NIST Additive Manufacturing Fatigue and Fracture Project: Facilities and Capabilities

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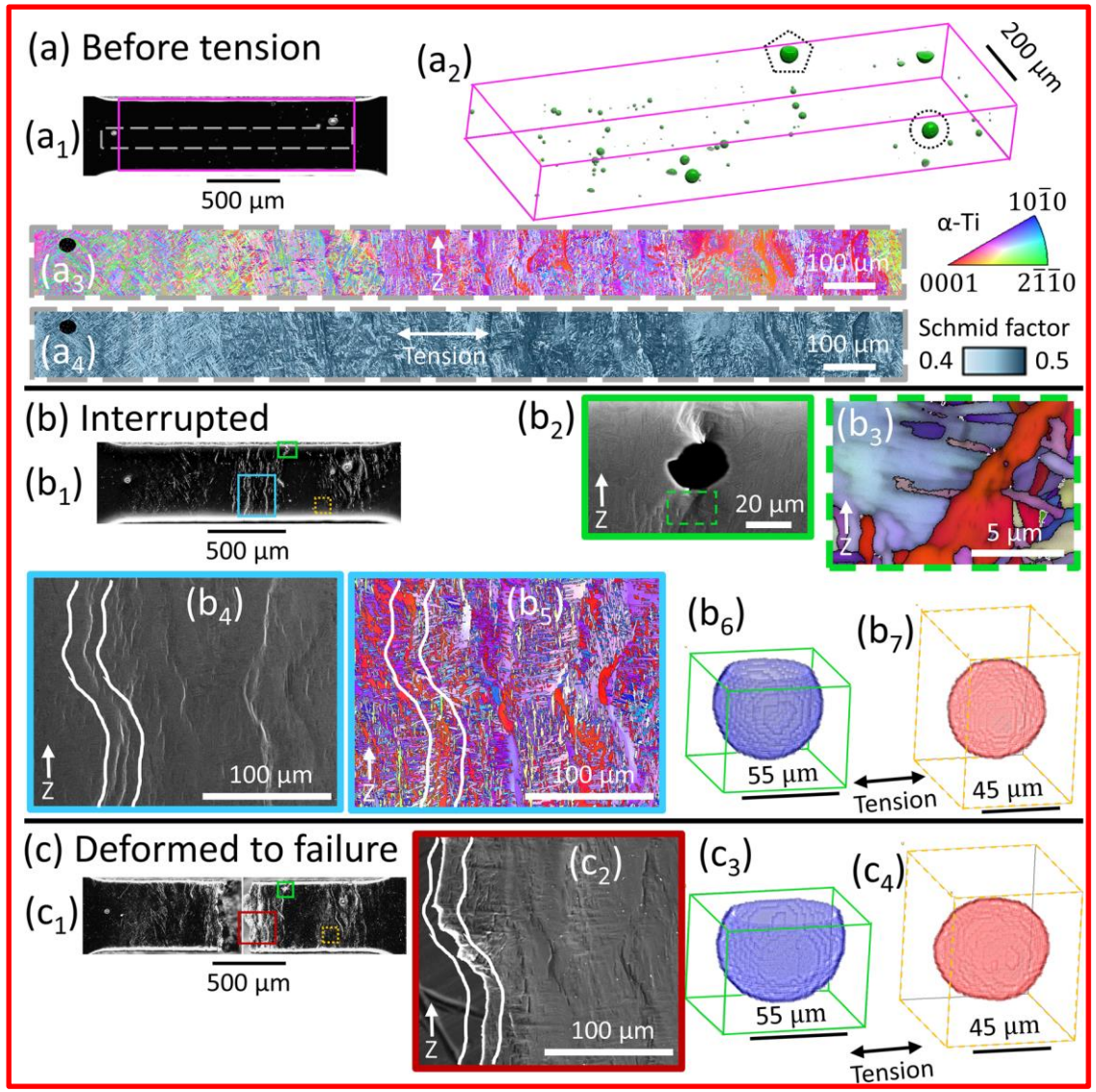
Material Measurement Laboratory (MML)
Applied Chemicals and Materials Division (ACMD)

NIST | NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

Mechanical Testing

- **Standard Size Specimens**
  - E.g. quasi-static tension/compression, high-cycle fatigue, low-cycle fatigue, fatigue crack growth rate (FCGR), rotating bending fatigue, instrumented Charpy, fracture toughness, etc
  - Digital Image Correlation (DIC)
  - Extreme environments (e.g. pressurized hydrogen)
  - Low temperature (liquid helium 4°K)
  - High temperature (1000°C)
  - Microhardness and Nanoindentation with mapping capabilities
- **Milli-Scale Specimens**
  - Quasi-static tension, small punch, FCGR
- **Meso-Scale Specimens**
  - Gauge section dimensions: hundreds of µm to several mm, and with larger grip sections
  - **Tensile tests** at strain rates from 0.001/s to 1/s
  - Shear tests at strain rates 0.001/s to 30/s
  - In-situ tensile tests in x-ray computed tomography (XCT) and scanning electron microscope (SEM)

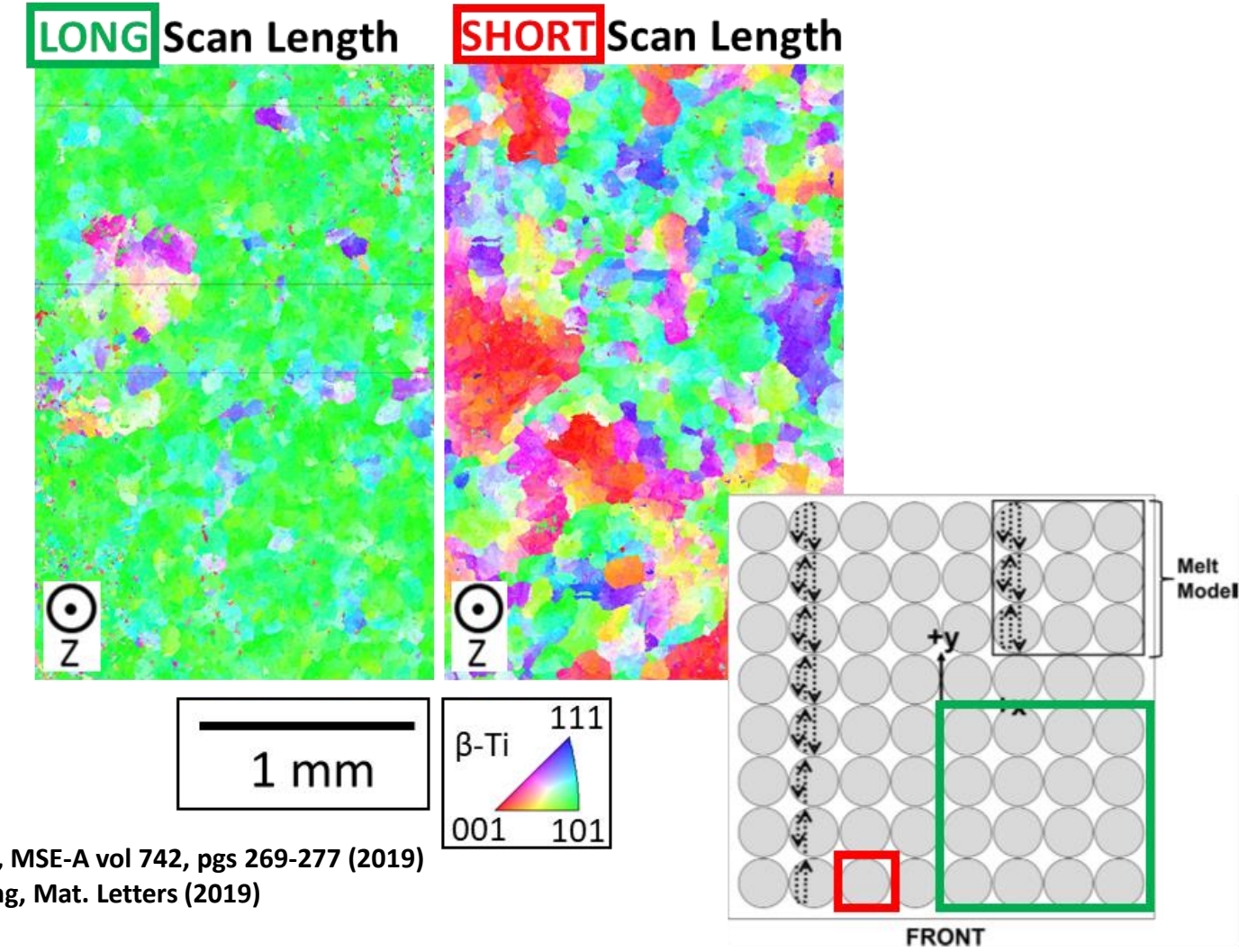


[1] Benzing, *Exp. Mech.* (2019)

Microstructure Characterization

- **Optical Microscopy**
  - Stereomicroscopy
- **Optical Profilometry**
  - Scanning white-light interferometry
- **Scanning Electron Microscopy (SEM)**
  - Focused ion beam (FIB)
  - Electron dispersive spectroscopy (EDS)
  - Large-area electron backscatter diffraction (EBSD)
  - Transmission-SEM (t-SEM)
- **Scanning Transmission Electron Microscopy (STEM)**
  - Electron energy-loss spectroscopy (EELS)
- **Atomic Force Microscopy (AFM)**
  - Scanning kelvin probe force microscopy (SKPFM)
- **Atom Probe Tomography (APT)**
  - Commercial APT
  - Extreme-UV APT

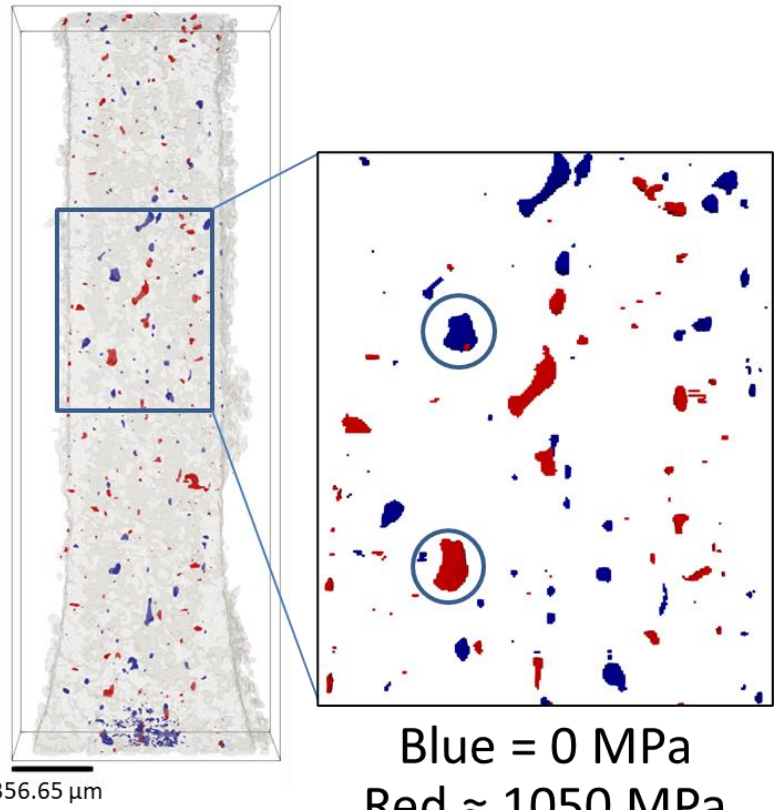
Large-area EBSD of AM titanium showing process-based texture variation



[1] Hrabe, MSE-A vol 742, pgs 269-277 (2019)
[2] Benzing, Mat. Letters (2019)

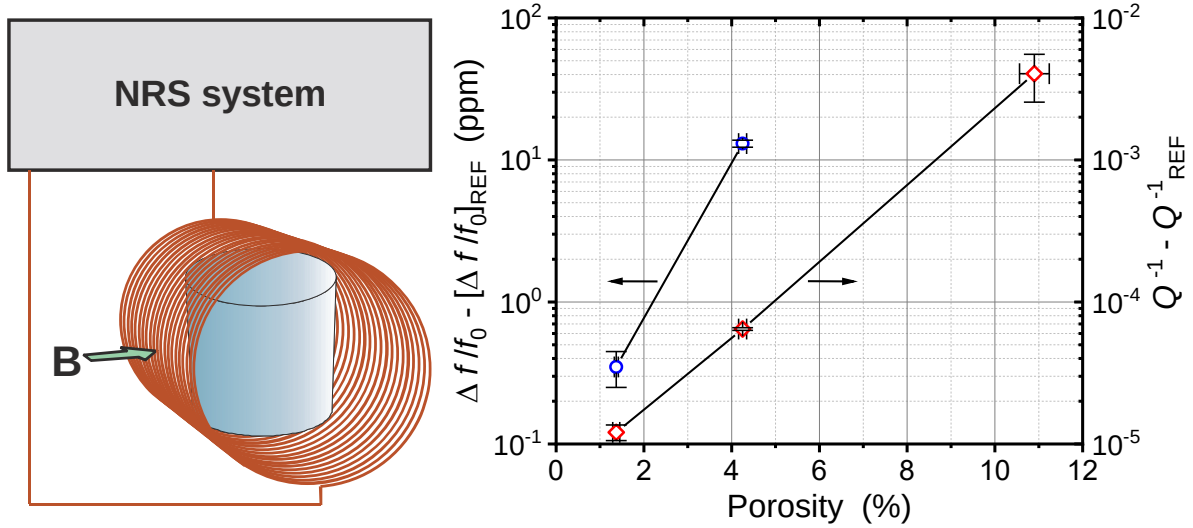
Nondestructive Evaluation

- **X-ray Computed Tomography (XCT)**
  - Two commercial XCT systems
  - Northstar has higher power to analyze larger specimens but with lower resolution (20µm voxel edge length)
  - Zeiss Xradia has lower power that limits specimen size but with better resolution (1µm voxel edge length)
  - In-situ tension/compression testing during XCT (loads <500N)



In-situ XCT mechanical testing, showing pores under zero load and 1050 MPa (past yield) in AM IN718 (Kafka, ICAM, 2021)

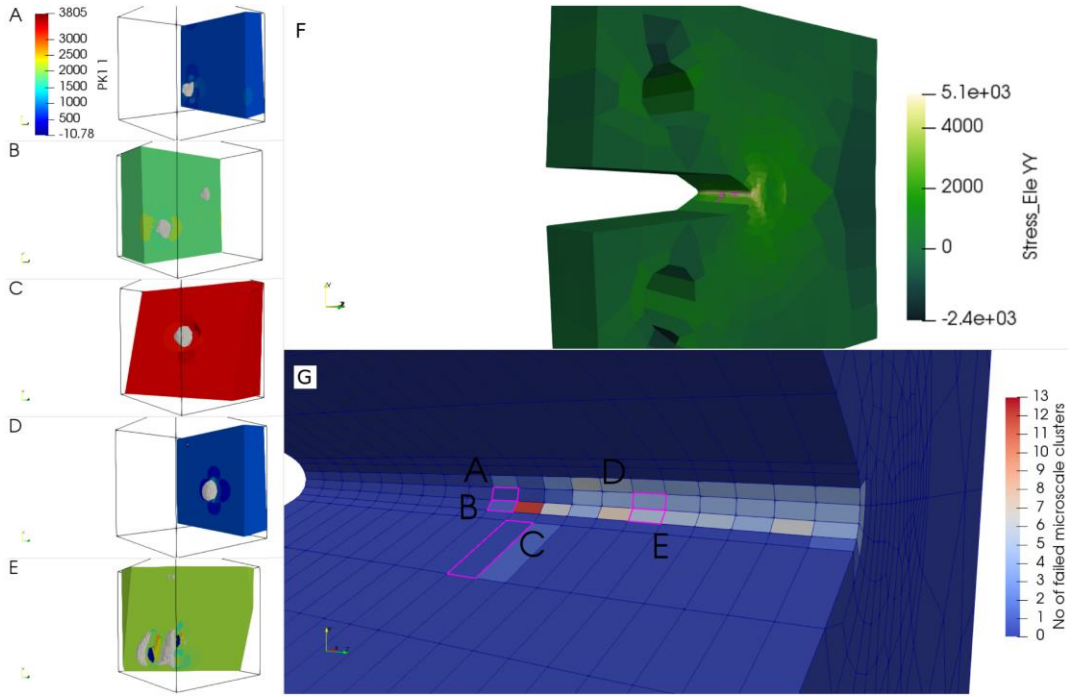
- **Acoustics**
  - Unique Nonlinear Reverberation Spectroscopy (NRS) system that provides ultra-precise noncontacting measurements of acoustic nonlinearity and loss.
  - Unique system for noncontacting resonant acoustic measurements of metals from 100 K to 1100 K.
  - Resonant Ultrasound Spectroscopy (RUS) for measurement of complete acoustic spectra
  - Scanning acoustic microscopy



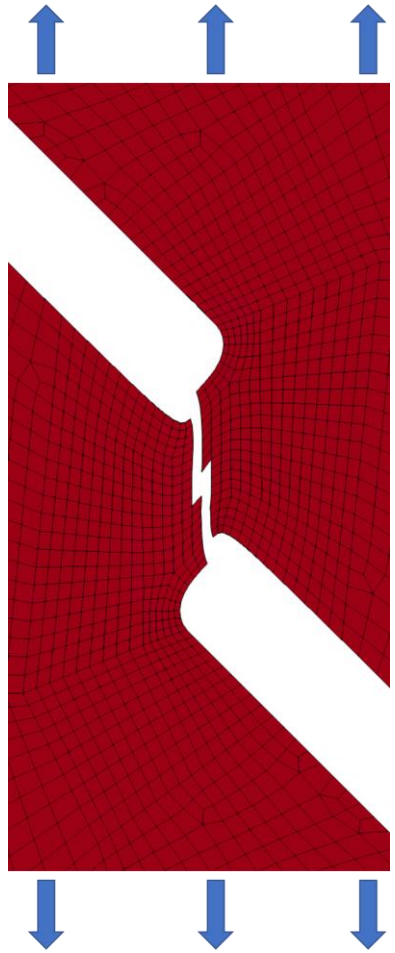
Resonant acoustic nonlinearity and loss in AM stainless steel. [W. Johnson *et al.*, AIP Conference Proceedings 2102, 020008 (2019)]

Computational

- **Facilities**
  - High-performance computer clusters for parallel computing, artificial intelligence, and general numerical methods.
  - Limited to about 128 processing cores and 2 GB to 4GB of RAM per node
- **Capabilities**
  - Finite element methods
  - Computational solid mechanics
  - Reduced order modeling
  - Metal plasticity
  - Damage mechanics
  - Contact-impact problems
  - Modal analysis
  - Crystal plasticity
  - Multi-scale modeling
  - Fracture mechanics
  - Fatigue life prediction.



Concurrent multiscale model for fracture initiation with varying microstructures [1]



Simulating fracture in a shear-type sheet metal specimen using a shear-modified GTN model [2]

[1] Kafka et al. (2021). Image-based multiscale modeling with spatially varying microstructures from experiments: Demonstration with additively manufactured metal in fatigue and fracture. *Journal of the Mechanics and Physics of Solids*, *150*, 104350.

[2] Moser et al. (2017). Predicting Ductile Fracture in Double-Sided Incremental Forming. *CIRP Annals Conference*