SAND2017-9603C

High-throughput testing reveals rare, catastrophic defects

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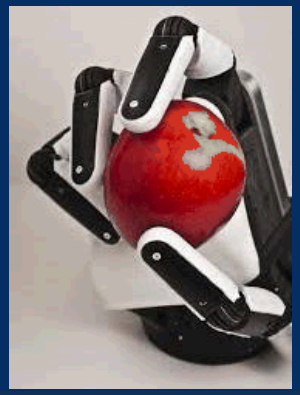

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration
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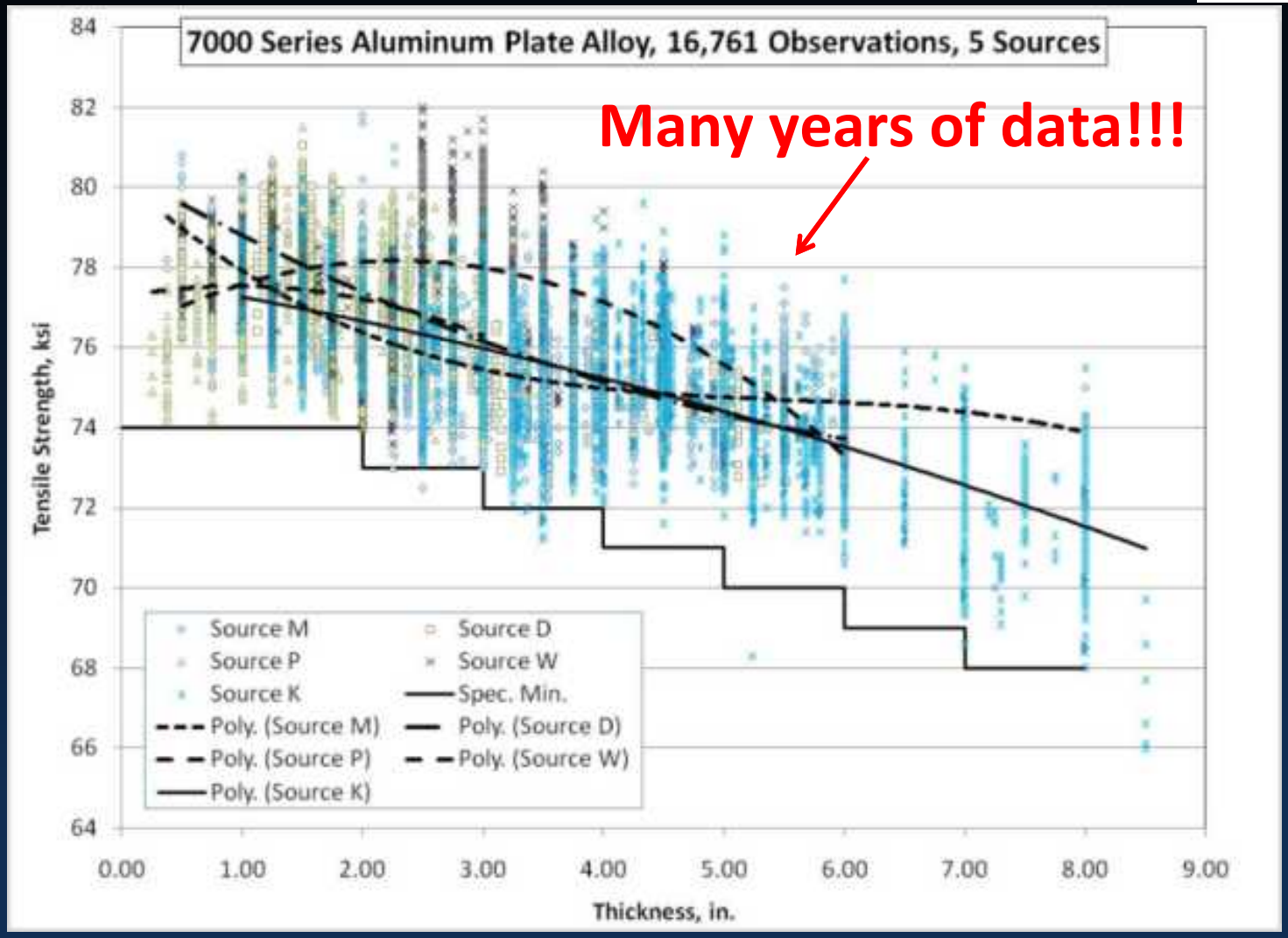
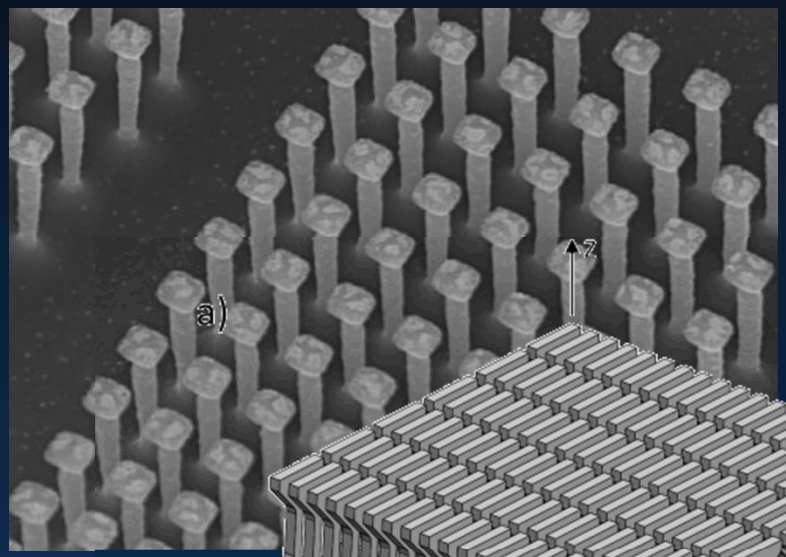
How conventional materials are qualified…

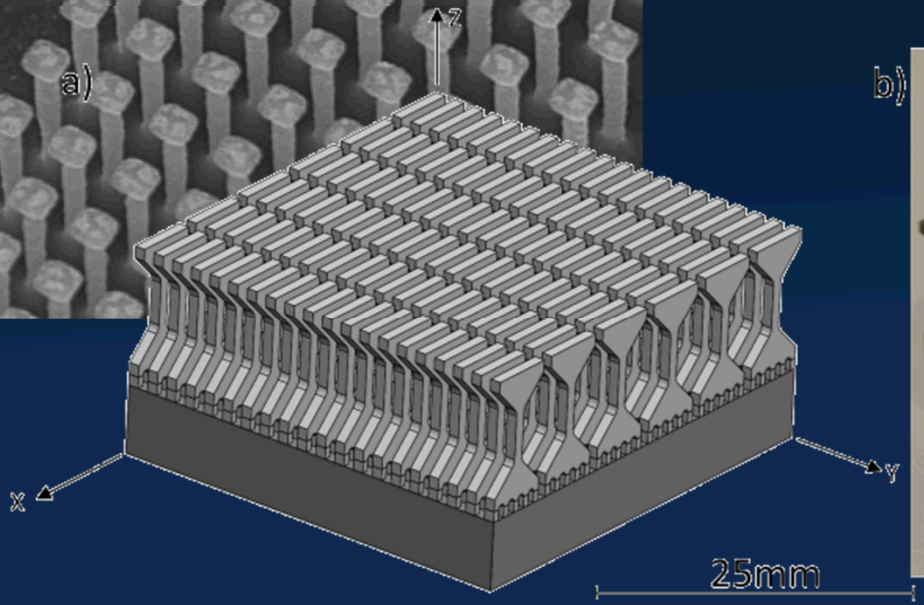


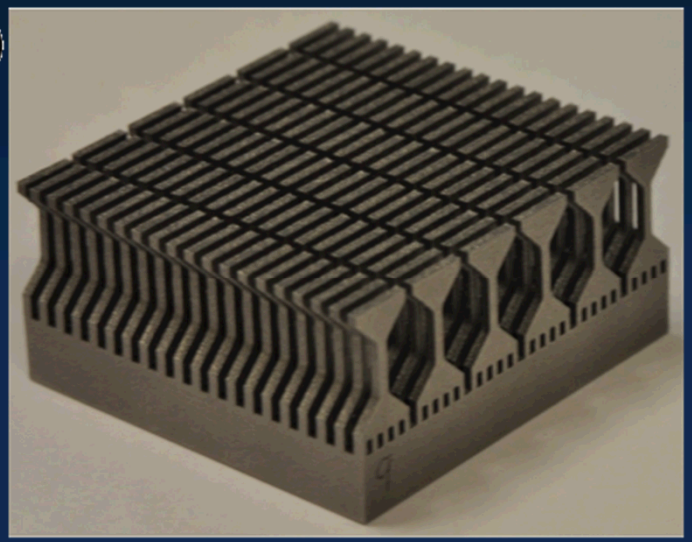
How can we rapidly qualify AM materials?

AM offers an opportunity for rapid statistics

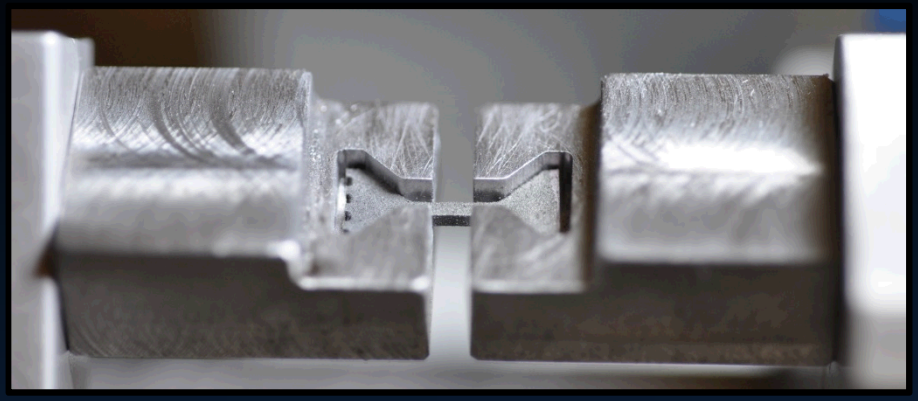


N. Chekurov et al.,
Nanotechnology 2009



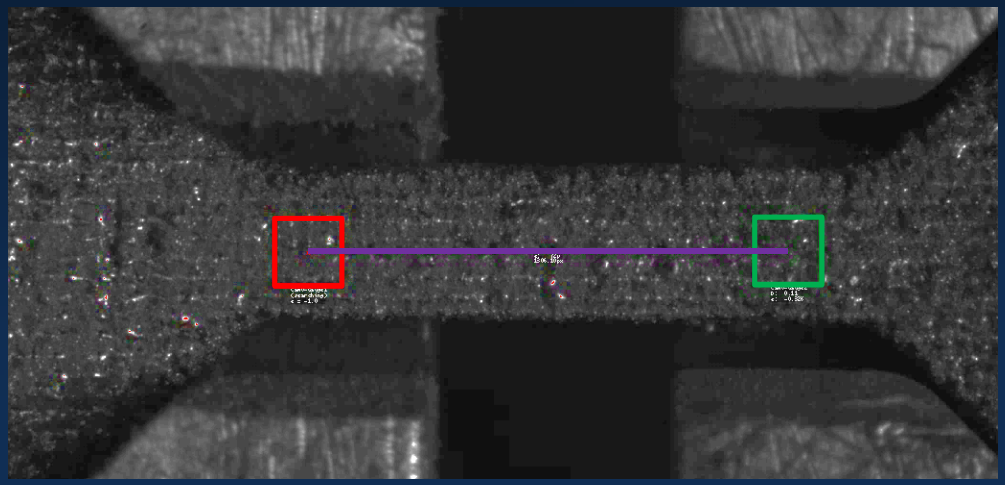


Streamline the testing process



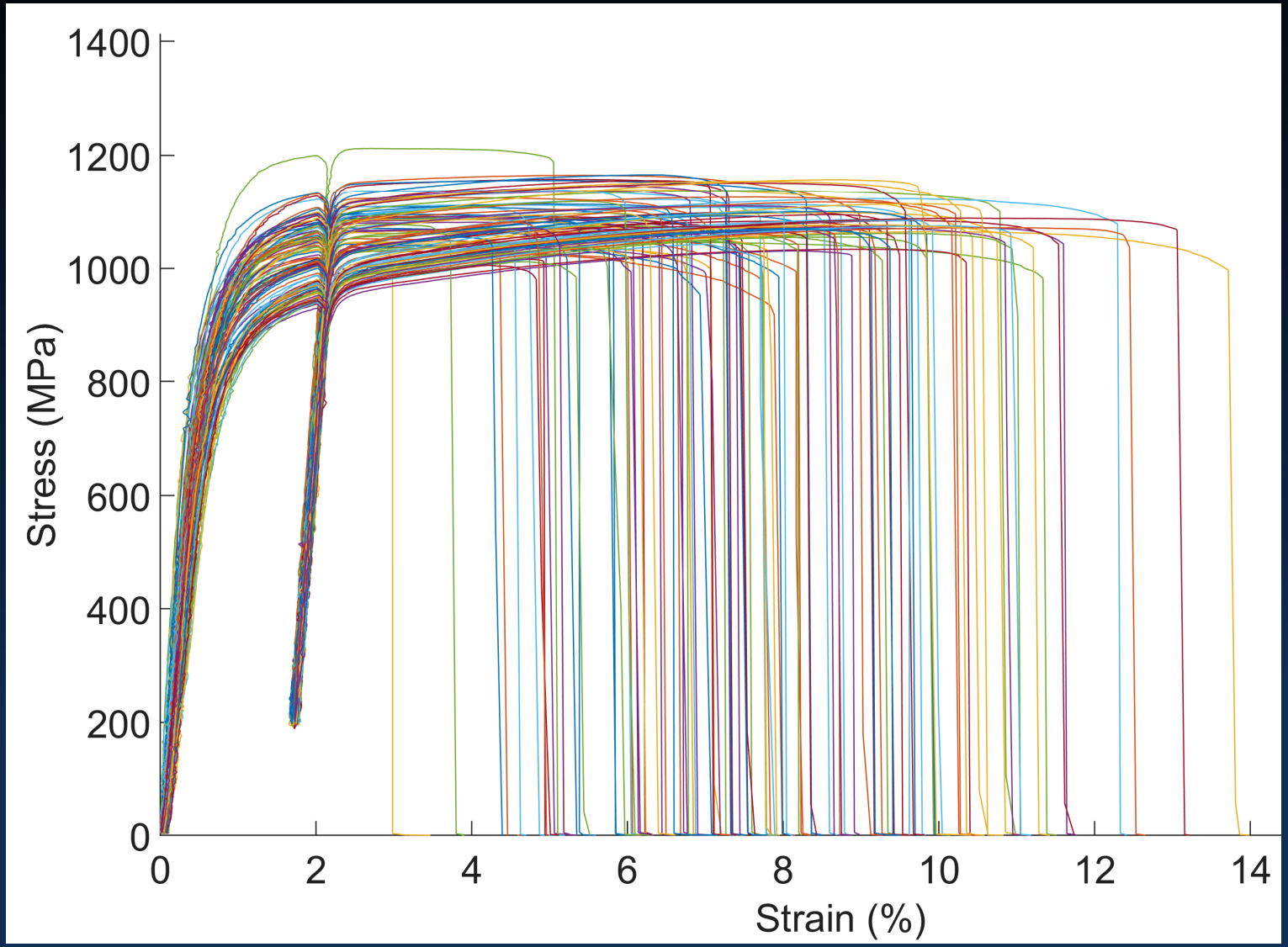
1. Self-aligning ‘drop-in’ grips

3. Maximize software automation to reduce burden on operator



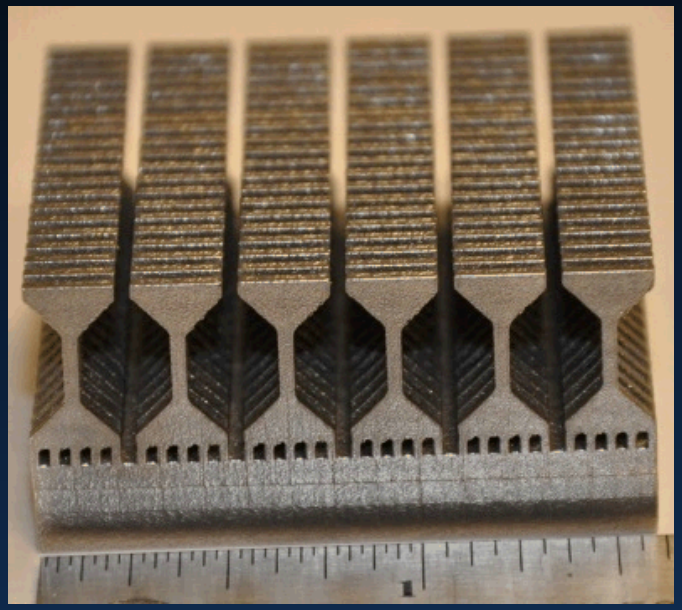
2. Non-contact virtual extensometer with “live” digital image correlation

100 tensile tests in 4 hours…



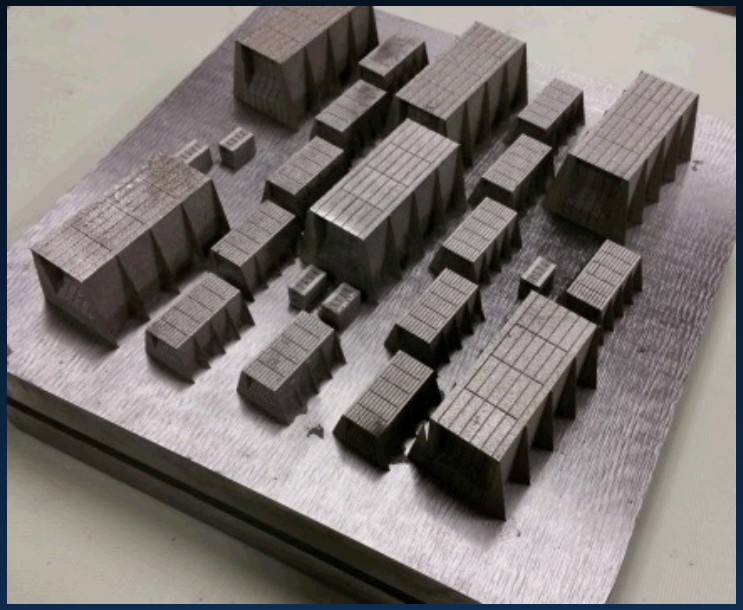
A comparison of 2 major commercial vendors

ConceptLaser Mlab



Vendor 1

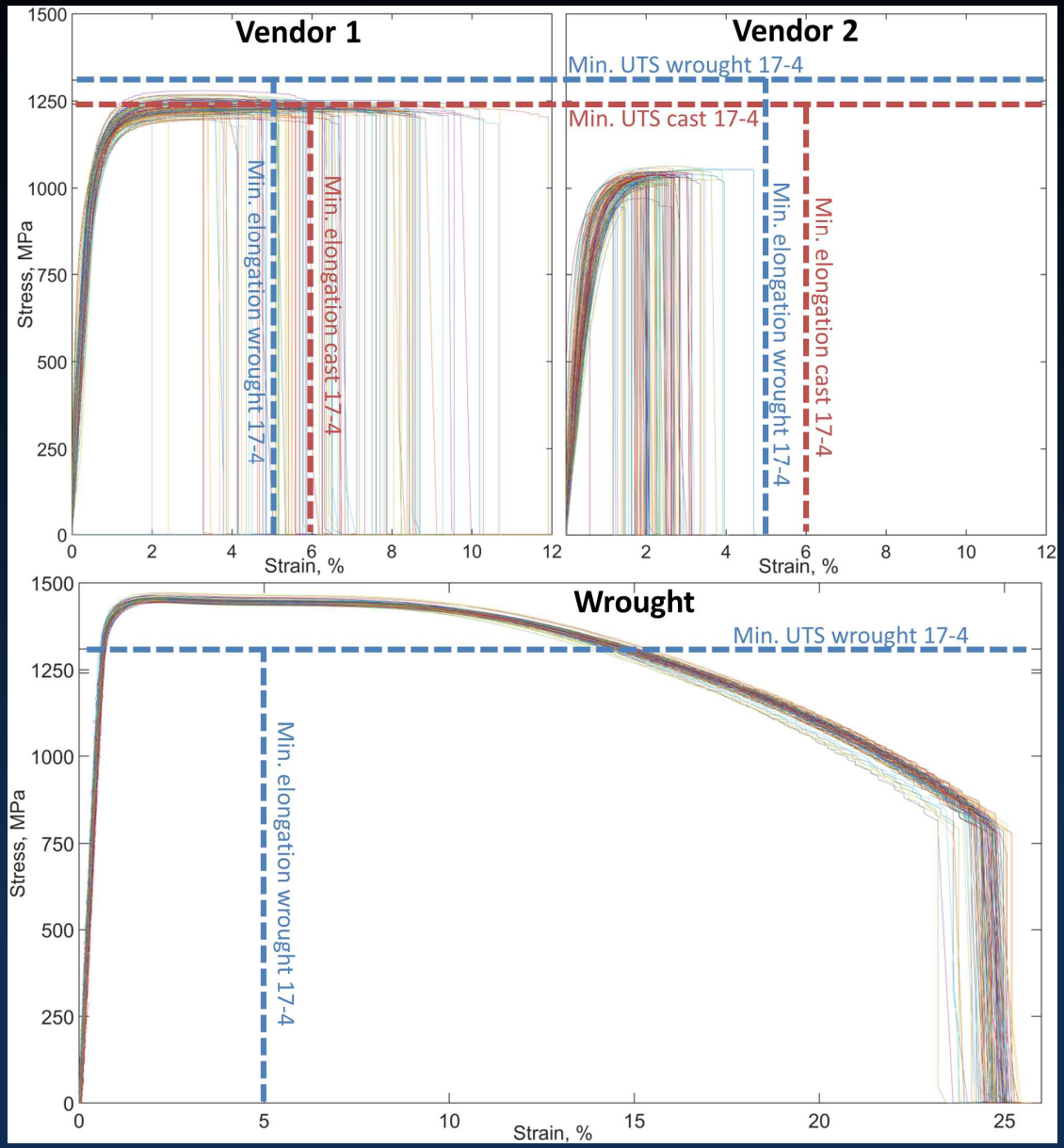
3D Systems ProX300



Vendor 2

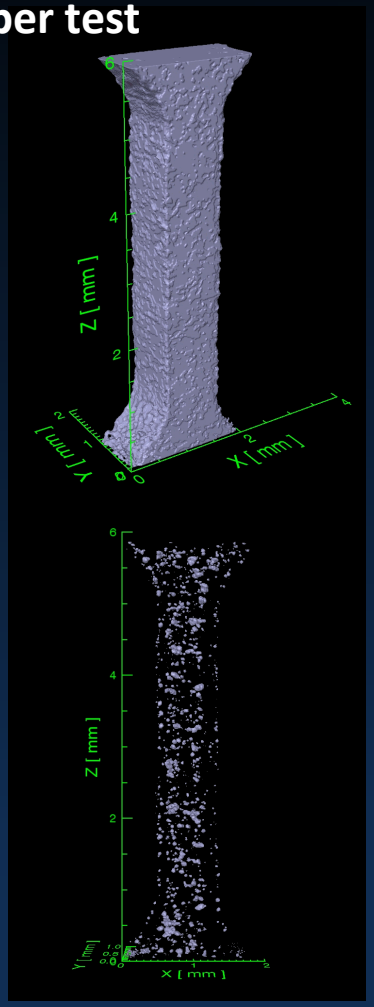
Alloy: PH17-4 H900 (preciptation hardenable martensitic stainless steel)

Comparing 100 tests from 3 sources



Opportunities for data mining…

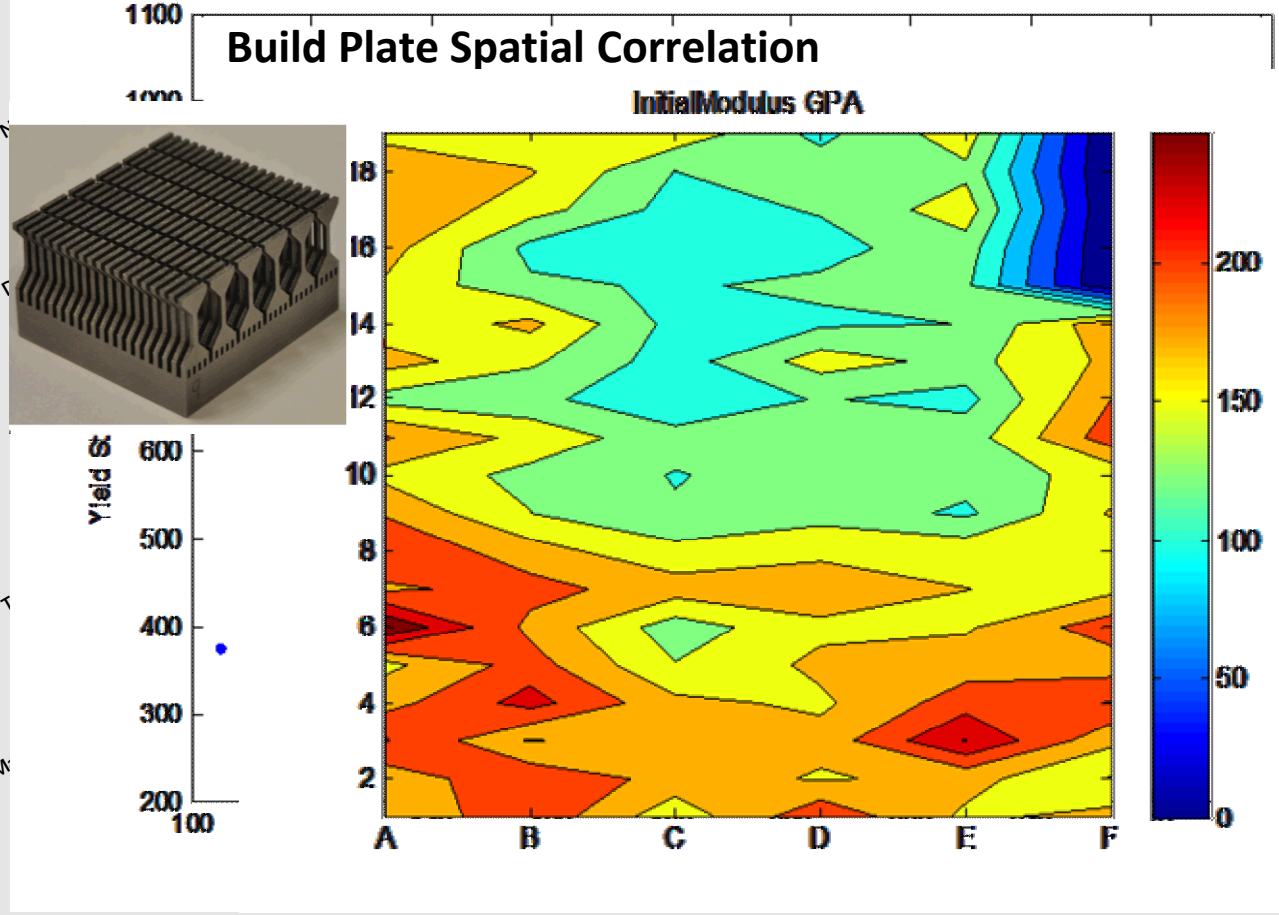
3 GB of CT data per test



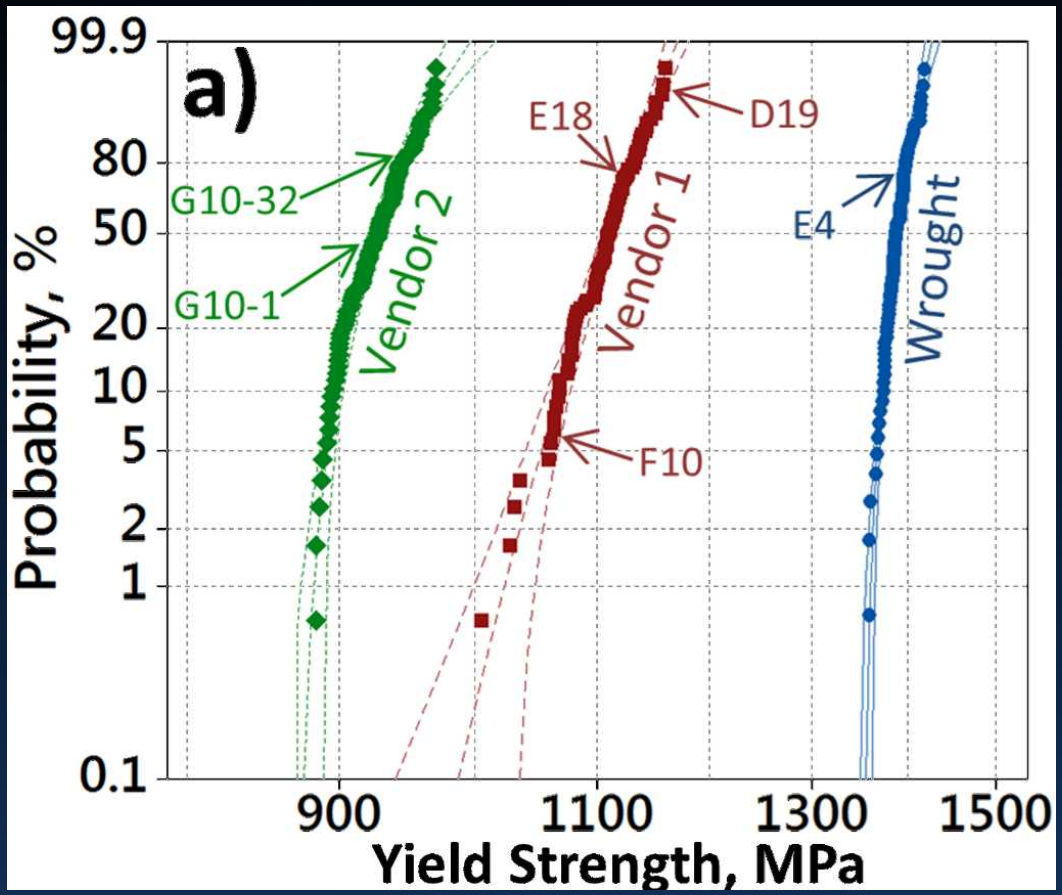
Pairwise Correlation Analysis

Cluster Analysis

Build Plate Spatial Correlation

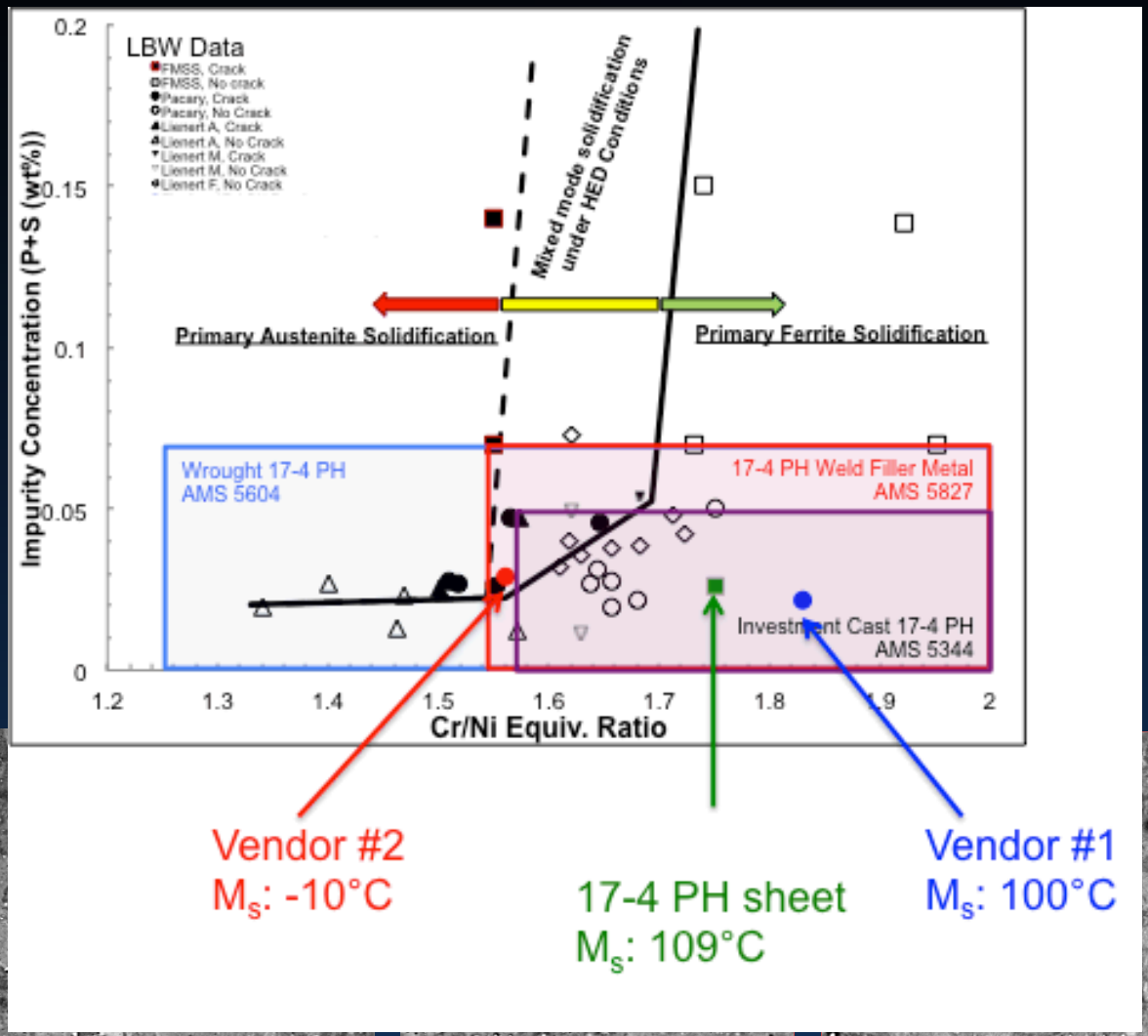


3-Parameter Weibull Fits to Distributions



What is the origin of different properties???

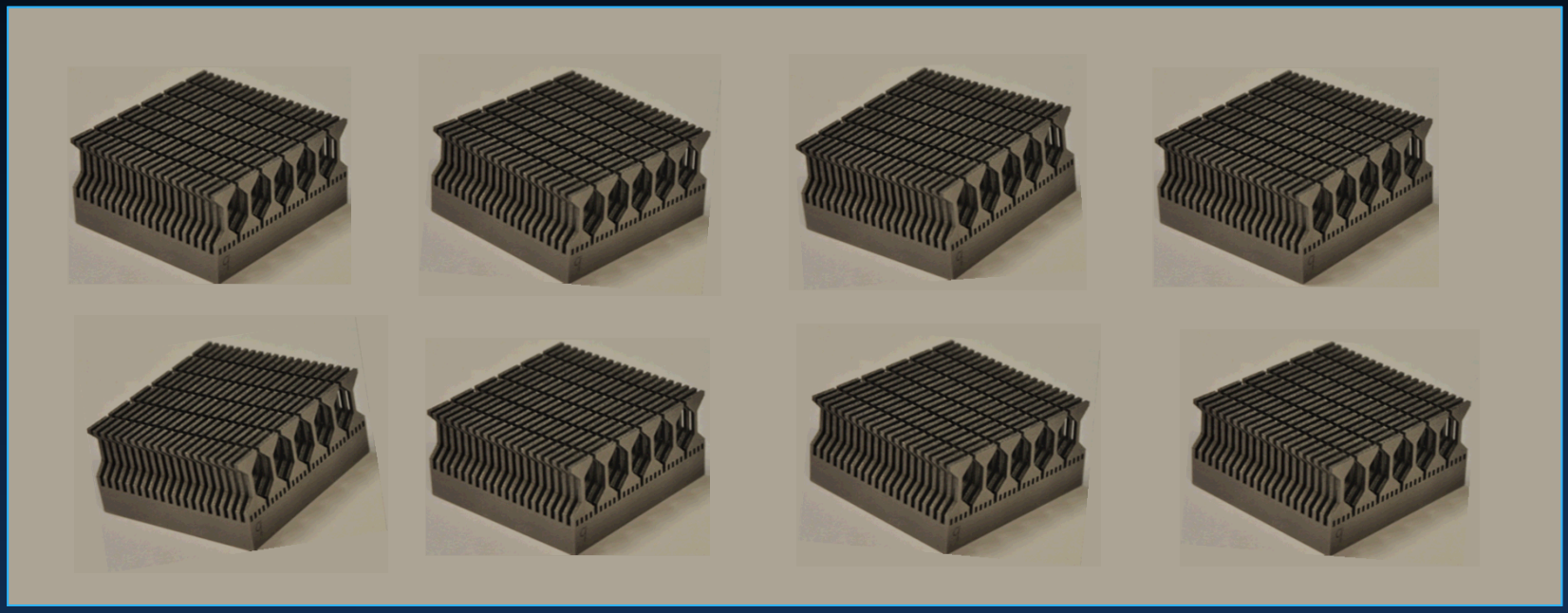
3-Parameter Weibull Fits to Distributions



Roughness complications strength determination:

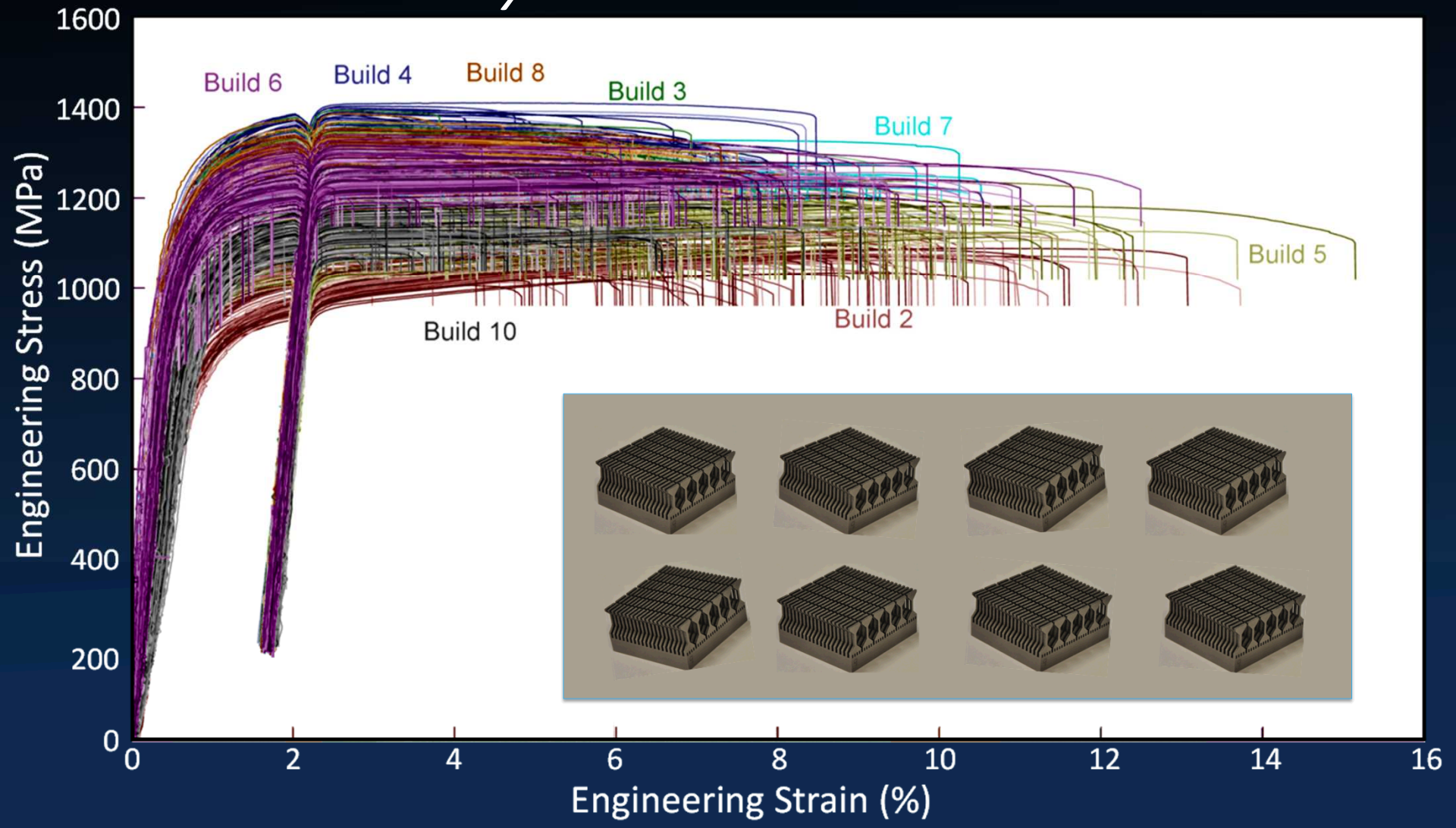
1. Caliper measurements overestimate true load-bearing area
2. Notch-like stress concentrations cause early yielding

How consistent are 8 separate builds of the same 'cooling fin' from the same vendor?

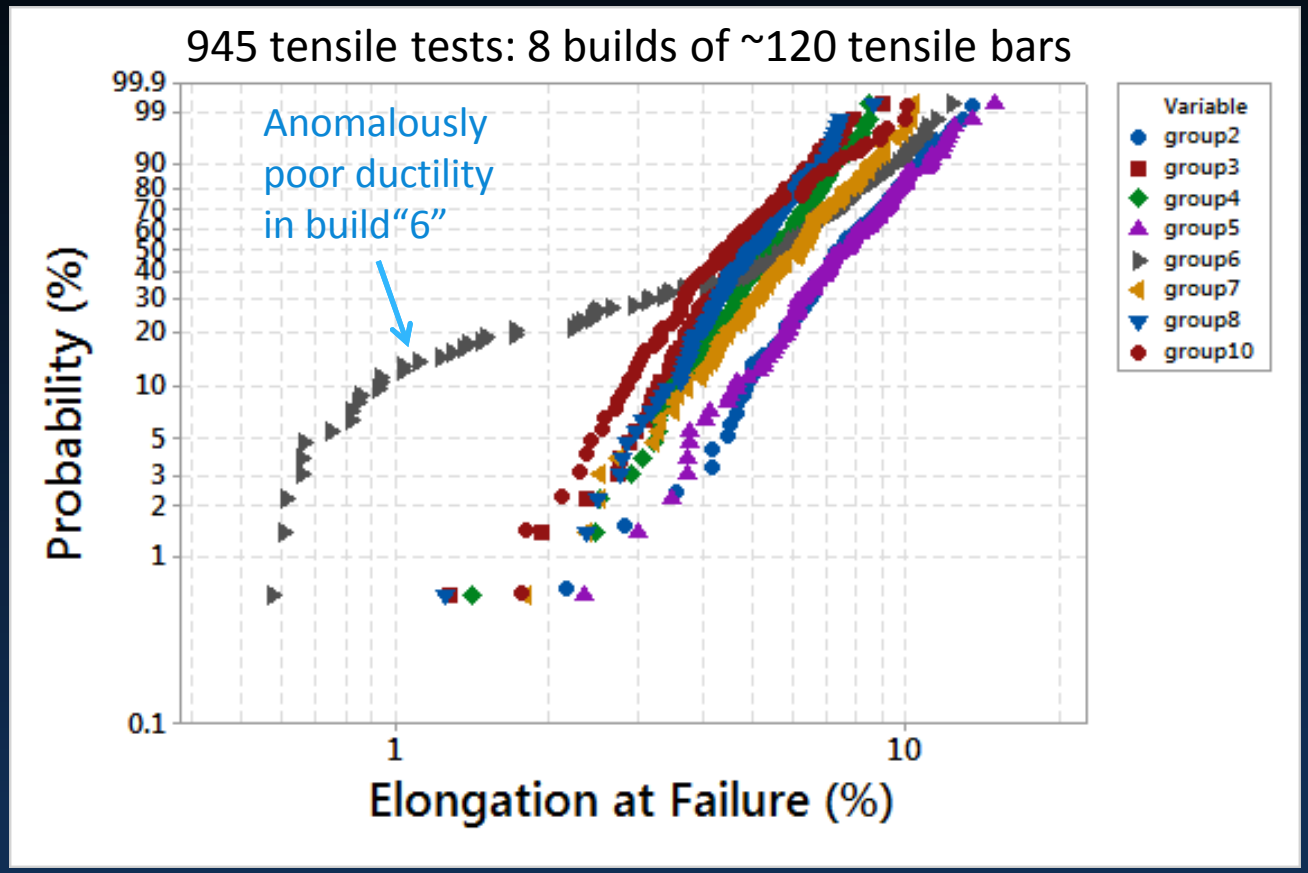


(960 tensile bars!)

"Big data"?: 945 tensile tests from 8 nominally identical builds

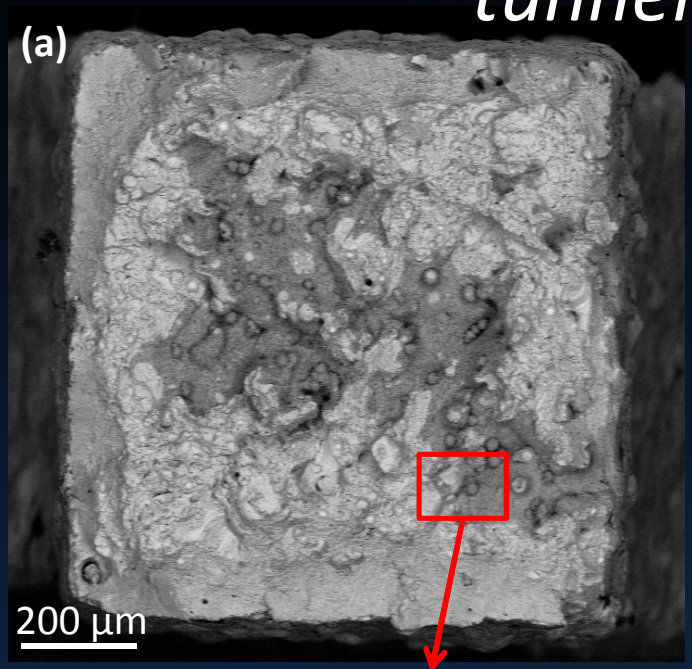


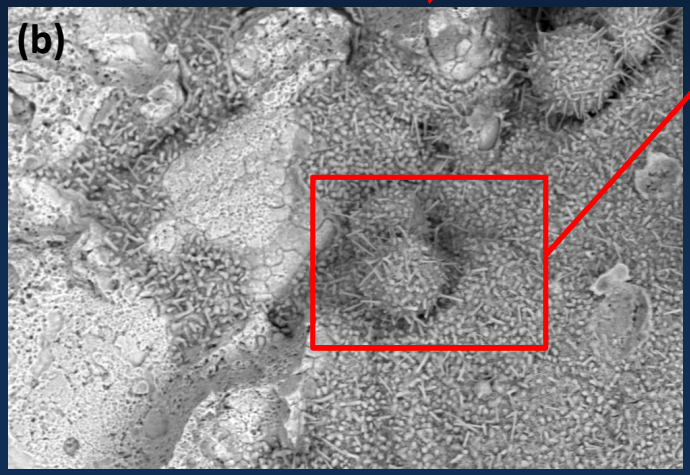
Distributions from 8 nominally identical cooling fins (Vendor 1)

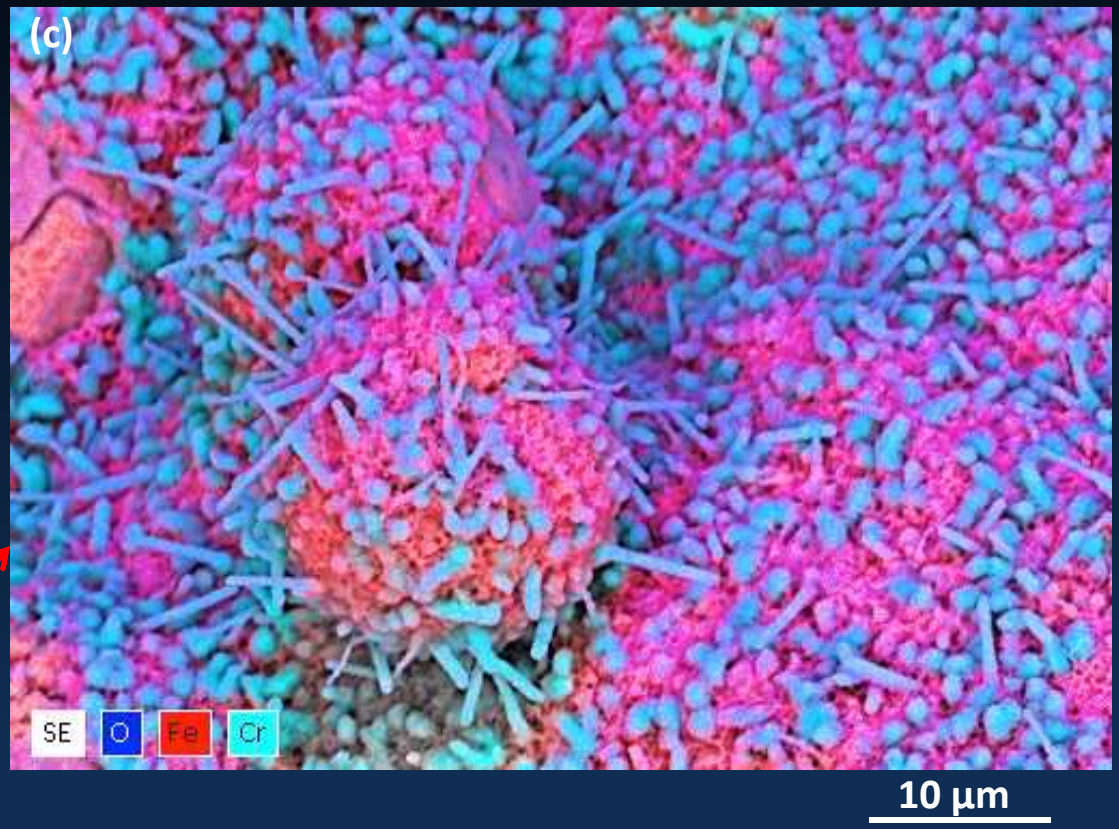


Why such poor ductility in one build???

Anomalous 'low ductility' caused by "tunneling porosity"

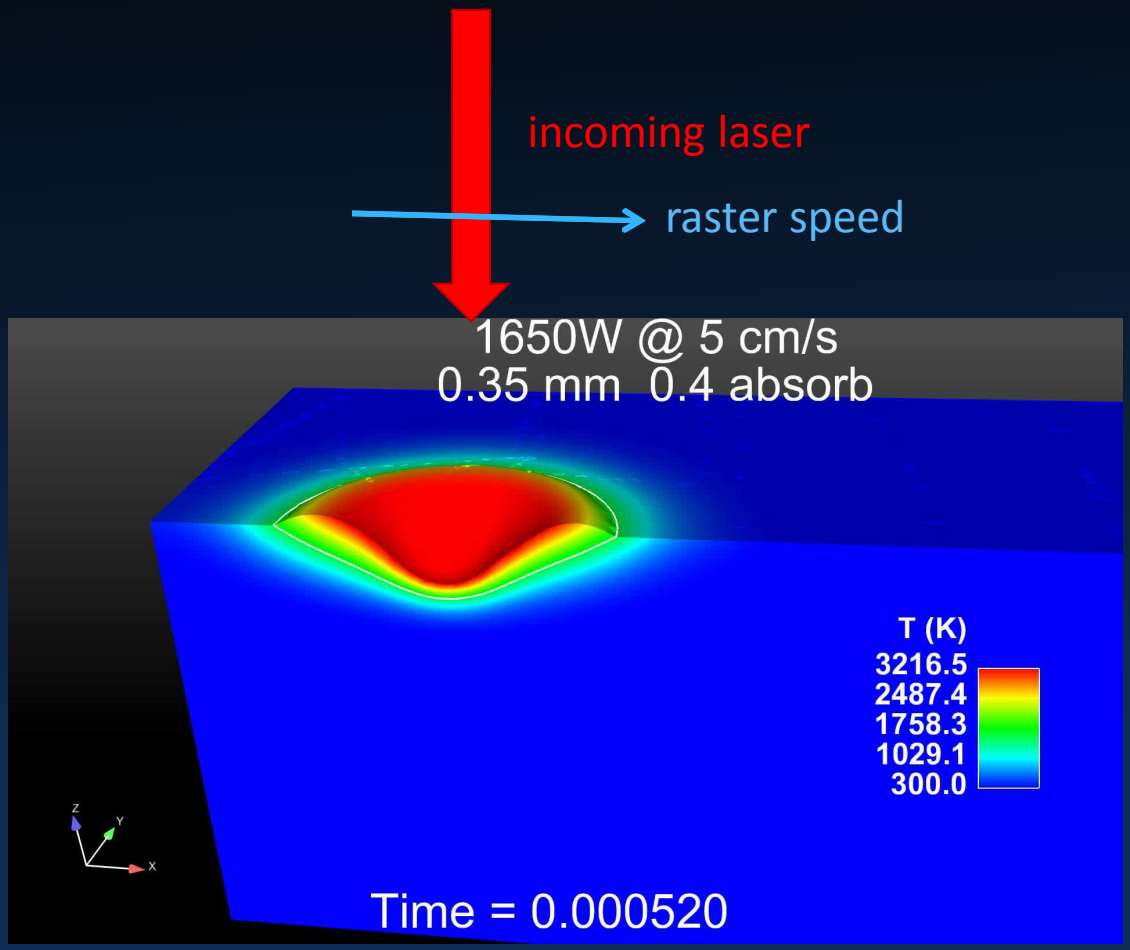






Is modeling the path to process optimization?

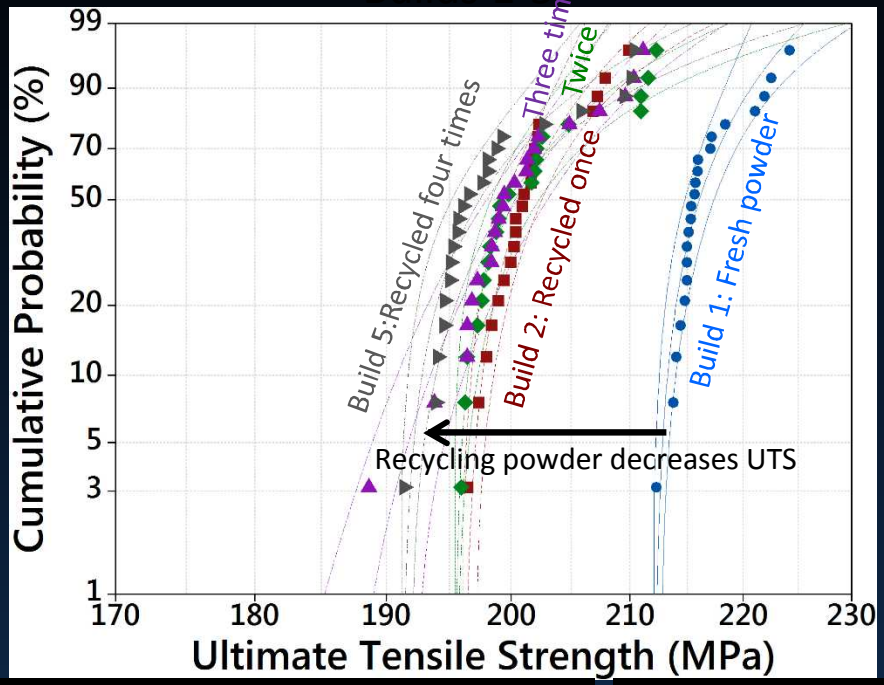
→ Understand and control the sources of flaw formation

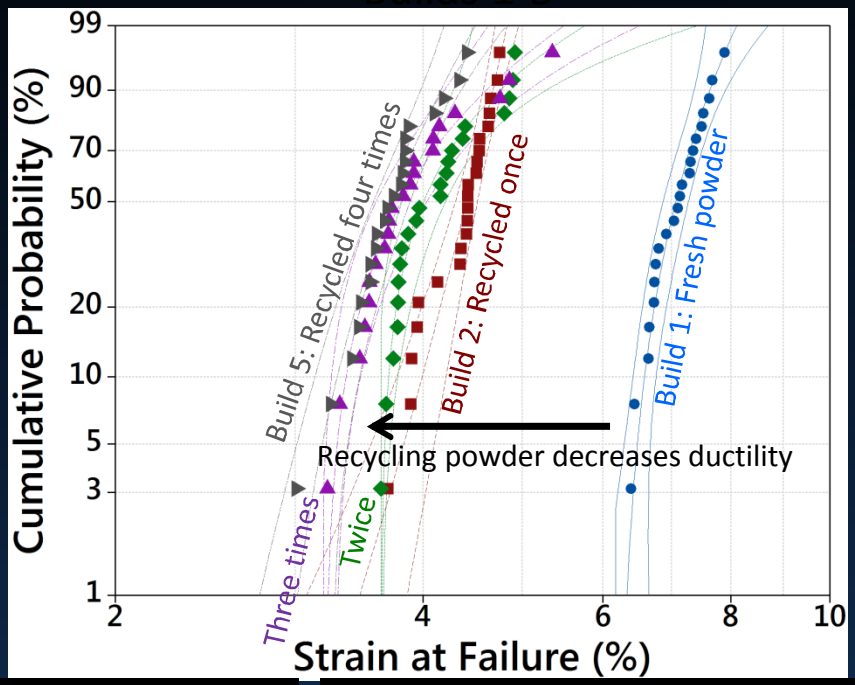


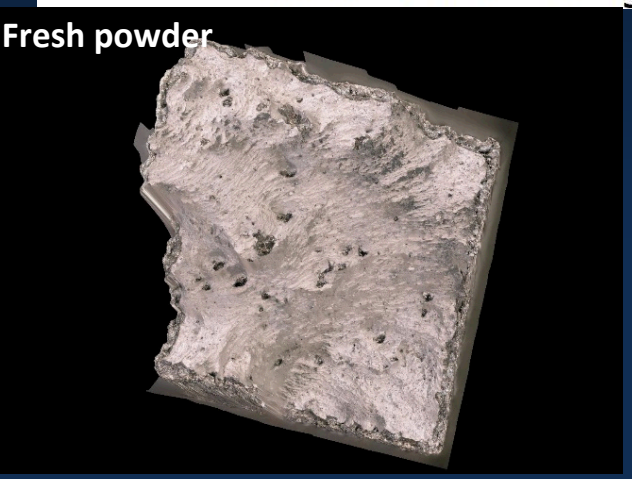
Laser/plume interactions, raytracing
Plasma fluid mechanics
Radiation heat transfer
Laser energy adsorption
Thermal expansion
Non-equilibrium vapor pressure
Evaporation with latent heat
Pressure-temperature relations
T-dependent heat capacity
Incompressible fluid dynamics
Convective/conductive heat transfer
Capillary forces
Marangoni forces
Hydrodynamic mixing
Multicomponent liquid-solid diffusion
Solidification macrosegregation
Solidification shrinkage
CTE thermal contraction
Thermomechanical residual stress
Solid-state diffusion
Anisotropic crystallization
Solid-state phase transformation

Powder recycling is clearly a concern

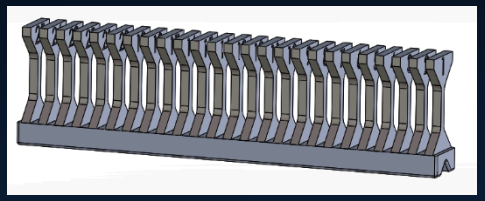
AlSi10Mg alloy

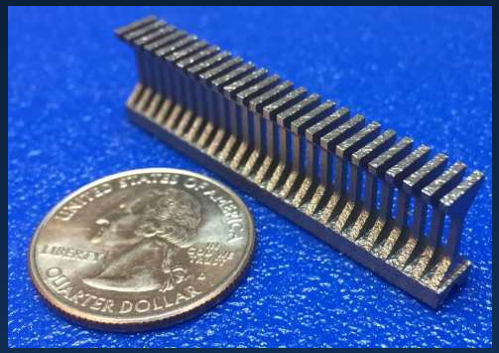


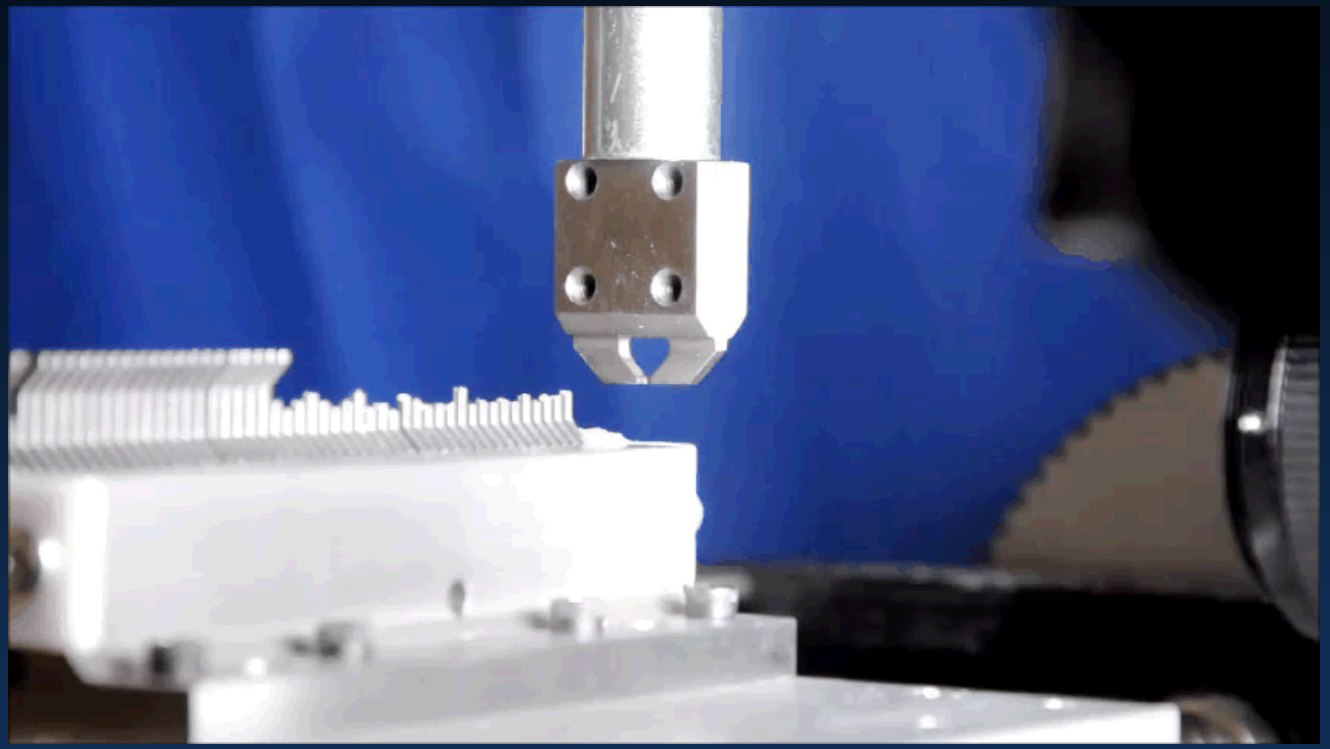




Around the corner…
Inspired by Bob Odette et al. @ UCSB:







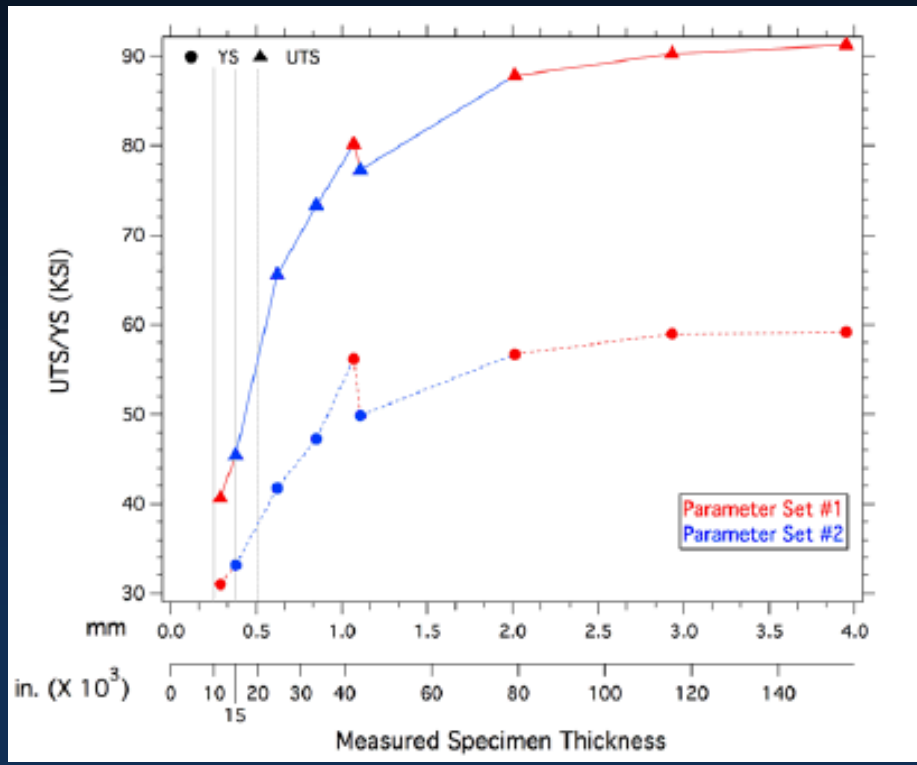
>100 tensile tests/hr with minimal operator burden

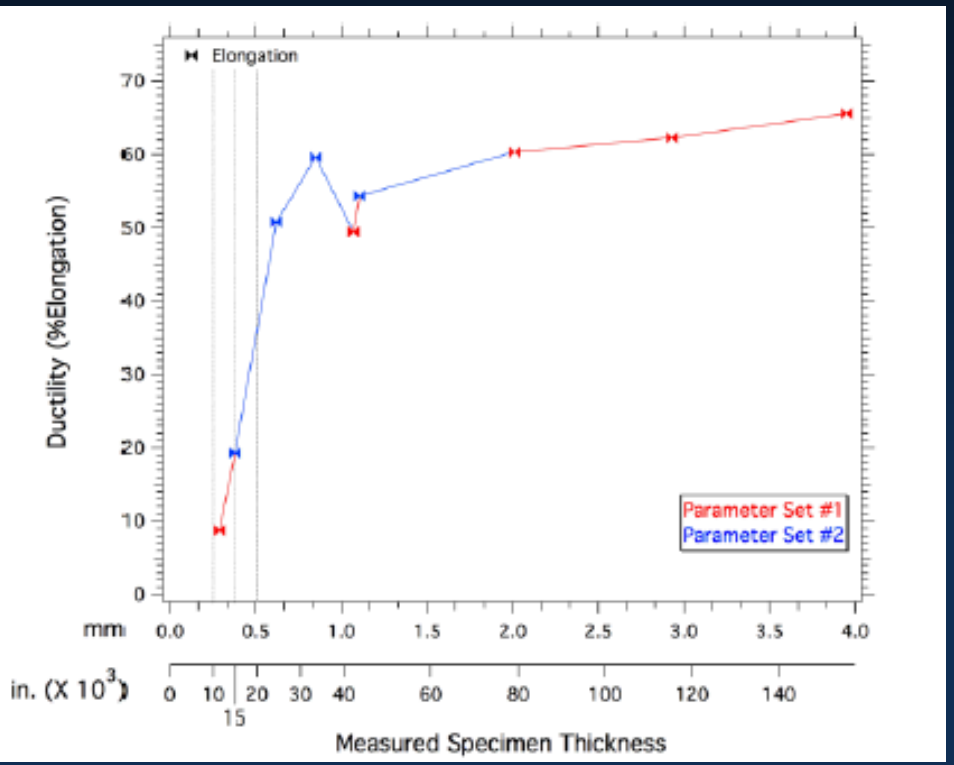
Opportunities for collaboration…

- Combinatorial process variation followed by high-throughput testing for rapid process optimization.
- In-process monitoring followed by high-throughput testing to develop correlations for process anomaly detection.
- Combining rapid property measurements with high-throughput microstructural characterization

Stay tuned…

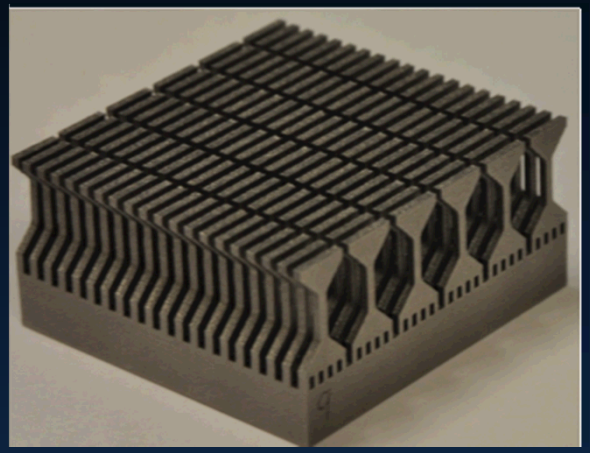
Size scale effects: separating intrinsic material properties from extrinsic structural dimensions





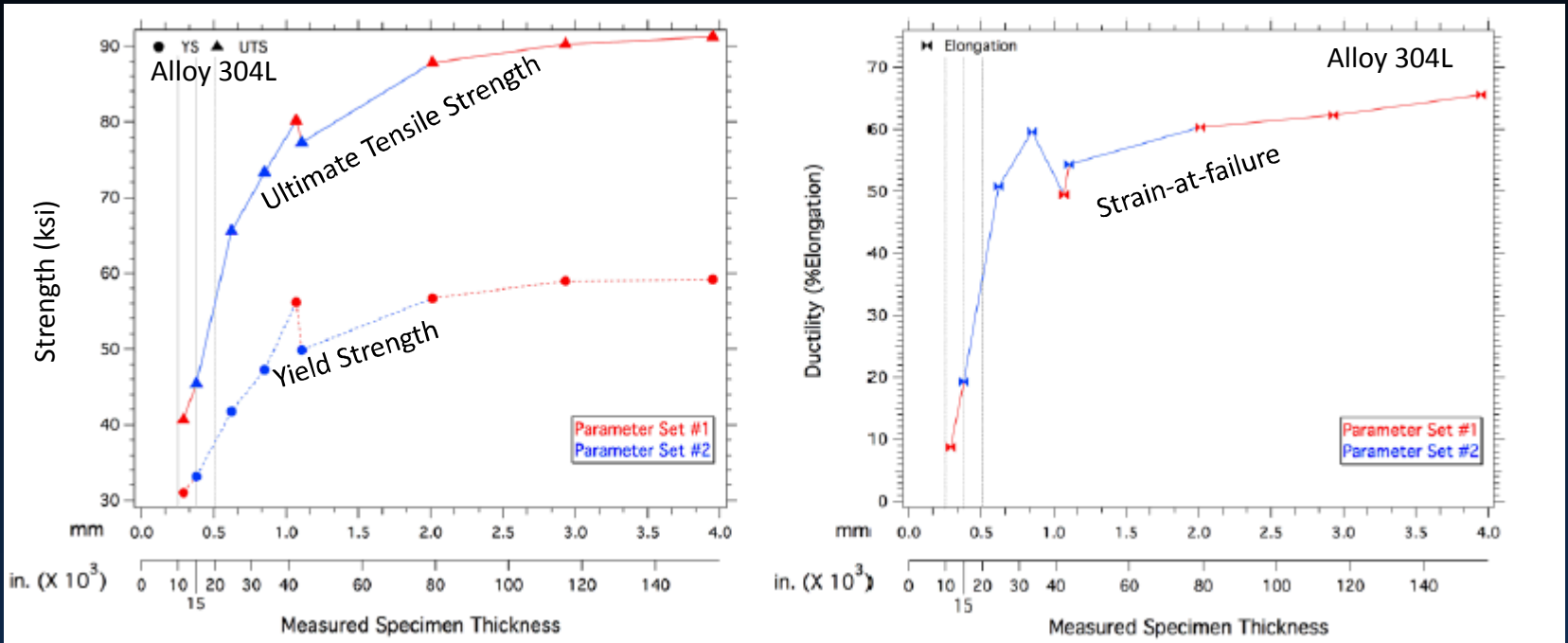
Summary…

High-throughput measurements of additively manufactured materials provides a rapid method for screening performance anomalies and diagnosing sources of poor reliability.



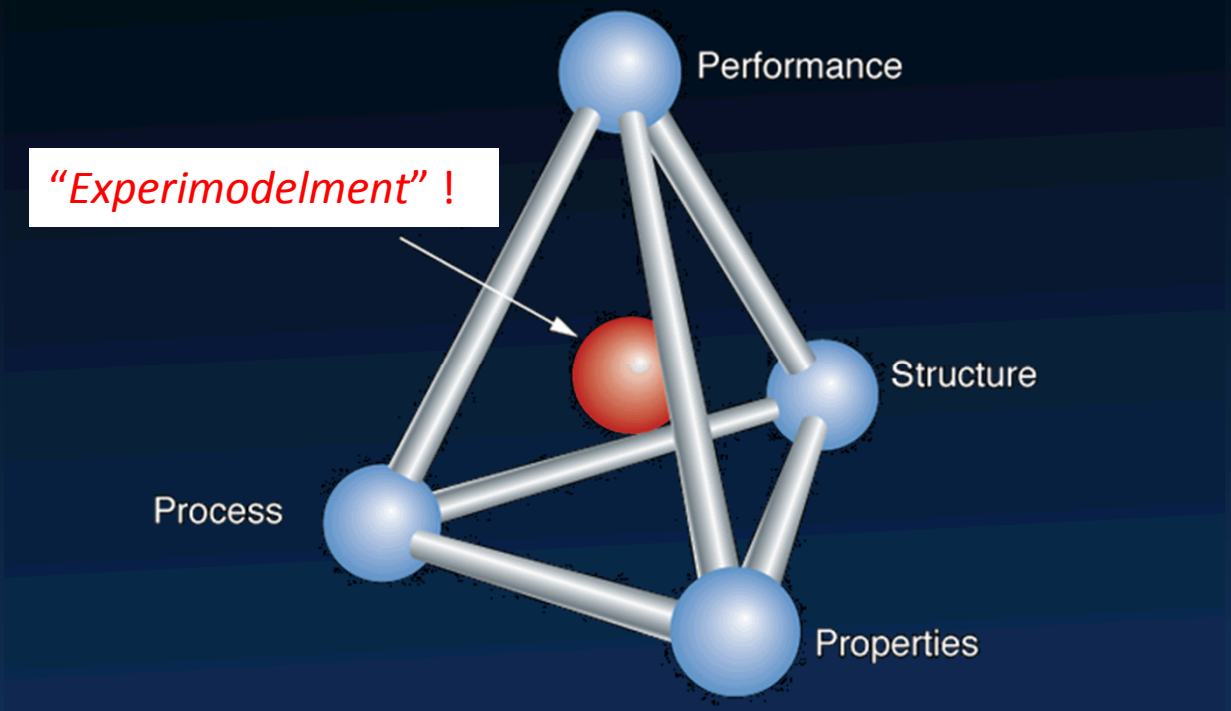
Eventually, we would like to screen using in-process monitoring/control. Rapid materials characterization will enable the development of needed process-structure-property correlations.

Future work…



How does sample thickness affect defect populations and resulting property distributions?

What is the origin of different properties?



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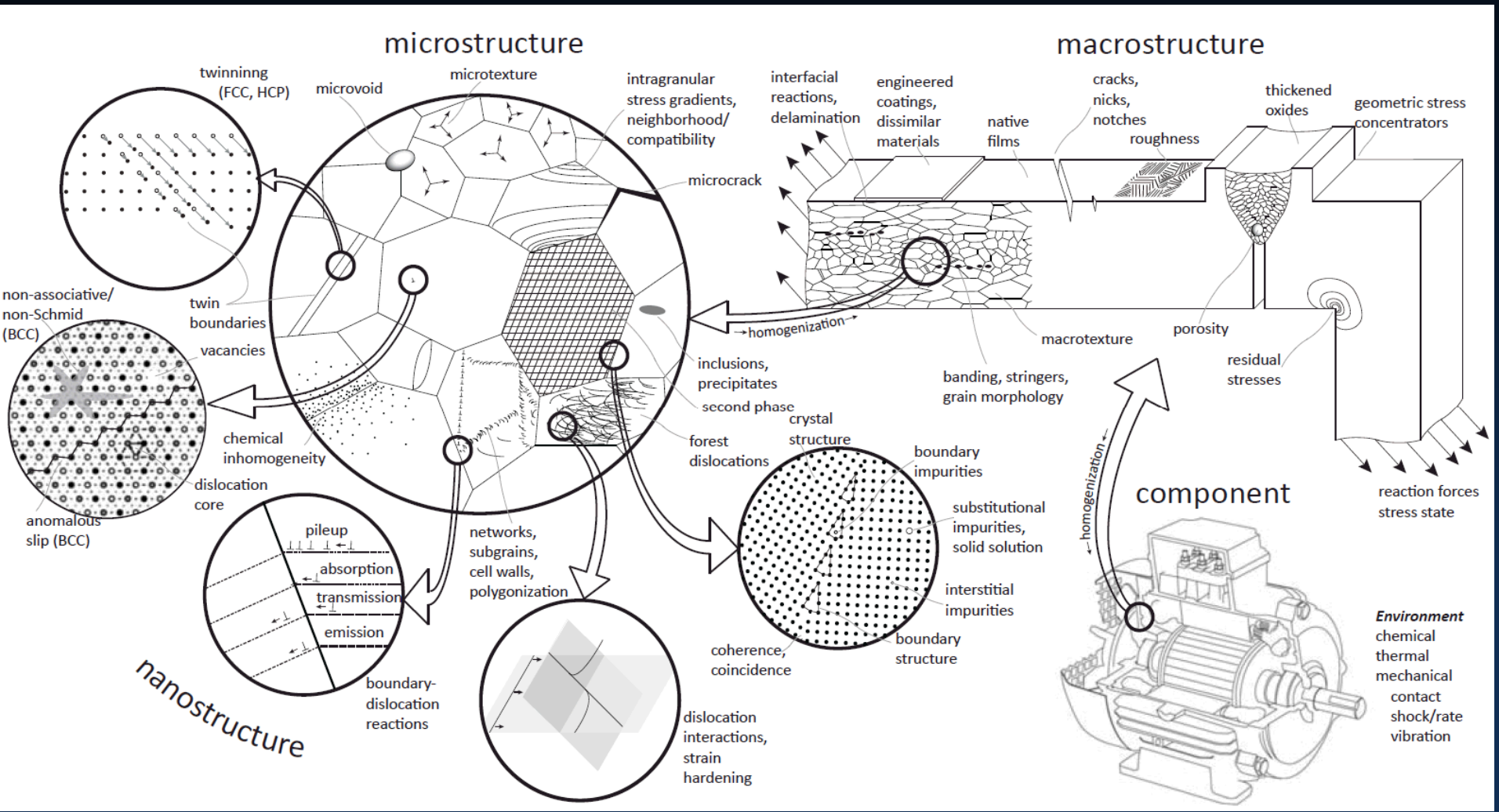
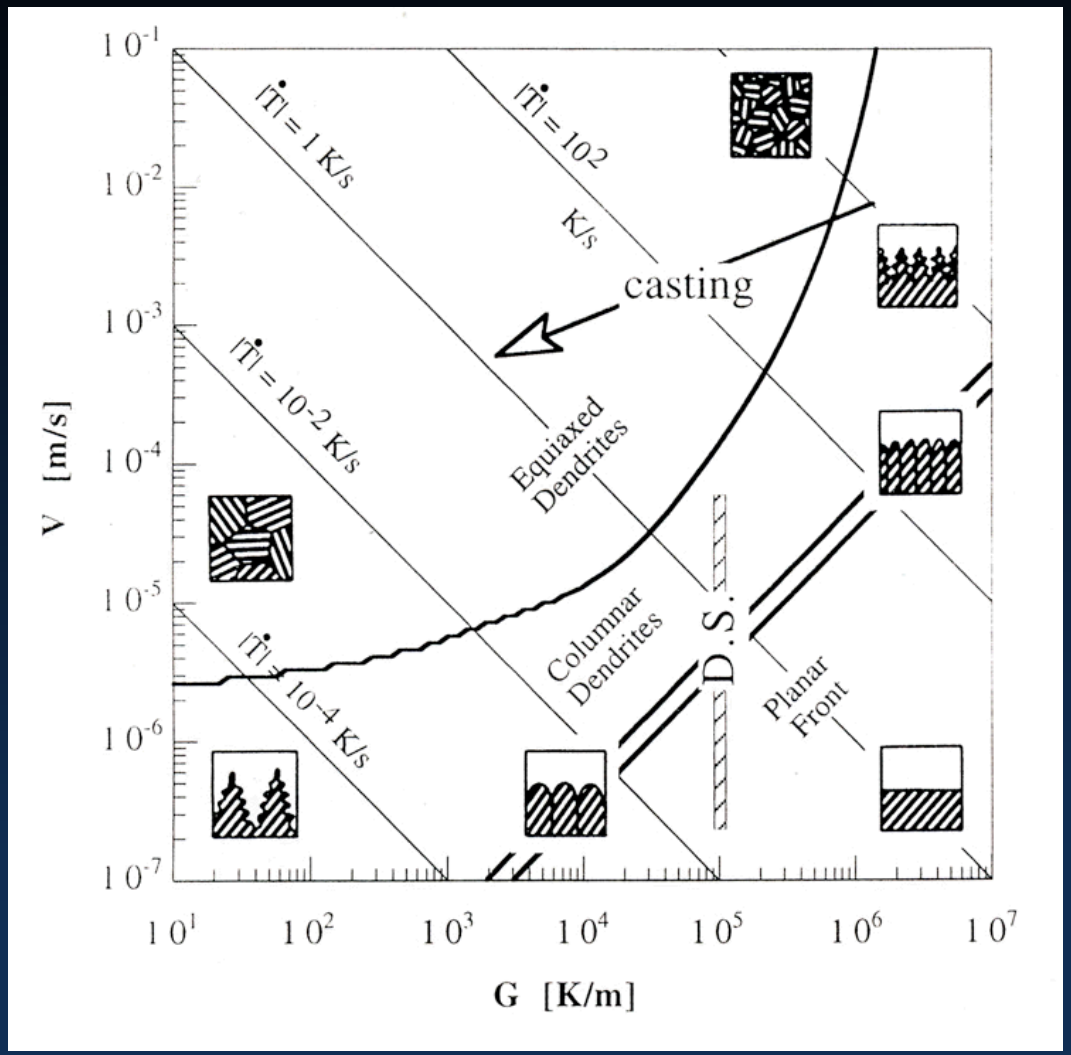


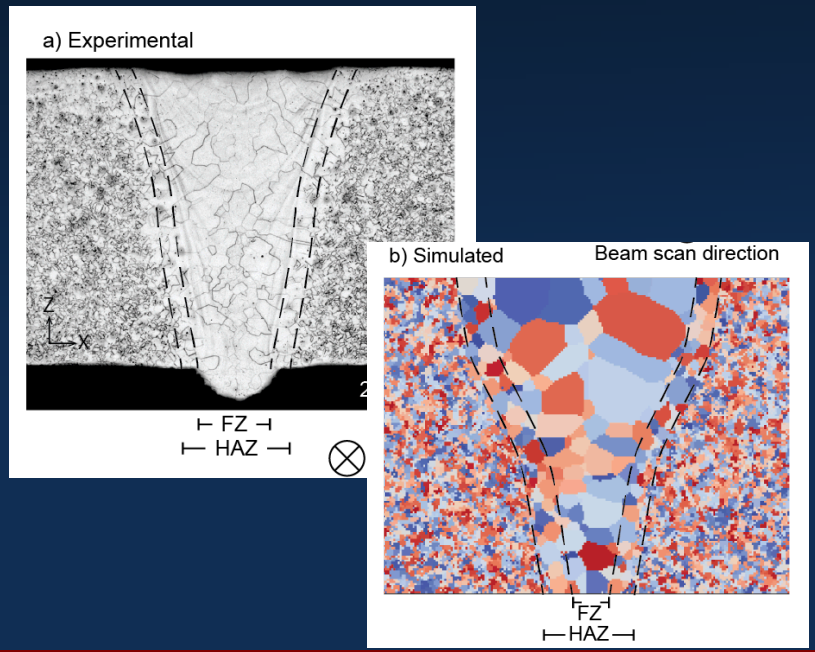
Ultimate goal: Predict solidification microstructure



Potts Kinetic Montre Carlo

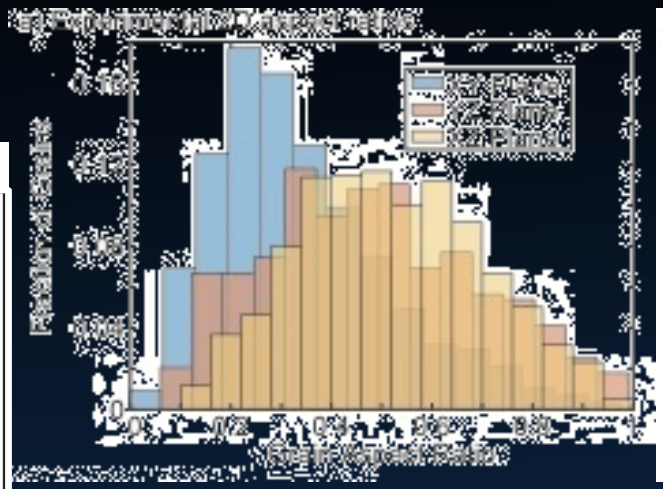
$$P = \begin{cases} \exp\left(\dfrac{-\Delta E}{k_B T_S}\right) & if\ \Delta E > 0 \\ 1 & if\ \Delta E \le 0 \end{cases}$$

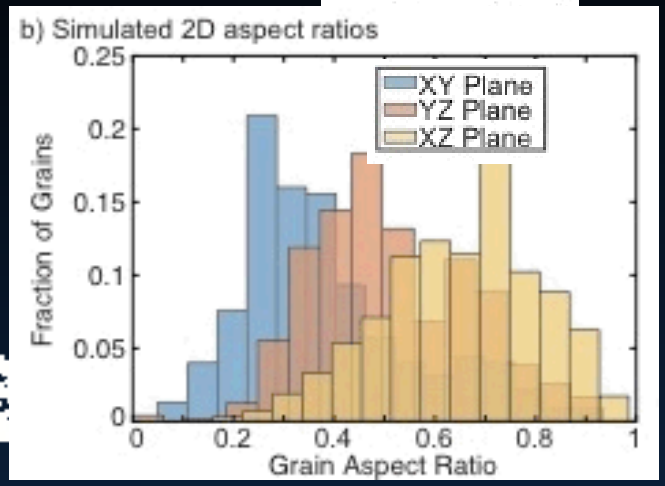
$$E = \frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{26}\left(1-\delta\left(q_i, q_j\right)\right)$$

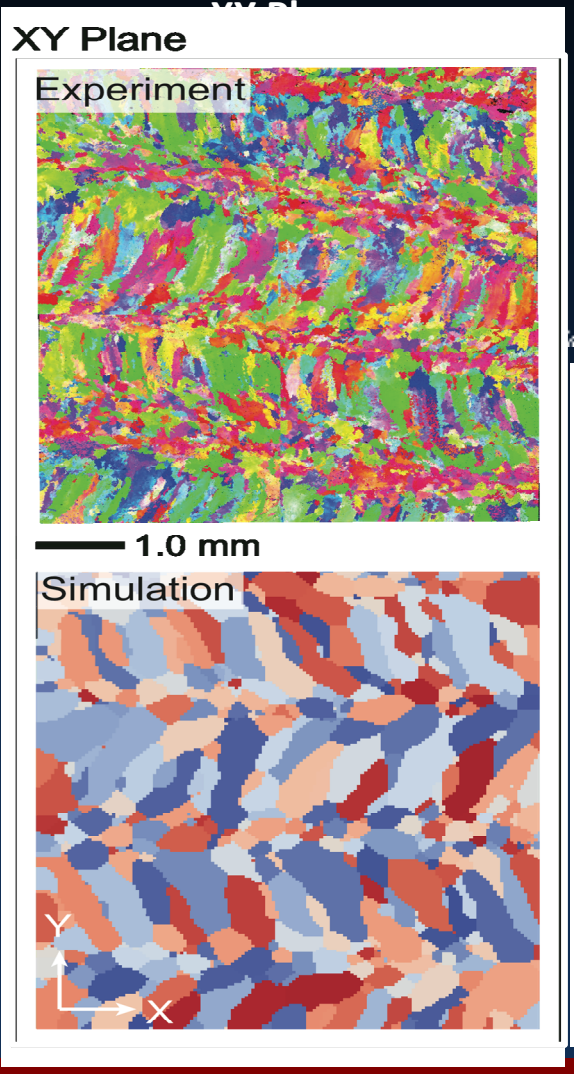


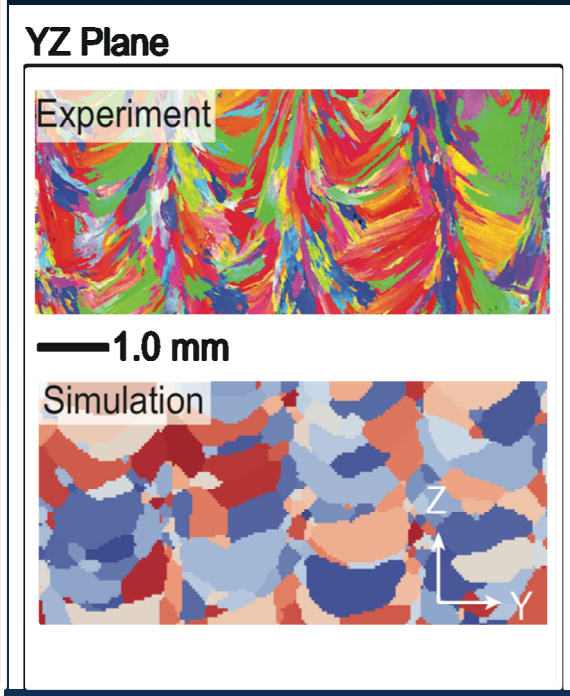
Kurz, W. and Fisher, D. J., Fundamentals of Solidification, Chapter 4: Solidification Microstructure, Trans Tech Publications (Enfield, NH, 1998)
Rodgers, Madsion, and Tikare, JOM, 2016

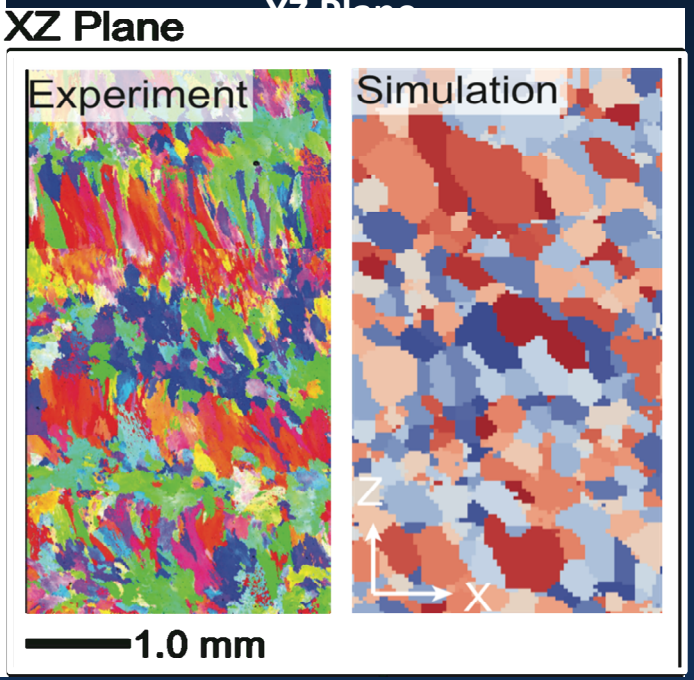
Capturing complex solidification microstructure



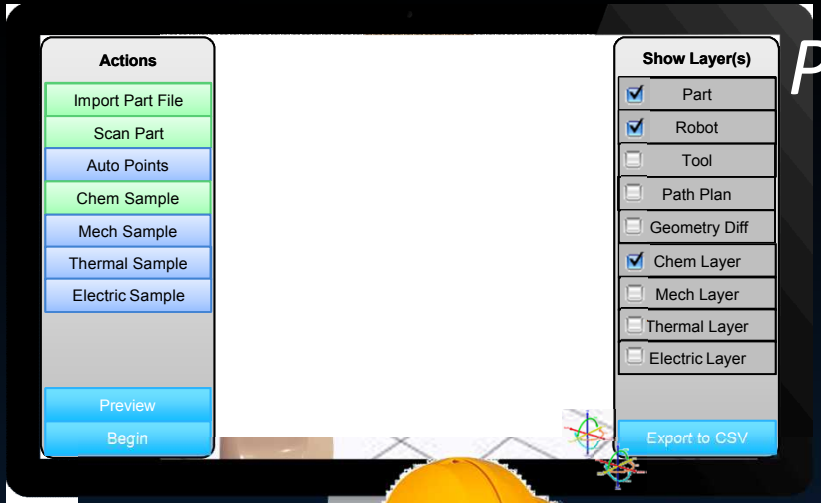








Properties 'Alinstante'



An Aspirational Goal:

Can we reduce materials science evaluation from months to hours?

(design-build-test loop in a day?)

Geometric metrology probe

Surface roughness probe

Mechanical properties probe

Compositional probe

Phase probe

Thermal probe

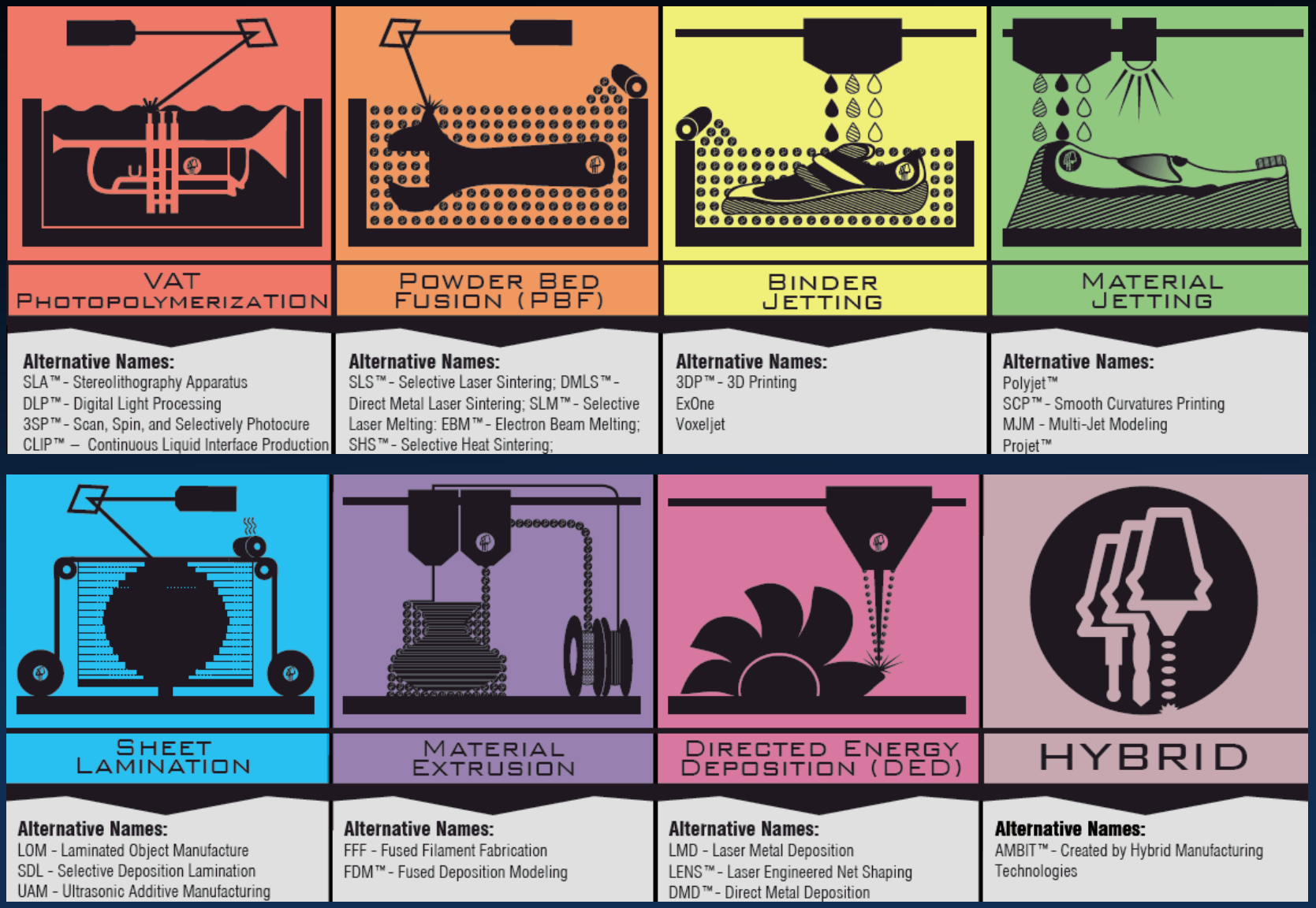
Electrical probe

Tribology probe

Resonance probe

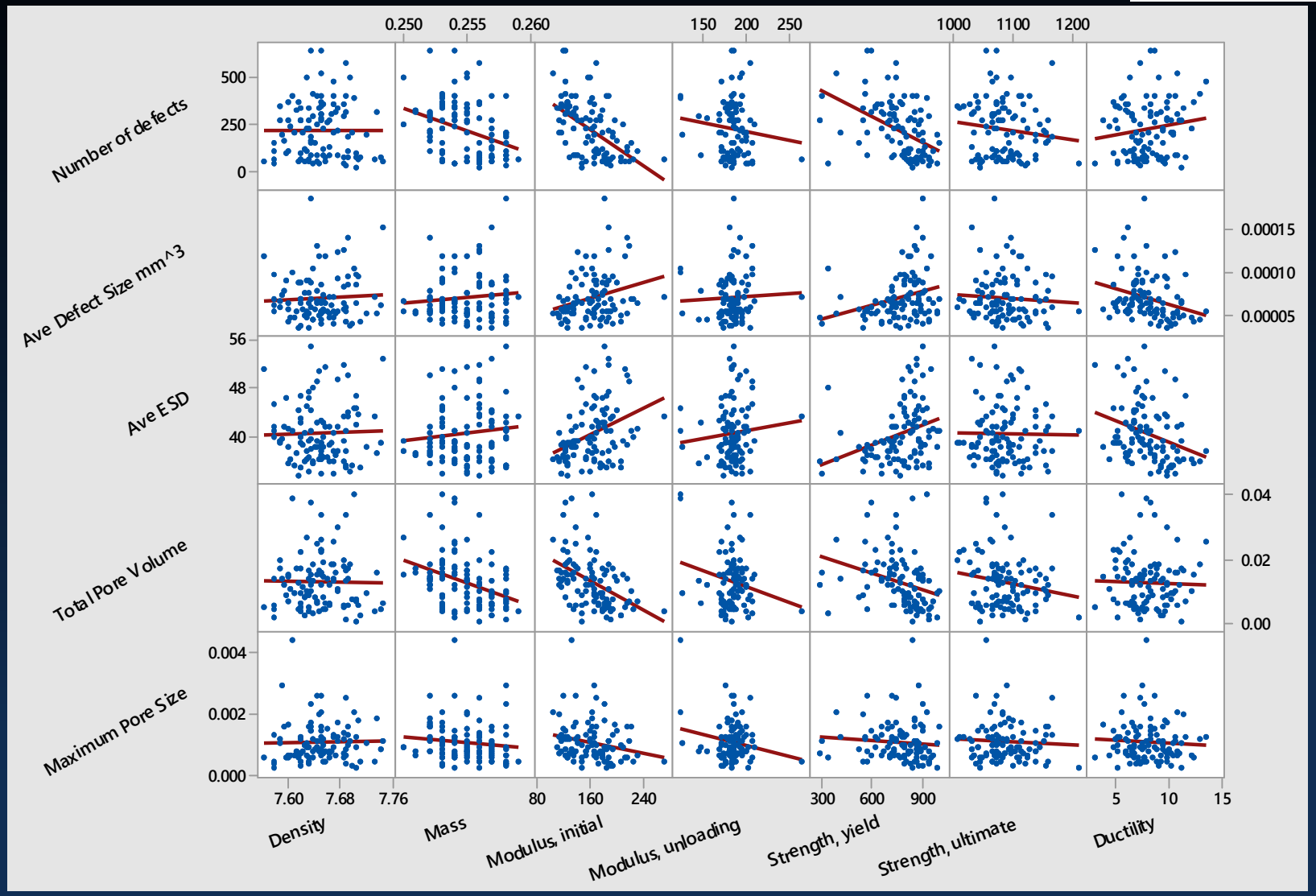
…

8 Families of AM Processes (ASTM F2794)



Graphic created by Hybrid Manufacturing Technologies based on ASTM F2794 definitions

Pairwise Correlations are Unconvincing



Cluster analysis seems promising