

NIST Additive Manufacturing Fatigue and Fracture Project: Facilities and Capabilities

National Institute of Standards and Technology (NIST), Boulder, CO, USA

Material Measurement Laboratory (MML)

Applied Chemicals and Materials Division (ACMD)



Mechanical Testing

- **Standard Size Specimens**

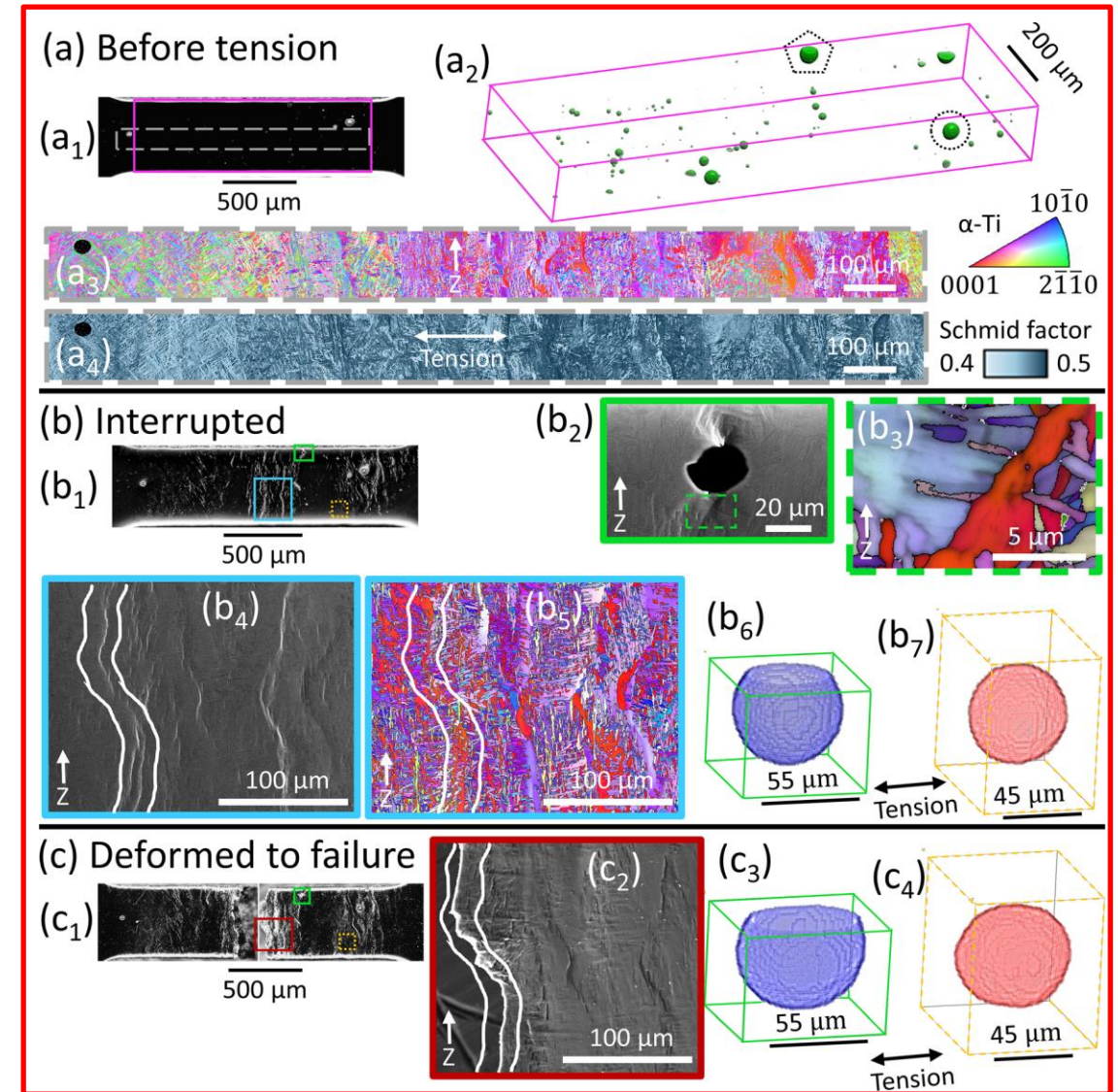
- E.g. quasi-static tension/compression, high-cycle fatigue, low-cycle fatigue, fatigue crack growth rate (FCGR), rotating bending fatigue, instrumented Charpy, fracture toughness, etc
- Digital Image Correlation (DIC)
- Extreme environments (e.g. pressurized hydrogen)
- Low temperature (liquid helium 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)

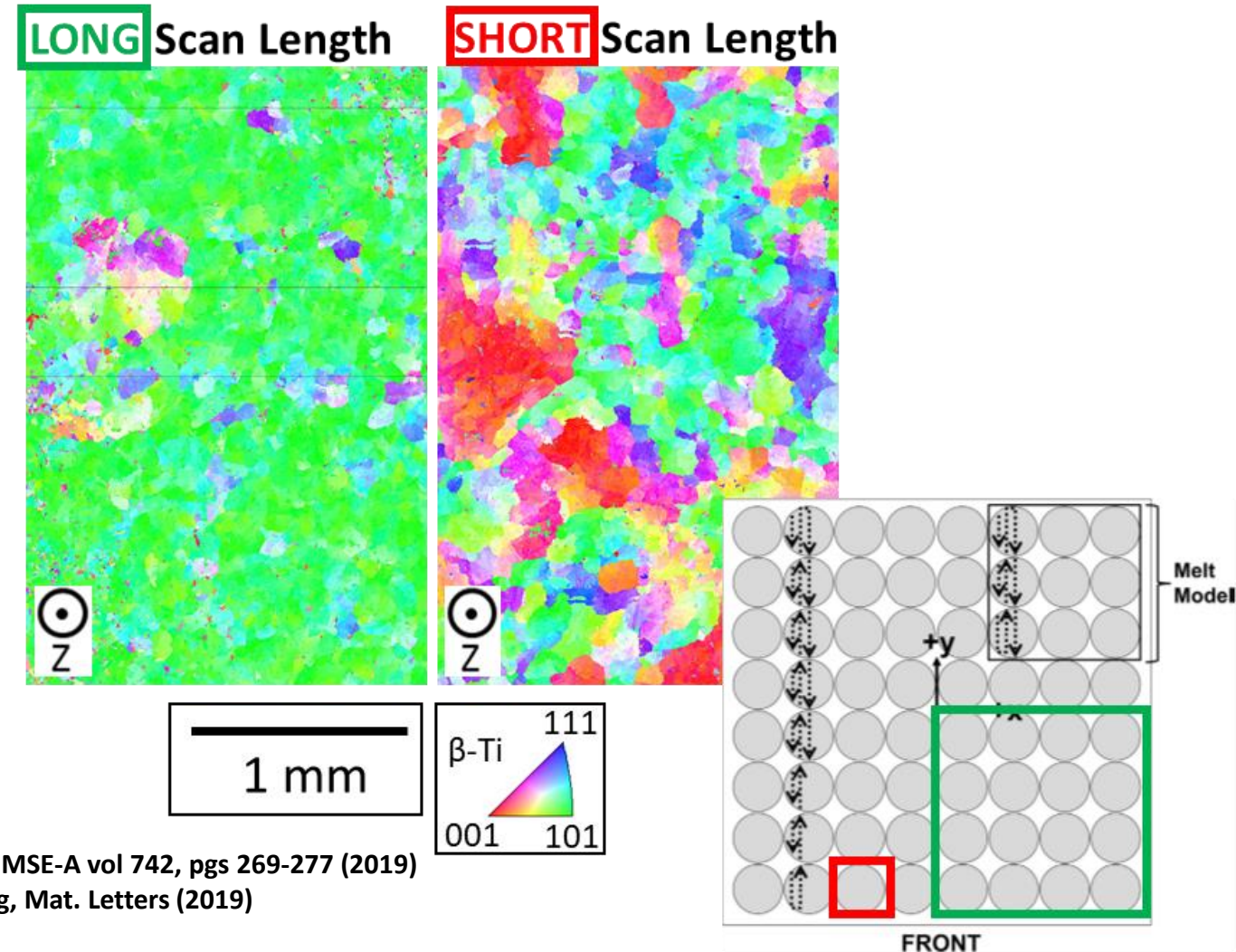


[1] Benzing, *Exp. Mech.* (2019)

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] Hrabec, MSE-A vol 742, pgs 269-277 (2019)

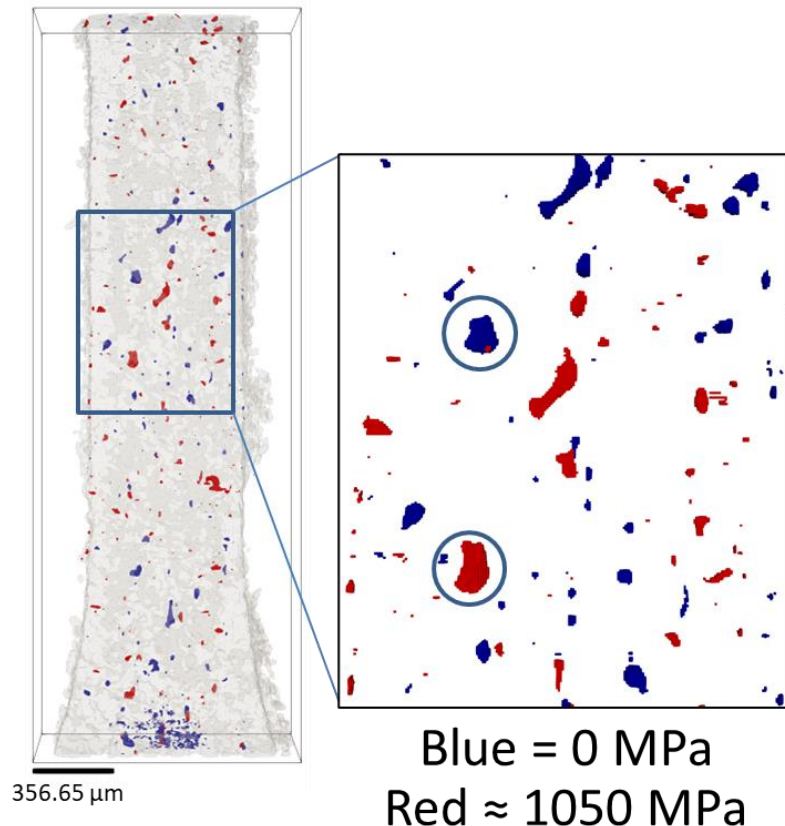
[2] Benzing, Mat. Letters (2019)

Nondestructive Evaluation

- **X-ray Computed Tomography (XCT)**

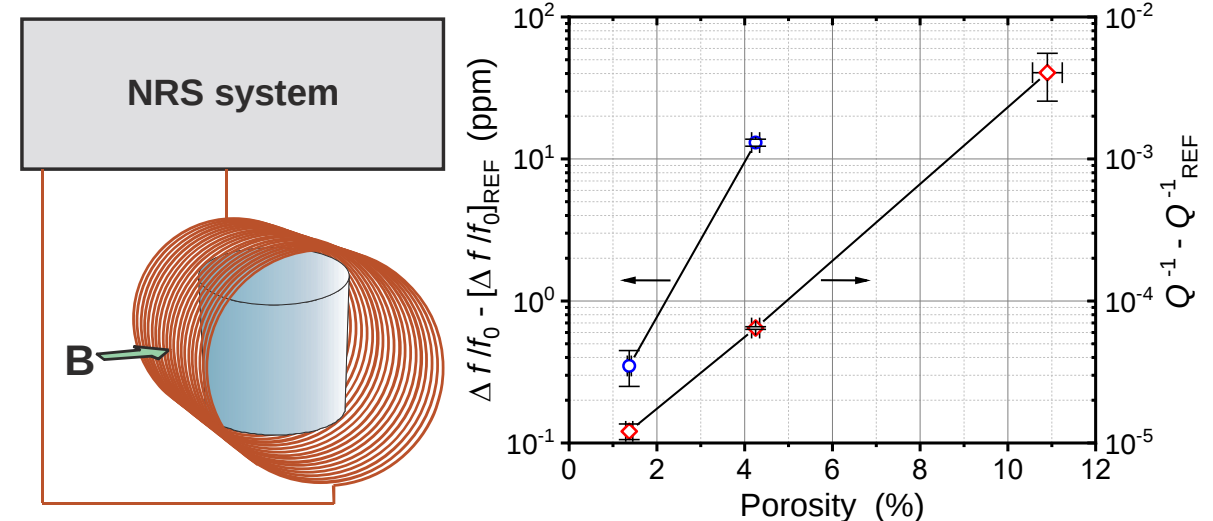
- Two commercial XCT systems
- Northstar has higher power to analyze larger specimens but with lower resolution (20 μ m voxel edge length)
- Zeiss Xradia has lower power that limits specimen size but with better resolution (1 μ m voxel edge length)
- In-situ tension/compression testing during XCT (loads <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)]

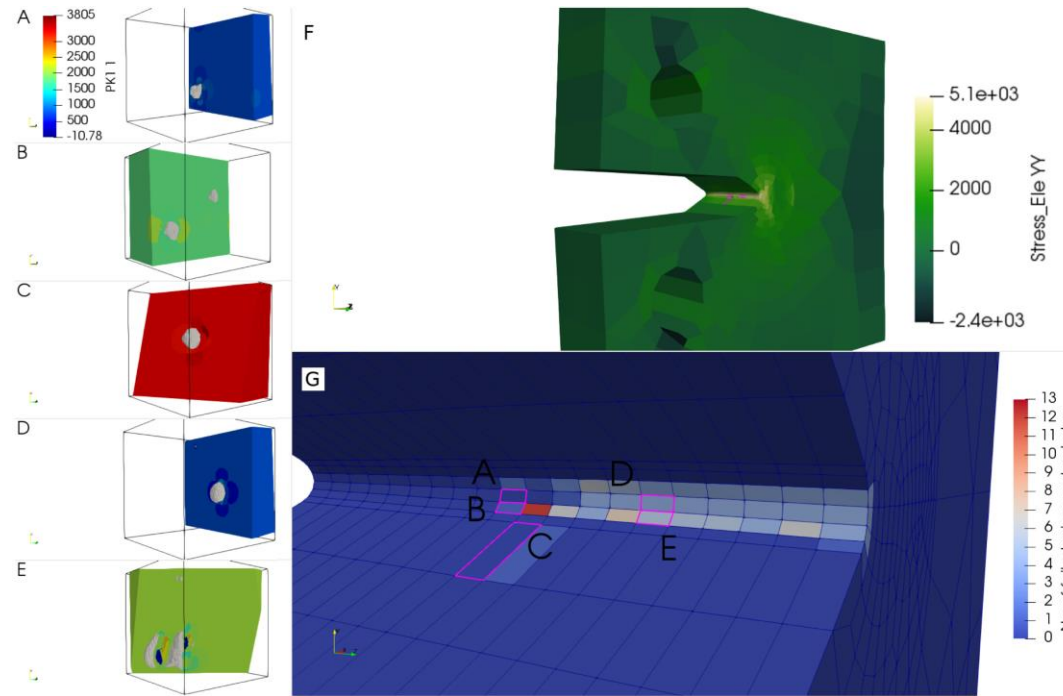
Computational

- **Facilities**

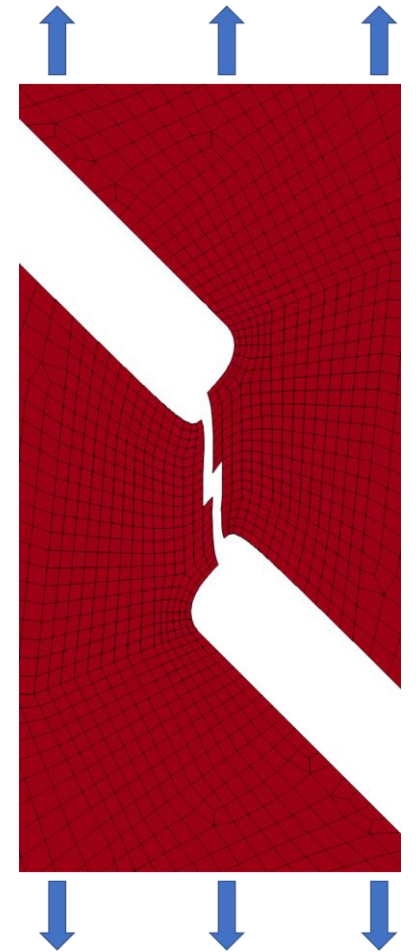
- High-performance computer clusters for parallel computing, artificial intelligence, and general numerical methods.
- Limited to about 128 processing cores and 2 GB to 4GB of RAM per node

- **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*