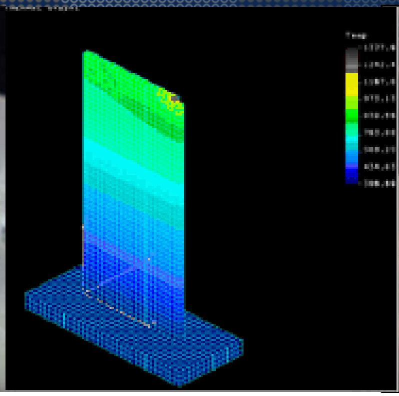
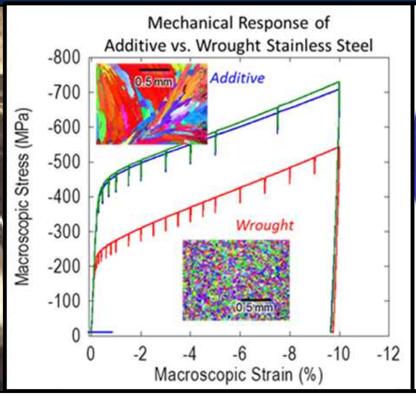
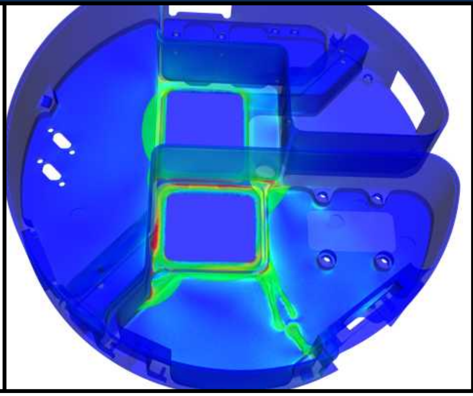
SAND2016-1073PE

Exceptional service in the national interest

Sandia National Laboratories





Additive Manufacturing at Sandia

Mark F. Smith
Deputy Director for Additive Manufacturing
Materials Science & Engineering Center

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

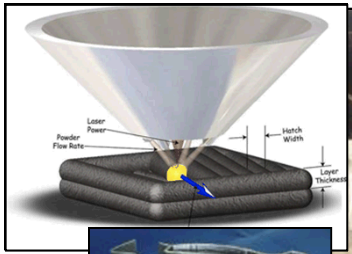
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2014-19962PE

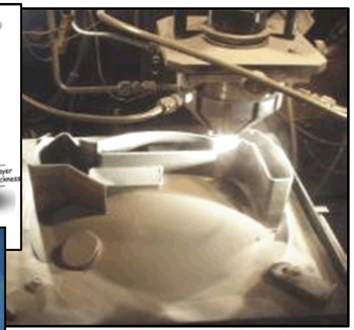
Sandia Additive Mfg.
Tech Development & Commercialization

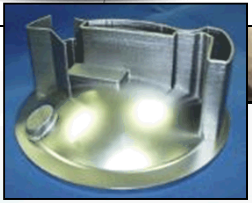
30+ yrs of Pioneering Process/Materials R&D

FastCast *
Development housing

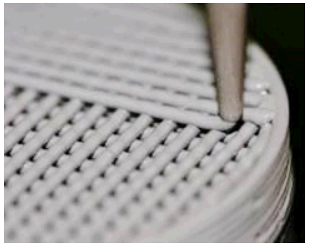
Laser Engineered Net Shaping LENS® *
Stainless housing

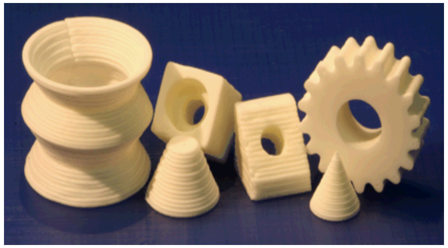




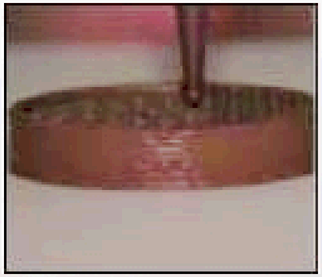


RoboCast *
Ceramic Parts

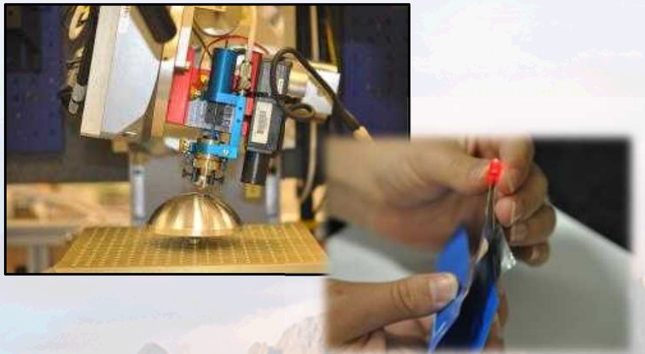




Energetic Materials

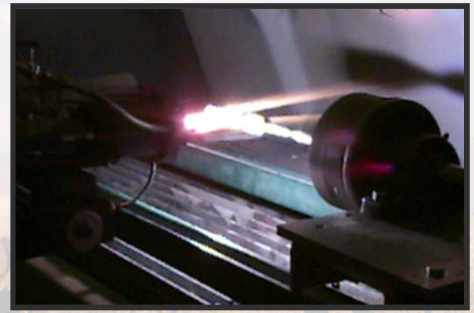


Direct Write
Conformal electronics



Printed battery

Spray Forming
Rocket nozzle



FY16 ~$16M, 70 Projects

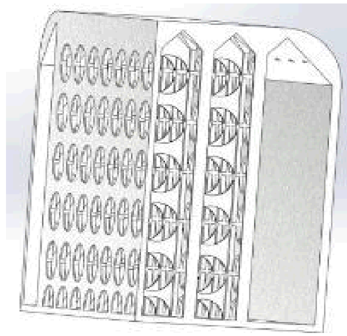
* Licensed/Commercialized Sandia AM technologies

Current Capability/Activity

Why AM at Sandia? – Mission Drivers

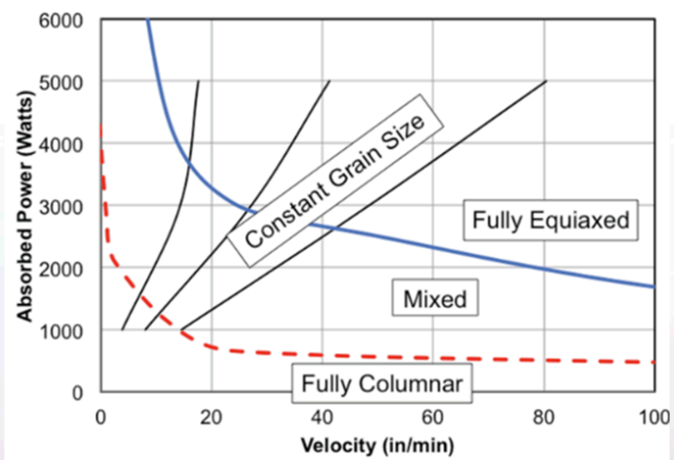
- Revolutionary New Design Possibilities
  - Optimize for Performance, Not Machinability
  - Engineering analysis driven designs
- Engineered Materials
  - Multi-material and graded material parts
  - Potential for microstructural control
- Cost/Schedule/Risk Benefits

Electronic Component Mass Mock

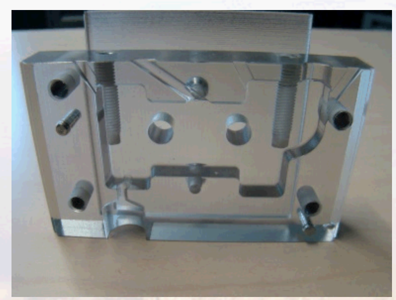


Customize mass, center of gravity, moment of inertia

LENS ® Microstructure Control



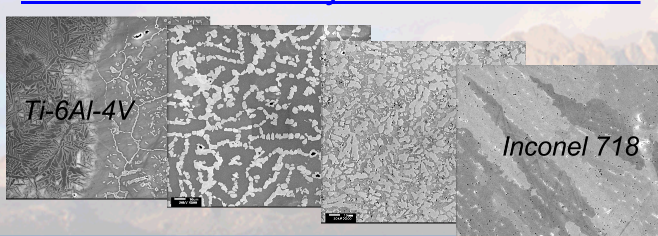
50% Cost Reduction for Neutron Generator Tooling 1st Yr



Connector Mold

Forming Tool

LENS® Functionally Graded Materials

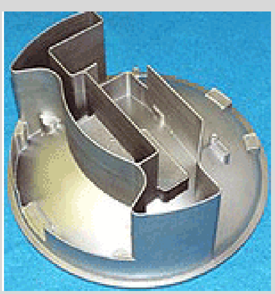


Sandia Additive Manufacturing Strategy

5 Strategic Thrust Areas

Today

Existing SNL Expertise, Capabilities, & Partnerships in Additive Mfg.



Identify Compelling Applications

Provide Analysis Driven Design Tools

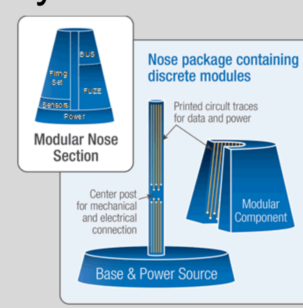
Provide Materials Assurance

Enable Engineered/Multi- Material AM

Enable Product Realization

Tomorrow

Deliver innovative, revolutionary national security products enabled by AM technology

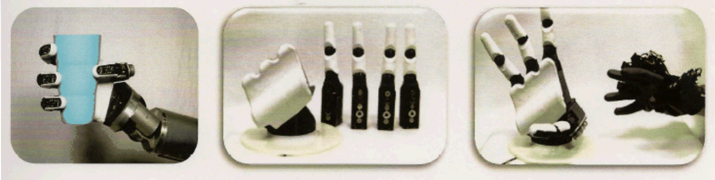


Example Applications

Sandia Hand – AM Enabled Innovative Design and Substantial Cost Reduction

(~*50% of hand built with AM*)

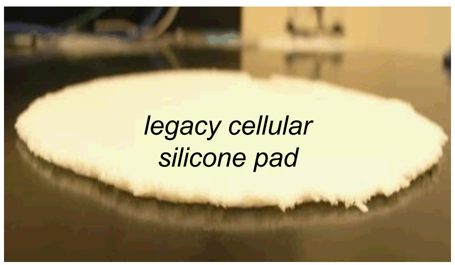
- Developed for bomb disablement
- AM Enabled rapid design iterations
- Cost \$10k vs. ~\$250k
- "Glove" controller
- Current version has "touch" sensors

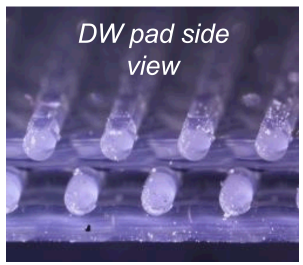


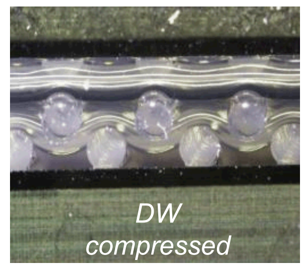
Fingers or other tools (drills, lights, …) can be quickly magnetically attached in many configurations

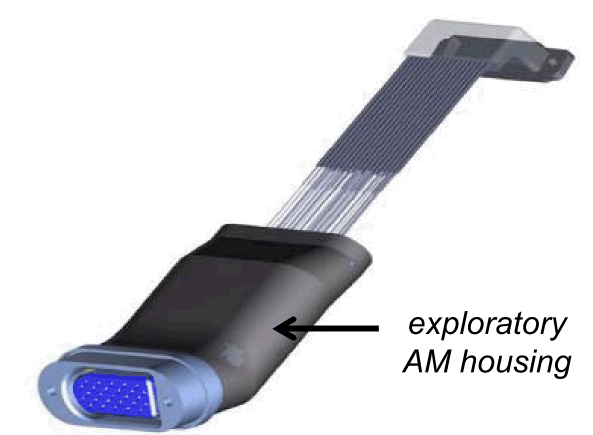
Example High Design Margin AM Applications

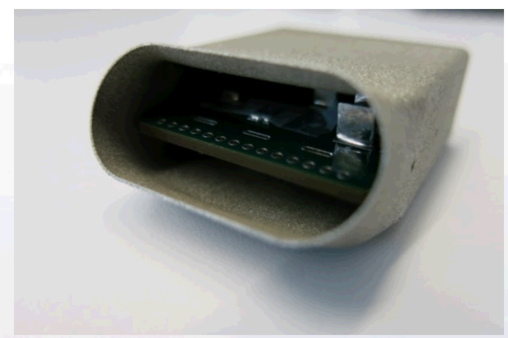
- Value Proposition to Replace Foam with Direct Write Pads
  - Prior manufacturing issues w legacy foam
  - Potential $2M cost & 90% mfg. floorspace savings @ NSC
  - Ability to custom tailor stress-strain response

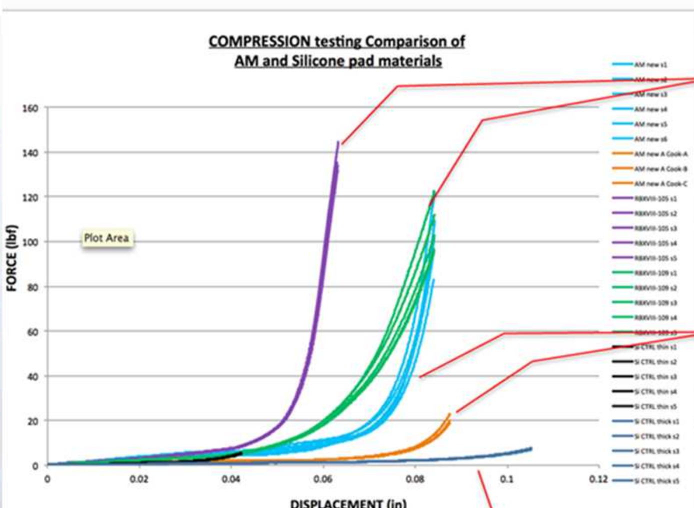




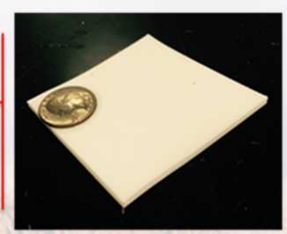








3D Printed Silicone (unmodified) NSC



3D Printed Silicone (modified) SNL

LEGACY MATERIAL

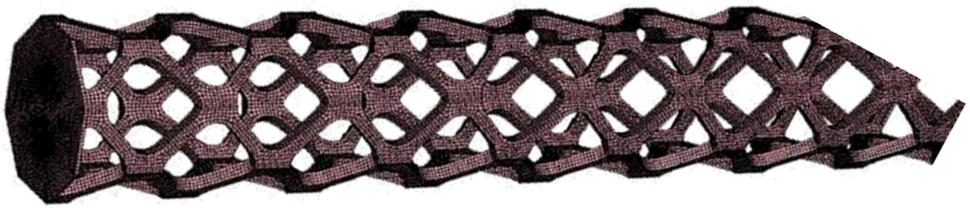
- AM Offers Potential Advantages for Complex, Thin-Walled Shape

Analysis Driven Design

Engineering Analysis Driven Design & Margins

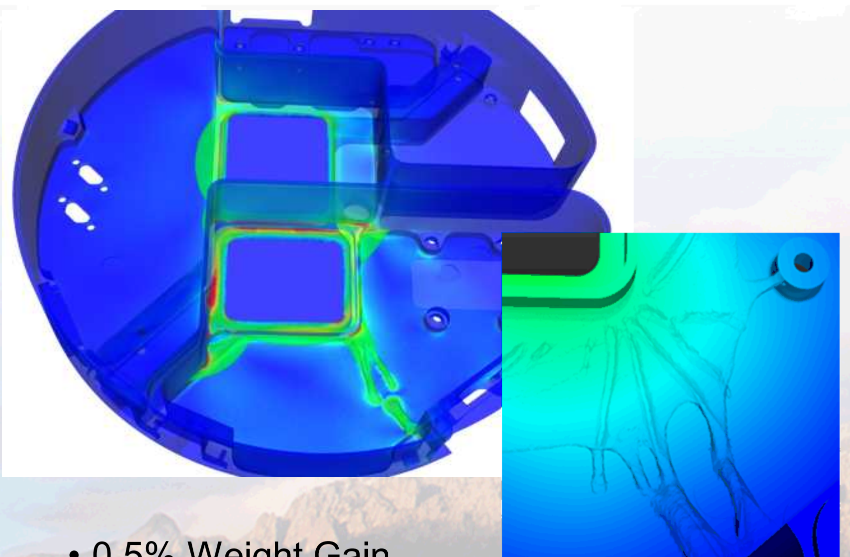
We combine Topology Optimization (TO) with eXtended Finite Element Modeling (X-FEM) & LENS® to optimize selected properties, e.g., strength/weight ratio.

"Titanium Cholla" LDRD -- Minimum Weight, Maximum Strength, Rapidly Manufactured!

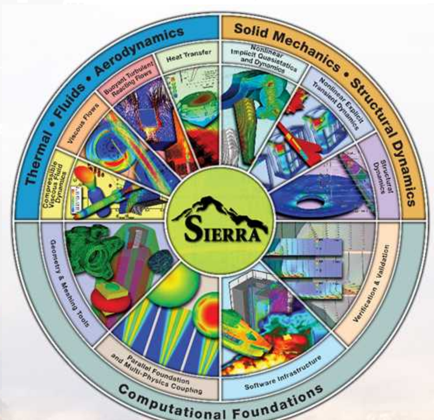


With AM it is faster and cheaper to build this optimized shaft than a solid shaft

Core of a dead Cholla cactus (bio-mimicry)



- 0.5% Weight Gain
- 52% Less Deflection Under Load

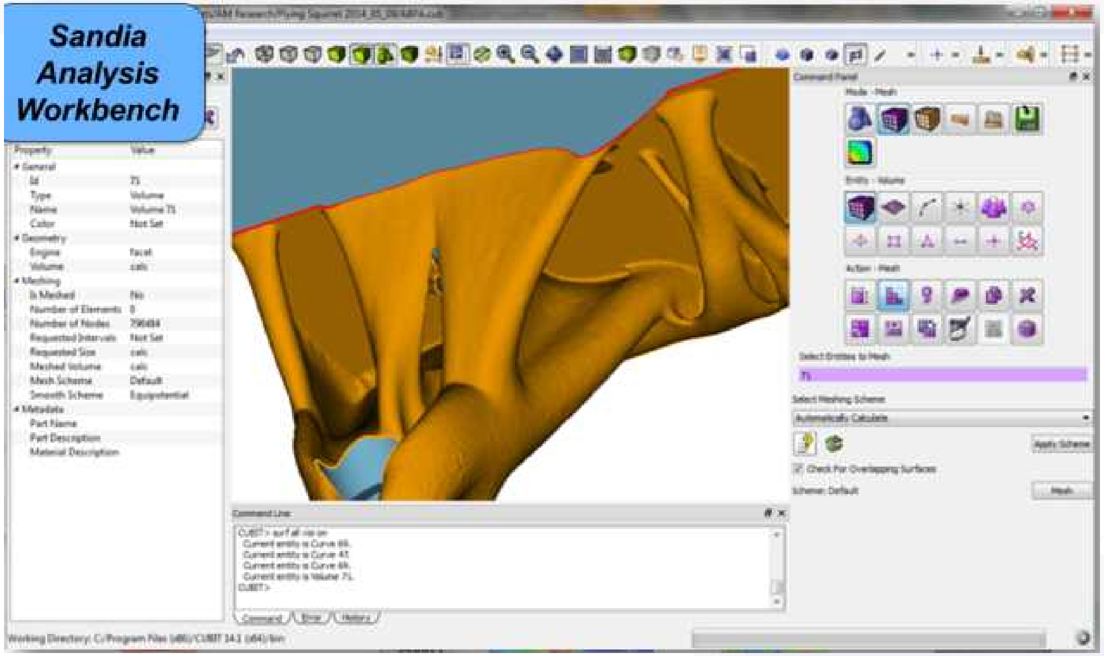


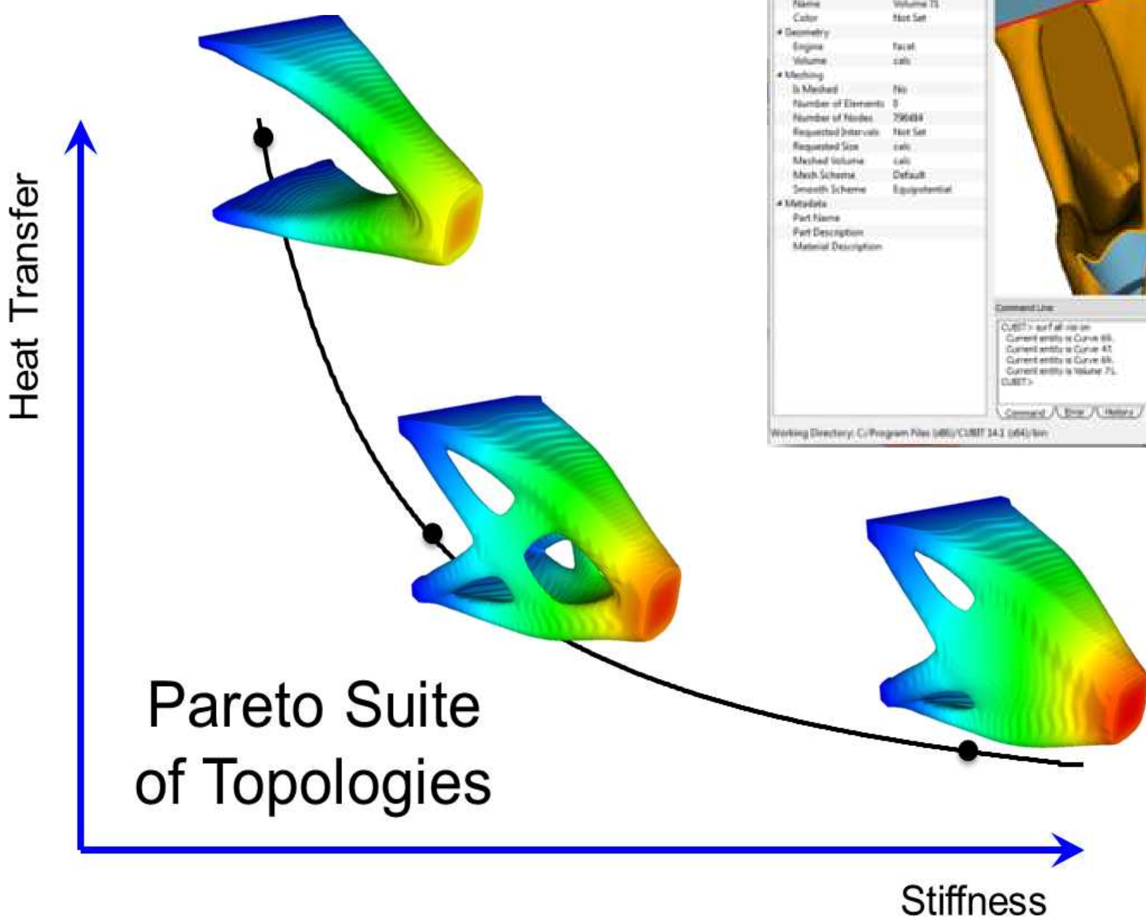
- NNSA lead lab for engineering code development
- Leverage extensive HPC codes/capabilities for AM

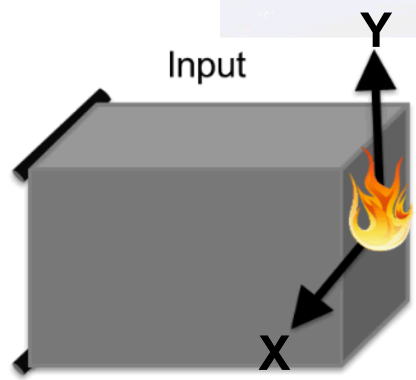
Sandia National Laboratories

AM Design Via Functional Prioritization

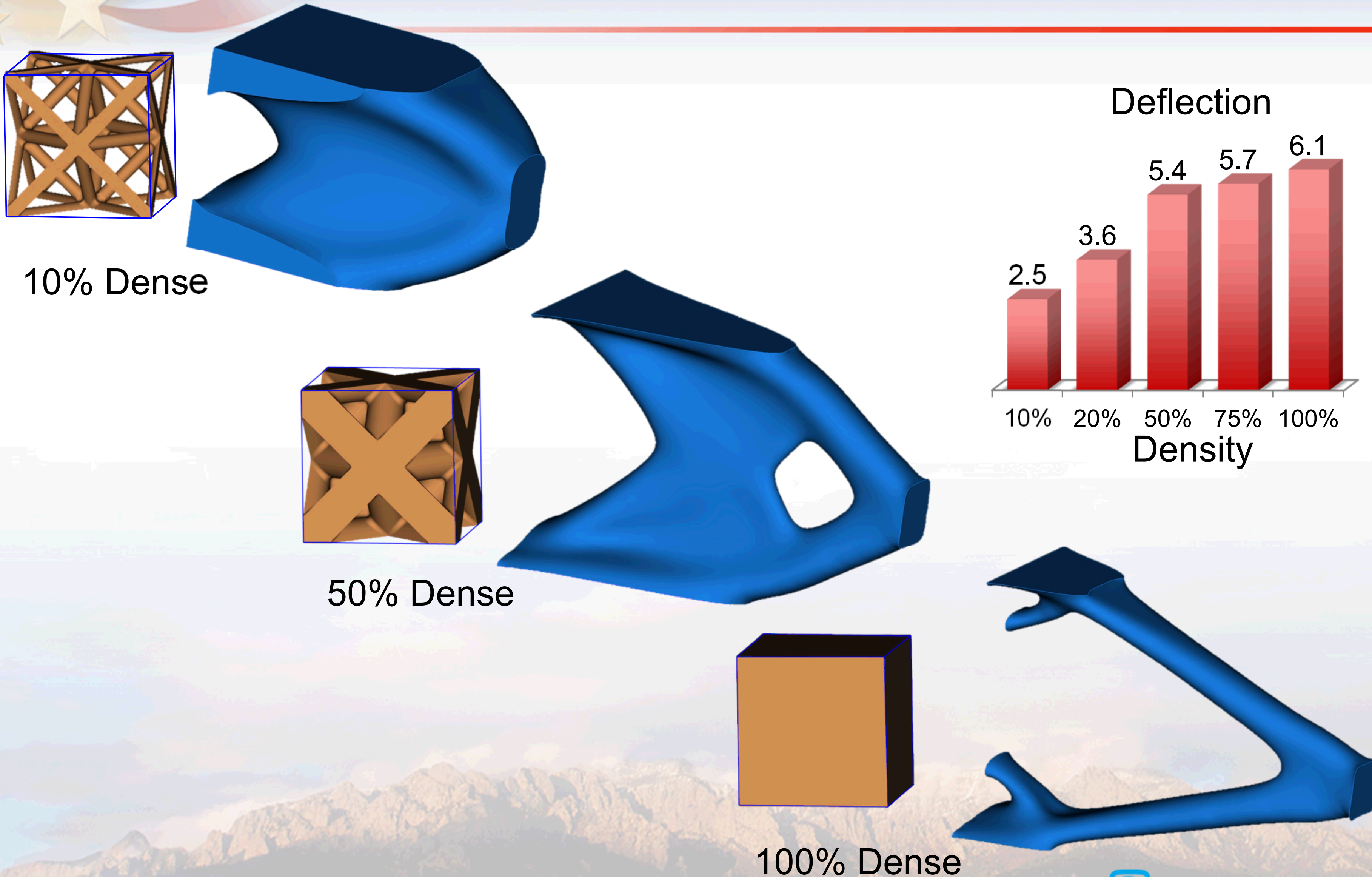
User Friendly Interface



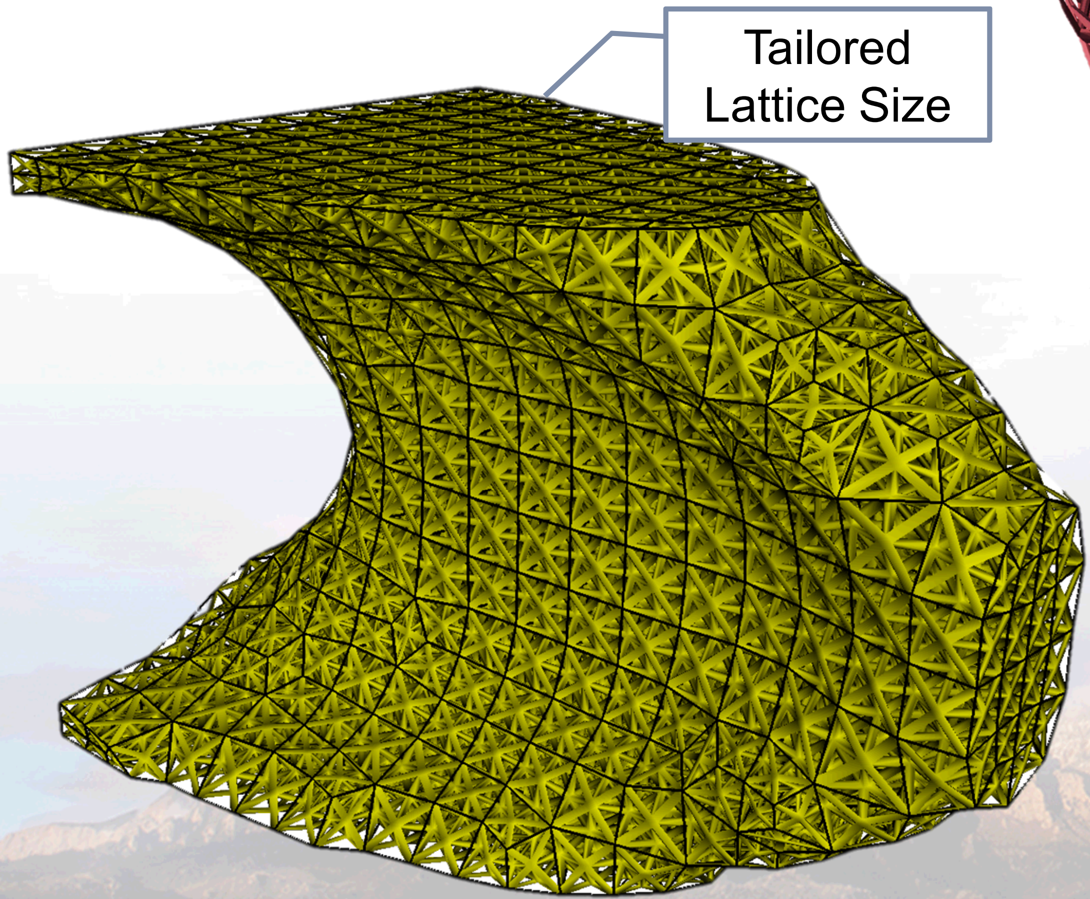


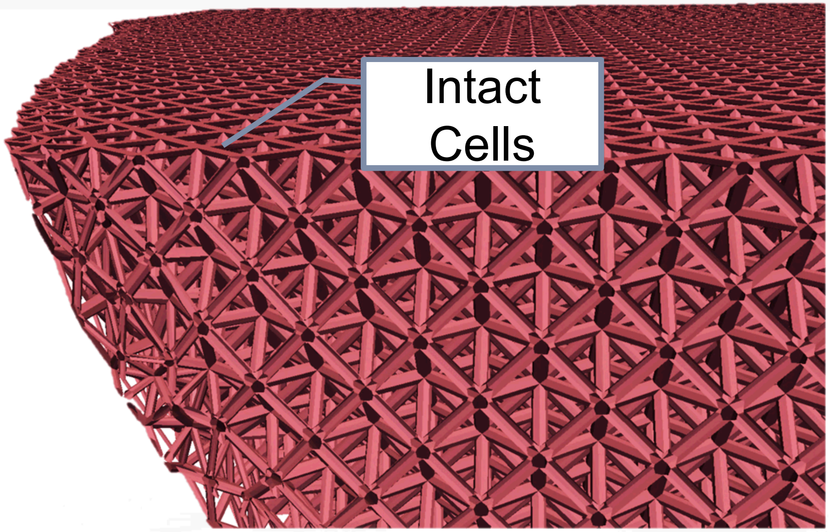


Optimizing Stiffness at Fixed Mass



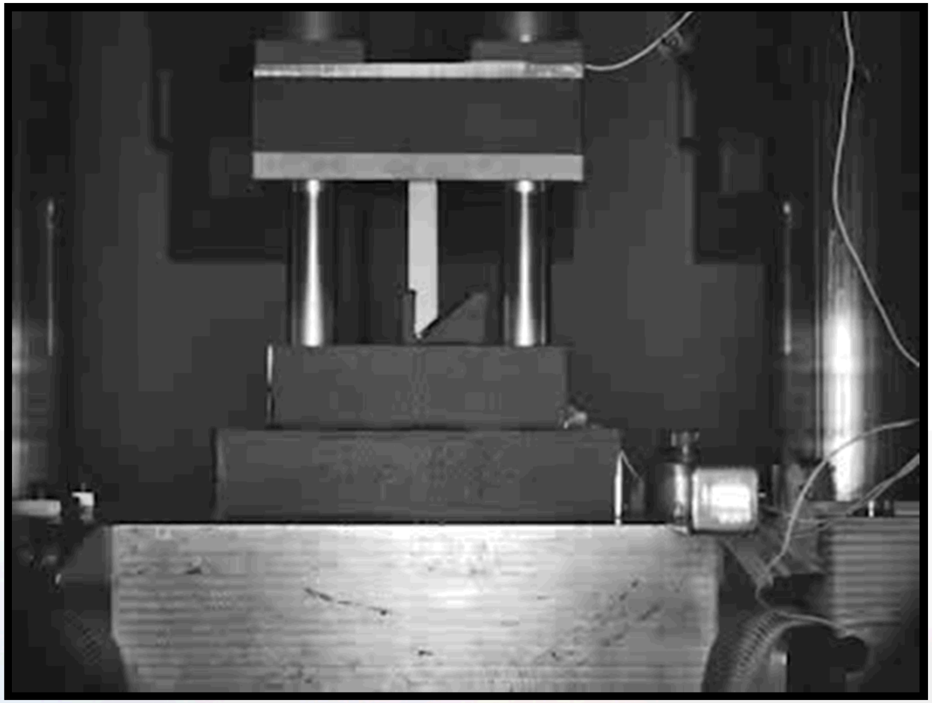
Tailored Geometry Avoids "Loose Ends"



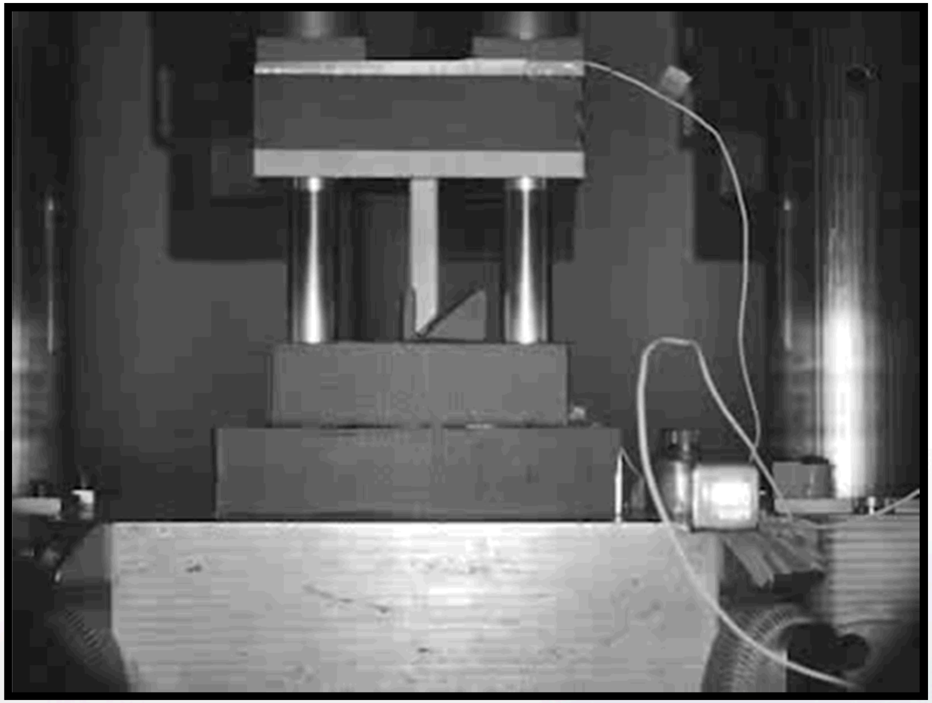


Materials Assurance

Longitudinal Impact Test

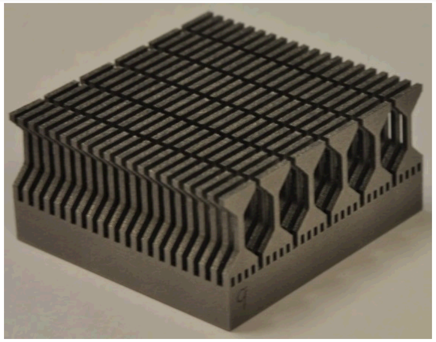


Machined/Welded Housing
4047 Al alloy

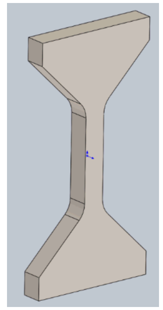


Additively Manufactured Housing
AlSi10Mg Al alloy

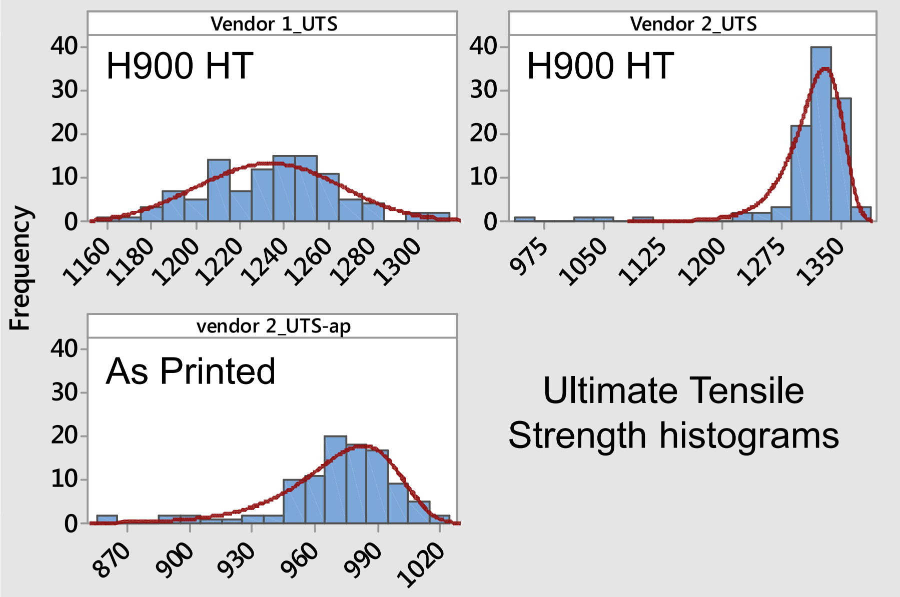
Leverage Sandia PPM to Quantify Variability/Defect Sensitivity



120 AM 17-4 PH SS tensile bars enable rapid, economical testing

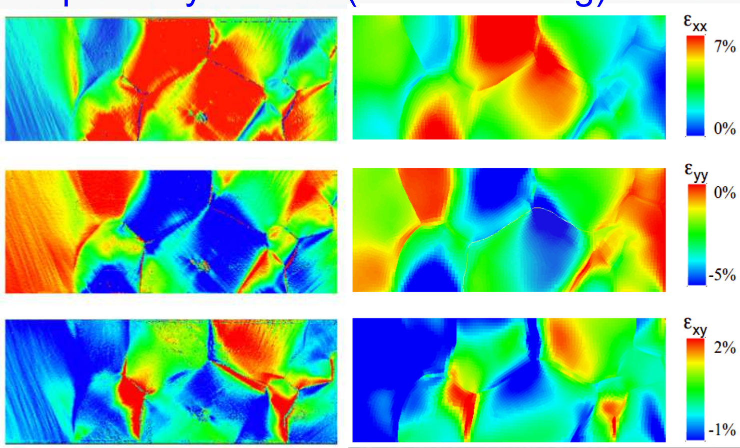


1x1 mm gage section sample



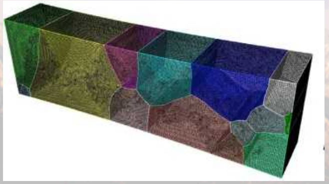
Ultimate Tensile Strength histograms

Oligocrystal experiments vs. crystal plasticity models (tensile loading)



Experimental Results Computed Simulations

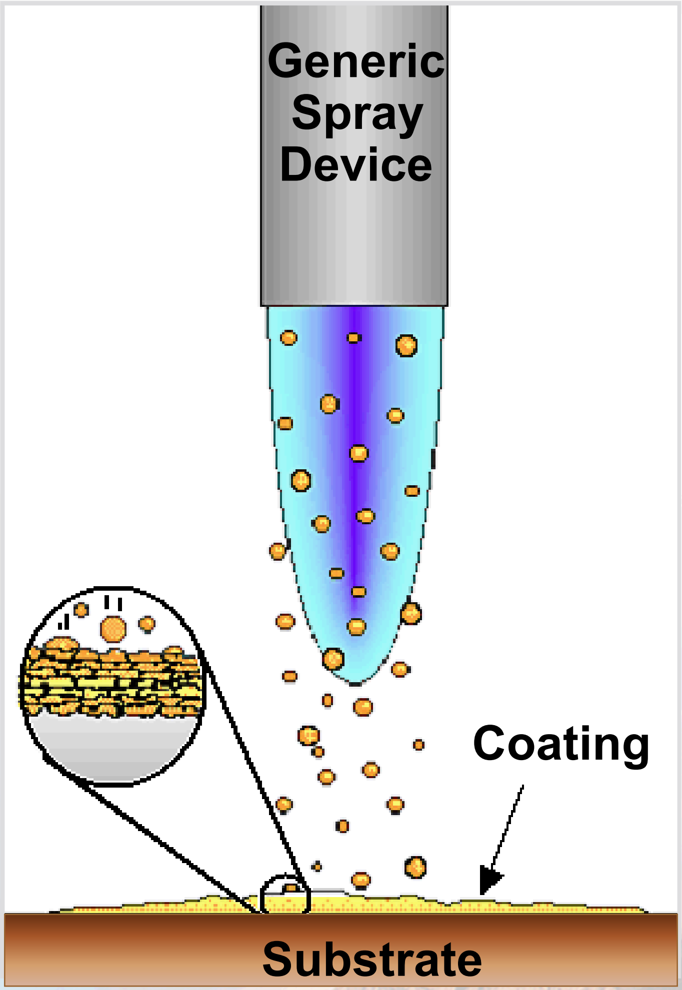
Sandia *Predicting Performance Margins (PPM)* initiative seeks to understand fundamental science of microstructural variability and defects and to quantitatively predict the resulting variability of materials properties



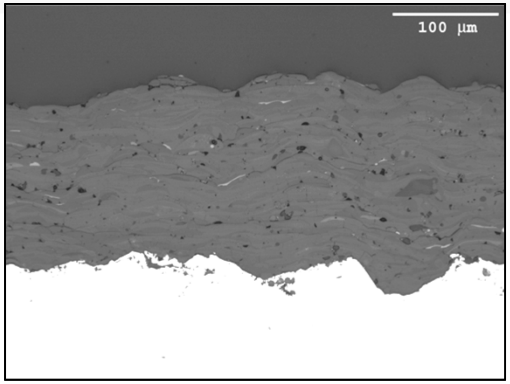
Gauge Section of Oligocrystal Tensile Specimen (1x3x5 mm)

Sandia National Laboratories

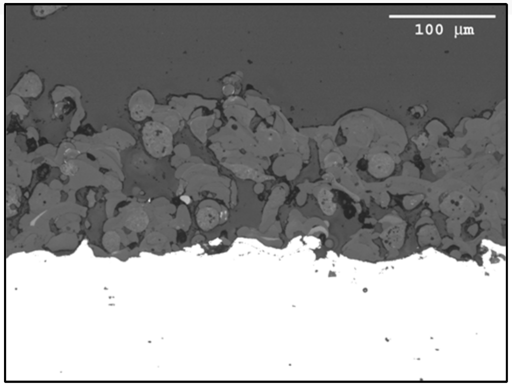
Build on Prior Success with Process Control of Another AM Process --Thermal Spray



Same System, Same Feedstock,

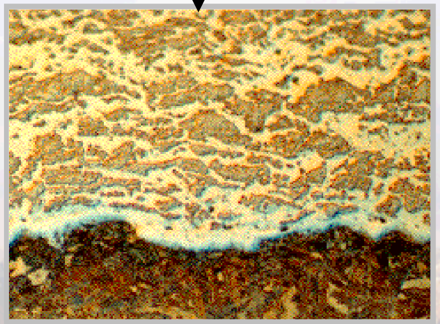


vs.



Very Different Results

Cemented Carbide Coating On Steel

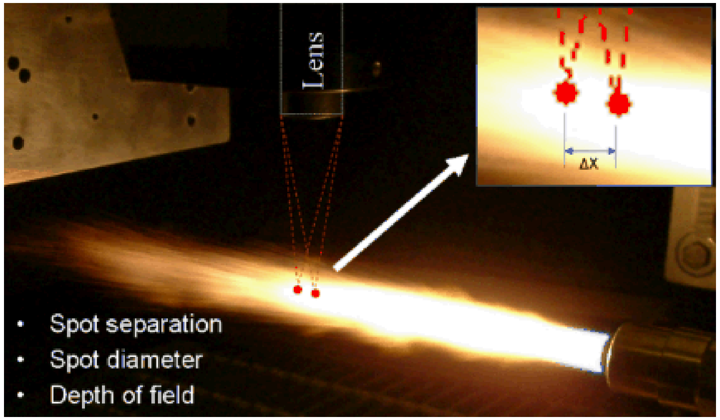


AM today is similar to Thermal Spray ~20 years ago

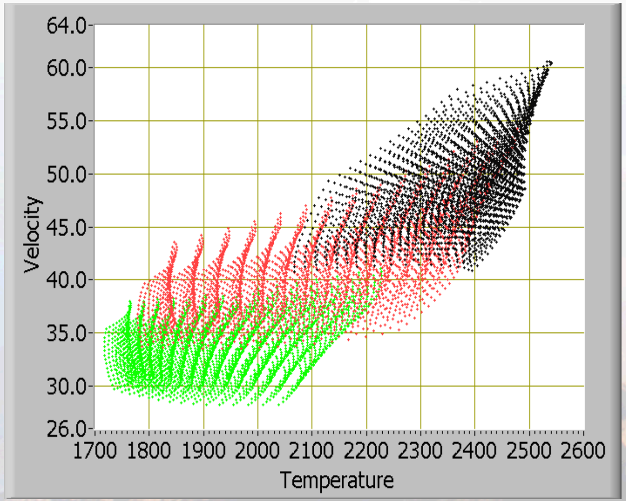
Sandia National Laboratories

Fundamental Process Understanding is Key to Controlling Variability

- Experimental/computational R&D used to develop processing-microstructure-properties relationships

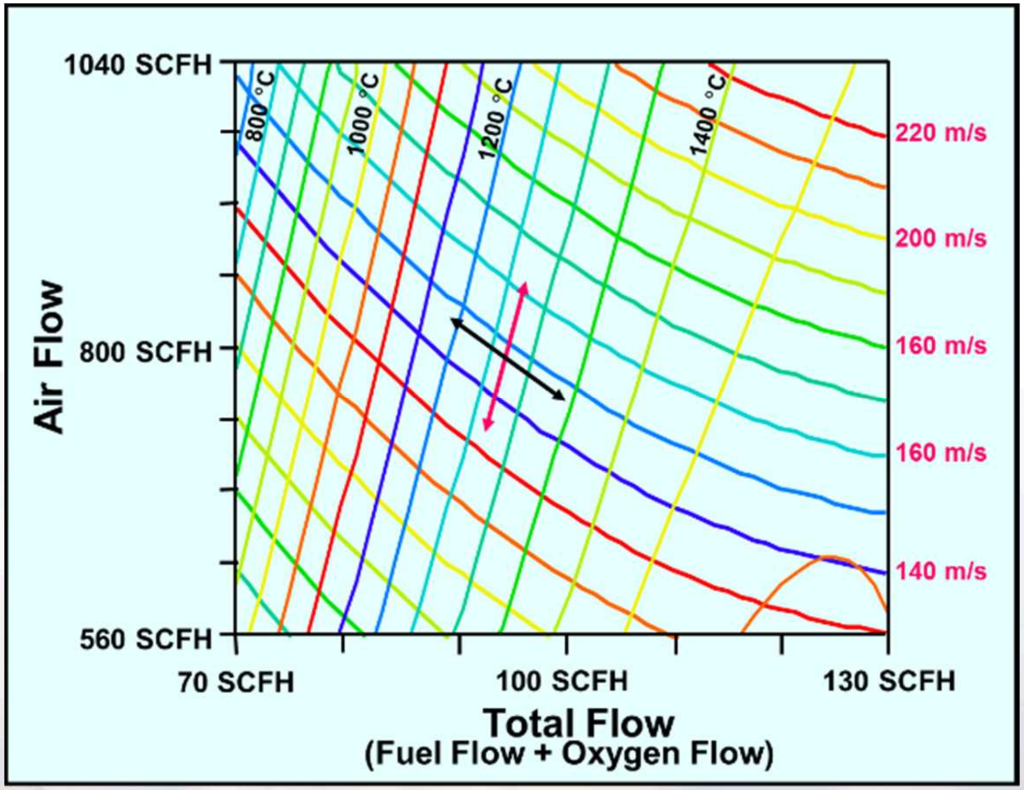


Process Diagnostics/Monitoring



Process Modeling
(All possible vel/temp regimes as a function of torch hardware)

- Fundamental process understanding used to implement <u>closed-loop control</u> based on droplet <u>*temperature*</u> and <u>*velocity*</u> to <u>reduce *variability*</u>

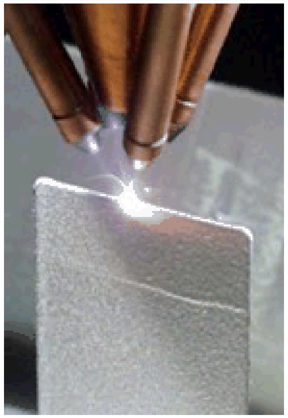


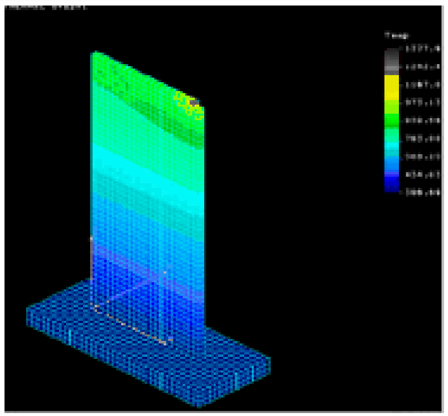
Response surface showing relationships between Process Inputs (Air Flow, Fuel Flow, Oxygen Flow) and Critical Outputs (droplet temperature, droplet velocity)

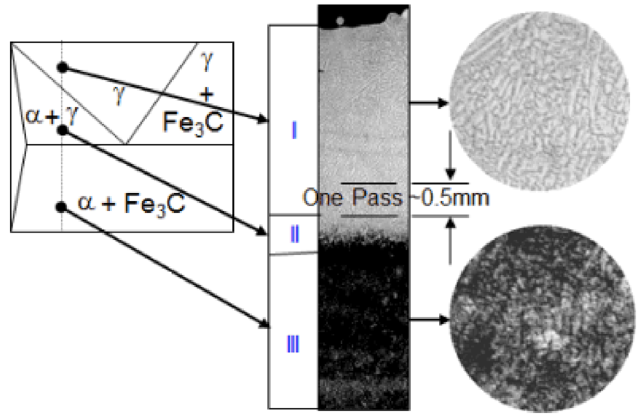
Sandia National Laboratories

LENS® Process & Materials R&D

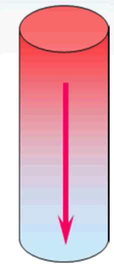
Process characterization/modeling





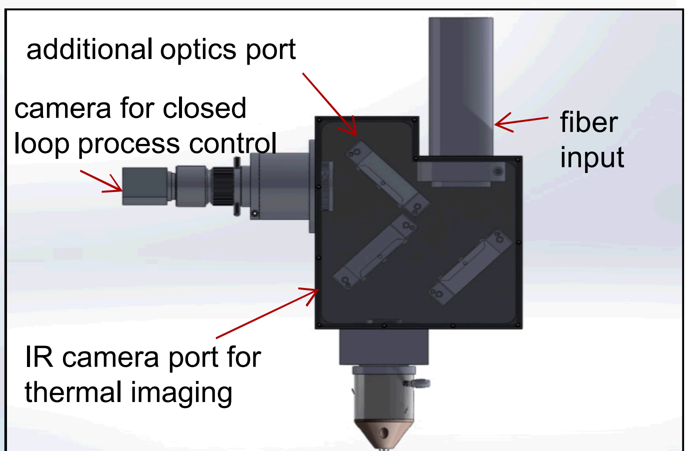


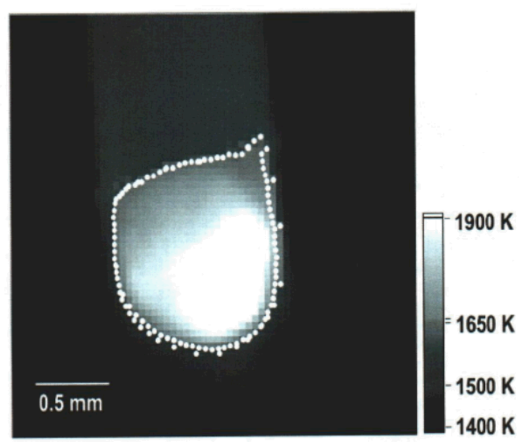
Part heats up during the build & heat flow changes -- so microstructure & properties in the top (I), middle (II), & base (III) may differ

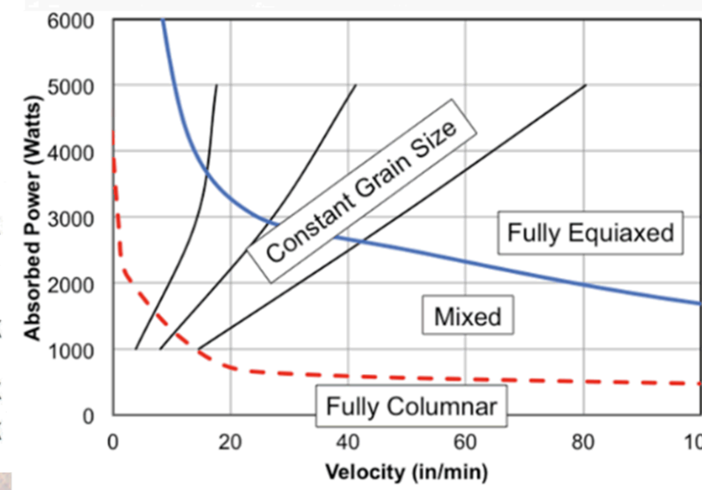


Uni-directional Solidification

- Built narrow “wires” to achieve 1-D heat flow
- Simplified comparison with model predictions



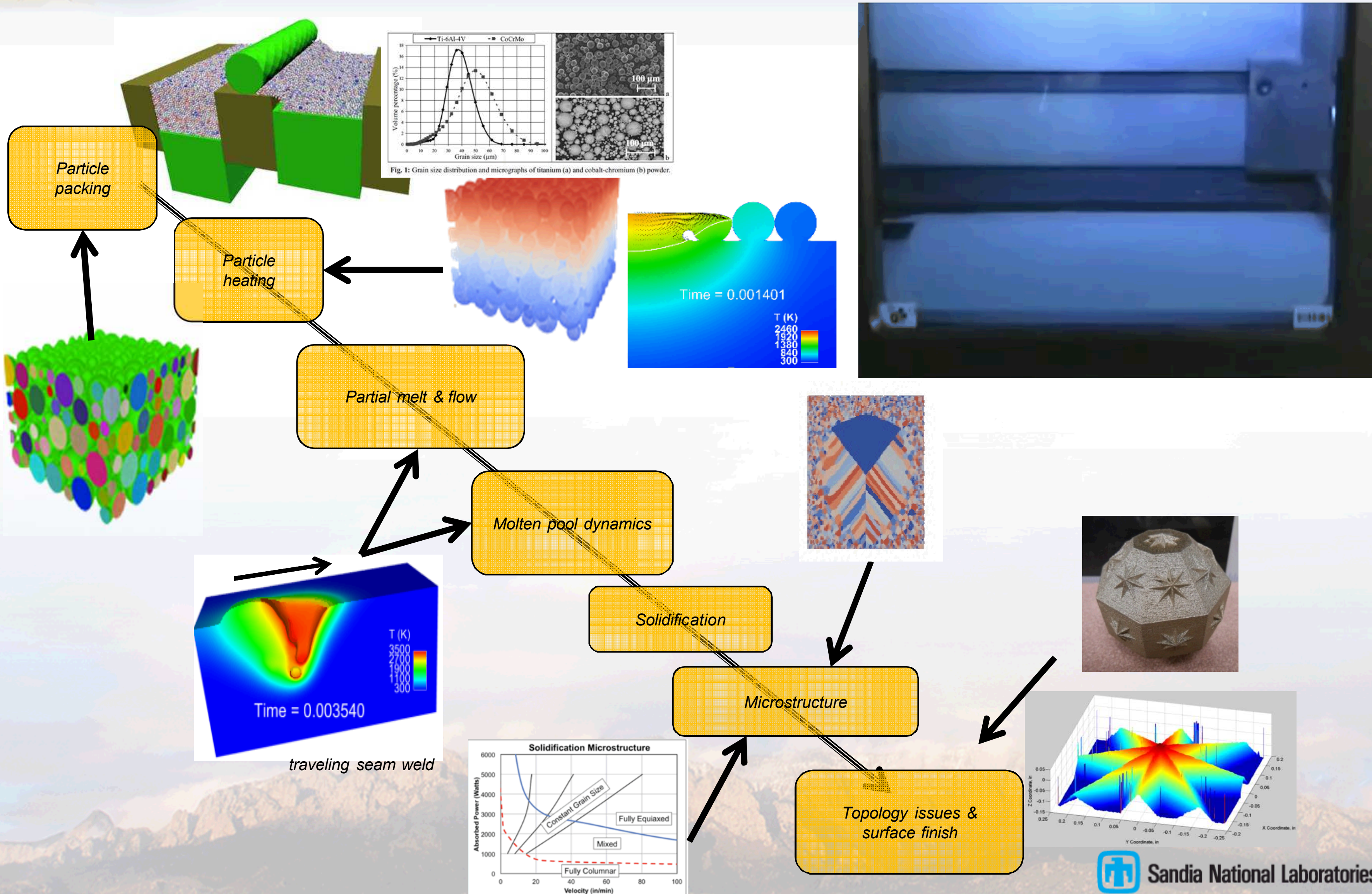




Successfully demonstrated control of melt pool size & temperature to control microstructure and reduce variability

Sandia National Laboratories

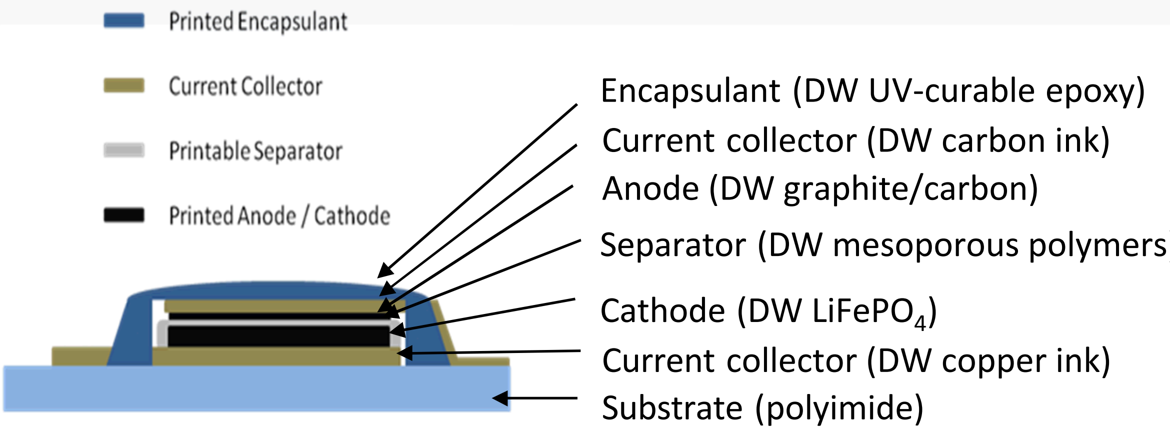
Working to Model Process → Microstructure

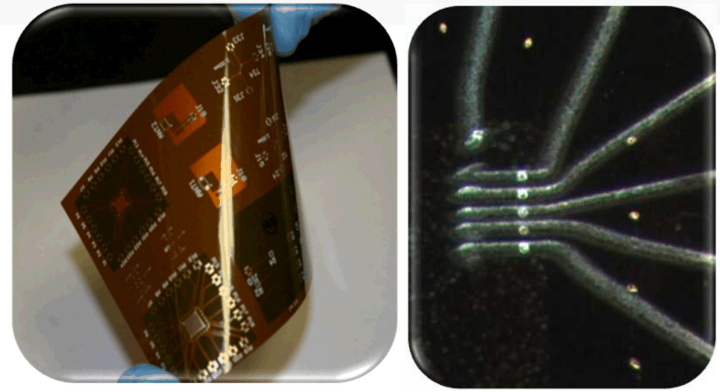


Sandia National Laboratories

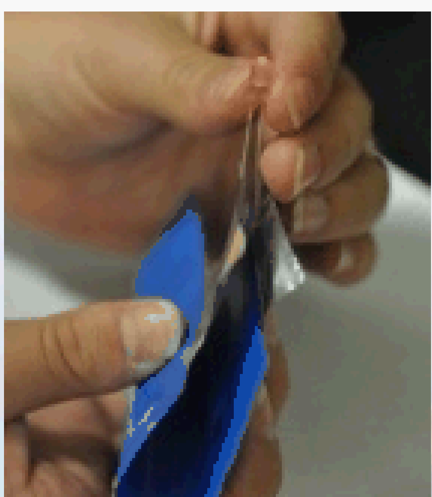
Multi-Material AM

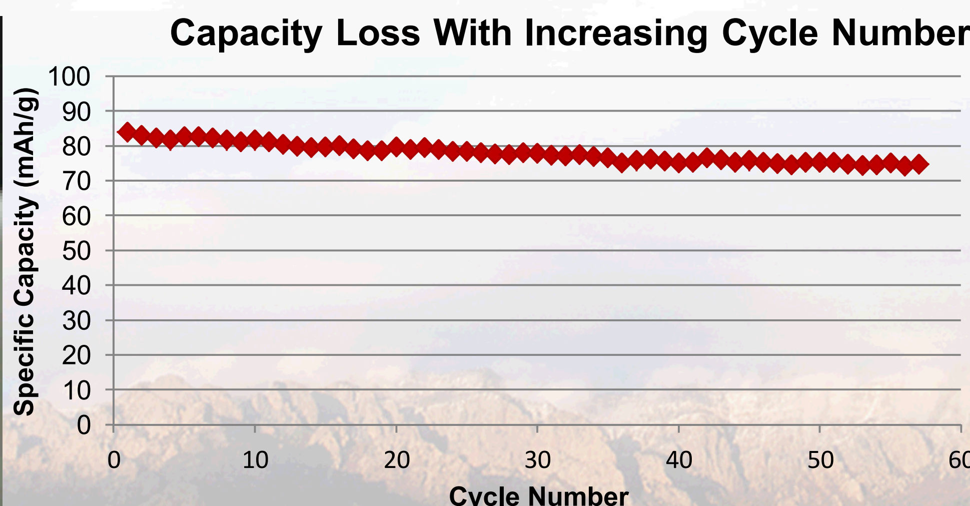
Printed Electronics

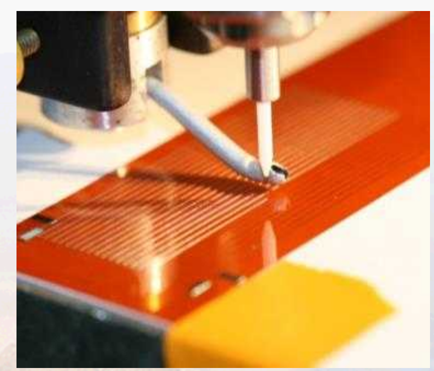




“Flexible Chips” with
Printed Wirebonds







Aerosol jet printing to 10 μm

Sandia National Laboratories

Summary

- Sandia has a Rich History in AM technology development & commercialization
- We are especially interested in Design for AM and Materials Assurance
- We have strong High Performance Computing & Experimental Capabilities
- We also have strong interest/expertise in Multi-Material AM
- We are very interested in working with others to advance AM technology