Additive Manufacturing: Technology and Applications

Natural Gas Infrastructure R&D and Methane Emissions Mitigation Workshop

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MDF
Manufacturing Demonstration Facility

ORNL has an extraordinary set of assets for delivering on national priorities

Science to solutions

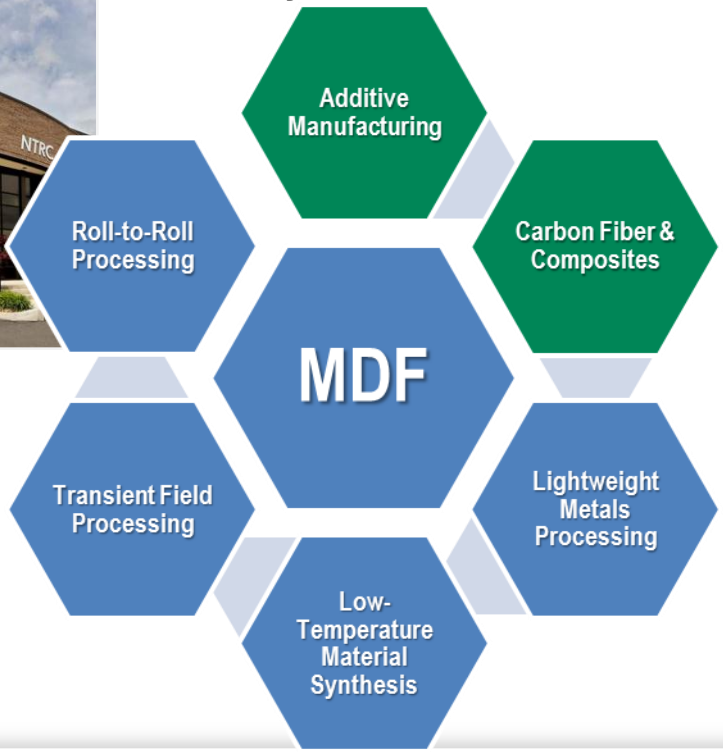
World-leading neutron science capability	World's most powerful scientific computing complex	Nation's largest advanced materials research program	Focused resources for systems biology and environmental sustainability	Nation's largest and most diverse energy R&D portfolio	Unique capabilities in nuclear science and technology

Manufacturing Demonstration Facility

Providing leading edge technology and business solutions for industry

- **Public-Private Partnership**
- **50+ active projects**
- **Addressing technical challenges across complete supply chain**

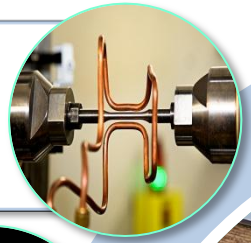
Reduce risk, accelerate commercialization of advanced technologies while reducing lifecycle energy



Leveraging DOE assets at ORNL

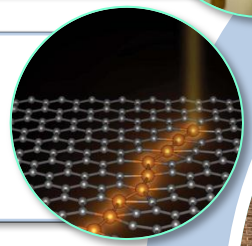
Neutron scattering: SNS and HFIR

- World's most intense pulsed neutron beams
- World's highest flux reactor-based neutron source



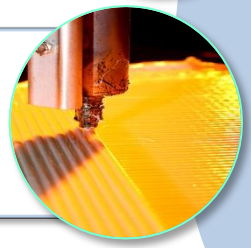
Leadership-class computing: Titan

- Nation's most powerful open science supercomputer



Advanced materials

- DOE lead lab for basic to applied materials R&D
- Technology transfer: Billion dollar impacts

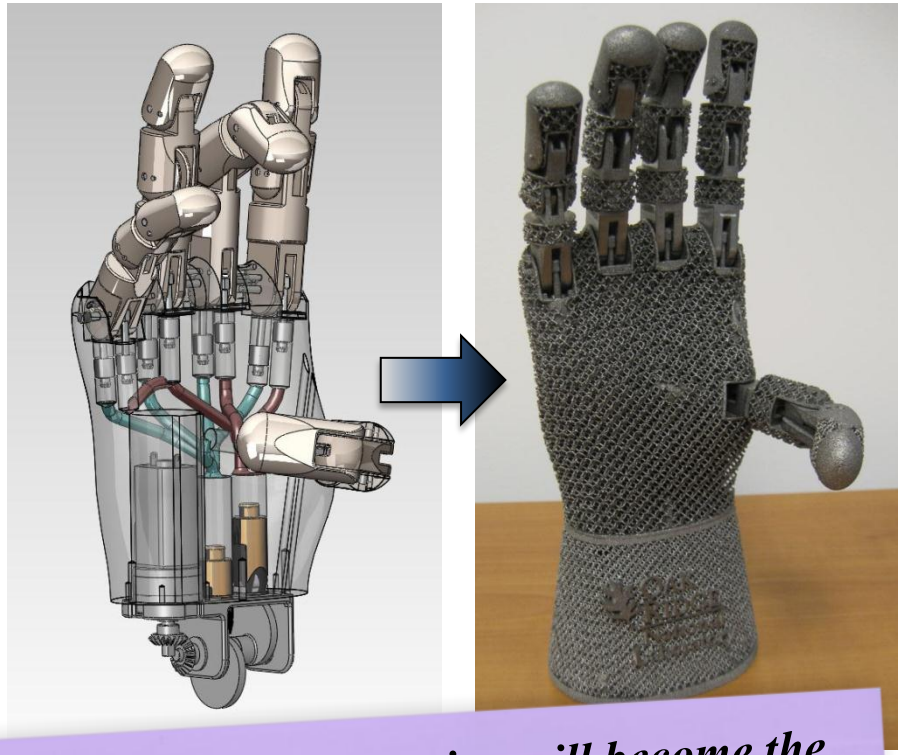


Demonstrated ability to work with and transition technologies to industry

- More than 800 on-going relationships with industry
- Leading DOE Laboratory for R&D 100 Awards (180)
- Mechanisms in place to rapidly implement working agreements allowing R&D to be initiated on industry's timeline
- Success in development and integration of multidisciplinary teams

Additive manufacturing

CAD Model to Physical Part



"Additive Manufacturing will become the most important, most strategic, and most used manufacturing technology ever."
Wohlers 2012

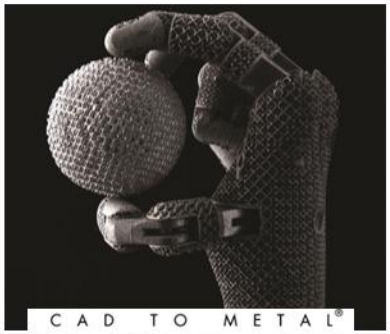
- Increased Complexity
- Topology Optimization
- Less Material Scrap
- Shorter Design Cycle
- Reduced Part Count
- Polymers, Metals, Ceramics, Multi material integration
- Tailored Microstructures and properties

Objectives in additive manufacturing

- **Developing advanced materials, evolving the supply chain**
  - Titanium alloys, Ni superalloys, advanced steels
  - High-strength, carbon-reinforced polymers
- **Implementing advanced controls**
  - In-situ feedback and control for rapid certification and quality control
- **Understanding material properties and geometric accuracy**
- **Developing new design concepts**
- **Exploring next-generation systems to overcome technology barriers for manufacturing**
  - Bigger, Faster, Cheaper
  - Integrating materials, equipment and component suppliers with end users to develop and evolve the supply chain
- **Training next-generation engineers & scientists**

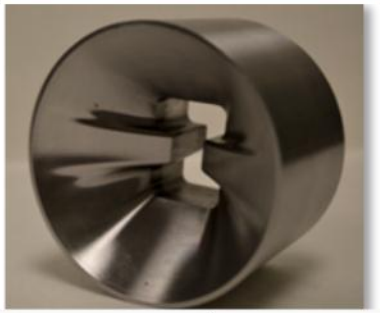
ORNL Additive Manufacturing Capabilities:

Electron Beam Melting



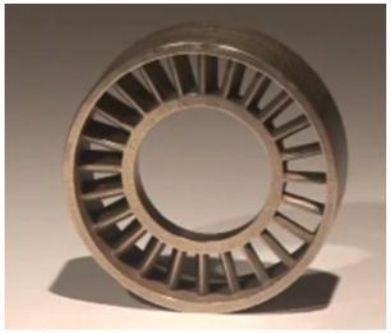
Laser Sintering

Laser Blown Powder Deposition



Ultrasonic Consolidation

Binder Jetting



Fused Deposition Modeling

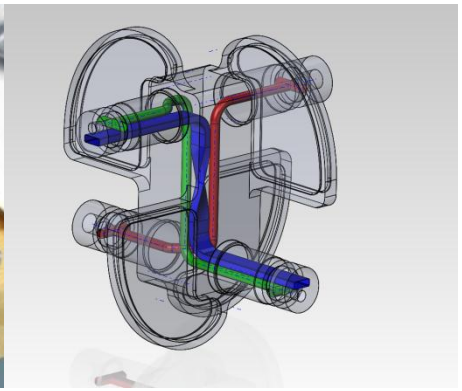
Multi-head Photopolymer

Large-Scale Polymer Deposition

Working with AM supply chain

Additive manufacturing for robotic systems

Robotic arm provided as backdrop in the White House as President Obama announced new two manufacturing innovation institutes.



All components produced by additive manufacturing

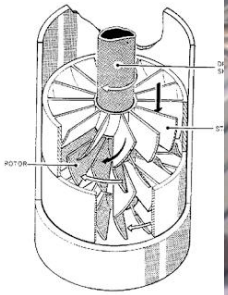
- 25-lbs total weight, 60” long arm
- Neutrally buoyant without floatation
- Fluid passages integrated into structure
- 7 degrees of freedom with 180 degree rotation at each joint
- Custom thermal valves for energy efficiency

Example of AM Stator

ExOne Metal Printing Method:
Cost: $75-$150 each

Traditional Method:
Method: Conventional machining
Cost: $400-$500 each

Specifications:
Customer: Ulterra
Part Name: Stator
Batch Size: 10
Part Size: 3-5 inch



Per ExOne …

S4 abrasion resistance dramatically exceeds wear of conventional 4145 steel

Traditional Method:
Wear after 200-300 hrs

ExOne Method: After 600 hrs
no measureable wear

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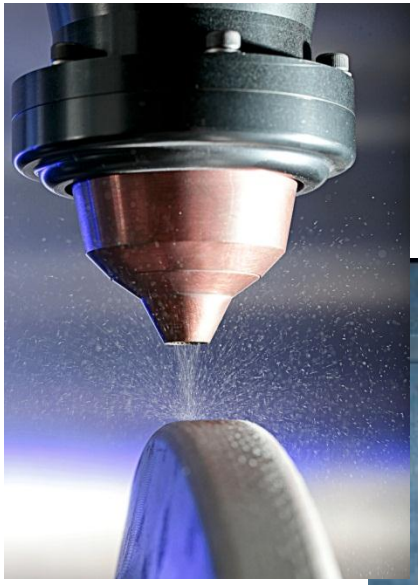
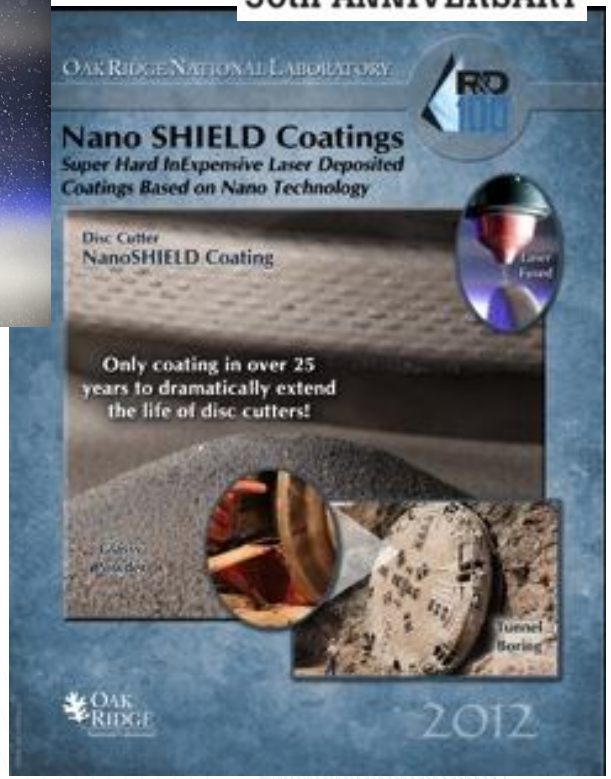
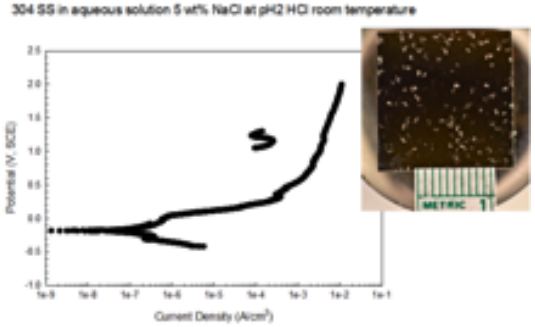
Nano-Composite Wear-Resistant Coatings

- Laser Fused Nanocrystalline Coatings
  - Surface Hardness 800 - 1500 kg/mm^2 (VHN), 2-5 X Harder Than Tool Steels
  - Order of Magnitude Improvement in Wear Compared to Steel Substrates
- Consolidation of Powder Into Bulk Components
  - Fracture Toughness and Strength of WC-Co
  - Half the Price
- New Stainless Compositions

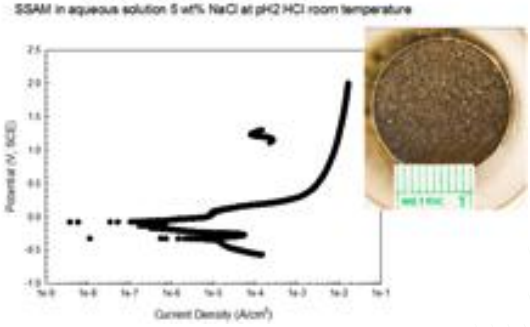




304 SS Presented Significant Pitting. Pits Are 20 to 25 mils in Width and 10 to 12 mils in Depth



SSAM Presented Minor Etching With No Significant 3-D Relief



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CermaCladding Amorphous Coating on Pipe for O&G

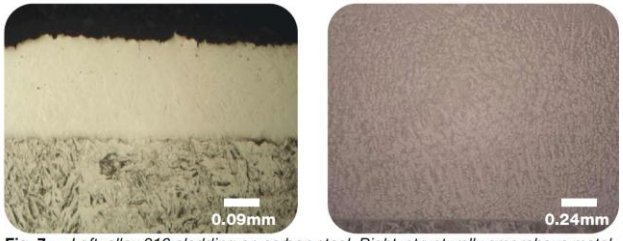
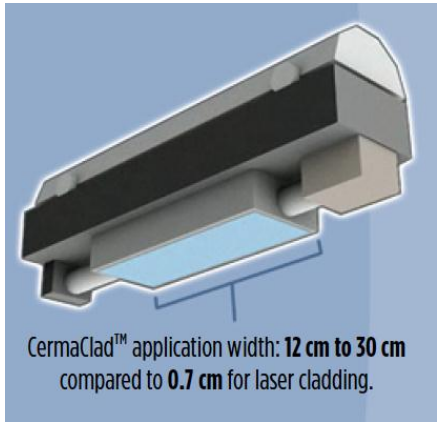


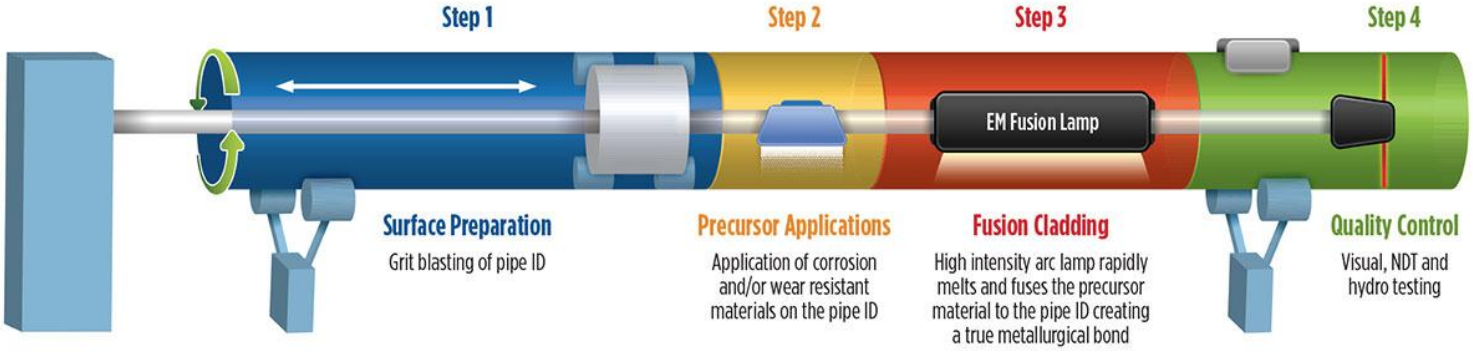
Fig. 7 — *Left, alloy 316 cladding on carbon steel. Right, structurally amorphous metal alloy NC8.*



CermaClad™

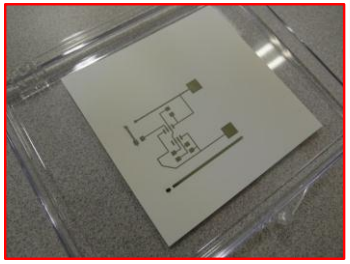
Seamless, Metallurgically Clad CRA Pipes

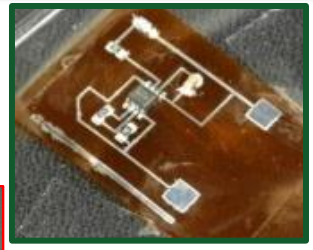
Application to Pipe Interior Surface

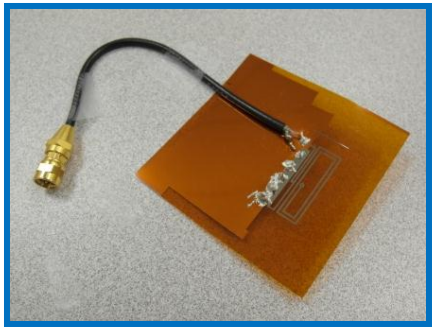


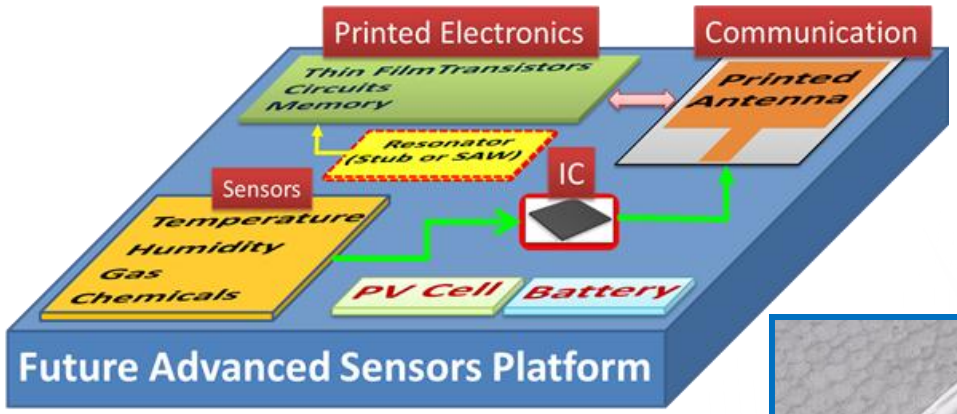
Low-Cost, Multi-Sensor Wireless Platform: Current Focus on SMART Buildings

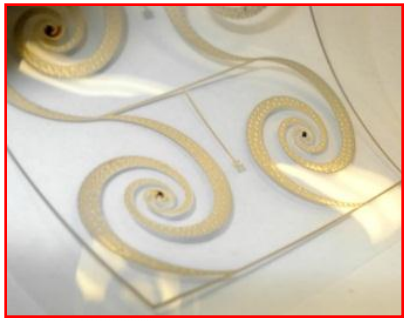
Current wireless sensor Platform: $150-$300/node → **Proposed Advanced Sensors Platform**: $1-$10/node

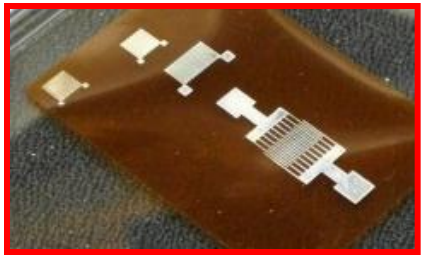












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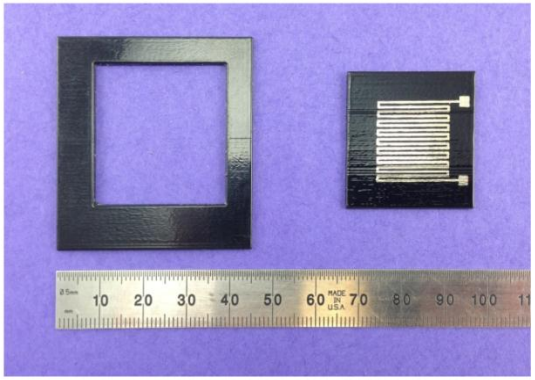
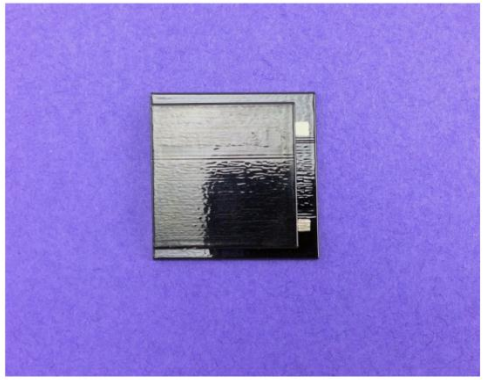
Multi-function Material Systems

Manufacturing Systems

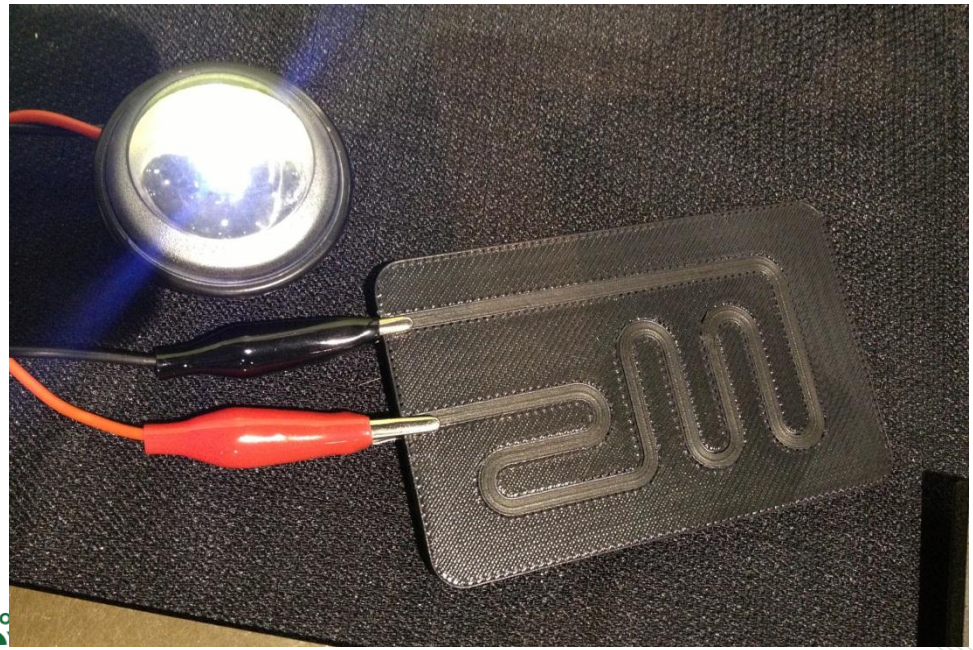
Integrate Functionality into Structure

- Electrical Circuits
- Sensors
- Communication
- Energy Generation
- Energy Storage





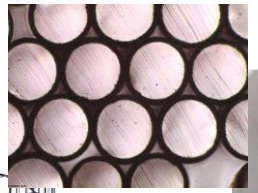
Successfully embedded printed strain gauge within an AM structure

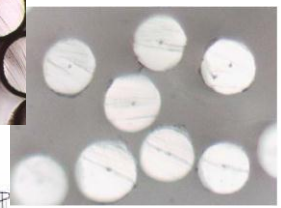


Big Area Additive Manufacturing

BAAMCI
BIG AREA ADDITIVE MANUFACTURING

CINCINNATI®
CINCINNATI INCORPORATED





Co Extruded
Hill's Micro Wire

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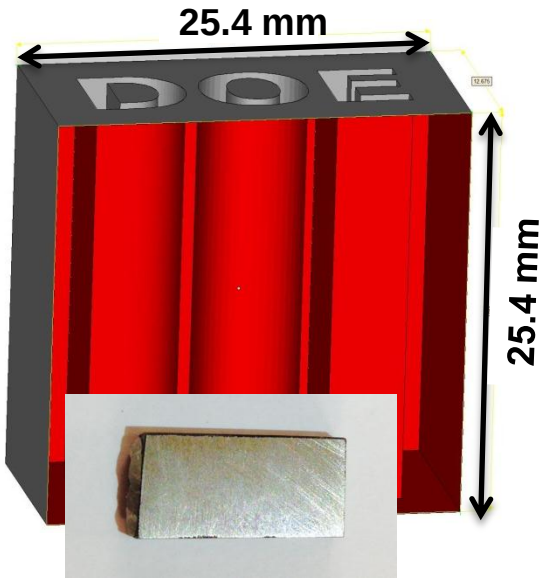
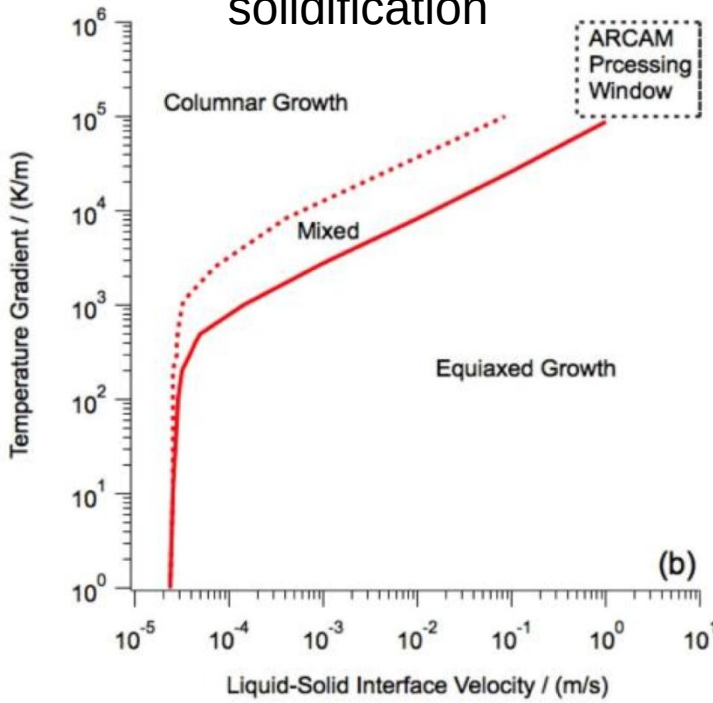
Advar
Manuf

Materials By Design: Ability to Control Local Microstructure in a Component

- Utilized well understood solidification behavior to locally control microstructure, properties
- Can we extend this to full scale components for topology/ property optimization, i.e. can we control fracture path, toughness, fatigue properties locally



Modify Processing Parameters to alter solidification



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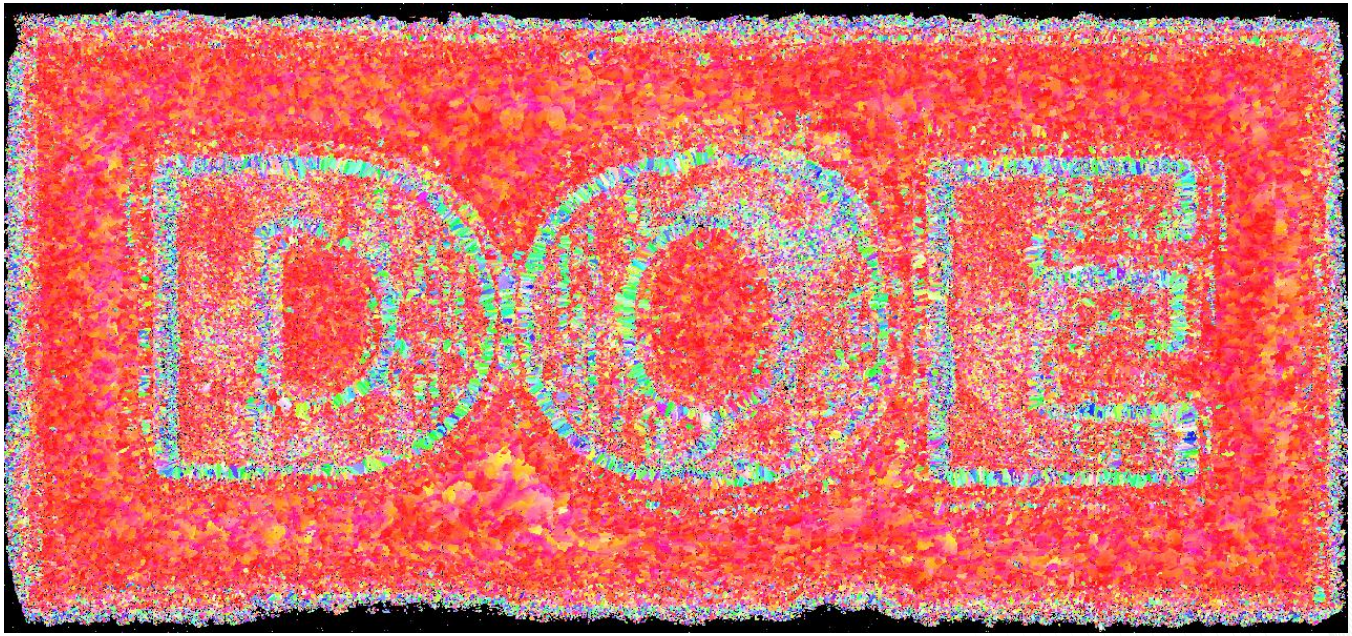

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