ARL and Additive Manufacturing Overview

U.S. National Committee on Theoretical and Applied Mechanics, 2016 (70th) Annual Meeting
***22 April 2016,* The National Academies Building, Washington, DC**

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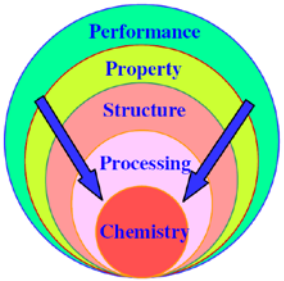
The Nation's Premier Laboratory for Land Forces

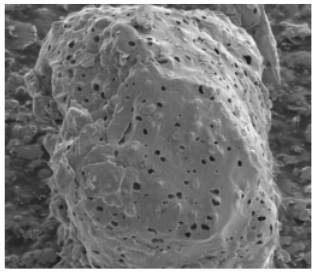
ARL and Additive Manufacturing R&D Overview

M.A. Tschopp

ARL: An Intro to Our Organization

ARL Research Campaigns,
Open Campus





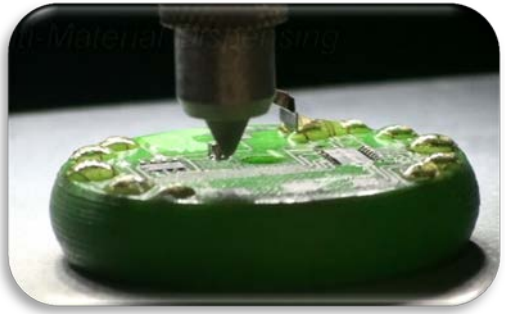
ICME & Metal Powder Feed Stocks

L.J. Holmes

History of AM and
ARL AM Roadmap

Cold Spray Technology

ARL AM R&D
(and other acronyms)



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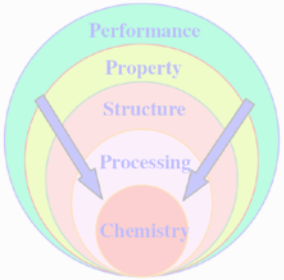

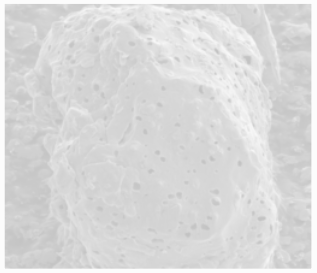

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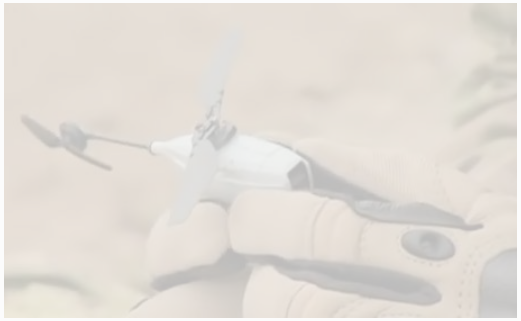

Cold Spray Technology

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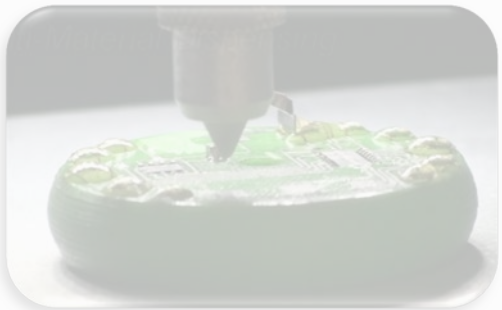


Our Organization: A Functional View

The U.S. Army Research, Development and Engineering Command

RDECOM Forward Element Commands:
- RFEC Americas
- RFEC Atlantic
- RFEC Pacific

Army Research Laboratory

- Extramural Basic Research
- Structural Materials & Components
- Energetics and Propulsion Science
- Sensory/Perceptual Performance
- MANPRINT - Human Systems Integration
- Impact Physics
- Launch & Flight Science

Armament Research, Development and Engineering Center

- Munitions Systems & Technologies
- Integrated Weapon Systems
- Energetics & Warheads
- Guidance, Navigation & Control
- Fuzing System
- Remote Weapon Stations/Weapon Pods
- Fire Control Systems
- Grenades/Demolitions
- Non-Lethal Weapons & Target Effects
- Ammunition Logistics

Aviation and Missile Research, Development and Engineering Center

- Airframe Structures
- Rotors & Rotor Systems
- Sensors and Seekers
- Guidance, Navigation, and Control
- Propulsion
- Warhead & Fuze Integration
- Fire Control

Communications-Electronics Research, Development and Engineering Center

- Night Vision Technology
- EO/IR & Multi /Hyperspectral Sensors
- Antennas Technologies
- C-IED & Counter Mine Technology
- Cyber Security
- Networks and Communications
- Electronic Warfare
- Mobile Power / Advanced Battery Tech.
- Surveillance Systems

Edgewood Chemical Biological Center

- Chemistry and Biological Sciences
- CB Agent Handling and Surety
- CBRNE Materiel Acquisition
- CBRNE Analysis and Testing
- CBRNE Munitions and Field Operations
- Science and Technology for Emerging Threats

Natick Soldier Research, Development and Engineering Center

- Textiles and Uniforms
- Shelters
- Joint Combat Feeding
- Cognition
- Soldier Performance/ Assessment
- Body Armor

Tank Automotive Research, Development and Engineering Center

- Advanced ground system technologies.
- Survivability
  - Autonomy
  - Vehicle Electronic Architecture
  - Power & Mobility
  - Fuels & Lubricants
- Ground system technology integration.
- Virtual and physical ground system analysis.

Ensuring the Decisive Edge for the Joint Warfighter and Nation

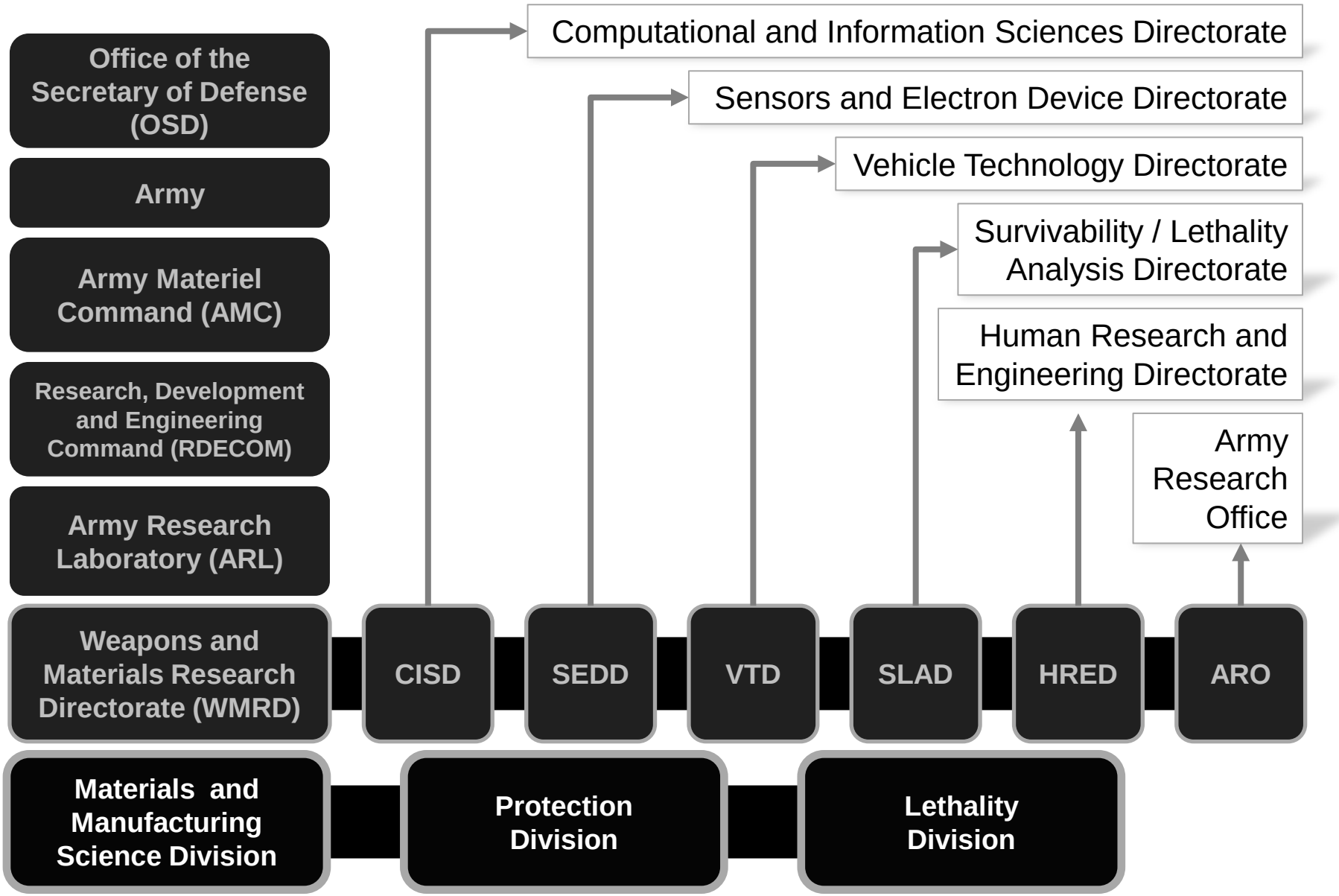
What does the Army Research Laboratory do?

U.S.ARMY
ARMY STRONG.

What does the Army Research Laboratory do?

U.S.ARMY
ARMY STRONG.

ARL Directorates / Divisions



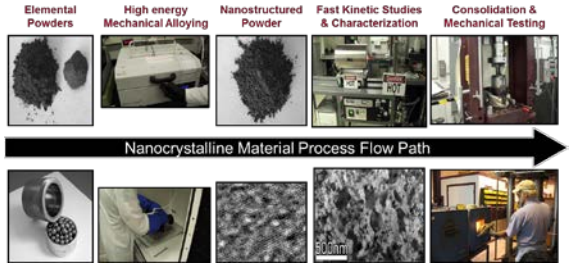
ARL Directorates / Divisions

- Office of the Secretary of Defense (OSD)
- Army
- Army Materiel Command (AMC)
- Research, Development and Engineering Command (RDECOM)
- Army Research Laboratory (ARL)
- Weapons and Materials Research Directorate (WMRD)
- **Materials and Manufacturing Science Division**

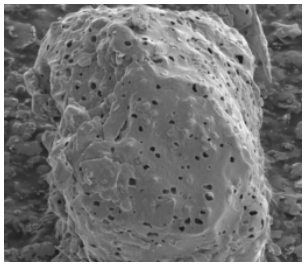
Materials and Manufacturing Science Division Capabilities

- Manufacturing science and pilot-scale processing
- Advanced military coatings formulation, application and characterization
- Composite and filled polymer processing and fabrication
- Environmental degradation of materials
- Ion implantation facility and plasma physics laboratory
- Mechanical characterization/ High strain rate laboratory
- Organic and inorganic nanomaterials synthesis and processing
- Electron microscopy and surface characterization
- 7 acres under one roof, ~280,000 sq. ft. laboratory facility under one roof, 140 laboratories

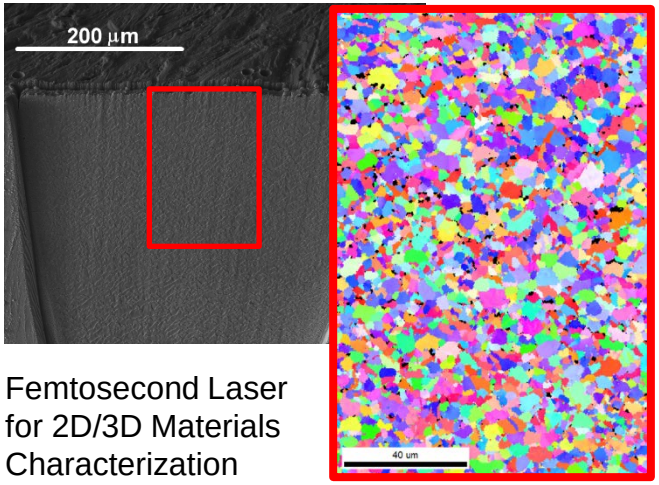
Utilizing state-of-the-art capabilities/infrastructure and alloy-processing-structure-property relationships to innovate and design the next-generation of metal systems



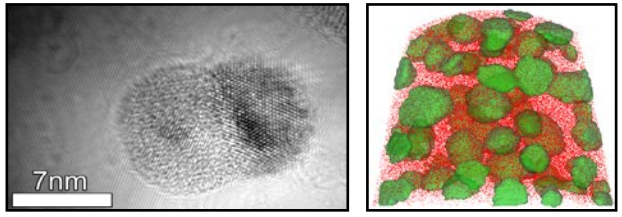
Processing & Synthesis of Ultrafine-Grained / Nanocrystalline Alloys



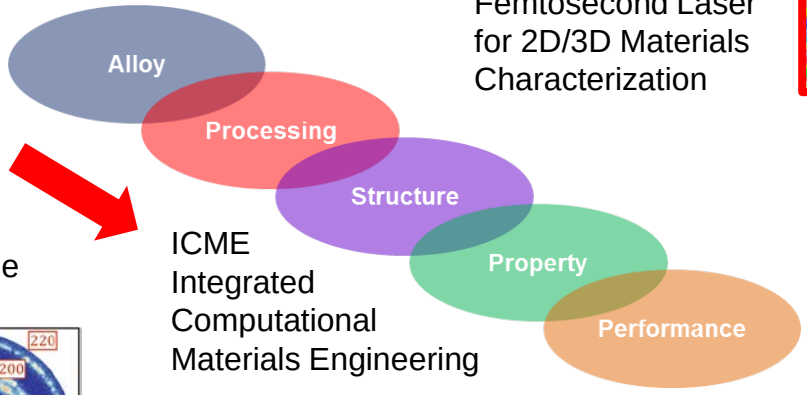
Novel Metal Powder Feedstocks for Additive Manufacturing



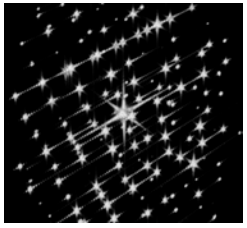
Femtosecond Laser for 2D/3D Materials Characterization

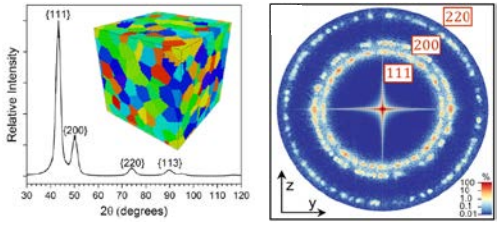


Microstructure Characterization at the Nanoscale



ICME Integrated Computational Materials Engineering





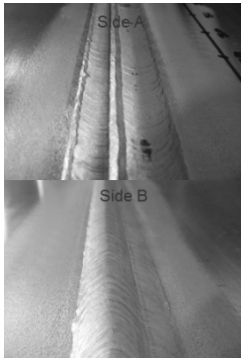
Simulations to Complement/Guide Experiments

Lightweighting

Protection & Lethality

Aluminum, Magnesium, Steel, Titanium, Copper, and Beyond…

Energy Coupled with Matter

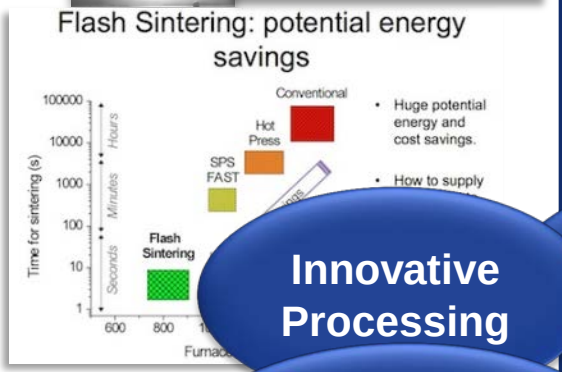


Material Property and Performance Assessment

WMRD - Materials Manufacturing Technology Branch

Coupling design, novel materials, and advanced manufacturing

Photoemission accompanied by rapid densification of B6O

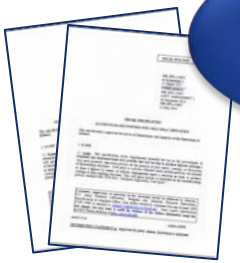


Innovative Processing

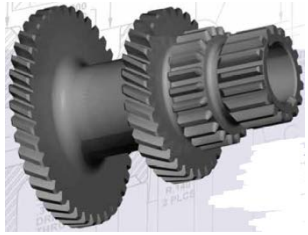
Agile Manufacturing

Rapid Transition

Near Net Shape Processing



MIL Specs & Standards



Topology Optimization

Manufacturing using Indigenous Materials

Mission:
Develop innovative processing & agile manufacturing technologies for rapid delivery of technology and materials to enable Warfighter Capabilities in a persistent conflict environment.

Capabilities:

- **Manufacturing Science**
- **Material System Integration**
- **Material Selection and Trade Studies**
- **Manufacturing Readiness Assessments**
- **Warfighter Protection**
- **Non-destructive Evaluation (NDE)**
- **Military Specifications**
- **Additive Manufacturing**

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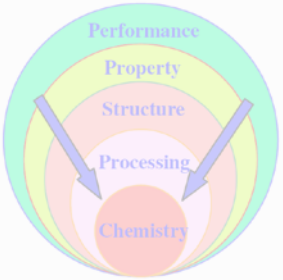

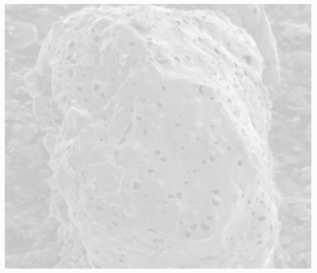

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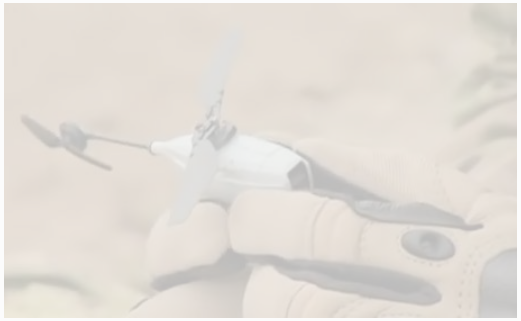

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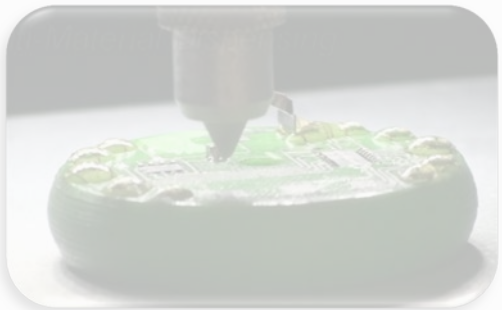
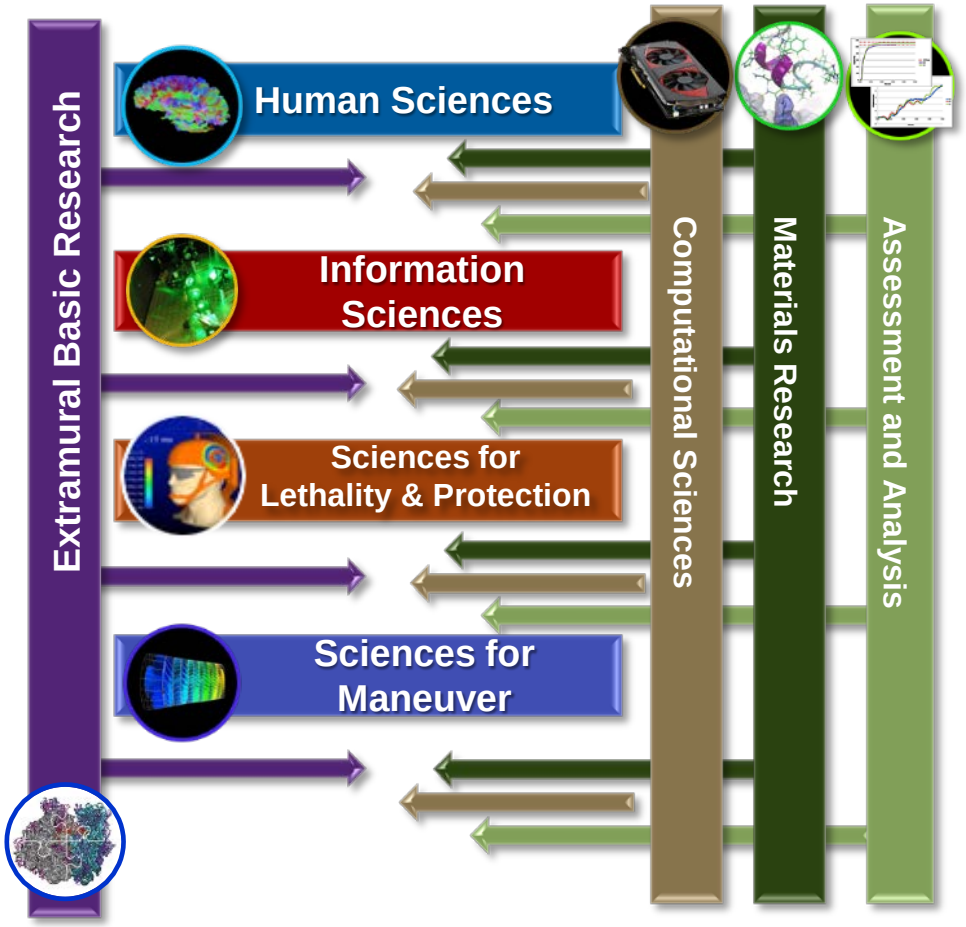


Changing the Paradigm in ARL

S&T Campaign Plans



Open Campus Business Model

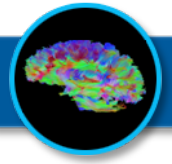
"We will need new technology over the next 10 years to make a leaner and more capable Army."

GEN Raymond T. Odierno
38th Chief of Staff, Army

ARL Campaign Publications:
http://www.arl.army.mil/publications

ARL S&T Campaigns

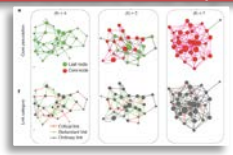
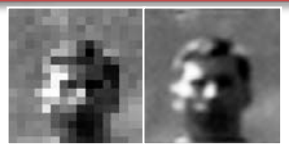
Extramural Basic Research
Steering and oversight of the systematic study to increase fundamental knowledge and understanding in physical, engineering, environmental, and life sciences related to long-term national security needs.

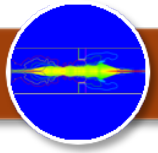


Human Sciences
Fundamental understanding of Warfighter performance enhancement, training aids, and man-machine integration.

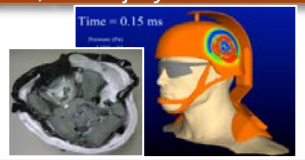


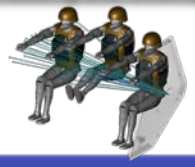
Information Sciences
Fundamental understanding of information generation, collection, assurance, distribution, and exploitation.

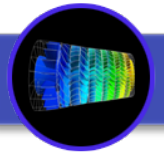



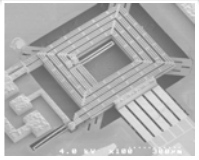
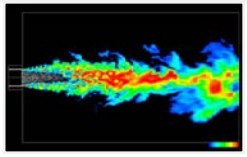
Sciences for Lethality & Protection
Fundamental understanding of emerging technologies that support weapon systems, protection systems, and injury mechanisms affecting the Warfighter.

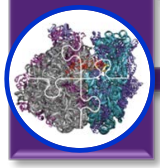







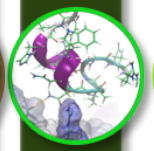
Sciences for Maneuver
Fundamental understanding of the design, integration, control, and exploitation of highly adaptive platforms in complex environments.

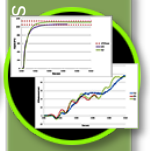


Computational Sciences
Fundamental understanding of computer hardware, high efficiency algorithms, and novel mathematical methods.

Materials Research
Fundamental understanding of structural, electronic, photonic, and energy materials & devices.



Assessment and Analysis
Quantitatively Assess the development and application of analytical tools and methodologies to quantitatively assess the military utility of Army, DoD, and foreign combat systems.



ARL Campaign Publications: http://www.arl.army.mil/publications

Open Campus: Building the Ecosystem

- **Army Leadership Support**
- **Collaborative Mechanisms**
  - Cooperative Research and Development Agreements (CRADAs)
  - Patent License Agreements
  - Educational Partnerships
  - Partnership Intermediary Agreements
- **Opportunities Advertised**
  http://www.arl.army.mil/opencampus/
- **Openly Sharing Technical Strategies**
- **Infrastructure**
  - Enhanced Use Lease
  - Collaborative Network and Data Sharing
  - Layered Security
- **People**
  - Flexible Work Places and Schedules
  - Sabbatical Leave
  - Entrepreneurial Separation
- **Open Campus Open House**

> 200 People Into and Out of Laboratory Under Open Campus Pilot So Far
> 60 CRADAs, 28 Academic and 32 Industry

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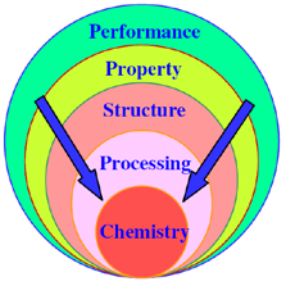

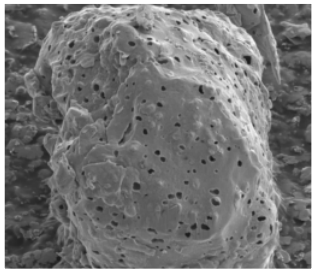

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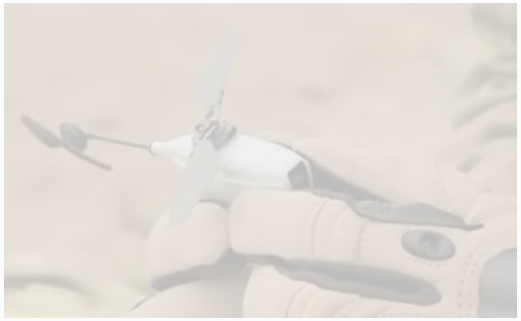

Cold Spray Technology

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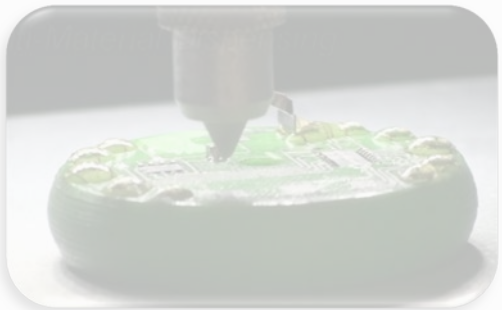


What is ICME for Additive Manufacturing?

The development (and qualification/certification) cycle for materials in additive manufacturing must be reduced significantly!

"We're going to have to innovate quickly and get products to market faster, and the materials genome is a way to do that."
–Cyrus Wadia

"TiAl required 30 years to complete development for the GEnx engine."

"GE's Rene 41 superalloy is named because a usable alloy was discovered on the 41st iteration."

RE Schafrik, Keynote lecture, Superalloys 2008 Proceedings.

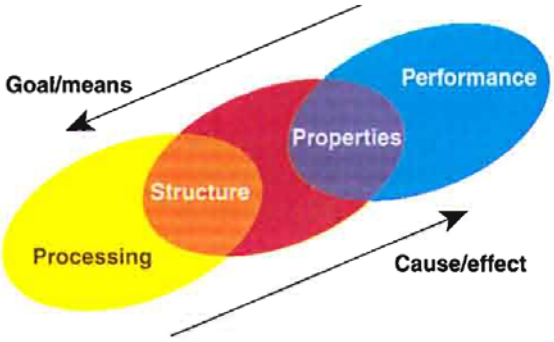
The key to ICME and Materials by Design is not only the ability to understand these relationships, but also to quantify these relationships.

Chemistry – Processing – Structure – Property – Performance

MGI – The Drive for Data!
How do quantify the AM process?

Metamodeling
Design Optimization
SA and UQ

Olson, Science, 2000



Big four. Four-element paradigm of modern materials science and engineering.

Process
Modeling and
Simulation

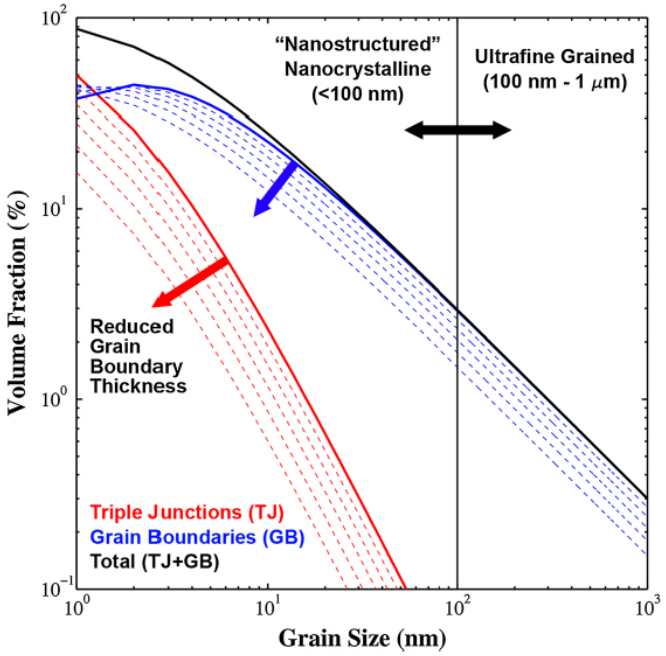
Topology
Optimization

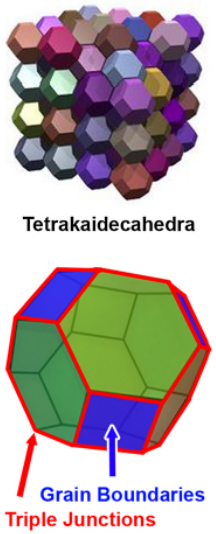
Data Mining

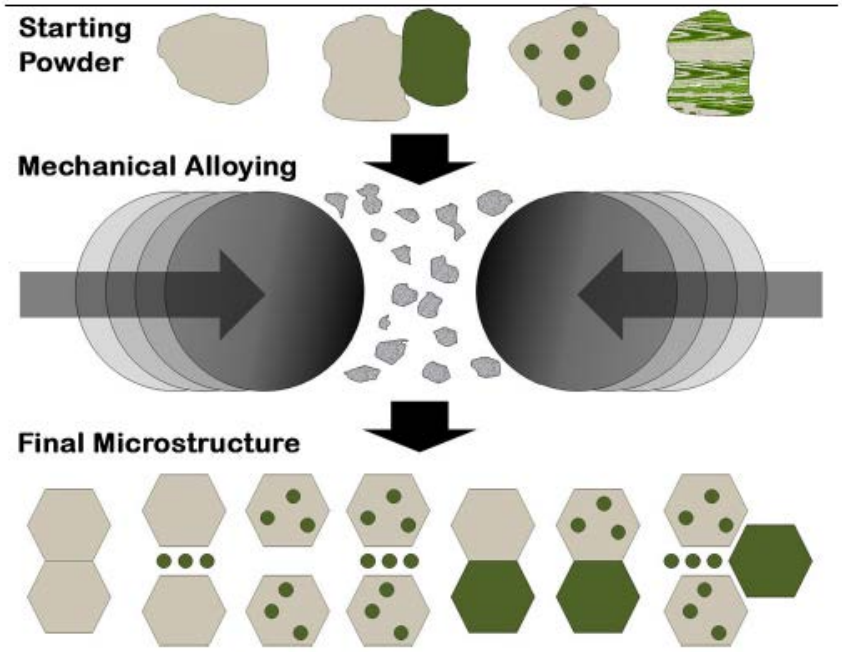
Thermodynamic / Non-equilibrium

Lower Scale Modeling – Mesoscale and Below

The quest for bulk nanocrystalline parts! (for AM?)







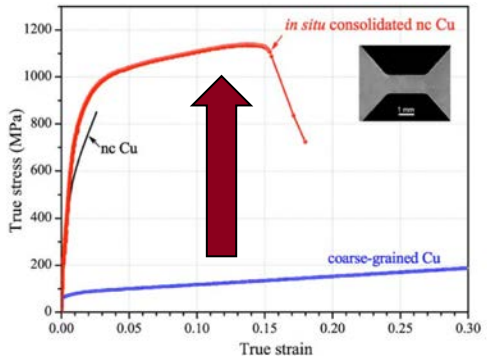
JOM, Vol. 66, No. 6, 2014
DOI: 10.1007/s11837-014-0978-z

"Bulk" Nanocrystalline Metals: Review of the Current State of the Art and Future Opportunities for Copper and Copper Alloys

M.A. TSCHOPP,[1,2] K.A. MURDOCH,[1] L.J. KECSKES,[1] and K.A. DARLING[1]

ResearchGate
M.A. Tschopp
LANL talk, 2014

The quest for bulk thermally stable nanocrystalline parts! (for AM?)



Nanocrystalline Cu-Ta

2-3 times stronger

		Cu-1Ta 700 (168 nm)	Cu-10Ta 900 (213 nm)	Cu-10Ta 700 (70 nm)	NC Pure Cu (70 – 250 nm)	NC Ta (44 – 250 nm)
HV		2.12	2.12	3.75	1.35-1.0	4.1-2.5
HV/3		0.7	0.7	1.23	0.45-0.35	1.36-0.83
HV/6		0.35	0.35	0.62	0.23-0.18	0.68-0.42
SPT	σ_{YS}	0.43	0.45	0.69		
QS	σ_{YS}	0.7	0.66	1.1	0.45-0.35	1.3-0.9
	$\sigma_{0.1}$	0.8	0.8	1.3		1.6-0.95
DY	$\sigma_{0.1}$	1.0	1.0	1.5	0.88-0.55	2.0-1.2

- **Tech Breakthrough – scalable HT stable nanocrystalline metals**
  - Utilized advanced thermodynamic concepts to control and stabilize grain size
  - Computational assisted prediction of alloy composition and multi-modal structures
  - 5-10X key properties (strength and ductility) through far from equilibrium processing
  - **Successful development** of powder metallurgy process for bulk nanocrystalline parts

The quest for bulk thermally stable nanocrystalline parts! (for AM?)

Nanocrystalline Cu-Ta

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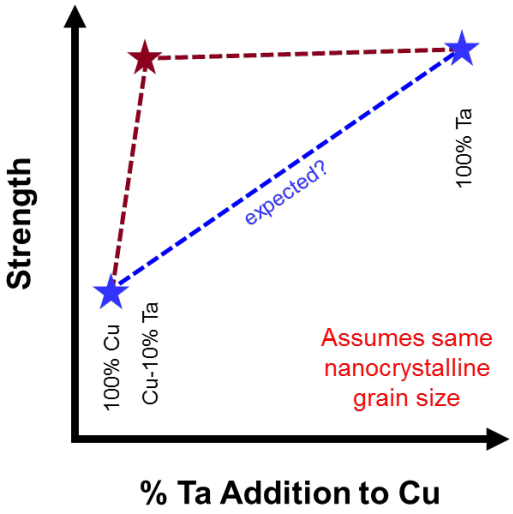

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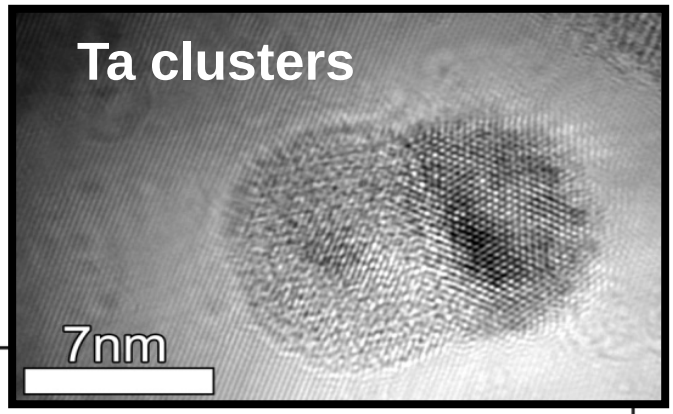
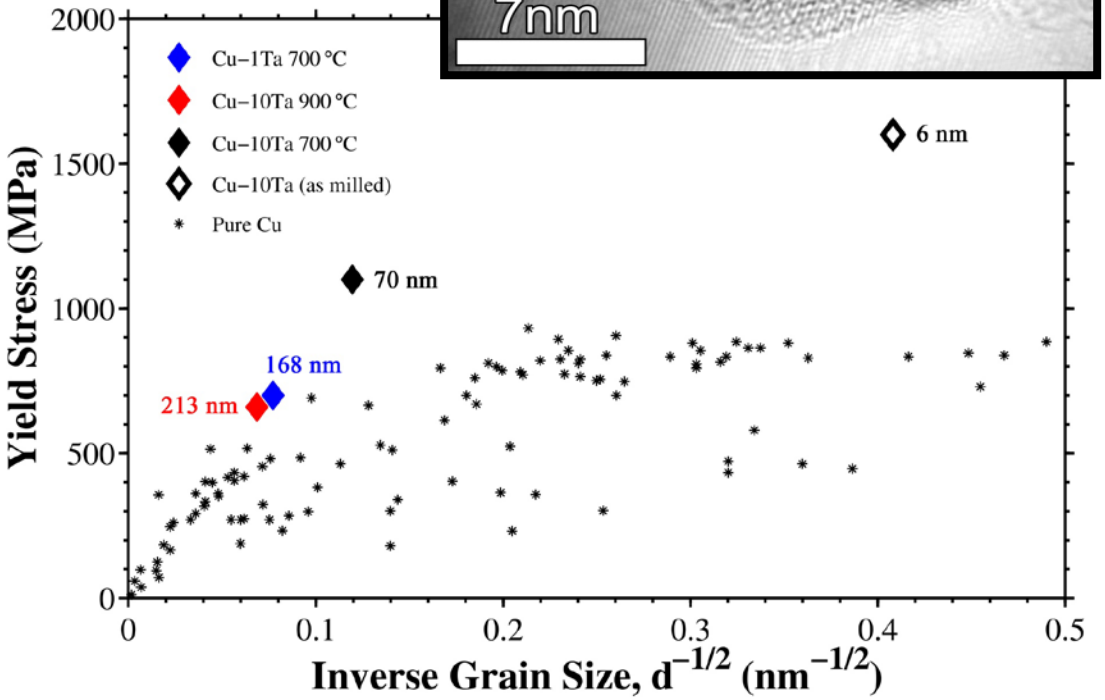
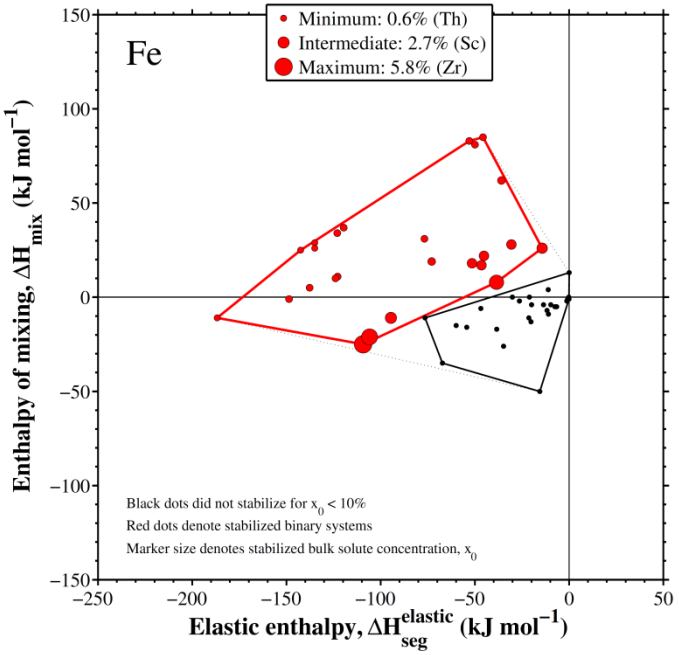
Metal Feed Stocks for Additive Manufacturing

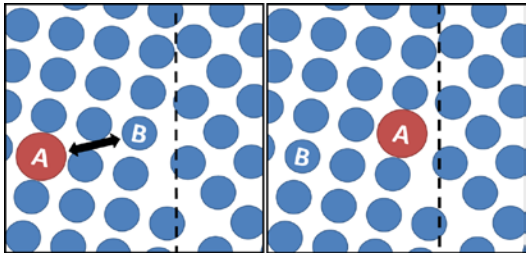
Nanoscale precipitates for thermal stability and strength







Thermodynamic Modeling of Stabilizing Solutes

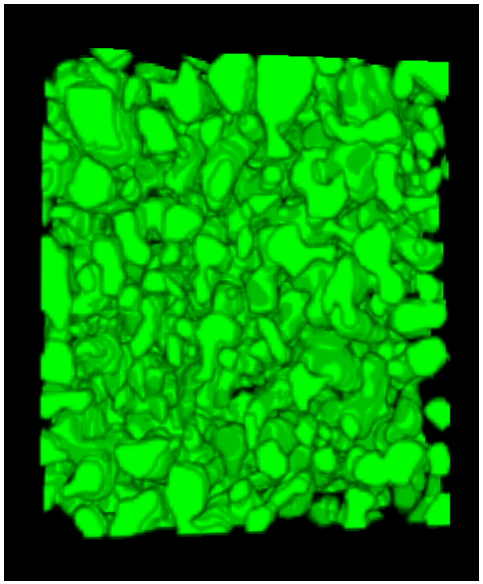


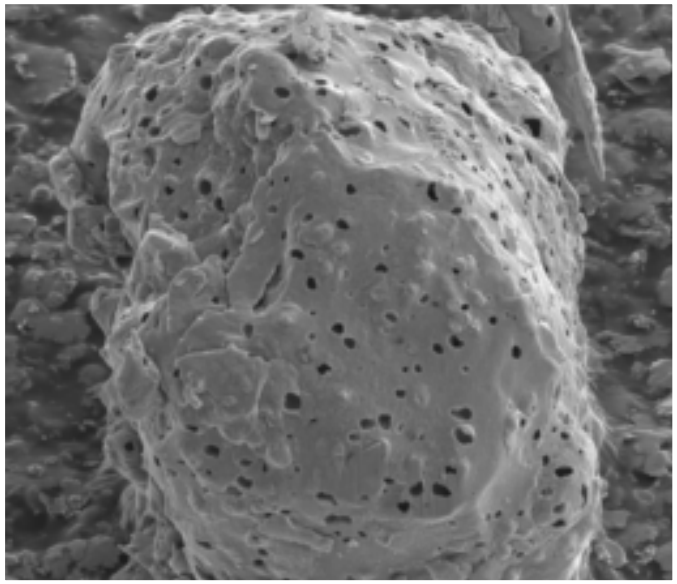
Do we lose the nanocrystalline structure and/or precipitate structure?
Is the thermal stability high enough for AM processes? Cold spray?

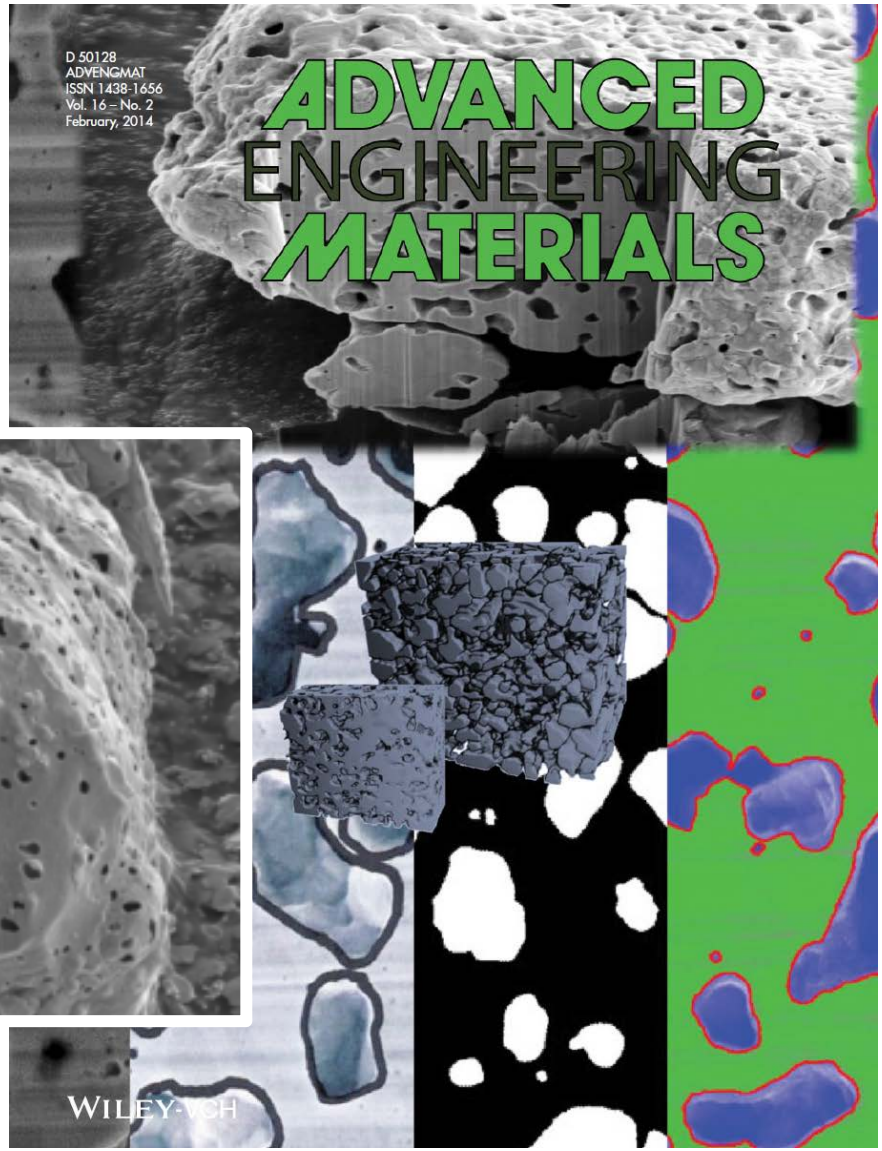
Engineering porosity into AM

Atwater, Darling, Tschopp, Adv. Engr. Mater. (2014)

- Cu powder
- ~70% porosity
- Interconnected
- ~1 μm pore
- 1-3 μm wall
- Solid state foaming process

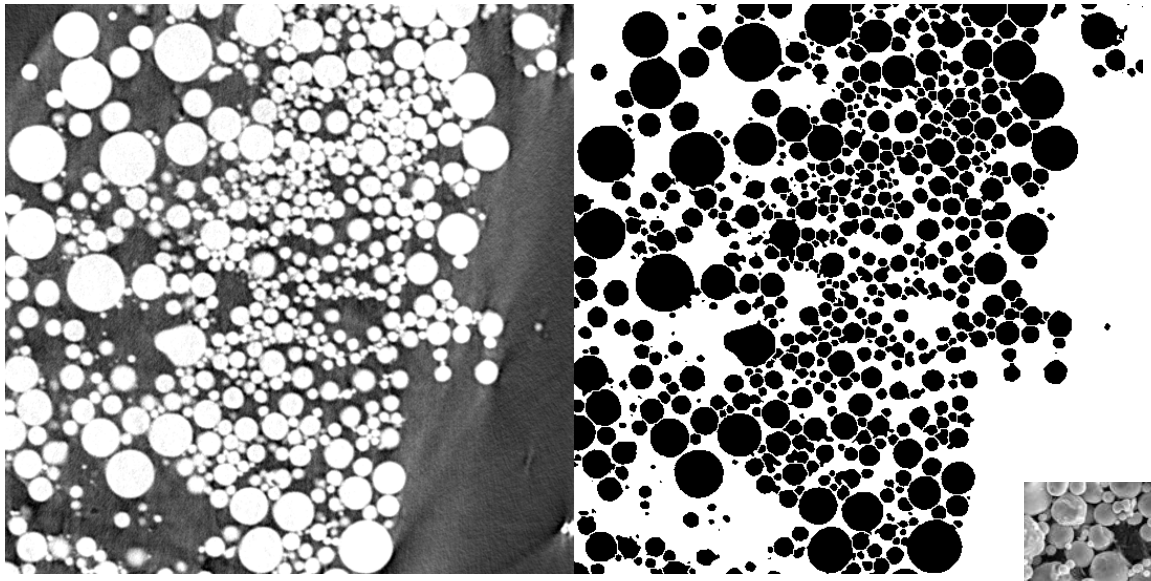






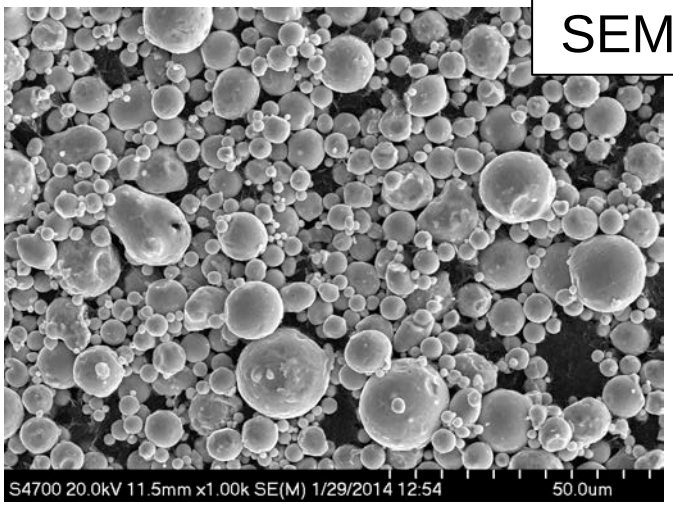
Avenue for foamed metal additive parts?

How do we characterize powders (metrology)?



X-Ray Computed Tomography

POC: Jennifer Sietens, ARL

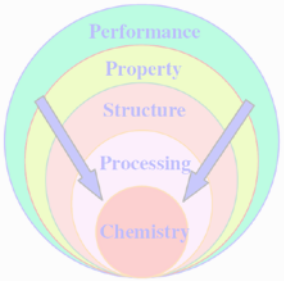


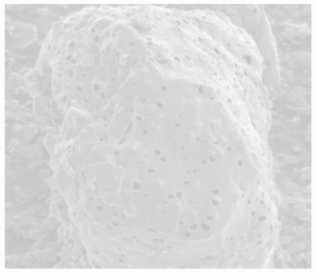
ARL and Additive Manufacturing R&D Overview

M.A. Tschopp

ARL: An Intro to Our Organization

ARL Research Campaigns, Open Campus





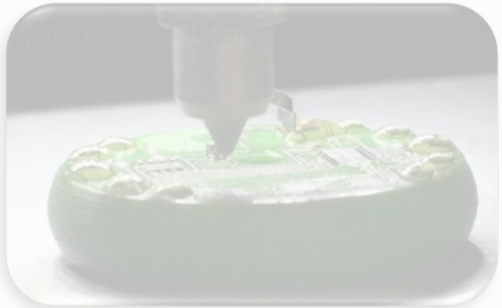
ICME & Metal Powder Feed Stocks

L.J. Holmes

History of AM and ARL AM Roadmap

Cold Spray Technology

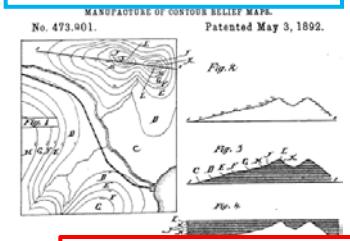
ARL AM R&D (and other acronyms)



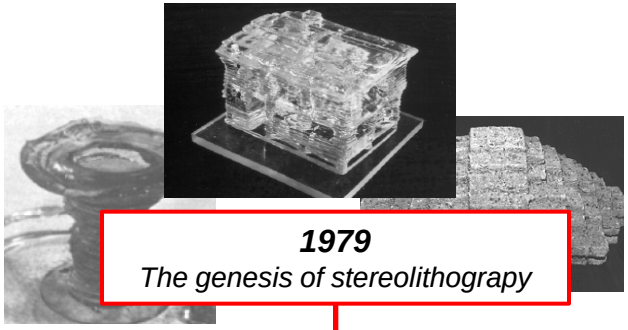
History of Additive Manufacturing

*It is not widely known, but three dimensional printing has been around for almost **150 years…***

3D Maps



1890
Topographic Map



1979
The genesis of stereolithograpy

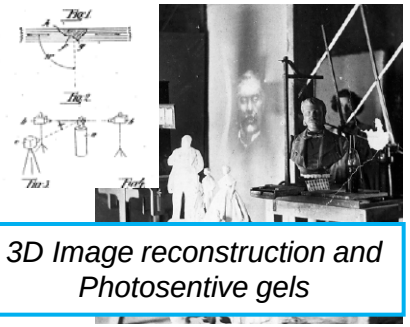
1988
Fused Deposition Modeling enters the market

1989
Metals Printing become real

1998
Multi-material inkjet printing

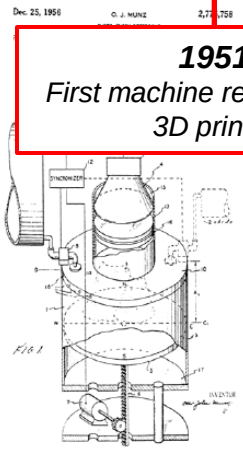
1850 ***2016***

1860
Photosculpturing



3D Image reconstruction and Photosentive gels

1951
First machine resembling a 3D printer



1986
3D Systems founded

1987
Selective Laser Sintering is introduced

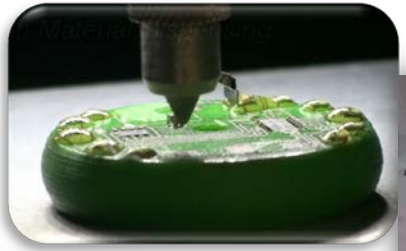
[1] Bourell et al., 2009,
[2] P.J. Ba´rtolo (ed.), 2011, *Stereolithography: Materials, Processes and Applications*

The BIG Army Vision

- **Expeditionary**
- Adaptive to location - jungle, mountain, desert, etc.
- Reduce the logistical tail
- Adaptable, configurable
- Real-time, on-time manufacturing
- Point of use; In-field
- **Organic capability**
- Realize lightweightening
- Complex manufacturing
- **Man-machine interface**
- Unmanned vehicles
- Robots
- **Networks**

AM is Adaptive Manufacturing!

Planning for the Future Army



FAR TERM

Capability

- Printable, Affordable, Attritable Autonomous Systems
- Threat Responsive Protection with Lethality Overmatch
- Fully Networked Systems

Tech Gaps

- Computational Assisted Qual/Cert for End Item
- Multi-Functional Printed Primary Structures
- Indigenous Materials Sources for Reduced Logistics Burden
- Fully Integrated and Automated Materials, Manufacturing, and Design Optimization
- $, 100,000's

MID TERM

Capability

- Affordable Structural Components
- Micro Air and Ground Systems – some assembly required
- Threat Responsive Lethality Overmatch

Tech Gaps

- Structural Materials and Processing
- Computational Assisted Qual/Cert for subsystem components
- Net Shape
- Multi-Material AM
- Pick-and-Place (e.g., processors, motors, power sources)
- $$, 1000's

NEAR TERM

Capability

- Affordable Repairs and Spares
- Secondary Structures
  - ❖Framework: e.g., μ-UAV

Tech Gaps

- Digital Design and Manufacturing
- Deployable AM
- Near Net Shape, - with minimal finishing and post-processing
- AM Specific Materials and Designs
- $$$$, 100's

AM Research Road Map

For references, contact POC Larry R. Holmes, Jr. larry.r.holmes.civ@mail.mil

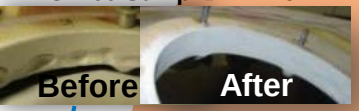
Material and Technology Certification and Qualification

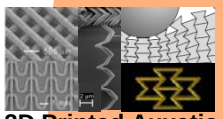
Materials Development

Technology Development

Mtls &Tech Integration

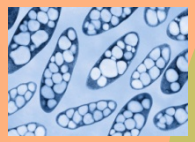
Sikorsky, ARL, AMCOM and NAVAIR qualify cold spray for UH-60 Sump ➔ TRL 9





3D Printed Auxetic Structures for acoustic energy manipulation

ARL Patent Awarded for E-field particle alignment in 3D printed polymer structures



Multi-Material & Self Healing Structures

Ballistic Surrogates soft and rigid materials

Print In-Field and on demand

Microfluidics

Next-Gen In-Progress

Prosthetics, Implants and Surrogates

Generation After Next

Structural, Electronic, Network and Systems Engineering

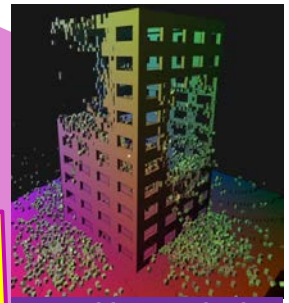
Print-to-Fit, printed armor

3D Electronics and Antennas

Air, Ground and Aquatic Autonomous Systems

Structural Health Monitoring through integrated sensing

Generation After Next After Next….



• Voxel-by-Voxel print any material in free space with seamless Integration

• Manufacturing Systems that manufacture manufacturing systems

Large-Scale "print and drive"

2000- 2016 2030 2045

ARL and Additive Manufacturing R&D Overview

M.A. Tschopp

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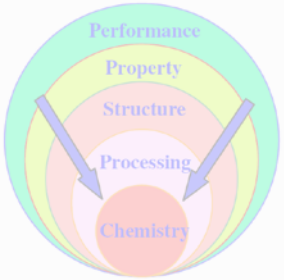
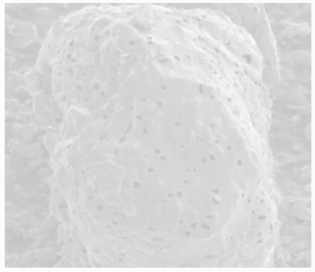
Open Campus

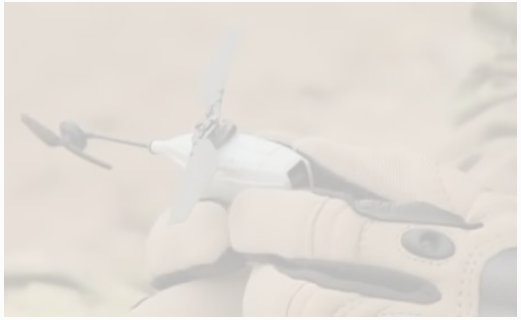




ICME & Metal Powder Feed Stocks

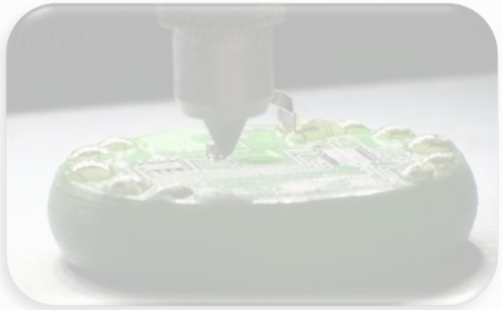
L.J. Holmes

History of AM and
ARL AM Roadmap



Cold Spray Technology

ARL AM R&D
(and other acronyms)



ARL Cold Spray: From Concept to Transition

Industry

AF RIF

DMS&T & Army Mantech

AMRDEC

NAVAIR

AFRL

TIPS

DLA

TMR

SBIR

ARL CII

ONR

2014

TRL 9

TRL 8

TRL 7

TRL 6

TRL 5

TRL 4

TRL 3

TRL 2

TRL 1

2005

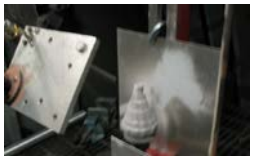
Flexible Robot Environment

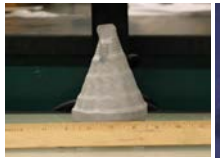
PRODUCTION SCALE-UP

UH-60 Sump Repair

MEO T7631

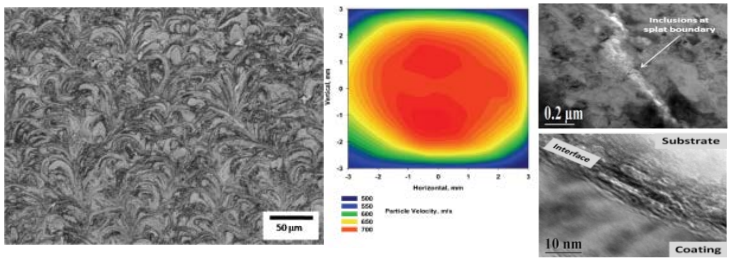
First Approved Army-Navy & Air Force Application



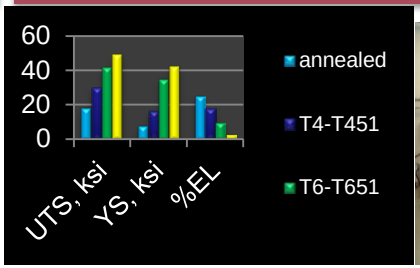


Reactive Materials Shaped Charge Liners

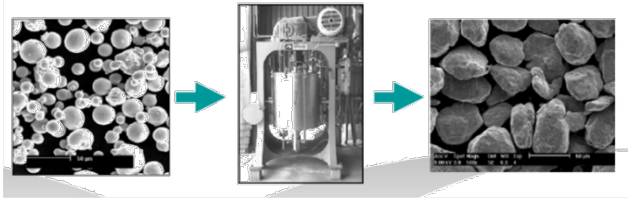
CHARACTERIZATION & TESTING



POWDER CONSOLIDATION

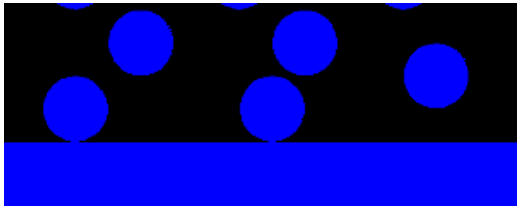


POWDER SYNTHESIS

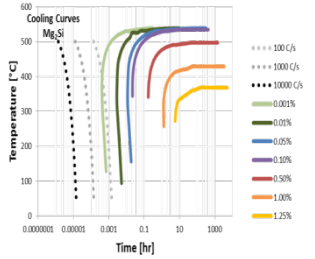


Nano and High Strength Al

MODELING & SIMULATION



Multi-Particle Interaction



Cold Spray Delivers: Build & Repair Capability in 7 yrs

- **Tech Breakthrough: Materials by Design & on Demand**
  - **Multiscale materials research yielded exceptional feedstock for CS process**
  - **Processing Science produced exceptional repair properties**
  - **Manufacturing Science produced automated equipment**

Enables repair of complex parts

$18M Savings

Liner bore seat damage in UH-60 helo gearbox $55k part
No Current Repair Available

~$100M annual DoD Savings

Seawolf

$33M Savings

Periscope repair $225k part

Enables new class of reactive materials unachievable by conventional ingot metallurgy.

B-1

5 yr successful demo

Qualified by Air Force and ATK and approved for acquisition

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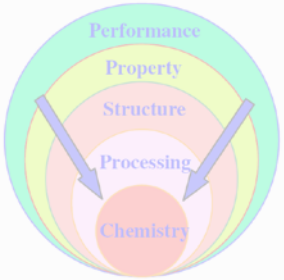

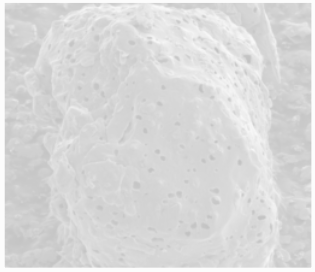

ICME & Metal Powder Feed Stocks

L.J. Holmes

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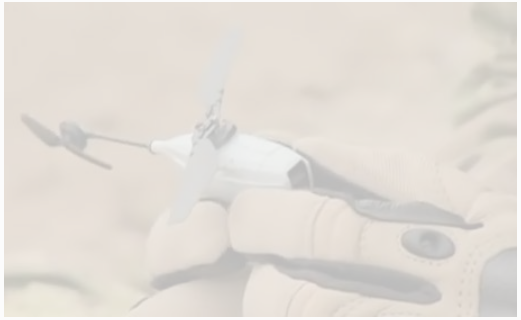
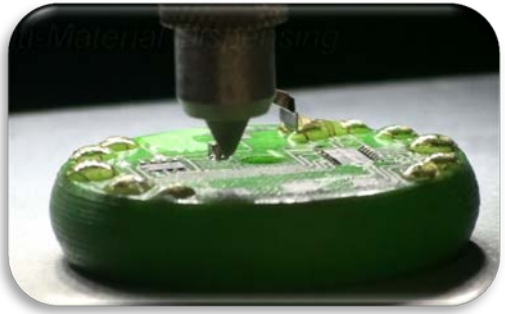


Cold Spray Technology

ARL AM R&D
(and other acronyms)



AM Research Thrusts

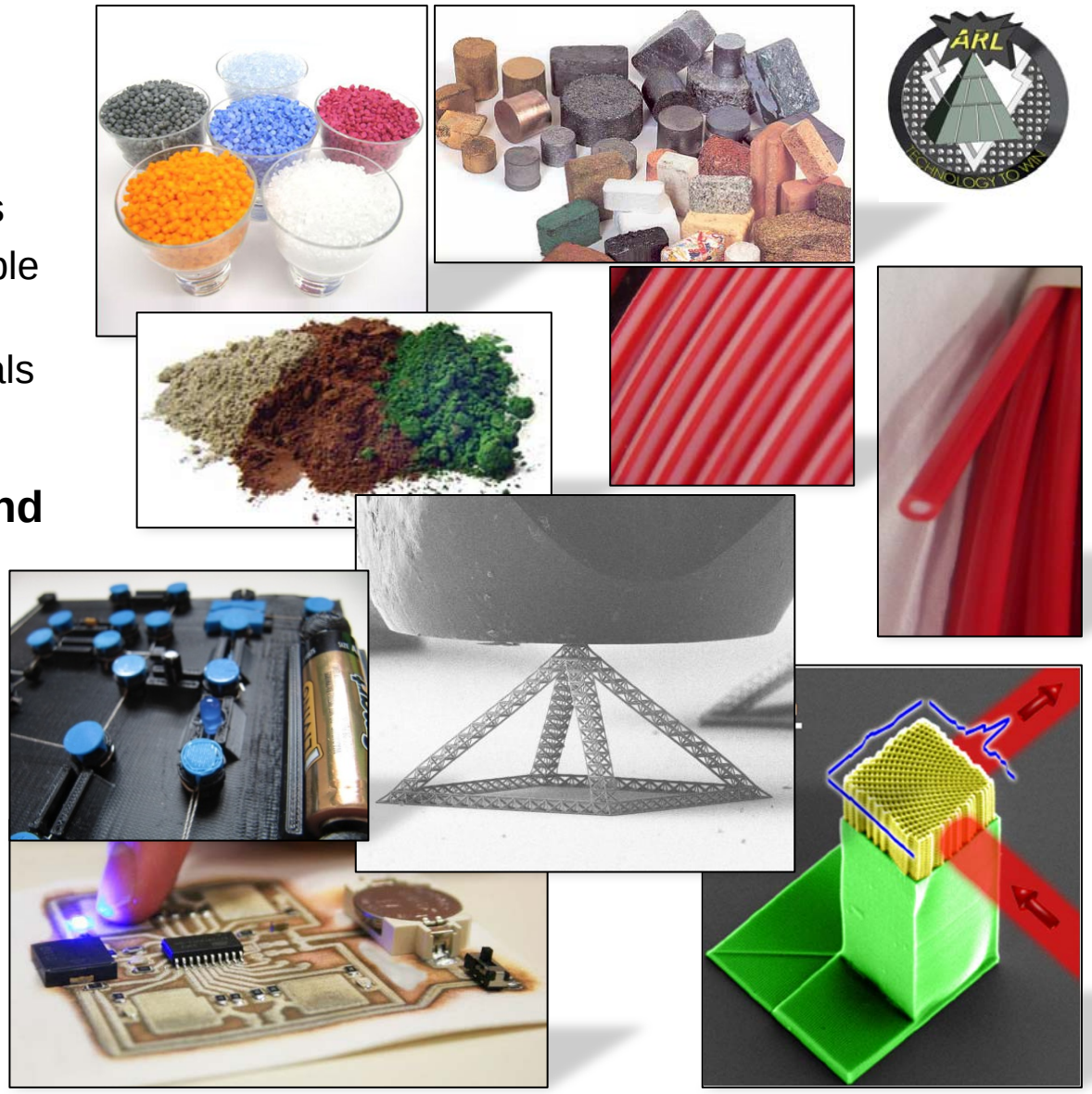
For references, contact POC Larry R. Holmes, Jr. larry.r.holmes.civ@mail.mil

Materials Development for Additive Manufacturing

- Develop Army robust materials
- Electrically/Thermally compatible and efficient materials
- Tunable and functional materials

Hybridization of Materials and Processing Technologies

- Graded material/structure
- Multi-material processing systems
- Multifunctionality
- Ultrahigh fidelity additive manufacturing
- Repeatable performance

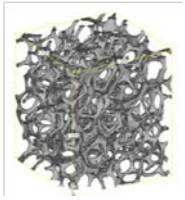


Center for Additive Manufacturing

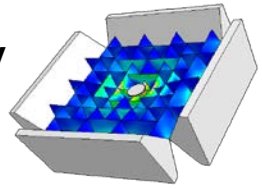
For references, contact POC Larry R. Holmes, Jr. larry.r.holmes.civ@mail.mil

The Center for Advanced Materials and Manufacturing is ARL's Flagship Research facility for Direct Write and Additive Manufacturing Development

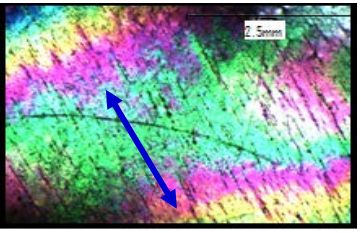
ARL is Developing Next Level Functionality for Additive Manufacturing Technologies Through:

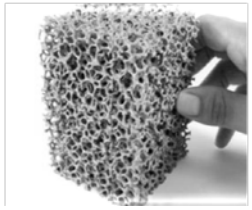


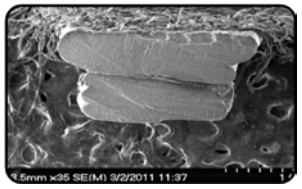
- Material Development
- Material Multifunctionality
- Material Compatibility
- Processing Control
- Processing Technology

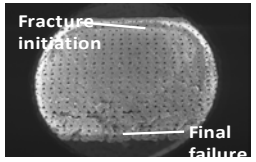


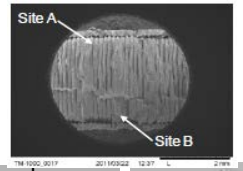
Commercial Processes	• Polymer micro-extrusion • Micro-dispensing pump • Vat polymerization • InkJet • Aerosol jet • Cold spray • Micro-machining • Direct Metal Laser Sintering
ARL Novel Experimental Processes	• Field-aided vat polymerization • Fiber reinforced micro-extrusion • Multi-material vat polymerization • Capillary cold spray • PRINT, a roll-on deposition • 6 axis multi-material processing • Direct Write/AM combined

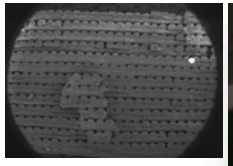


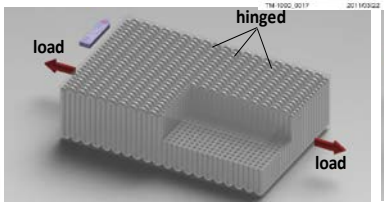


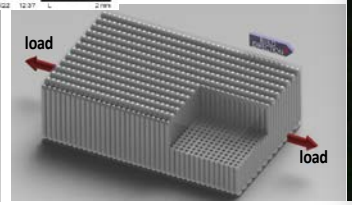


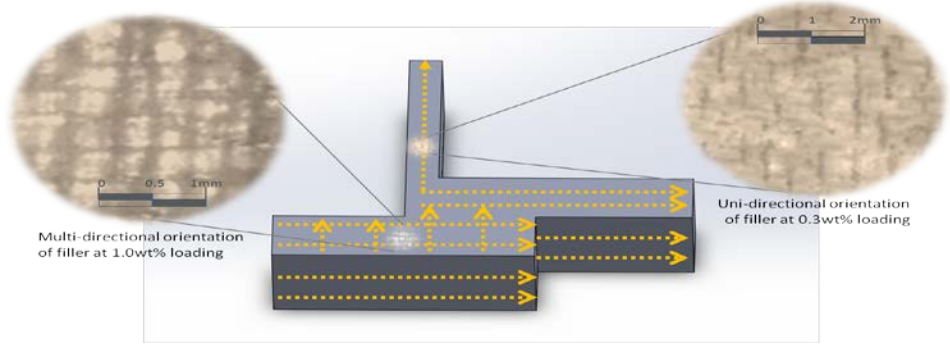


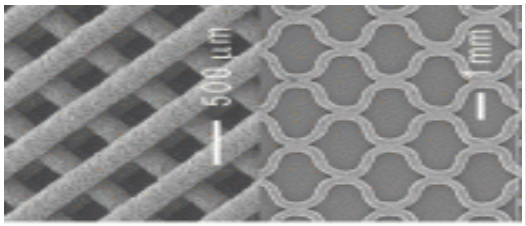




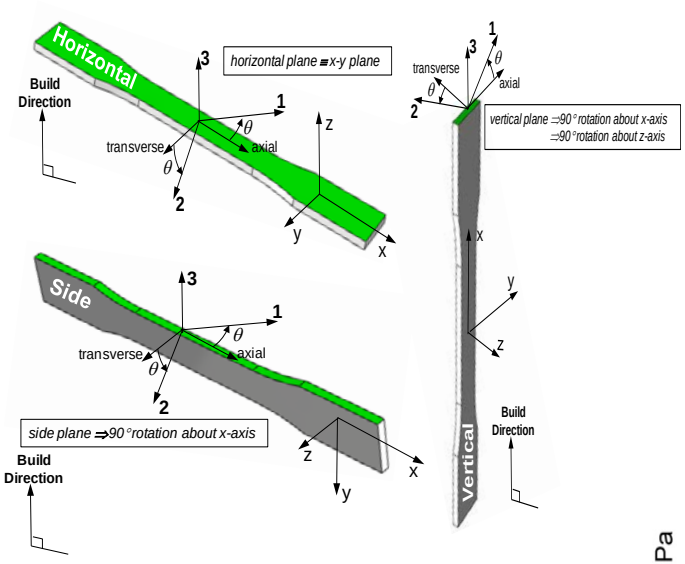








Anisotropy of ABS by FDM due to Build Orientation



Effect of Manufacturing Parameters on Failure in Acrylonitrile–Butadiane–Styrene Fabricated by Fused Deposition Modeling

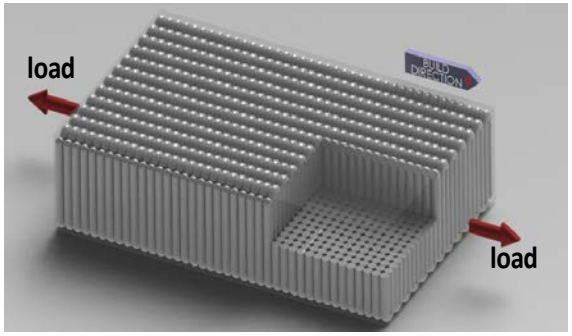
Jaret C. Riddick,[1] Asha J. Hall,[1] Mulugeta A. Haile,[1] and Ray Von Wahlde,[2]
Vehicle Technology Directorate, US Army Research Lab, Aberdeen Proving Ground, MD, 21005

Daniel P. Cole[3] and Stephen J. Biggs[4]
Motile Robotics, Inc., Joppa, MD, 21085

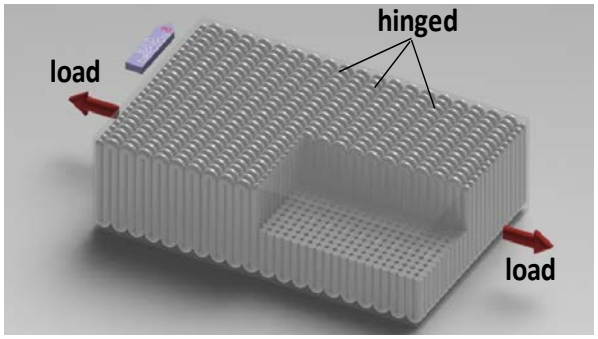
Specimens of acrylonitrile–butadiene–styrene (ABS) material fabricated by fused deposition modeling (FDM) technique were tested in uniaxial tension in accordance with ASTM Standard D638 to assess the effect of anisotropy on the mechanical response. Build directions were varied between horizontal, side and vertical, and the raster orientations were varied between 0°, 90°, and 0°/90°. The stress-strain results were characterized by a monotonic increase with an abrupt failure signifying brittle fracture. The tensile modulus ranged from 2.31GPa for the 0°/90° vertical build specimen to 2.79 GPa for the 0° side build specimen. Tensile strength ranged from 4.57 MPa for the 0° vertical build to 34.17 MPa for the 0° side build specimen. Rasters aligned in the direction of loading offer the greatest load bearing capacity. Cross-polymerization of adjacent rows offers the least significant failure resistance mechanism. The results highlighted in this study are fundamental to the development of optimal designs of complex structural materials for ultra lightweight components where structural tailoring may offer added benefit via weight reduction and structural efficiency.

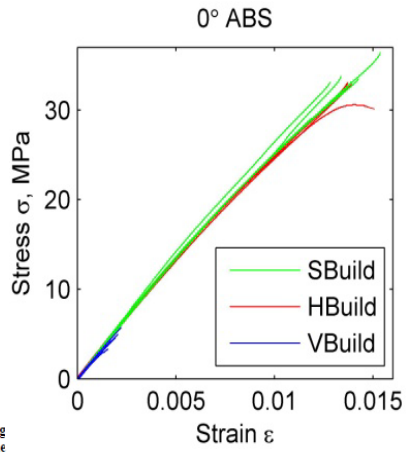
Riddick, et al., AIAA-2012-1571

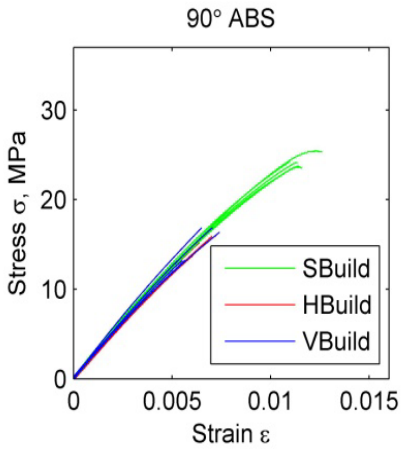
Vertical built 90°

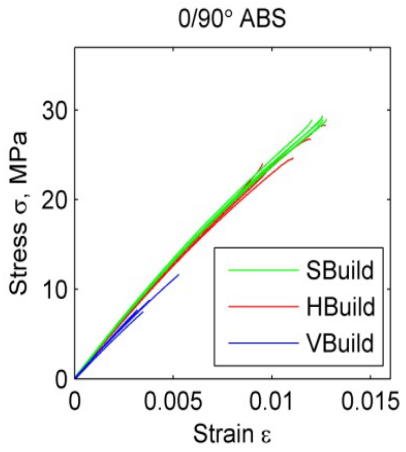


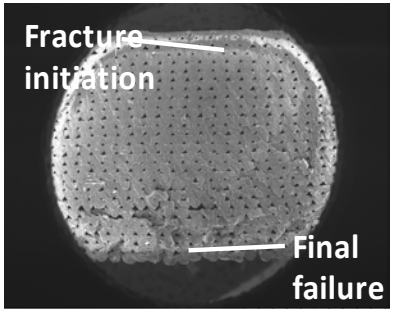
Side built 90°

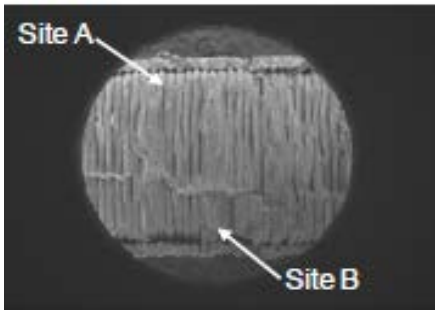


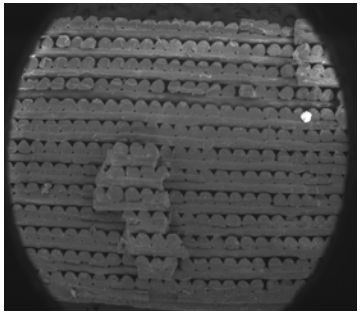








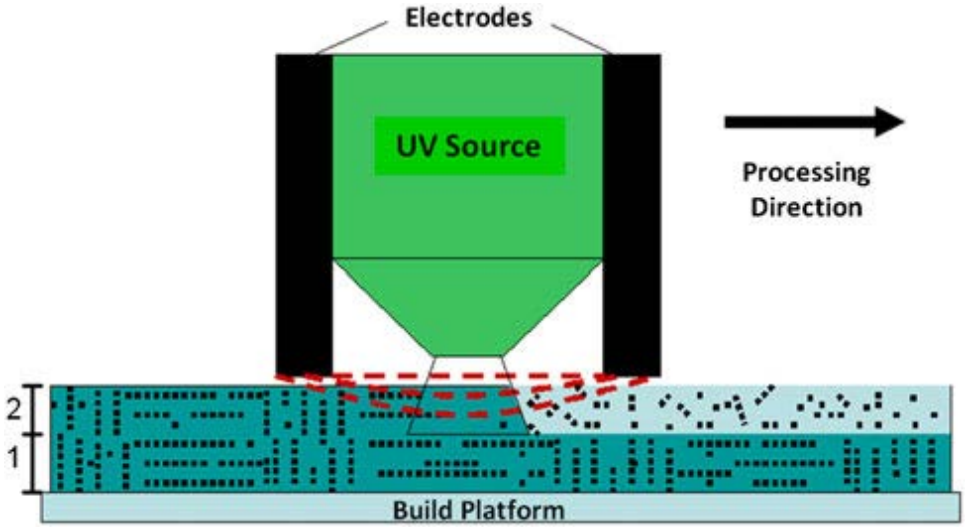




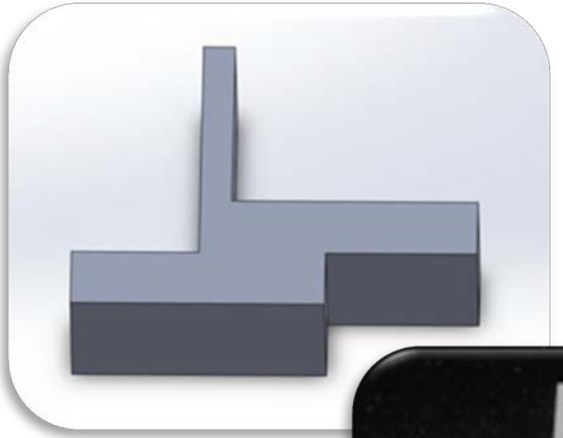
1) Understanding Anisotropy and 2) Tailoring Anisotropy for AM Design

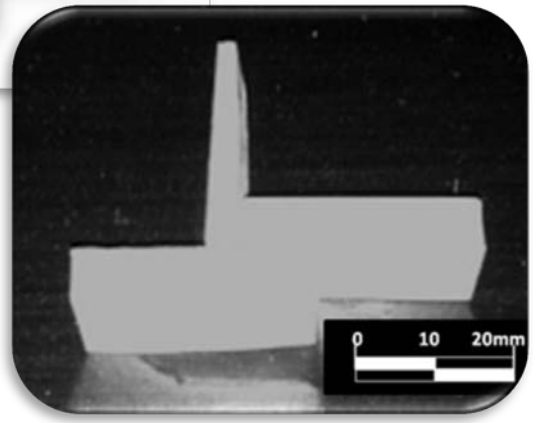
Field-Aided Laminar Composite (FALCom) Processing

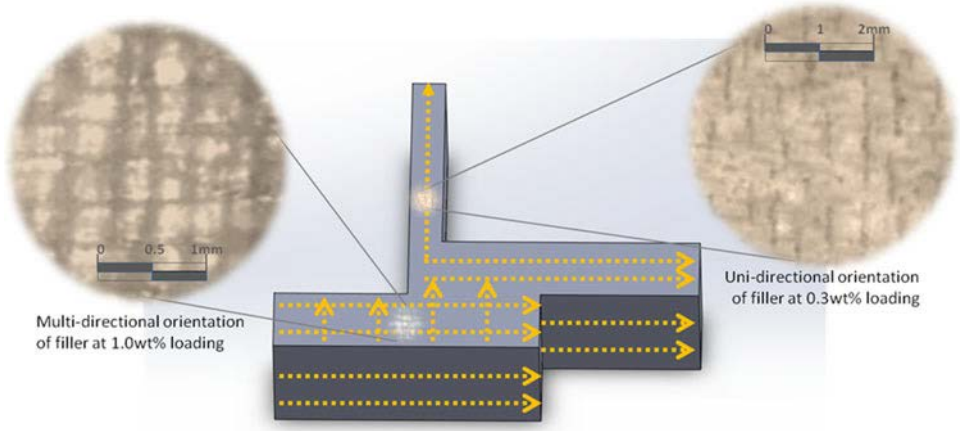
A novel additive manufacturing technology is used to create micro-composites, which can be tailored for specific end-use applications. The Field-Aided Laminar Composite (FALCom) process uses specifically focused electric fields to align nano- to micro-sized particles into chain-like structures, which are referred to as pseudo-fibers. These pseudo-fibers are then immediately frozen into place by incident ultraviolet radiation on the photopolymer matrix. The pseudo-fibers are arranged by design, and they are used to create three dimensional composite structures.



Holmes, L., Riddick, J., "Research Summary of an Additive Manufacturing Technology for the Fabrication of 3D Composites with Tailored Internal Structure," JOM, Vol 66, No 2, 2014.







ARL

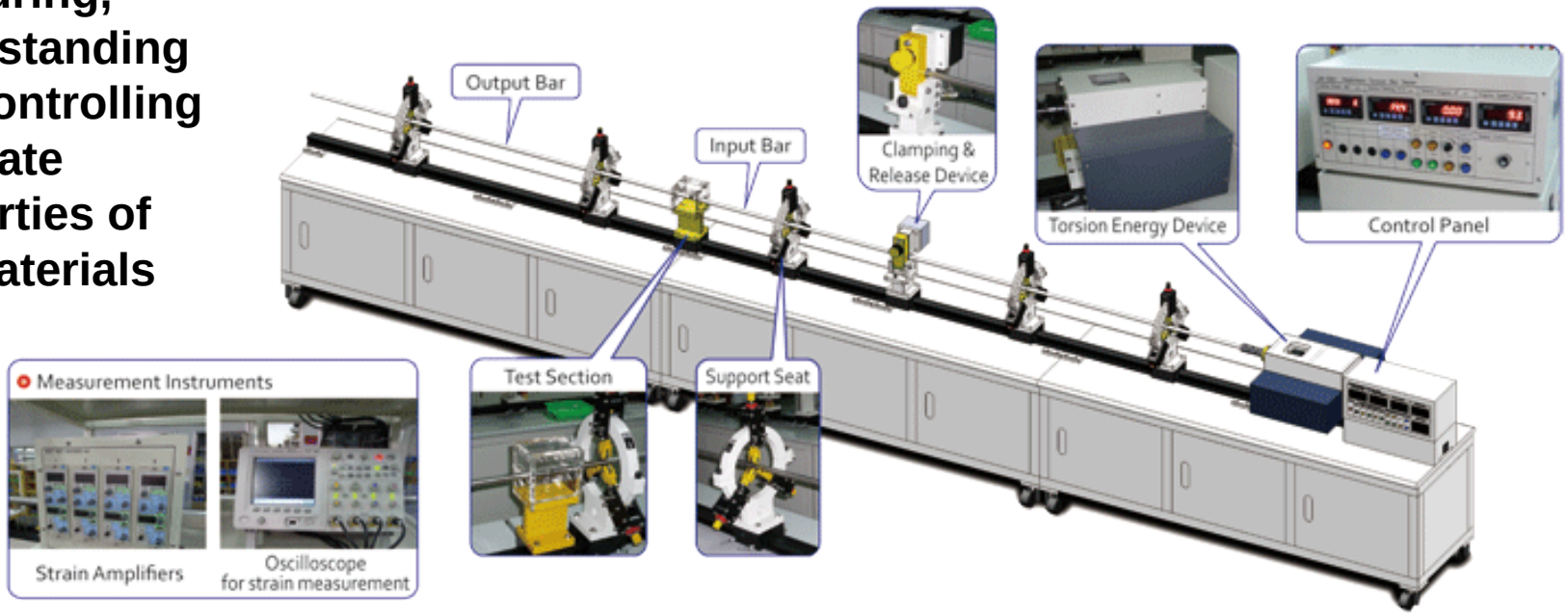
UNIVERSITY OF WISCONSIN-MADISON COLLEGE OF ENGINEERING

Polymer Engineering Center

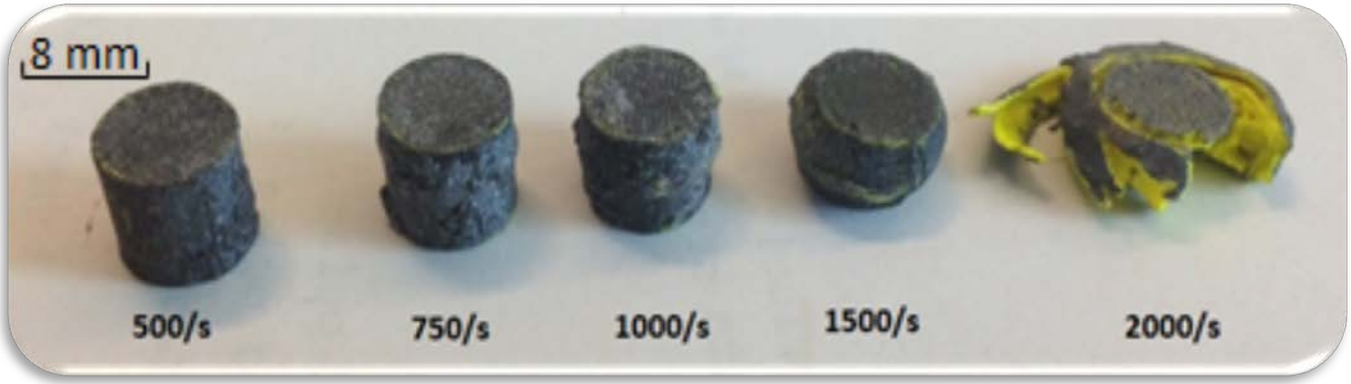
Dynamic Characterization of ABS Fabricated by FDM

For references, contact POC Larry R. Holmes, Jr. larry.r.holmes.civ@mail.mil

Measuring, understanding and controlling high rate properties of AM materials



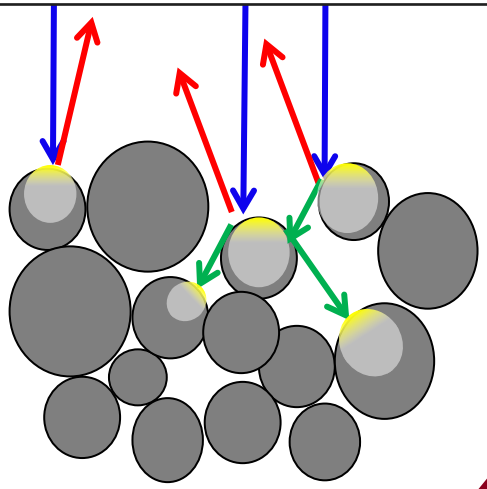
Schematic of Split-Hopkinson Pressure Bar

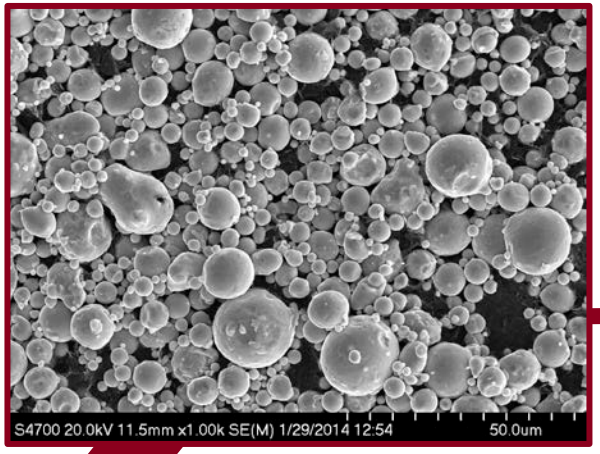


DMLS: Quantifying Matter-Energy Interaction

For references, contact POC Larry R. Holmes, Jr. larry.r.holmes.civ@mail.mil

Typical metals powders are spherical and have dimensions proportional to the incident radiation's wavelength. Therefore Mie scattering is present!





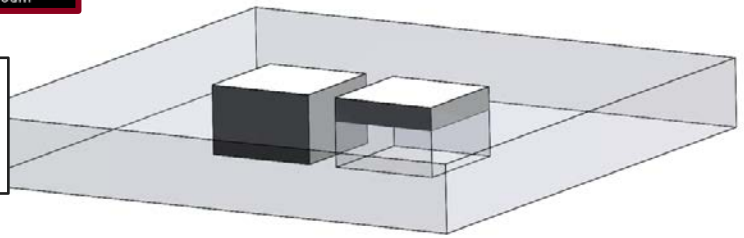
W.M. KECK CENTER FOR 3D INNOVATION

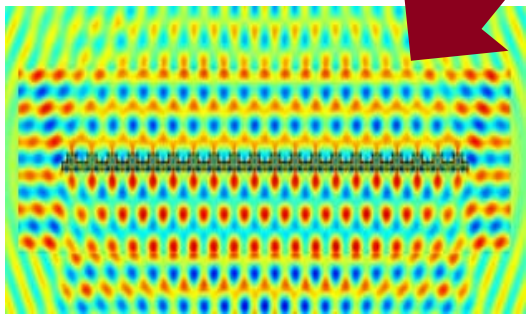
UTEP

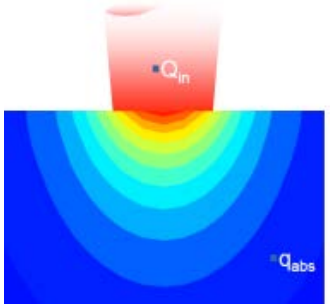
CIMP-3D

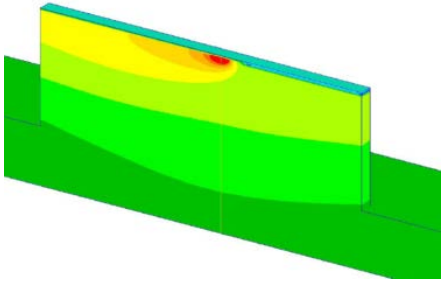
PENNSTATE ARL

Built in powder bed imaging gathers actual powder particle geometries that is built into electromagnetic model.









An understanding of a powder's interaction with incident electromagnetic energy will allow for a better understanding of how efficiently thermal energy is dissipated during a part's build

Coupling the electromagnetic model with a rigorous thermal-fluidic model, build parameters could be adjusted accordingly for any particle, of any material

For references, contact POC Larry R. Holmes, Jr. larry.r.holmes.civ@mail.mil

Hybrid Manufacturing

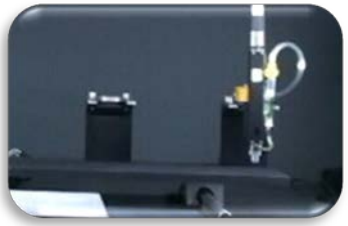
An active example of a multi-technology printing system. The system is based on universal processing controls and software, which are fully open for manipulation (i.e., variable processing parameters). This system includes:

- Line Scanning
- Thermoplastic Extrusion (up to 400°)
- Thermoset Deposition (0 to 2,000,000 cP, with pico-liter control)
- Ink Deposition
- 6-Axis Motion Control
- Tool Switching
- Pick-n-Place

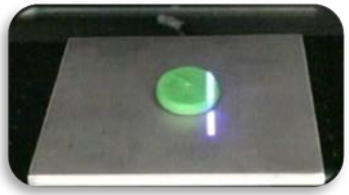
To be added:

- Micro-spray
- Micro-milling
- Laser Sintering
- Aerosol Jet Deposition
- Micro Cold Spray Deposition
- Hopper and auger based feeding

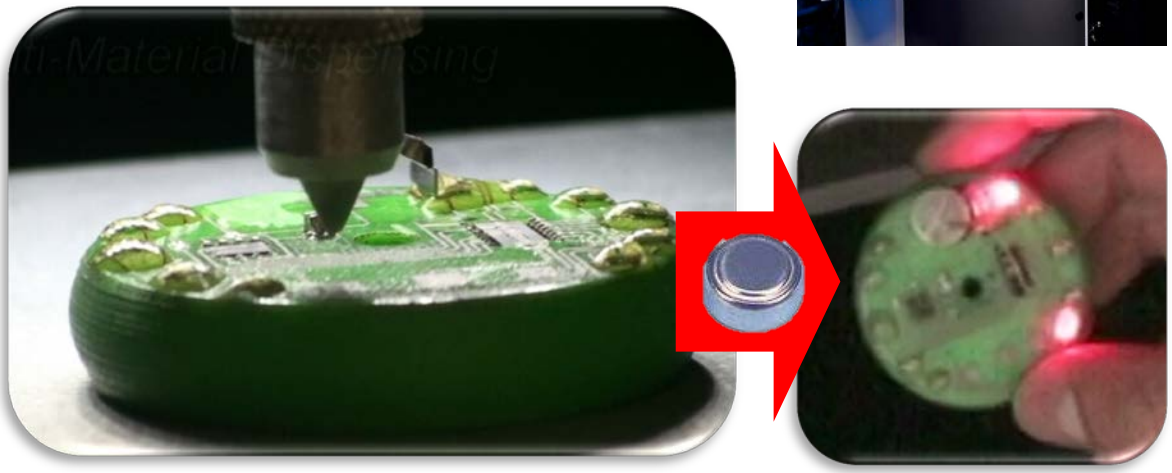
Fabricate a functioning device



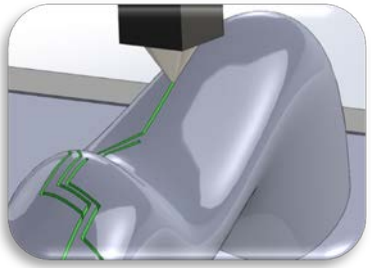
Tools can be added as needed



Scan-to-Print



Conformal Printing



- With Scan-to-print capability, the SuperScrypt can deposit on complex curves, or build 3D shapes from scan data.
- Inverse kinematics enabled 6-axis motion control allows for true 3D printing instead of stacking 2D layers.
- Robust hardware allows for +/- 200nm precision.

AM Research Road Map

For references, contact POC Larry R. Holmes, Jr. larry.r.holmes.civ@mail.mil

Material and Technology Certification and Qualification

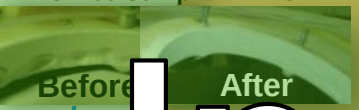
Mtls &Tech Integration

Technology Development

Materials Development

Generation After Next After Next….

Sikorsky, ARL, AMCOM and NAVAIR qualify cold spray for UH-60 Sump ➔ TRL 9



Multi-[illegible] Structures

[illegible] Structures

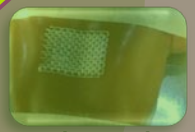
Prosthetics, Implants and Surrogates

Structural Electronic, [illegible] Systems

3D Printed Auxetic Structures for acoustic energy manipulation

Print In-Field and on demand

Generation After Next



Print-to-Fit, printed armor

ARL Patent Awarded for E-field particle alignment in 3D printed polymer structures

Next-Gen In-Progress

Air, Ground and Aquatic Autonomous Systems

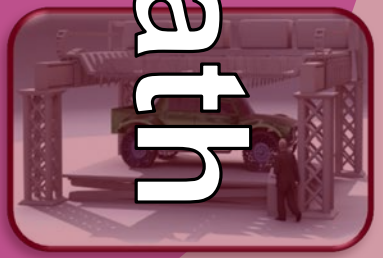
Structural Health Monitoring through integrated sensing

Microfluidics

3D Electronics and Antennas

• Voxel-by-voxel print any material in free space with seamless integration

• Manufacturing Systems that manufacture manufacturing systems



Large-Scale "print and drive"

Future Path

In Progress

2000 - 2016 2030 2045

Discover – Innovate – Transition

For references or technical POCs, contact:

Mark.a.tschopp.civ@mail.mil - Larry.r.holmes.civ@mail.mil