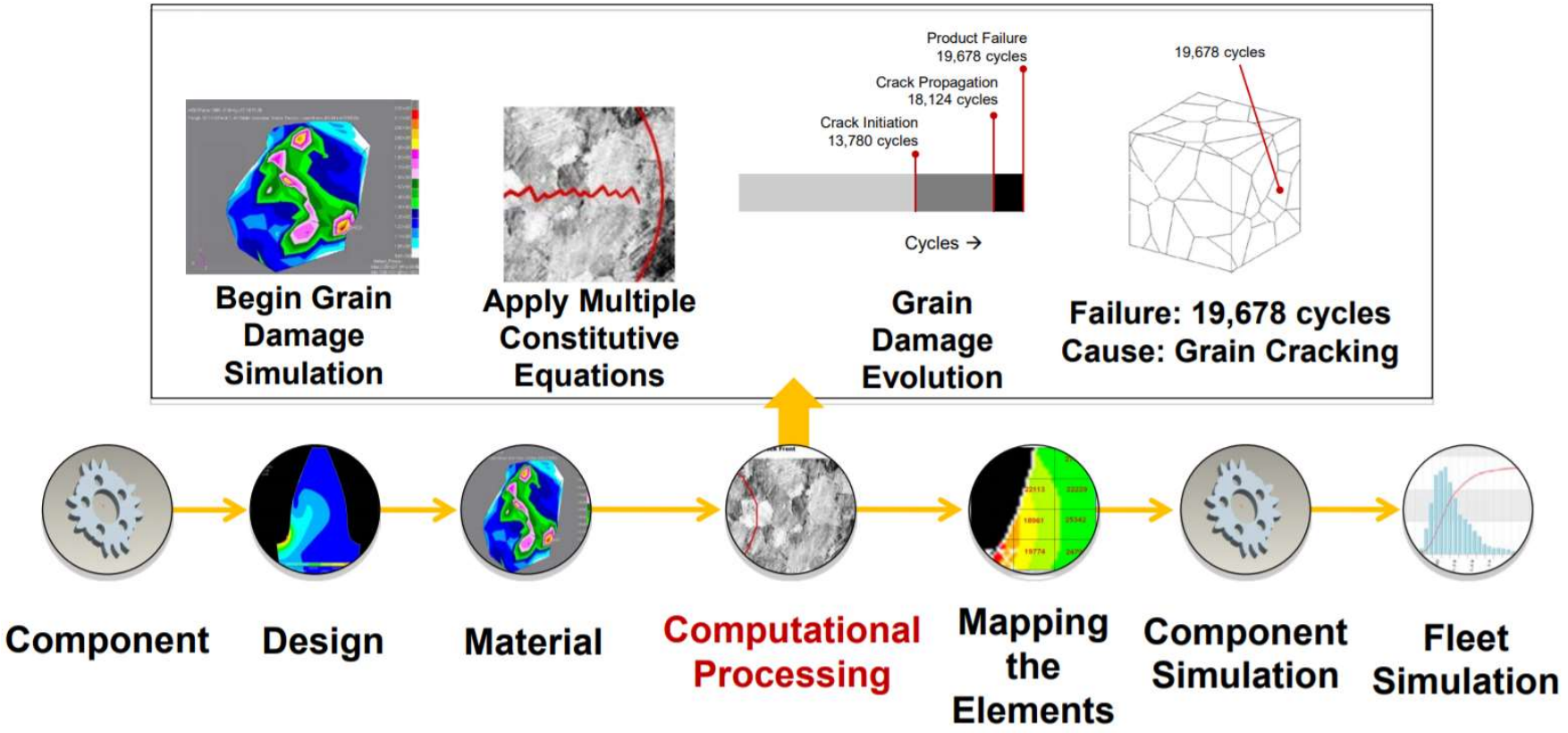
Microstructural Volume Element

- Microscale matrix material model
- Voids and NMIs



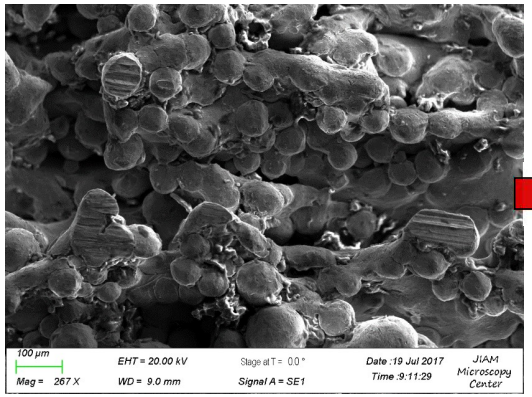
Statistical Volume Element (SVE) of Microstructural Feature

Computational Process Flow

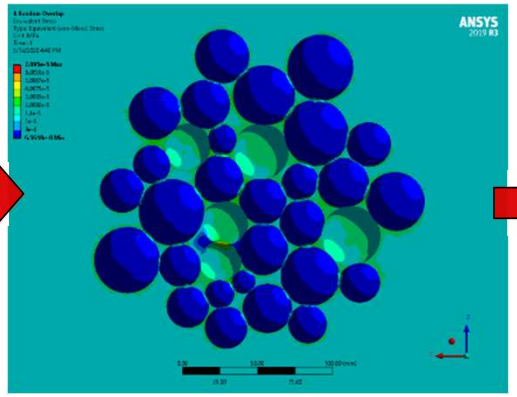


Application of ICME to Surface Roughness

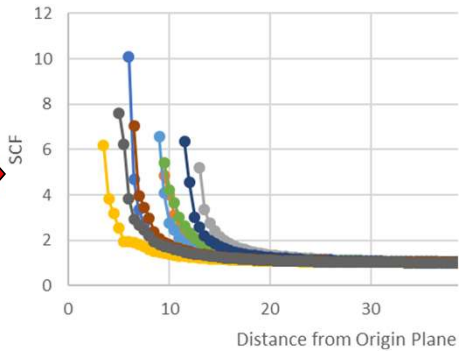
Surface Geometry



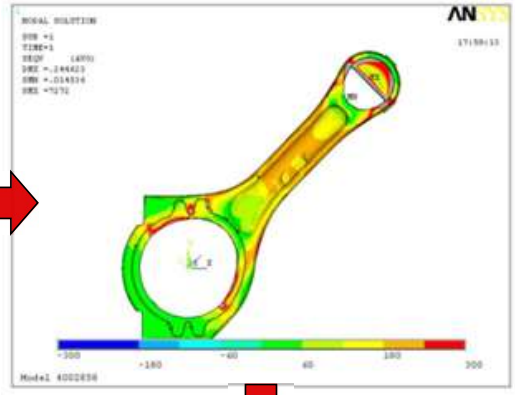
FEA of Surface



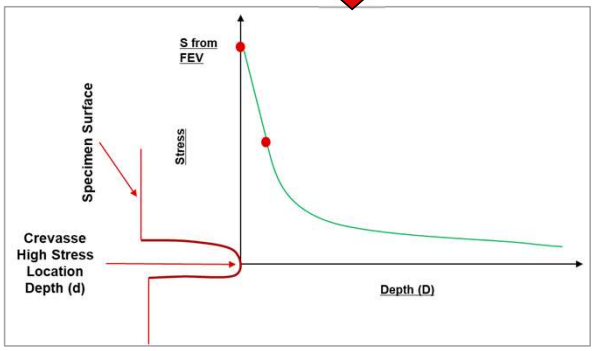
Random Surface kt



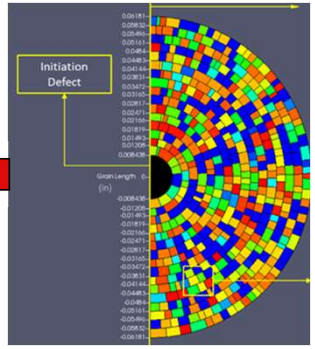
FEA of Part



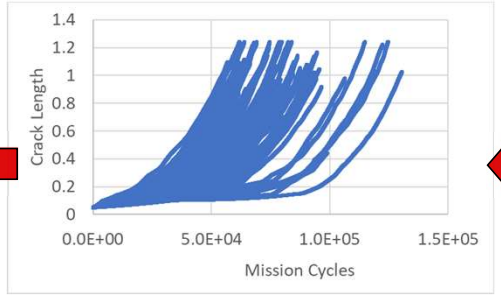
Model Surface with Population of Features



Generate Subsurface Microstructure



Simulate Small Crack Growth for each Feature



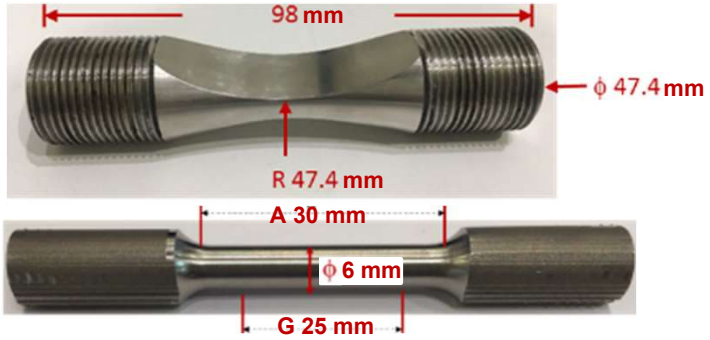
Predict Statistical Distribution of Fatigue

Allowable Surface Roughness

- 10 specimens simulated at each stress for each surface roughness condition
- 3 load levels simulated for a total of 90 specimen test
- Between 20,000 and 40,000 features per in^2 is the tipping point

Additive Manufacturing of IN-718

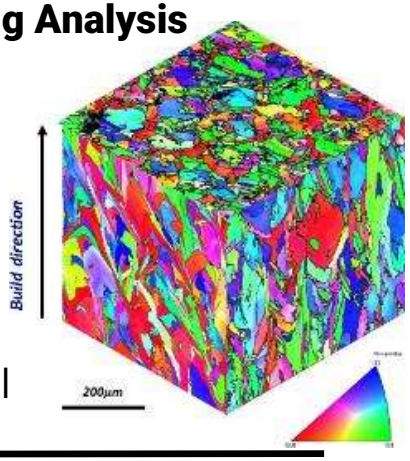
SLM → Heat Treated & Hardened IN-718



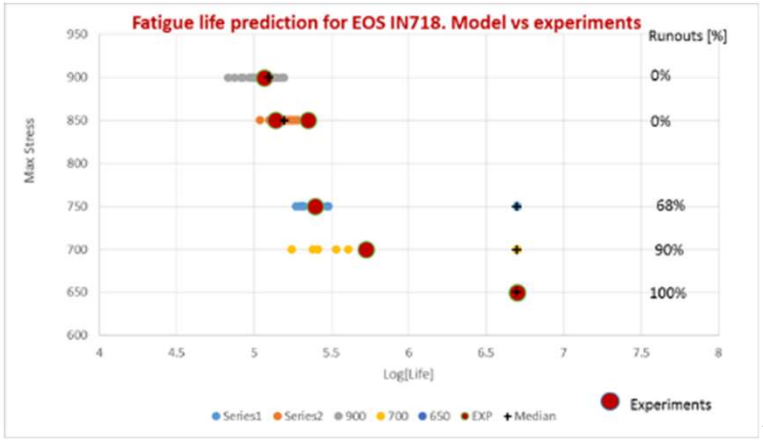
- Fatigue and tensile specimens built

Orientation Imaging Analysis

- Grain size and orientation in different directions within the specimens
- Used as inputs to VPS-MICRO model



Calibrated Fatigue Model w/Experiments



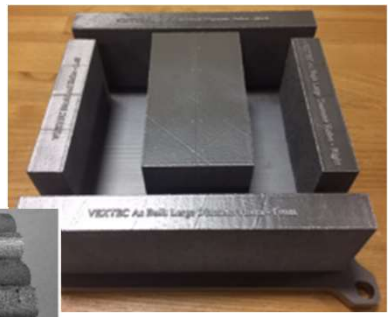
Conclusions

- Material and damage models in VPS-MICRO can predict fatigue response of SLM IN-718
- Evaluation of scatter in fatigue life for certifying AM components (difficult to do with limited physical tests) can be readily performed using this ICME method

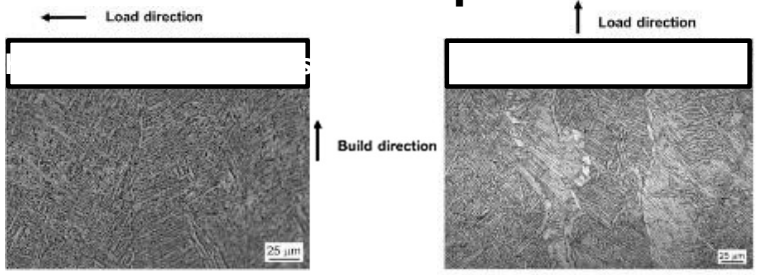
Additive Manufacturing of Ti-6Al-4V

Microstructure and Surface Finish

- Ti-6Al-4V blocks built via Electron Beam Melting (EBM) AM method



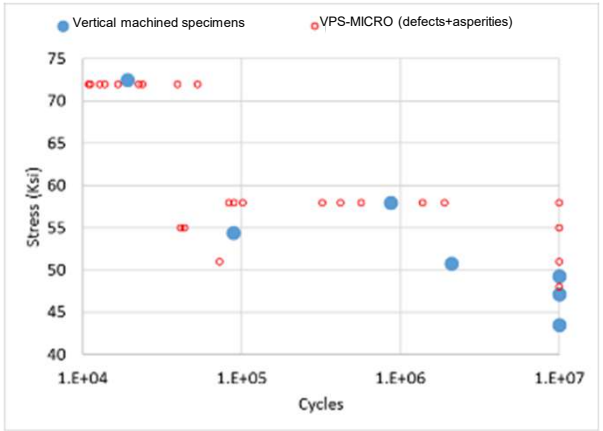
Build Orientation Dependence



- Higher UTS (no build defects)
- Smooth fatigue fracture surface

- Lower UTS (build defects)
- Rough fatigue fracture surface

Simulation & Testing Comparison



Conclusions

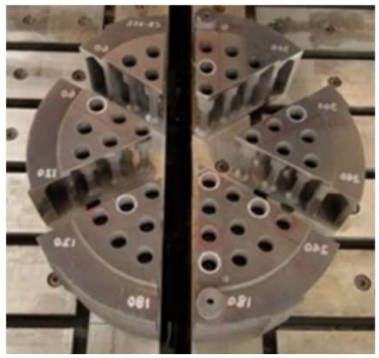
- ICME fatigue model previously calibrated to wrought Ti-6Al-4V was leveraged to predict fatigue behavior of EBM Ti-6Al-4V

- Predicted fatigue behavior of AM Ti-6Al-4V by modeling the differences in microstructure between wrought and EBM methods, and differences in EBM build direction

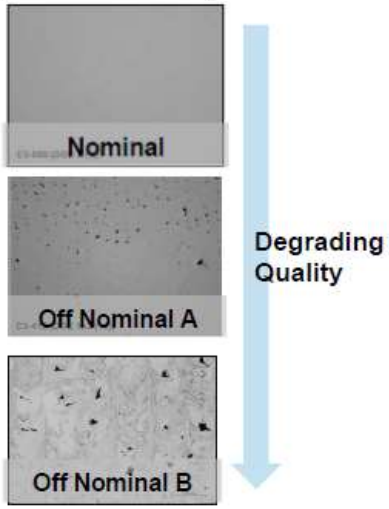
Burst Prediction of AM Nickel

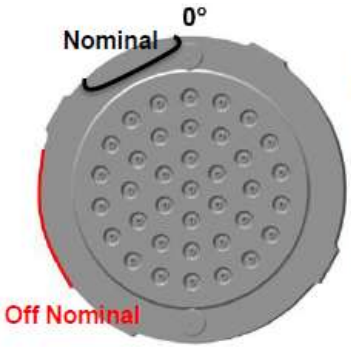
Superalloy Nozzle

- SLM Mondaloy



Unit	Operating Pressure	Proof Pressure	Vextec Calculated Burst	Actual Burst
Nominal	6.5 KSI	7.8 KSI	>13 KSI	15.KSI
Off-Nominal A	6.5 KSI	7.8 KSI	11-13 KSI	12.2KSI
Off-Nominal B3	6.5 KSI	7.8 KSI	11-12 KSI	10.5KSI
Off-Nominal B2	6.5 KSI	7.8 KSI	11-12 KSI	9.2 KSI





VEXTEC accurately predicted burst test location & pressure for different AM process settings.

DISCUSSION